THE EFFECTS OF WHEAT MIDDLINGS, PARTICLE SIZE, COMPLETE DIET GRINDING, AND DIET FORM ON NURSERY AND FINISHING PIG GROWTH PERFORMANCE

by

JON ANDREW DE JONG

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Approved by:

Major Professor
Joel DeRouchey

Abstract

Seven experiments using a total of 2,997 nursery and finishing pigs were used to determine the effects of: 1) dietary wheat middlings (midds), dried distillers grains with solubles (DDGS), and NE diet formulation on nursery pig growth performance; 2) corn particle size, complete diet grinding, and diet form on finishing pig growth performance, and carcass characteristics, and 3) particle size, complete diet grinding, and diet form on nursery pig growth. Experiments 1-4 evaluated dietary wheat middlings at levels of up to 20% of the diet for 7 to 23 kg pigs. Increasing dietary midds decreased growth performance but mainly when 10% of more was added. Balancing diets containing 10 or 20% midds on a NE basis had no significant effects on performance compared with not adjusting for NE of the diet. In Exp. 5, the effects of decreasing particle size, complete diet grinding, and diet form were evaluated on finishing pig growth performance, and carcass characteristics. Diet form × portion ground interactions existed for ADG, ADFI, and HCW as grinding the complete diet in meal form was detrimental to performance but advantageous to performance when diets were fed in pelleted form. Reducing the particle size of corn improved G:F and caloric efficiencies. Pelleting the diet improved ADG, G:F, caloric efficiencies, HCW, and loin depth. Experiment 6 evaluated varying particle sizes, diet form, and complete diet grinding on nursery pig growth performance. Pigs fed pelleted diets had improved ADG, G:F, and caloric efficiencies. Fine grinding corn or the complete diet with high by-products diet decreased ADG, ADFI, G:F, and final BW. Experiment 7 evaluated varying particle sizes of corn and DDGS, diet form, and complete diet grinding on nursery pig growth performance. Pigs fed finely ground corn had decreased ADFI when the diet was fed in pellet form and more severe reductions in ADFI when diets were fed in meal form resulting in a diet form × corn particle size interaction. Pigs fed pelleted diets had decreased ADG, ADFI, G:F and final BW, but improved caloric efficiencies. Finely grinding corn decreased ADG, and feeding DDGS decreased ADG, ADFI, and NE caloric efficiency.

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Dedication

I dedicate my thesis to my wife Karis, my parents, brother, and sisters. Thanks.

Chapter 1 - The effects of dietary wheat middlings, dried distillers grains with solubles, and NE formulation on nursery pig growth performance

ABSTRACT

Four experiments were conducted to determine the effect of dietary wheat middlings (midds), 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 age) were fed 1 of 5 diets for 21 d with 6 pigs per pen and 6 replications per treatment. The diets were corn-soybean meal based and included 0, 5, 10, 15, or 20% midds. Increasing midds decreased (linear; $P < 0.05$) ADG and ADFI; however, the greatest reduction was observed in pigs fed 20% midds. Caloric efficiency improved (linear; $P < 0.02$) on both an ME (NRC, 1998) and NE (INRA, 2004) basis as dietary midds increased. In Exp. 2, 210 pigs (6.85 ± 0.01 kg BW and 26 d age) were fed 1 of 5 diets for 35 d with 7 pigs per pen and 6 replications per treatment. The diets were corn-soybean meal-based and contained 0, 5, 10, 15, or 20% midds. Increasing midds did not affect overall ADG or ADFI, but decreased (quadratic; $P < 0.01$) G:F at levels above 15%. Caloric efficiency for both ME and NE improved (quadratic; $P < 0.01$) as dietary midds increased. In Exp. 3, 180 pigs (12.18 ± 0.4 kg BW and 39 d age) were fed 1 of 6 experimental diets arranged in a 2 × 3 factorial with main effects of DDGS (0 or 20%) and midds (0, 10, or 20%) for 21 d with 6 pigs per pen and 5 replications per treatment. There were no DDGS × midds interactions and DDGS did not influence ADG, ADFI, or G:F. However, increasing dietary midds decreased (linear; $P < 0.03$) ADG, G:F and final BW. In Exp. 4, 210 pigs (6.87 kg BW and 26 d age) were fed 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% midds diets, to balance to the same NE as the positive control (0% midds). Overall, there were no midds × fat interactions. Regardless of formulated energy value, caloric efficiency and G:F was poorer ($P < 0.01$) on an ME basis as midds increased from 10 to 20% of the diet but did not change when calculated on an NE basis. Overall, these studies showed that midds can 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 midds when compared to a corn soybean-meal control diet.

Keywords: Caloric efficiency, DDGS, growth, NE, nursery pigs, wheat middlings

INTRODUCTION

Wheat middlings (**midds**) are a by-product 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 of the offal from the wheat milling process (Blasi et al., 1998). While midds have mainly been used in ruminant diets, their use in swine diets has steadily increased because of high costs of traditional ingredients. Recently, Salyer et al. (2012) and Asmus et al. (2012) conducted experiments examining dietary midds for finishing pigs. They concluded dietary midds decreased both ADG and G:F. This can be explained by a lower energy content of midds (3,025 vs 3,420 kcal/kg of ME; NRC, (1998)) than that of corn. They also observed that added midds led to a decrease in diet bulk density and diet energy as well as an increase in NDF. While studies have been conducted to conclude the effects of midds on finishing pig growth performance, little work has been done to determine the effects of dietary midds on nursery pig growth performance.

Distillers dried grains with solubles (**DDGS**) have become a common ingredient used in swine diets (Stein and Shurson, 2009). Distillers dried grains with solubles are similar to midds in the aspect that they are another by-product ingredient with a high crude fiber content (7.3%). Little data is available on the interactive effects of midds and DDGS in nursery diets as well as the effect of NE formulation of diets containing midds.

Therefore, the objectives of these experiments were to determine the effect of: 1) increasing dietary midds; 2) potential interactive effects of midds and DDGS, and 3) diet formulation on an NE basis on nursery pig growth 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, Manhattan. 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(s) prior to implementation of experimental diets. The common diets did not contain midds. 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 (iso-caloric). Therefore as the level of midds increased, dietary energy decreased. Diets within phase for all experiments were formulated to a constant standard ileal digestible (**SID**) lysine concentration based on the value of the control diet to ensure that changes in growth performance were due to the addition of midds rather than AA concentrations. For diet formulation, the assumed ME and NE values of DDGS were similar to that of corn (3,420, 2,650 kcal/kg; NRC, 1998, and INRA, 2004), and the ME and NE values of midds were 3,025 and 1,850 kcal/kg (NRC, 1998, and INRA, 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 (2004). Values from NRC (1998) were used instead of NRC (2012) values as they 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

Samples of each diet were collected from feeders between each weigh day, blended and sub-sampled to Ward Laboratories, Inc. (Kearney, NE) for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), P (AOAC 965.17/985.01, 2006) ADF (ANKOM Technology, 1998), NDF (ANKOM Technology, 1998), and nitrogen free extract which was calculated with the equation: NFE = 100 - CP - crude fiber - fat – ash (Ward Laboratories, Inc.). Bulk density of the midds, DDGS, and complete diets were also determined (Clementson et al. 2010) as well as particle size of the midds and DDGS (ASAE, 2008).

Experiment 1

A total of 180 mixed sex nursery pigs (327 × 1050; PIC, Hendersonville, TN; 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 midds on nursery pig growth performance and caloric efficiency. Pigs were allotted to pen by initial BW and pens were assigned to treatments in a completely randomized design (CRD). There were 6 pigs per pen and 6 replications per treatment. The 5 treatment diets included 0, 5, 10, 15, or 20% midds (Table 1.1). 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. However, younger and lighter BW pigs were used to evaluate the response in pigs expected to have a lower feed intake. Thus, a total of 210 mixed sex nursery pigs (327 × 1050; PIC; 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 midds on pig growth 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 CRD. The 5 treatment diets included 0, 5, 10, 15, or 20% midds (Table 1.2). Diets were fed in two 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 similar BW range as Exp 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 (327 × 1050; PIC; 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 midds and DDGS on pig growth 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 CRD. 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 midds (0, 10, and 20%) with or without 20% DDGS (Table 1.3). 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 (327 × 1050; PIC; 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 or not, on pig growth 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 CRD. The 5 corn-soybean meal–based diets were: (1) corn-soybean meal diet (positive control); 2) 10% added midds; 3) 20% added 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 1.4). Feed ingredients were assigned a NE (INRA, 2004) value for the growing pig, and they were fed in two phases from d 0 to 12 and 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 CRD using the MIXED procedure of SAS (SAS Institute, 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 pre-planned contrasts in Exp. 1 and 2 included the linear and quadratic effects of increasing dietary midds. In Exp. 3, the pre-planned contrasts included: 1) main effects of DDGS and midds; 2) interactive effects between midds and DDGS, and 3) linear and quadratic effects of increasing dietary midds regardless of DDGS inclusion. In Exp. 4, the pre-planned contrasts included; 1) interactive effects of midds and equal NE formulation; 2) main effects of midds and added fat, and 3) linear and quadratic effect of increasing dietary midds regardless of energy formulation. 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 midds verified nutrient values to be similar to those used in diet formulation (Table 1.5). The minor differences found would not be expected to influence the results of the experiments. Nutrient analysis of the treatment diets showed that for most of the nutrients, the levels were similar to formulated values (Tables 1.6 to 1.9). The only exception was CF, Ca, and P which on average were all slightly higher than formulated values.

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

Experiment 1

Overall (d 0 to 21), as dietary wheat middlings increased, ADG decreased (linear; P < 0.05). The reduction in ADG was primarily a result of decreased (linear; $P < 0.005$) ADFI in pigs fed increasing midds. There was no difference in G:F as midds increased. Caloric efficiency also decreased ($P < 0.02$) on an ME and NE basis as the level of dietary midds increased.

Experiment 2

During Phase 1 from d 0 to 14, increasing midds had no effect on growth performance. However, during phase 2 from d 14 to 35, pigs fed increasing midds had decreased (linear, $P < 0.02$) ADG and G:F.

Overall, (d 0 to 35), as dietary midds increased, G:F decreased (quadratic, $P < 0.004$). This effect was mainly attributed to a notable decrease in G:F for pigs fed 20% midds. For caloric efficiency, the response was quadratic ($P < 0.01$) on an ME and NE basis as the level of midds increased in the diet, and was driven by the poorest caloric efficiencies for both ME and NE at 0 and 20% inclusion rates.

Experiment 3

Overall (d 0 to 21), no midds × DDGS interactions ($P > 0.12$) were observed. Increasing dietary midds decreased (linear, $P < 0.02$) ADG, final BW, and G:F with no effect on ADFI.

Adding 20% DDGS, to the diet did not influence growth performance ($P > 0.59$). For caloric efficiencies, there was no differences when calculated on an ME or NE basis.

Experiment 4

During phase 1 (d 0 to 12), there was a midds × fat interaction ($P < 0.01$) for ADFI. As more midds were added to the diet and not balanced for NE pigs had increased ADFI. Conversely ADFI decreased as dietary midds increased in diets balanced for NE. During phase 2 (d 12 to 29), increasing dietary midds decreased (quadratic; $P < 0.03$) G:F, but ADG and ADFI were not significantly influenced. Overall (d 0 to 29), no midds × fat interactions ($P > 0.34$) were observed. Pigs fed increasing dietary midds had a tendency for poorer (linear, $P < 0.06$) G:F and caloric efficiency when expressed on an ME basis mainly due to poorer performance during the second phase. Poorer ($P < 0.01$) G:F and caloric efficiency on an ME basis were also found as midds were included in the diets regardless of formulated energy value, but no differences were observed for energetic efficiency on an NE basis.

DISCUSSION

The majority of published research with midds or wheat shorts has been conducted with finishing pigs. Young (1980) conducted two studies which showed that growing pigs fed increasing wheat shorts from 18 to 44 kg had decreased ADG but only after inclusion of 64.4% midds were included in the diet while finishing pigs fed from 21 kg to slaughter had decreased ADG after 32.2% midds inclusion. In both studies, G:F decreased as dietary wheat shorts were added to the diet. It should be noted that dietary lysine and energy decreased as wheat shorts were added to the diet; however, all lysine levels were at or above recommended concentrations (NRC, 1979), which subsequently also met requirements from NRC (1998). Feoli et al. (2006) also conducted a study feeding increasing levels of midds to finishing pigs from 65 kg BW to slaughter. Pigs were fed midds at inclusion rates of 0, 15, and 30% with or without the use of a commercial enzyme. Diets were not iso-caloric but were iso-nitrogenous such that as midds increased in the diet energy content decreased but amino acid levels remained constant. They observed that pigs fed increasing midds from 0 to 30% had decreased ADG, G:F and HCW. There were no effects of the added enzyme but the increasing midds decreased apparent digestibility of DM, N, and GE. More recently Asmus et al. (2012) fed midds to finishing pigs from 38 kg to slaughter at levels of 0 and 19% with iso-caloric and iso-nitrogenous diets. Pigs fed diets containing midds had decreased ADG, G:F, final BW, and HCW. Erickson et al. (1985) fed pigs 20, 40 and 60% midds from 11 and 21 kg BW to slaughter. They observed that pigs fed increasing midds had decreased ADG and G:F mainly due to decreases that occurred after the 20% inclusion rate. In this study, diets were iso-nitrogenous and iso-caloric such that as midds increased in the diet lysine and energy levels were held constant.

In the present studies with nursery pigs, a common finding was that despite linear decreases in ADG and G:F the greatest detriment was observed with midds greater than 10 or 15% of the diet. This response occurred in spite of the fact that calculated dietary energy was reduced. Shaw et al. (2002) observed that 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) found that increasing dietary midds as an equal replacement for corn at levels of 0, 10, 20, and 30% decreased ADG and G:F and increased ADFI when fed to pigs for 4 weeks with an initial BW of 11 kg.

The variability in response to midds inclusion in diets for nursery pigs may be due to the variability between midds sources. Cromwell et al. (2000) observed that 14 sources of midds had sizeable differences in bulk density, DM, CP, Ca, P, Se, and NDF. Cromwell et al. (1992)

previously had found that “heavy” midds, classified by a high bulk density, resulted in improved performance compared to pigs fed identical levels of “light” midds. Light midds have very few starch particles and consist of a larger proportion of bran when compared to “heavy” midds. The differences among sources of 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 then soft red wheat. It should be noted that all midds used in our experiments based on bulk density analysis would be considered “heavy” midds and may have contained more starch then other “light” midds sources. This may explain the similar performance between pigs fed diets containing 10 to 15% midds and pigs fed the corn-soybean meal control diets.

In Exp. 2 and 4, increasing dietary midds did not affect performance of nursery pigs from 7 to 10 kg; however, greater than 10% midds had negative effects on both ADG and G:F after 10 kg. This supports work done by Weber et al. (2008) who found that fibrous feed ingredients (DDGS, soybean hulls, and citrus pulp) did not affect growth 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 midds were increased. In Exp. 1 of the present studies pigs decreased ADFI as midds increased as feed intake may have been limited by gut fill due to the low bulk density of the midds. The reduction in diet bulk density may have hindered pigs from consuming more total feed in order to meet their energy requirement. Avelar et al. (2010) found 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 showed that diet bulk density was associated with a decrease (linear; $P < 0.001$)

affected 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 effects on nursery pig growth performance at levels up to 45% (Senne et al., 1995, 1996; Lineen et al., 2006; Weber et al., 2008), or even slightly improve G:F (Barbosa et al., 2008). However, all of these studies were in corn-soybean meal based diets without other co-products. While data is available in finishing pigs fed increasing combinations of DDGS and midds, none has been reported in nursery pig diets. In the current studies there were no interactions between DDGS and midds for nursery pig growth performance. This was in spite of even further decreased diet bulk density and increased dietary fiber levels when both ingredients were included in the diets. The finishing pig research of Asmus et al. (2012) and Salyer et al. (2012) also found no interactions when midds and DDGS were fed in combination in finishing pig diets, even though midds negatively affected performance.

While the first 3 trials in the present study were not balanced for energy, the final experiment evaluated equal NE formulation using added soybean oil to balance the NE levels when diets contained 10 or 20% midds. In this case, performance was restored and no negative effects of increasing midds in the diet were found for growth rate. This would support the work by Shaw et al. (2002) and Salyer et al. (2011) in finishing pigs which showed that the use of added fat to balance the dietary energy concentration when midds were added to diets can mitigate the negative effects of 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 by-products such as midds and DDGS, assigning accurate energy concentrations to these by-products are essential to establish accurate feeding values. Caloric efficiency can be calculated to determine if the assigned ingredient energy concentration is accurate. This can be applied for all energy systems utilized 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 would be found. If significant differences in caloric efficiencies of diets containing increasing levels of the test ingredient are found, it is likely that the energy level for the ingredient was under or overestimated in formulation. However, the energy level of an ingredient may change based on its level used in the diets, especially in higher fiber ingredients. Just (1982) showed that for every 1% increase in the crude fiber content of a diet, the digestible metabolizable energy decreased by 1%. This suggests that an ingredients actual energy value may change as the level of the ingredient changes in the diet. Stewart et al. (2013) estimated the NE value of midds utilizing complete body composition of growing (25.4 kg BW) and finishing (84.8 kg BW) pigs fed 0 and 30% midds. They observed that the NE of the diet containing midds was lower ($P < 0.05$) than the basal diet for growing pigs and tended to be lower ($P = 0.05$) in the finishing phase. The energy concentration of midds was also numerically greater when fed to finishing pigs (1,015 vs 959 kcal.kg) compared to growing pigs. This suggests that current NE values (1,560 kcal/kg, NRC, 1998; 1,850, INRA, 2004) may be overestimating the caloric content of midds. However, as only one level of midds inclusion was tested which was much greater than any levels used in the present experiments, it might suggest that as 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 midds.

In conclusion, nursery pigs fed diets with increasing midds had decreased performance when diets were not balanced for energy. However, the decrease in performance occurred only when midds were fed at levels over 10 to 15% of the diet. Finally, the IRNA (2004) NE value of wheat midds appears to be a more accurate energy value then 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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.

TABLES AND FIGURES

Table 1-1 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
Total	100	100	100	100	100
Calculated analysis					
Standardized ileal digestible (SID) AA, %					
Lys	1.28	1.28	1.28	1.28	1.28
Iso:Lys	61	61	60	59	59
Leu:Lys	129	127	125	123	121
Met:Lys	34	34	33	33	33
Met & 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 Lysine:ME, g/Mcal	3.86	3.88	3.90	3.93	3.95
CP, %	21.2	21.1	21.0	20.9	20.9
CF, %	9.3	10.6	12.0	13.3	14.6
NDF, %	3.6	3.9	4.3	4.7	5.1
ADF, %	1.6	1.8	1.9	2.1	2.3
Ca, %	0.69	0.69	0.69	0.69	0.69
P, %	0.63	0.64	0.65	0.66	0.67
Available P, %	0.42	0.42	0.42	0.42	0.42

[1]Treatment diets fed for 21 d.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO.) provided 749.4 FTU/kg, with a release of 0.12% available P.
[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

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

	Phase 1					Phase 2				
Item — Wheat middlings, %:	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
Total	100	100	100	100	100	100	100	100	100	100
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	
Iso:Lys	62	62	61	60	60	61	61	60	59	59
Leu:Lys	127	125	123	121	119	129	127	125	123	121
Met:Lys	34	34	34	34	34	34	34	33	33	33
Met & 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
CP, %	21.8	21.7	21.6	21.6	21.5	21.2	21.1	21.0	20.9	20.9
CF, %	2.3	2.6	2.8	3.0	3.2	2.7	2.9	3.1	3.3	3.6
NDF, %	8.1	9.4	10.7	12.1	13.4	9.3	10.6	12.0	13.3	14.6
ADF, %	3.1	3.5	3.9	4.2	4.6	3.6	3.9	4.3	4.7	5.1
Ca, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %	0.66	0.67	0.68	0.69	0.70	0.63	0.64	0.65	0.66	0.67
Available P, %	0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42

[1] Phase 1 diets were feed from d 0 to 14; phase 2 diets were fed from day 14 to 35.
[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B12.
[3] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO.) provided 749.4 FTU/kg, with a release of 0.12% available P
[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

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

Item	DDGS, %:	0			20		
	Wheat middlings, %:	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
Dried distillers grains with solubles		---	---	---	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
Total		100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) AA, %							
Lys		1.28	1.28	1.28	1.28	1.28	1.28
Iso:Lys		61	60	59	65	64	62
Leu:Lys		129	125	121	150	146	142
Met:Lys		34	33	33	30	30	30
Met & 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 Lysine:ME, g/Mcal		3.86	3.90	3.95	3.85	3.90	3.94
CP, %		21.2	21.0	20.9	23.5	23.4	23.2
CF, %		2.7	3.1	3.6	2.2	2.6	3.1
NDF, %		9.3	12.0	14.6	14.4	17.0	19.6
ADF, %		3.6	4.3	5.1	6.1	6.8	7.6
Ca, %		0.69	0.69	0.69	0.69	0.69	0.69
P, %		0.63	0.65	0.67	0.60	0.63	0.65
Available P, %		0.30	0.30	0.30	0.30	0.30	0.30

[1] Treatment diets fed for 21 d.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

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

[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

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

	Phase 1					Phase 2				
Wheat middlings, %:	0	10	20	10	20	0	10	20	10	20
Item Soybean oil, %:	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
Total	100	100	100	100	100	100	100	100	100	100
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
Iso:Lys	62	61	60	61	59	61	60	59	60	59
Met:Lys	34	34	34	34	34	34	33	33	33	33
Met & 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 Lysine:ME, g/Mcal	3.99	4.04	4.08	3.95	3.91	3.86	3.90	3.95	3.82	3.78

CP, %	21.8	21.6	21.5	21.6	21.4	21.2	21.0	20.9	20.9	20.7
CF, %	2.3	2.8	3.2	2.8	3.2	2.7	3.1	3.6	3.1	3.5
NDF, %	8.1	10.7	13.4	10.6	13.1	9.3	12.0	14.6	11.8	14.3
ADF, %	3.1	3.9	4.6	3.8	4.5	3.6	4.3	5.1	4.3	5.0
Ca, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %	0.66	0.68	0.70	0.68	0.70	0.63	0.65	0.67	0.65	0.67
Available P, %	0.36	0.36	0.36	0.36	0.36	0.30	0.30	0.30	0.30	0.30

[1]Treatment diets fed for 21 d.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B12.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

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

[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Table 1-5 Chemical analysis of wheat middlings, (as-fed basis)[1,2,3]

	Exp. 1	Exp. 2	Exp. 3		Exp. 4
Item	Midds	Midds	Midds	DDGS	Midds
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)	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 parenthesis indicate those used in diet formulation.
[2] Values in parenthesis are taken from NRC (1998).
[3] Values in parenthesis for DDGS are taken from Stein (2007).
[4] Values not listed were not available.
[5] Standard deviation for particle size is listed in parenthesis.

Table 1-6 Chemical analysis of diets containing wheat middlings, Exp. 1 (as-fed basis)[1]

	Wheat Middlings, %				
Item,	0	5	10	15	20
DM, %	89.56	88.93	89.39	89.19	89.58
CP, %	20.90	20.30	21.60	19.70	21.00
ADF, %	3.20	3.20	3.60	3.70	4.10
NDF, %	8.10	8.00	9.40	9.00	11.60
Crude fiber, %	2.40	2.40	3.00	3.00	3.20
Ca,%	0.75	0.85	0.86	0.90	0.87
P, %	0.64	0.64	0.65	0.65	0.66
Bulk density, g/L	794	758	715	702	646

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

Table 1-7 Chemical analysis of diets containing wheat middlings, Exp. 2 (as-fed basis)[1]

	Phase I					Phase II				
Item Wheat middlings, %:	0	5	10	15	20	0	5	10	15	20
DM, %	89.51	89.82	90.49	89.83	90.60	88.73	88.62	89.01	88.66	89.45
CP, %	22.20	21.30	22.00	24.00	20.90	21.40	20.90	21.10	21.30	21.10
ADF, %	3.10	3.20	4.10	4.70	4.10	3.30	4.10	5.00	5.10	5.60
NDF, %	6.70	8.00	9.10	11.40	11.20	7.60	9.10	14.10	11.90	14.00
Crude fiber, %	1.80	2.20	2.60	3.00	2.90	2.40	2.70	3.40	3.30	3.70
NFE, %	57.20	57.70	57.10	53.90	58.10	57.50	57.80	56.00	55.40	56.50
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
Fat, %	2.30	2.20	2.40	2.50	2.50	2.60	2.50	2.80	2.50	2.90
Ash, %	5.93	6.35	6.31	6.39	6.26	4.78	4.79	5.66	6.17	5.20
Bulk density g/L	804	764	716	670	646	746	696	640	627	600

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

Table 1-8 Chemical analysis of diets containing wheat middlings (midds) and dried distillers grains with solubles, Exp. 3 (as-fed basis)[1]

	DDGS, %					
	0			20		
Item Midds, %:	0	10	20	0	10	20
DM, %	91.08	90.94	91.19	91.55	91.83	91.81
CP, %	22.30	21.60	21.20	23.90	23.80	22.30
ADF, %	2.30	3.10	3.70	4.40	5.50	5.50
NDF, %	9.20	12.10	14.90	11.40	14.60	14.70
Crude fiber, %	2.40	2.90	3.30	3.10	3.80	4.30
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
Fat, %	2.60	2.90	3.00	3.90	4.20	4.30
Ash, %	5.11	5.44	5.46	5.18	5.58	5.18
Bulk density, g/L	798	728	694	729	672	634

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

Table 1-9 Chemical analysis of diets containing wheat middling, Exp. 4 (as-fed basis)[1]

	Phase 1					Phase 2				
Wheat middlings, %:	0	10	20	10	20	0	10	20	10	20
Item Fat, %:	0	0	0	1.4	2.8	0	0	0	1.4	2.8
DM, %	90.31	89.52	90.07	90.14	90.56	89.91	89.68	89.55	89.69	90.63
CP, %	21.8	22.0	21.2	22.0	21.8	21.5	22.3	21.7	21.6	20.8
ADF, %	4.1	4.1	4.2	3.7	3.3	2.8	4.4	5.1	4.1	4.9
NDF, %	8.0	8.9	10.0	8.5	9.6	9.0	13.2	13.5	10.0	13.0
Crude fiber, %	2.4	2.5	2.9	2.4	2.8	2.2	2.9	3.4	2.8	3.4
NFE, %	55.9	55.4	54.7	55.4	55.2	58.4	55.8	55.8	55.6	55.5
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
Fat, %	2.5	2.7	2.7	3.5	4.1	2.4	2.6	2.6	3.6	5.3
Ash, %	7.83	6.99	8.47	6.77	6.67	5.19	6.11	6.14	6.09	5.60
Bulk density, g/L	818	767	722	752	695	788	703	651	671	619

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

Table 1-10 The effects of increasing wheat middlings on nursery pig growth 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	0.05	0.66
ADFI, g	945	941	903	916	892	13	0.004	0.80
G:F	0.611	0.603	0.626	0.620	0.613	0.007	0.37	0.35
Caloric efficiency, Mcal/kg								
ME	5.43	5.47	5.25	5.26	5.29	0.06	0.02	0.37
NE	3.87	3.88	3.68	3.66	3.66	0.04	0.001	0.38
Wt, kg								
d 0	11.9	11.9	11.8	11.9	11.9	0.2	0.96	0.92
d 21	24.0	23.8	23.7	23.8	23.4	0.3	0.26	0.85

[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. There were 6 pigs per pen and 6 pens per treatment.

Table 1-11 The effects of increasing wheat middlings on nursery pig growth 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	0.99	0.89
ADFI, g	328	313	316	318	334	15	0.76	0.30
G:F	0.621	0.669	0.666	0.627	0.628	0.023	0.69	0.25
d 14 to 35								
ADG, g	585	585	578	569	543	12	0.02	0.26
ADFI, g	878	862	880	861	860	18	0.55	0.93
G:F	0.666	0.679	0.657	0.662	0.632	0.008	0.004	0.07
d 0 to 35								
ADG, g	433	435	432	422	408	12	0.11	0.39
ADFI, g	658	643	654	644	647	16	0.69	0.81
G:F	0.658	0.677	0.660	0.655	0.631	0.007	0.004	0.01
Caloric efficiency, Mcal/kg								
ME	5.04	4.87	4.97	4.98	5.14	0.06	0.10	0.01
NE	3.61	3.46	3.51	3.48	3.57	0.04	0.61	0.01
BW, kg								
d 0	6.9	6.9	6.9	6.9	6.9	0.6	0.88	0.93
d 14	9.7	9.8	9.8	9.7	9.8	0.2	0.95	0.90
d 35	22.0	22.1	22.0	21.6	21.3	0.4	0.15	0.49

[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 1-12 The effects of wheat middlings (midds) and dried distillers grains with solubles (DDGS) on nursery pig growth performance, Exp. 3[1]

	DDGS, %:	0			20				Probability[2,3], *P* <	
Item	Midds, %:	0	10	20	0	10	20	SEM	Linear	Quadratic
d 0 to 21										
ADG, g		596	565	565	582	580	547	13	0.02	0.98
ADFI, g		953	928	940	931	954	925	16	0.56	0.78
G:F		0.627	0.609	0.601	0.626	0.608	0.594	0.011	0.01	0.82
Caloric efficiency, mcal/kg										
ME		5.29	5.39	5.41	5.31	5.42	5.49	0.10	0.15	0.81
NE		3.78	3.78	3.74	3.83	3.84	3.83	0.07	0.84	0.77
BW, kg										
d 0		12.1	12.1	12.0	12.1	12.1	12.6	0.3	0.59	0.79
d 21		24.7	24.1	24.2	24.4	24.4	23.7	0.3	0.02	0.98

[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] No wheat midds × DDGS interactions were observed, *P* > 0.12.
[3] No DDGS effects, *P* > 0.41.

Table 1-13 The effects of increasing wheat middlings and net energy formulation on nursery pig performance, Exp. 4[1]

	Treatment						Probability, $P <$			
	1	2	3	4	5		Midds × balanced NE	Midds		Midds
Wheat middlings, %:	0	10	20	10	20					
Item, Soybean oil, %:	0	0	0	1.4	2.8	SEM[2]	interaction[3]	Linear[4]	Quadratic[5]	level[6]
d 0 to 12										
ADG, g	252	258	261	275	258	9	0.33	0.56	0.27	0.49
ADFI, g	424	428	466	465	423	14	0.01	0.25	0.36	0.88
G:F	0.597	0.602	0.563	0.590	0.609	0.024	0.18	0.67	0.81	0.63
d 12 to 29										
ADG, g	576	569	540	581	569	11	0.46	0.15	0.37	0.09
ADFI, g	878	863	861	874	899	16	0.44	0.91	0.52	0.50
G:F	0.656	0.660	0.628	0.665	0.634	0.009	0.96	0.03	0.03	0.001
d 0 to 29										
ADG, g	442	440	425	454	440	9	0.95	0.41	0.25	0.12
ADFI, g	690	683	698	705	701	14	0.54	0.60	0.96	0.71
G:F	0.641	0.645	0.610	0.644	0.627	0.013	0.34	0.06	0.11	0.01
Caloric efficiency, mcal/kg										
ME	5.17	5.09	5.33	5.20	5.40	0.08	0.82	0.06	0.11	0.01
NE	3.74	3.62	3.74	3.73	3.81	0.06	0.76	0.64	0.17	0.11
BW, kg										
d 0	6.9	6.9	6.9	6.9	6.9	0.1	0.98	0.98	0.96	0.95
d 12	9.9	10.0	10.0	10.2	10.0	0.2	0.46	0.68	0.41	0.60
d 29	19.7	19.6	19.2	20.0	19.7	0.3	0.83	0.56	0.36	0.23

[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] No effects of balancing on NE ($P < 0.12$).

[3] Interactive effects of midds level and balanced on an NE basis.

[4] Combines treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds linear contrast.

[5] Combines treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds quadratic contrast.

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

Chapter 2 - The effects of corn particle size, complete diet grinding, and diet form on finishing pig growth performance

ABSTRACT

A total of 855 pigs (PIC TR4 × (Fast Genetics York-AND × PIC Line 02), initially 25.65 kg BW) were used in a 111-d trial to evaluate the effects of corn particle size, complete diet grinding, and diet form (meal or pellet) on finishing pig growth performance, and carcass characteristics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 9 replications per treatment. All pigs were fed the same corn-soybean meal–based diet containing 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings (midds). Diets were fed in four phases from d 0 to 35, 35 to 65, 65 to 93, and 93 to 111. Different processing techniques were used to achieve the 5 dietary treatments: (1) roller-mill ground corn to approximately 650 µ with the diet fed in meal form; (2) hammer-mill ground corn to approximately 320 µ with the diet fed in meal form; (3) treatment 2 pelleted; (4) corn initially roller-mill ground to approximately 650 µ, then the complete mixed diet reground through a hammer-mill to approximately 360 µ with the diet fed in meal form; and (5) treatment 4 pelleted. Overall (d 0 to 111), diet form × portion ground interactions were observed ($P < 0.02$) for ADG, ADFI, final BW, percentage pig removals per pen, and HCW. These interactions occurred because fine grinding the complete diet reduced all measurements when fed in meal form, whereas pigs fed that same diet in pellet form had increased responses for each of the measurements. Reducing particle size of the corn from 650 to 320 µ did not affect ADG or ADFI but improved ($P < 0.003$) G:F, and caloric efficiency. Pelleting the diet improved ($P < 0.001$) ADG, G:F, caloric efficiency, final BW, HCW, and loin depth and tended to increase ($P < 0.07$) BF. In conclusion, reducing corn particle size and pelleting complete diets improved

performance and carcass characteristics. Fine-grinding the entire diet was detrimental when fed in meal form but improved performance when pelleted.

Key words: finishing pig, growth, ingredient processing, particle size, pellet

INTRODUCTION

Grain processing and feed manufacturing is a vital part of swine production. Producers initially learned to grind cereal grains to improve digestibility and pig growth. Currently, grinding occurs through a variety of different mill types ranging from 1, 2, 3, or even 4 high roller-mills or hammer-mills with varying sizes of screens capable of producing a wide variety of ingredient particles. Wondra et al. (1995a) observed that decreasing corn particle size from 1,000 to 400 µ improved apparent digestibility of DM, N, and GE. Owsley et al. (1981) and Giesemann et al. (1990) also saw improved digestibility of both sorghum, and corn-based diets, respectively, as particle size was reduced. A large amount of research has been conducted investigating grinding corn and other high energy, low fiber feed ingredients. However few studies have determined the effects of fine grinding high fiber, lower energy ingredients such as dried distillers grains with solubles (**DDGS**) and wheat middlings (**midds**). Also, there is little reported research on the effects of grinding complete diets after mixing.

Pelleting is another feed processing technology that is currently being used throughout the swine industry. Stark (1994) and Wondra et al. (1995a) have shown that pelleting diets improves ADG and feed efficiency of finishing pigs. However, little data is available on the interactions of pelleting high fiber diets in the presence of varied particle sizes of ingredients or the entire diet.

Therefore, the objective of this experiment was to determine the effects of corn particle size, complete diet grinding, and diet form on finishing pig growth performance, caloric efficiency and carcass characteristics.

MATERIALS AND METHODS

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and use Committee. The study was conducted at the New Fashion Pork Research Facility (Round Lake, MN) in a commercial research-finishing barn in northwestern Iowa. The barn was tunnel ventilated and double-curtain-sided. Pens (2.4 × 17.8 m) had concrete slatted floors, and deep pits for manure storage. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a waterer for ad libitum access to feed and water. There were 19 pigs per pen allowing for 0.75 m2/pig. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. 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. All diets were prepared at the New Fashion Pork feed mill (Estherville, IA).

Chemical Analysis

Samples of ground corn, soybean meal, midds, and DDGS were collected at the mill as well as samples of each diet between each weigh day, blended within phase, and sub-sampled. All ingredient and feed samples were analyzed for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), P (AOAC 965.17/985.01, 2006), ADF (ANKOM Technology, 1998), NDF (ANKOM Technology, 1998) and NFE which was calculated with the equation: NFE = 100 - crude protein - crude fiber - fat – ash at Ward Laboratories, Inc. (Kearney, NE).

Animals and Diets

A total of 855 pigs (PIC TR4 × (Fast Genetics York-AND × PIC Line 02), initially 25.6 kg BW) were used in a 111-d trial. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 9 replications per treatment and 19 pigs per pen in a completely randomized design. The same corn-soybean meal–based diet containing 30% DDGS and 20% midds was used for all treatments. Diets were fed in four phases from d 0 to 35, 35 to 65, 65 to 93, and 93 to 111. Different processing techniques were used to achieve the 5 dietary treatments: (1) roller-mill ground corn to approximately 650 μ with the diet fed in meal form; (2) hammer-mill ground corn to approximately 320 μ with the diet fed in meal form; (3) treatment 2 pelleted; (4) corn initially roller-mill ground to approximately 650 μ, then the complete mixed diet reground through a hammer-mill to approximately 360 μ with the diet fed in meal form; and (5) treatment 4 pelleted. All ingredients were ground and mixed at a commercial feed mill in Estherville, IA. All 620 μ corn was ground using a 2-high roller mill (RMS Roller Grinder, Tea, SD). All ingredients that were finely ground were processed using a full circle hammer-mill (Jacobsen Machine Works, Minneapolis, MN) equipped with a 1.59 mm screen. Diets were pelleted with a CPM pellet mill (California Pellet Mill, San Francisco, CA) equipped with a 4.3 mm die.

Feed samples were collected from each feeder during each phase to measure bulk density (Seedburo Model 8800, Seedburo Equipment, Chicago, IL). Bulk density of a material represents the mass per unit volume (g per liter). Bulk density was also determined for all ingredients pre and post grind using methods from Clementson et al., (2010). Particle size of the corn, soybean meal, midds, DDGS, and complete diets also were determined using the ASAE (2008) standard method for determining particle size. Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan, were used. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for 10 min without the use of a flow agent. A geometric mean particle size (dgw) and the log normal standard deviation (sgw) were calculated by measuring the amount of grain remaining on each screen. For all diets in pelleted form, pellet durability index (PDI) and percentage fines were determined. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987) and modified PDI by altering the procedure by adding 5 13-mm hexagonal nuts prior to tumbling. Percentage fines (ASAE, 1987) and angle of repose (Appel, 1994) were also determined for all pellet and meal diets respectively.

Pigs and feeders were weighed approximately every 2 weeks to calculate ADG, ADFI, and G:F. 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 (2004). Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by dietary energy (mcal/kg) and dividing by total pen gain. Values from NRC (1998) were used instead of values from NRC (2012) as they had not been published at the time of formulation. On d 93 of the trial, pens of pigs were weighed and the 3 heaviest pigs (selected by the marketing serviceman) were loaded and transported 350 miles to a commercial packing plant (Triumph Foods in St. Joseph, MO) for harvest. Similarly, on d 100, the next 3 heaviest pigs, as selected by the marketing serviceman, were loaded, and transported for harvest. The remaining pigs were than slaughtered on d 111. Due to the transportation length and summer temperatures, carcass yield (calculated using live weight at the farm and plant HCW) was lower for all marketing events than typical commercial carcass yields. Before harvest, pigs were tattooed according to pen number to allow for carcass data collection at the plant and data retrieval by pen. At the plant, backfat depth and loin depth were measured, and percentage lean was calculated using NPPC (1991) guidelines for lean containing 5% fat.

Statistical Analysis

Data were analyzed as a completely randomized design using the PROC-Mixed procedure of the Statistical Analysis System (SAS Institute, 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 pre-planned contrasts included 1) main effects of grinding corn in meal diets 2) interactive effects of diet form and the portion of the diet that was ground; 3) main effects of complete diet grinding; and 4) main effects of diet form. Because there were treatment differences in HCW, it was used as a covariate for backfat, loin depth, and percent lean adjustment. Differences between treatments were determined by using least squares means ($P < 0.05$), and trends were declared at $P < 0.10$.

RESULTS

Chemical analysis

Ingredient samples of corn, soybean meal, DDGS, and midds were verified to be similar to those used in formulation (Tables 2.1 and 2.2). The minor differences would not be expected to influence the results of the experiment. Nutrient analysis of the treatment diets (Table 2.3) showed that for most of the nutrients, the levels were similar to formulated values. The only exception was ADF and NDF which on average were lower than formulated values. This would be expected as ADF and NDF values for ingredients used in formulation were all slightly greater than analyzed values.

Analysis of diets (Table 2.4) revealed that, as expected, as the portion of the diet that was ground increased from corn to the complete diet, the particle size of the diet decreased, which led to an increase in the diet angle of repose. Bulk densities of meal diets were all relatively similar. Diets that were pelleted were higher in bulk density when compared to the meal diets. Grinding the complete diet versus only grinding the corn on average increased both the standard and modified PDI and decreased the percentage of fines in pelleted diets.

Growth and carcass

Overall (d 0 to 111), diet form × portion ground interactions were observed ($P < 0.02$) for ADG, ADFI, final BW, percentage pig removals per pen, and HCW (Table 2.5). These interactions occurred because fine grinding the complete diet reduced each variable when fed in meal form, whereas pigs fed that same diet in pellet form had increased responses for each of the measurements.

Reducing particle size of the corn from 650 to 320 μ did not affect ADG or ADFI but improved ($P < 0.003$) G:F, and caloric efficiency. Pelleting the diet improved ($P < 0.001$) ADG, G:F, caloric efficiency, final BW, HCW, and loin depth but tended to increase ($P < 0.07$) BF.

DISCUSSION

In the current experiment, particle size reduction improved G:F and caloric efficiency; however, fine grinding the complete diet was actually detrimental to performance when fed in meal form. Particle size reduction of corn has been consistently shown to improve performance in finishing pigs. Hedde et al. (1985) observed that pigs fed finer particle corn compared to simple cracked corn had improved ADG and G:F. Wondra et al. (1995 a, b) found that reducing particle size from 1,000 to 400 or 800 to 400 µ improved G:F and apparent digestibility of diets. Wu et al. (1984) found that decreasing particle size increased the total particle surface area but worsened mill production rate and grinding efficiency. Feed efficiency and digestibility of DM, N, and energy all improved as particle size decreased, suggesting the increase in surface area led to increased enzymatic breakdown of particles and improved absorption of nutrients along the small intestine. Thus, mills and producers must balance decreased mill efficiency with growth benefits.

The improved feed efficiency from most research evaluating reducing particle size may point to improved digestibility of the diets with finely ground ingredients. A possible way to estimate energy digestibility of a diet without conducting a digestibility experiment is by calculating caloric efficiencies. Johnson et al. (2003) discussed the history of energetic efficiency research and noted that efficiency requires both a numerator and a denominator being the unit of gain and the unit of diet energy respectively. Caloric efficiencies are, and have been, a common calculation and benchmark that has been used in ruminant nutrition. In the current experiment, caloric efficiencies were calculated by using the total energy consumed and dividing it by total gain, thus a lower value equates to improved caloric efficiency. We hypothesized that grinding the corn, complete diet, and pelleting would have allowed for more calories to be available to the pig, thus improving caloric efficiency. However, only grinding the corn portion and pelleting the diets improved caloric efficiency. Interestingly, grinding the diet post-mix did not improve caloric efficiency over that of the diet with only the corn ground fine, which means that fine grinding of the other major ingredients (soybean meal, DDGS and midds) did not create additional diet energy for the pig regardless of feed form.

In the current experiment, not only was corn finely ground but the complete mixed diet was also ground. This method of grinding post-mix is currently not common in many North American feed mills. In limited research evaluating this processing method, Hedde et al. (1985) fed pigs corn-soybean meal diets containing either cracked corn or the complete diet passed through a hammer mill. They concluded that pigs fed the post-mix ground diet had improved ADG and G:F. However, pigs fed the post-mix ground diet had lighter stomach weights and increased ulcer scores and numerically more pigs were culled or died during the experiment. It should be noted that ADFI was similar between treatments; however, in the current trial ADFI decreased when the complete diet was finely ground. The decrease in ADFI may have been a result of decreased palatability of the diet when finely ground. Work by Mavromichalis et al. (2000) and Wondra et al. (1995a) both showed that finely ground ingredients in diets decreased ADFI, which supports data from the current experiment.

Ulceration of the pig's esophageal region of the stomach are a concern when feeding finely ground ingredients or diets. Much research has been conducted and concluded that fine grinding ingredients for swine can increase the chance of ulceration of the stomach lining. Mahan et al. (1966) reported that feeding diets containing finely ground corn increased the incidence of gastric lesions. They also reported that stomachs with lesions were significantly more fluid filled and had a lower pH than the contents of normal stomachs. Maxwell et al. (1970) conducted similar experiments in which pigs were fed diets containing various corn particle sizes. They also reported that pigs fed diets containing finer particle size corn increased the formation of gastric lesions. They also reported increased pepsin activity and acidity of stomachs of pigs fed finely ground diets. The increase in pepsin activity and decrease in pH were most likely from an increase in gastric mixing of the stomach contents due to increased fluidity of the digesta. Flatlandsmo and Slagsvold (1971) reported that pigs fed finely ground diets in meal or pellet form had a higher incidence of ulceration in the stomach. They also showed that pelleting diets increased the incidence of ulcers as well. The increased incidence of ulceration of the esophageal region due to both pelleting and fine grinding diets is a concern; however, little research has shown ulceration to cause poor performance in finishing pigs. Guise et al. (1997) conducted an experiment using pigs from a farm consisting of two units with a historically high prevalence of ulcers (44 and 60% as determined at the abattoir) to determine if differences existed in growth rate of pigs with or without ulcers at time of harvest. During the study, pigs were fed similar diets and pigs were weighed and tagged individually at approximately 5 weeks of age and weighed again approximately one week before slaughter. Pigs were then followed to the abattoir where the prevalence of ulcers in the two farms were determined to be 56 and 53% respectively. There were no significant differences between the daily live weight gains of pigs with or without ulcers. This would suggest that if the effect of ulceration isn't severe enough to be fatal, normal growth performance can be achieved. In the current experiment, there were increased removals/pen for pigs fed the diet that was post-mix ground and pelleted. However, no clear link was found between removals and feed processing in this study. Most removals reported during the study appeared to be caused by reasons other than experimental treatment effects (lameness, prolapse, and intestinal torsion). More research needs to be conducted to evaluate whether this effect was specifically diet-related.

Fine grinding ingredients and complete diets can also lead to feed handling issues. In the current experiment, angle of repose was used as an indicator of the flowability of the diet. Fine grinding only the corn fraction of the diet didn't affect angle of repose when compared to the control. This was most likely caused by only a small portion of the diet consisting of corn

(30-40%). However, when the complete diet was reground there was an increase in the angle of repose when compared to the control or the meal diet with finely ground corn. According to Carr (1965), the angles of repose reported in the present study ranging from 51.8 to 59.1˚ would be considered to have poor or very poor flowability. However, no feed bridging or out of feed experiences were reported throughout the trial. Reduced flow ability can lead to out of feed events, leading to fighting and aggressive behavior detrimental to the animal's health, increased incidences of ulceration, hemorrhagic bowel syndrome, and increased days to slaughter (Brumm 2005). Groesbeck et al., (2006) conducted an experiment investigating the effects of particle size, particle size standard deviation, and mill type on the angle of repose of corn. The study showed that hammer-mill ground corn had increased angle of repose compared to roller-mill ground corn at a similar particle size mean. This was mainly due to the increased standard deviation of the particle sizes for the hammer-mill ground corn compared to the roller-mill. Liu et al. (2011) also showed that adding DDGS to swine diets and decreasing the particle size of the DGGS increased the angle of repose. Ganesan et al. (2007) reported that high oil DDGS (9.3% fat) had decreased flowability characteristics when compared to low oil (2.1% fat) DDGS. The DDGS used in the current study were analyzed to contain 11.4% fat and may have been a cause for the increased angles of repose. Feed handling is complicated even further with high by-product diets such as the ones used in the present study. The increase in fibrous material can lead to a decrease in the bulk density of the diets. Bulk densities of the pelleted diets were substantially higher than the meal diets in this experiment and may have improved feed handling characteristics. This is supported by Behnke (2001) who noted that pelleting diets improves the ease of handling, and increases the bulk density of the diet.

In tandem with fine grinding diets, pelleting is another common form of feed processing that was used in the current experiment. Many experiments show that pelleting can be utilized to increase ADG and G:F or energy digestibility in finishing pigs (Paulk et al., 2011; Potter et al., 2010; and Skoch et al., 1983). The exact mode of action that leads to pigs having increased gain and feed efficiencies may come from various aspect of pelleting. Hanrahan et al. (1984) suggested that two main reasons exist for the improved performance: reduced feed wastage and improved digestibility of the pelleted diet. The current experiment would suggest that diet energy digestibility was improved when the diet was pelleted. This is shown by the improved caloric efficiencies of the pelleted diets compared to diets in meal form. McKinney et al. (2003) conducted an experiment to determine the effective caloric value (ECV) which can be attributed to pelleting and pellet quality when fed to broilers. By feeding diets with varying pellet qualities and a mash control, the researchers were able to determine that pelleting improves the caloric value of diets based on the pellet quality as measured by percent fines. At 100% pellet quality with no fines, pelleting provided 187 kcal MEn/kg feed consumed. The ECV of pelleting decreased as pellet quality decreased. Researchers also noted that as the proportion of pellets in the feeder increased, birds were observed eating less and resting more frequently. The decreased time spent eating and more time spent resting may have lowered the bird's energy requirements for maintenance. However, it appears more viable that the added nutritive value available from the pellets when compared to the meal diet provided the increased ECV.

Stark et al. (1994) conducted 2 experiments with nursery and finishing pigs which were fed pellets that were screened or contained 15, 25, or 30% fines. In the first experiment, G:F tended to decrease as fines were added to the diet and G:F numerically decreased as fines increased in the second experiment. Schell et al. (1998) conducted two similar experiments feeding pelleted diets containing 2.5, 13, 25, and 40% or 3, 12, 23, and 37% fines respectively. In the first experiment pigs fed increasing fines had poorer feed efficiency and higher feed disappearance which would suggest that the increased level of fines may have led to more feed wastage by the pigs. In the second experiment ADG was lower for pigs fed the 12 and 37% fines diets compared to those fed the 3% fines diet. Feed efficiency was also worse for all diets when compared to the 3% fines diet. More recently, Nemechek et al. (2013) conducted an experiment feeding screened pellets and pellets with 50% fines to finishing pigs. They concluded that pigs fed pellets with 50% fines had numerically worse ADG and significantly worse G:F. This work suggests that increased feed wastage may result when increasing percentage of fines are fed. In the current study, all pelleted diets had less than 20% fines suggesting pellet quality should not be a contributing factor of the results reported.

To improve pellet quality, various formulation techniques can be used. Fahrenholz et al. (1988) conducted two experiments feeding increasing levels of midds to finishing pigs fed pelleted diets. They reported that increasing the inclusion rate of dietary midds improved pellet durability. The increased pellet durability was most likely due to the increased fibrous material in the diet, which allowed for more cross linking of fibers within the pellets. More recently, Fahrenholz et al. (2008) conducted a series of experiments to determine the effect of DDGS level on pellet quality. Distillers dried grains with solubles were fed to finishing pigs at inclusion levels of 0, 10, 20, 30, and 40% in pellet form. In the first experiment, the inclusion of DDGS had no effect on pellet durability but did decrease production rate and diet bulk density whether in meal or pellet form. In the second experiment, pellet quality decreased as DDGS were included in the diet. It should be noted that even with decreases in PDI, all pelleted diets were still well above 80% for their respective PDI values, which the authors consider acceptable for both poultry and swine diets. Also, as in the first experiment, increasing the dietary DDGS level led to decreased production rate and bulk density for meal and pelleted diet forms. Pellet durability indexes from the current trial were on average above 90% and percent fines were all below 20% which suggest pellets were high quality. It appeared that finely grinding either the corn or complete diet did improve pellet quality.

In conclusion, fine grinding corn and pelleting the diet can improve performance, carcass characteristics, as well as caloric efficiency of finishing pigs. However, grinding the complete diet and feeding it in meal form had detrimental effects to all criteria measured which may be due to reduced palatability of a finely ground diet presented in meal form. Finally, post-grinding a complete diet did not provide any advantage in growth performance to that of a diet with only finely ground corn, thus indicating that fine grinding DDGS, midds and soybean meal does not provide an additional benefit.

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TABLES AND FIGURES

Table 2-1 Diet composition of experimental diets (as-fed basis)[1]

	Phase			
Item	1	2	3	4
Ingredient, %				
Corn	30.94	34.82	39.03	32.69
Soybean meal (46.5% CP)	16.81	12.98	8.77	15.09
Wheat middlings	20.00	20.00	20.00	20.00
Dried distillers grains with solubles	30.00	30.00	30.00	30.00
Limestone	1.50	1.50	1.50	1.50
Salt	0.35	0.35	0.35	0.35
VTM premix[2,3]	0.10	0.10	0.10	0.10
L-Lys HCl	0.30	0.25	0.25	0.25
Ractopamine HCL,[4] 20g/kg	---	---	---	0.03
Total	100	100	100	100
Calculated analysis				
Standard ileal digestible (SID) AA, %				
Lys	0.98	0.85	0.75	0.90
Iso:Lys	70	74	75	73
Met:Lys	32	34	36	34
Met & Cys:Lys	63	68	73	67
Thr:Lys	63	67	69	66
Trp:Lys	19	19	19	19
Val:Lys	73	80	86	78
Total Lys, %	1.16	1.02	0.91	1.07
ME,[5] kcal/kg	3,373	3,376	3,379	3,373
NE,[6] kcal/kg	2,327	2,352	2,379	2,338
SID Lys:ME, g/Mcal	3.03	2.62	2.30	2.78
CP, %	21.2	19.7	18.1	20.5
Crude fiber, %	4.6	4.5	4.4	4.5
NDF, %	22.3	22.4	22.4	22.3
ADF, %	8.8	8.7	8.6	8.7
Ca, %	0.67	0.66	0.64	0.66
P, %	0.60	0.59	0.57	0.59
Available P, %	0.42	0.41	0.41	0.41

[1] Phase 1 diets were fed from d 0 to 35, Phase 2 from 35 to 65, Phase 3 from 65 to 93, and Phase 4 from d 93 to 111.

[2] Provided per kg of premix: 5,292,000 IU vitamin A; 1,653,750 IU vitamin D_3; 55,125 IU vitamin E; 2,205 mg vitamin K; 4,961 mg riboflavin; 17,640 mg pantothenic acid; 26,460 mg niacin; 24.3 mg vitamin $B_{12;}$ 662 ppm Mn; 165,375 ppm Fe; 220,500 ppm Zn from0; 33,075 ppm Cu; 1,103 ppm I; and 662 ppm Se.

[3] Optiphos (Enzyvia LLC, Sheridan, IN.) provided 551.3 FTU/kg, with a release of 0.12% available P.

[4] Paylean; Elanco Aninmal Health, Greenfield, IN.
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Table 2-2 Chemical analysis of ingredients (as-fed basis)[1]

Item	Wheat middlings	DDGS[2]	Corn	Soybean meal
DM, %	90.76	90.63	87.73	91.14
CP, %	16.3(15.9)[3]	27.0(27.2)[4]	6.8(8.5)	46.5(46.5)
ADF, %	11.0	13.5	2.4	6.1
NDF, %	31.2	27.1	7.8	6.7
Crude fiber, %	7.6(7.0)	8.7(7.3)	1.8(2.2)	2.9(3.9)
NFE, %	56.4	37.2	75.0	32.7
Ca, %	0.14(0.12)	0.06(0.03)	0.06(0.03)	0.37(0.34)
P, %	1.19(0.93)	0.89(0.71)	0.29(0.28)	0.71(0.69)
Fat, %	3.7(4.2)	11.4(10.7)	2.99(3.9)	1.1(1.5)
Ash, %	5.47	4.28	1.09	5.94
Particle size, µ	627	580	647; 322[5]	1,070
Paticle size, SD	2.28	1.99	2.37	1.64
Bulk density, g/L	361	589	651; 620[6]	794

[1] Values in parenthesis indicate those used in diet formulation.
[2] Dried distillers grains with solubles.
[3] Values in parenthesis from NRC (1998).
[4] Values in parenthesis for DDGS are taken from Stein (2007).
[5] Average roller-milled corn was 647 µ; average hammer-milled corn was 322 µ.
[6] Average roller-milled corn was 651 g/L; average hammer-milled corn was 620 g/L.

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

Item[2]	Phase 1	Phase 2	Phase 3	Phase 4
DM, %	89.87	89.48	89.61	89.89
CP, %	20.6	19.3	18.4	20.6
ADF, %	7.1	7.3	7.1	7.2
NDF, %	15.9	16.3	15.8	26.8
Crude fiber, %	4.4	4.5	4.4	4.8
NFE, %	53.5	54.3	55.6	52.5
Ca, %	0.48	0.66	0.38	0.39
P, %	0.61	0.63	0.57	0.67
Fat, %	4.7	4.9	4.9	5.5
Ash, %	5.45	5.23	5.01	5.61

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Diet 1 was used for analysis, as all treatments were formulated identically.

Table 2-4 Analysis of diets[1]

Item	Portion ground:[2] / Diet form:	---[3] Meal	Corn Meal	Corn Pellet	Complete diet Meal	Complete diet Pellet
Bulk density, g/L						
Phase 1		586	578	789	600	801
Phase 2		574	570	768	569	790
Phase 3		570	578	785	574	803
Phase 4		581	577	794	578	802
Particle size, µ						
Phase 1		552	515	---	394	---
Phase 2		619	483	---	344	---
Phase 3		612	440	---	365	---
Phase 4		602	511	---	355	---
Angle of repose, º						
Phase 1		51.8	52.8	---	58.6	---
Phase 2		54.4	53.1	---	58.8	---
Phase 3		52.3	57.1	---	58.4	---
Phase 4		52.1	55.5	---	59.1	---
Standard pellet durability index						
Phase 1		---	---	96.1	---	96.3
Phase 2		---	---	94.4	---	96.7
Phase 3		---	---	92.9	---	93.0
Phase 4		---	---	94.5	---	97.2
Modified pellet durability index						
Phase 1		---	---	93.2	---	91.5
Phase 2		---	---	91.7	---	95.0
Phase 3		---	---	88.1	---	90.0
Phase 4		---	---	90.9	---	92.9
Fines, %						
Phase 1		---	---	14.1	---	11.3
Phase 2		---	---	31.7	---	15.7
Phase 3		---	---	8.1	---	7.8
Phase 4		---	---	13.8	---	14.6

[1] A composite sample of four subsamples was used for analysis.
[2] Ingredients or complete diets were ground through a hammer mill using a 1.59 mm screen. Corn was ground to an approximate particle size of 320 µ; complete diets were ground to approximately 360 µ.
[3] Corn for the first treatment was ground through a roller mill and was approximately 650 µ.

Table 2-5 The effect of grinding corn or a complete diet and diet form (meal vs. pellet) on finishing pig performance[1]

Treatments:	1	2	3	4	5					
Portion ground:[2]	---[3]	Corn	Corn	Complete diet	Complete diet		Probability, P <			
Corn µ	620	320	320	320	320					
Item, Diet form:	Meal	Meal	Pellet	Meal	Pellet	SEM	Corn µ[4]	Diet form × portion ground	Grinding[5]	Diet form[6]
d 0 to 111										
ADG, kg	0.92	0.93	0.96	0.90	0.98	0.01	0.15	.0009	0.89	0.0001
ADFI, kg	2.58	2.53	2.48	2.48	2.55	0.03	0.13	0.02	0.68	0.52
G:F	0.355	0.369	0.385	0.365	0.385	0.003	0.004	0.58	0.51	0.0001
Caloric efficiency[7]										
ME	9.54	9.16	8.78	9.26	8.79	0.08	0.003	0.59	0.50	0.0001
NE	6.65	6.39	6.12	6.46	6.13	0.04	0.002	0.54	0.50	0.0001
BW, kg										
d 0	25.6	25.7	25.7	25.6	25.7	0.4	0.93	0.96	0.99	0.98
d 111	122.8	125.0	125.5	121.8	129.4	1.1	0.15	0.002	0.76	0.0004
Removal/pen, %	6.6	8.8	4.1	2.3	12.9	2.69	0.56	0.005	0.65	0.26
Carcass										
HCW, kg	90.9	91.2	93.1	89.3	94.7	0.8	0.74	0.02	0.82	<.0001
Yield, %	73.6	72.6	73.0	73.2	72.7	0.3	0.06	0.21	0.72	0.83
Backfat depth, mm	19.2	19.5	19.7	19.3	20.5	0.3	0.52	0.10	0.36	0.07
Loin depth, mm	60.1	59.5	61.5	59.4	60.2	0.5	0.35	0.25	0.13	0.02
Lean,[8] %	52.9	52.7	53.0	52.8	52.5	0.2	0.35	0.07	0.15	0.91

[1] A total of 855 pigs (PIC TR4 × (Fast Genetics York-AND × PIC Line 02) initially 25.6 or 25.7 kg BW) were used in a 111-d trial, there were 19 pigs per pen and 9 pens per treatment.
[2] Ingredients or complete diets were ground through a hammer-mill using a 2 mm screen. Corn was ground to approximate particle size of 320µ; complete diets were ground to approximately 360 µ.
[3] Corn was ground through a roller-mill and was approximately 650 µ.
[4] Treatment 1 vs. 2.
[5] Treatments 2, 3 vs. 4, 5.
[6] Treatments 2, 4 vs. 3, 5.
[7] Caloric efficiency is expressed as mcal/kg of gain.
[8] Calculated using NPPC (1991) guidelines for lean containing 5%: Lean (5 % fat), lb = 2.83 + (0.469 × HCW, lb) – (18.47 × last rib fat thickness, in.) + (9.824 × loin muscle depth, in.

Chapter 3 - The effects of particle size, complete diet grinding, and diet form on nursery pig growth performance

ABSTRACT

Two experiments were conducted to determine the effects of ingredient particle size, complete diet grinding, and diet form on nursery pig growth performance. In Exp. 1, 675 pigs (11.1 kg BW) were fed 1 of 8 diets for 21 d. The 8 diets included 3 corn-soybean meal–based (CS) diets consisting of: (1) corn ground to ~620 μ, in meal form, (2) corn ground to ~352 μ in meal form, and (3) diet 2 in pellet form. The remaining diets were high by-product (HBP) diets containing 20% wheat middlings (midds) and 30% distiller dried grains with solubles (DDGS). Diets 4 to 8 consisted of: (4) corn, soybean meal, midds, and DDGS of ~ 620, 889, 534 and 701 μ, in meal form, (5) diet 4 but corn ~352 μ, in meal form; (6) diet 5 in pellet form, (7) corn, soybean meal, DDGS, and midds ground to ~352, 421, 377, and 357 μ, in meal form; and (8) diet 7 in pellet form. Overall (d 0 to 21), a grinding × diet form interaction was observed ($P < 0.02$) for ADG as pelleting significantly increased ADG when only the corn was ground but only slightly increased ADG when the complete diet was ground. Grinding the complete diet improved G:F and caloric efficiency on an ME and NE basis when fed in meal form but worsened both when fed in pelleted form resulting in another grinding × diet form interaction. Also, pigs fed pelleted diets had improved ($P < 0.03$) ADG, G:F, and caloric efficiency on an ME or NE basis. Reducing corn particle size reduced ADG ($P < 0.02$) and tended ($P < 0.08$) to reduce ADFI when fed in meal form. Pigs fed the HBP diet had reduced ($P < 0.001$) ADG, ADFI, and final BW with poorer ($P < 0.01$) G:F compared to those fed CS diets. Pigs fed diets with all fine ground major ingredients in meal or pellet form had reduced ($P < 0.05$) ADG, ADFI, and final BW. In Exp. 2, 687 pigs (11.6 kg BW) were fed 1 of 10 diets for 21 d. The 10 diets included 4 CS diets consisting of: (1) corn ground to ~638 µ in meal form, (2) treatment 2 in pellet form, (3) corn ground to ~325 µ in meal form, and (4) treatment 3 in pellet form. The remaining 6 diets were HBP diets containing 30% DDGS. Diets 5 to 10 consisted of: (5) corn and DDGS ground to ~638 and 580 µ, in meal form, (6) diet 5 in pellet form, (7) corn and DDGS ground to ~638 and 391 µ, in meal form, (8) diet 7 in pellet form, (9) corn and DDGS ground to ~325 and 391 µ, in meal form, and (10) diet 9 in pellet form. Overall (d 0 to 21), a corn particle size × diet form interaction was observed ($P < 0.01$) as a result of increased ADFI when corn was ground fine and fed in pellet form but decreased ADFI when fed in meal form. Pelleting diets decreased ($P < 0.0001$) ADG, ADFI, caloric efficiency, and final BW but increased ($P < 0.0001$) G:F. Fine grinding corn decreased ($P < 0.04$) ADG. Also, feeding 30% DDGS decreased ($P < 0.01$) ADG, ADFI, and NE caloric efficiency. In conclusion, fine grinding ingredients decreased ADG and ADFI for nursery pigs, while pelleting improved G:F and diet caloric value.

Keywords: Caloric efficiency, DDGS, feed processing, nursery pigs, particle size, wheat middlings

INTRODUCTION

Feed processing and manufacturing technologies allow for more efficient nutrient utilization of grains used in swine diets. Two primary technologies exist to improve ingredient utilization: fine grinding and pelleting. Feed mills utilize various grinders to reduce grain particle size. Grinders consist of either roller-mills with 1 to 4 sets of rollers stacked vertically or hammer-mills which consist of varying cylindrical shaped rotors with attached hammers capable of forcing grain through a sized screen. Particle size of the grain is controlled through the roller-mill by tightening or widening the gap between the side by side rolls and in the hammer-mill by increasing or decreasing the screen hole size. Owsley et al. (1981) and Giesemann et al. (1990) both observed improved digestibility of both sorghum and corn based-diets as particle size was reduced. Yanez et al. (2011) also found improved digestibility of distillers dried grains with solubles (**DDGS**) as particle size was decreased as well as improved digestibility of most amino acids. However, little is known about the effects of fine grinding other ingredients in combination with corn or the effect that diet particle size may have on nursery pig performance. Feed mills are not normally designed to allow for post mix grinding, and thus, ingredients other than cereal grains are not often fine ground.

Pelleting diets has been shown to improve ADG and feed efficiency of nursery pigs (Hansen et al., 1992; Stark et al., 1994; and Traylor et al., 1996). However, little data is available on the interaction between pelleting high fiber diets and particle size of ingredients or the entire diet and their effect on nursery pig performance. Thus, the objective of both experiments was to determine the effects of ingredient particle size, complete diet grinding, and diet form on nursery pig growth performance.

MATERIALS AND METHODS

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and use Committee. Both studies were conducted at the Kansas State University Segregated Early Wean facility (Manhattan, KS). Two groups of pigs were used within each experiment and then combined for analysis (there were no group × treatment interactions for either trial). Pens (1.22 × 1.22 m) had wire-mesh floors, and deep pits for manure storage. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. All pigs were fed common pelleted starter diets before implementation of experimental diets.

Feed was manufactured separately for each group of pigs within experiments. All ingredients were ground and mixed at the K-State Grain Sciences and Industry Feed Mill. All 620-µ corn was ground by a 3-high roller mill (Model TP 912, Roskamp Manufacturing, Cedar Falls, IA). All ingredients that were finely ground were processed using a full-circle teardrop hammer-mill (P-240D Pulverator, Jacobsen Machine Works, Minneapolis, MN) with a 1.59 mm screen. Diets from the 1st group of Exp. 1 and all diets in Exp. 2 were pelleted in a 30-horsepower pellet mill (30 HD Master Model, California Pellet Mill, San Francisco) with a 3.2-mm-thick die with 2/5-cm openings in the K-State Grain Sciences and Industry Feed Mill. Diets in the 2nd group of Exp. 1 were transported to Hubbard Feeds (Beloit, KS) post mixing to be pelleted. Diets were pelleted with a Sprout Waldron Pellet Mill, (model Ace 501) equipped with a 4.3 mm die. Corn was from the same source within experiments and was split at the mill to be ground through the hammer-mill or roller-mill.

For both experiments, diets were not balanced for energy, such that, as the level of wheat middlings (**midds**) or DDGS increased in the diet, dietary energy was decreased. All diets for all experiments were formulated to a constant lysine concentration based on the requirement of the control diet containing no midds or DDGS to ensure changes in performance were due to dietary energy or processing differences rather than differences in AA concentrations. For diet formulation, the assumed ME (3,420; NRC, 1998) and NE (2,650 kcal/kg; INRA, 2004) values for DDGS were same as corn values, and the ME and NE values of midds were 3,025 and 1,850 kcal/kg (NRC, 1998, and INRA, 2004), respectively (Tables 3.1 and 3.2).

Caloric efficiency of pigs were determined on both an ME and NE basis. 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 (2004). Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by the dietary energy level (mcal/kg) and dividing by total pen gain. Values from NRC (1998) were used instead of values from NRC (2012) as they had not been published at the time of formulation. Pig weight and feed disappearance were measured on d 0, 7, 14 and 21 of the experiments to calculate ADG, ADFI and G:F.

Chemical Analysis

Samples of each diet were collected from feeders between each weigh day, blended and sub-sampled for analysis of DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), P (AOAC 965.17/985.01, 2006), ADF (ANKOM Technology, 1998), NDF (ANKOM Technology, 1998), and NFE which was calculated by the equation: NFE = 100 - crude protein - crude fiber - fat – ash (Ward Laboratories, Inc. Kearney, NE).

Bulk density was determined for all ingredients pre- and post-grind as well as for the complete diets using methods from Clementson et al. (2010). Particle size of the corn, soybean meal, midds, DDGS, and complete meal diets also were determined using the ASAE (2008) standard method for determining particle size. Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan, were used. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for ten min. A geometric mean particle size (dgw) and the log normal standard deviation (sgw) were calculated by measuring the amount of grain remaining on each screen. For all diets in pelleted form, pellet durability index (PDI) and percentage fines were determined. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987) and modified PDI by altering the procedure by adding 5 13-mm hexagonal nuts prior to tumbling. Percentage fines (ASAE, 1987) and angle of repose (Appel, 1994) were also determined for all pellet and meal diets, respectively.

Experiment 1

A total of 675 pigs (1050 barrows; PIC, Hendersonville, TN; initially 11.1 kg BW and 37 d of age) were used in a 21-d study. Pigs were fed 1 of 8 diets for 21 d with 5 pigs per pen and 17 replications per treatment. Two groups of pigs (9 and 8 replications respectively) were used for the experiment and results were combined for analysis. The 8 experimental diets included 3 corn-soybean meal–based diets consisting of: (1)) corn ground to ~620 μ, in meal form, (2) corn ground to ~352 μ in meal form, and (3) diet 2 in pellet form. The remaining diets were high by-product diets containing 20% midds and 30% DDGS. Diets 4 to 8 consisted of: (4) corn, soybean meal, midds, and DDGS of ~ 620, 889, 534 and 701 μ, in meal form, (5) diet 4 but corn ~352 μ, in meal form; (6) diet 5 in pellet form, (7) corn, soybean meal, DDGS, and midds ground to ~352, 421, 377, and 357 μ, in meal form; and (8) diet 7 in pellet form.

Experiment 2

A total of 687 pigs (1050 barrows; PIC, Hendersonville, TN; initially 11.6 kg BW 37 d of age) were used in a 21-d study. Pigs were fed 1 of 10 experimental diets for 21 d with 5 pigs per pen and 14 replications per treatment. Two groups of pigs (7 replications per group) were utilized for the experiment and results were combined analysis. The 10 experimental diets included 4 corn-soybean meal-based diets consisting of: (1) corn ground to ~638 μ in meal form, (2) treatment 2 in pellet form, (3) corn ground to ~325 μ in meal form, and (4) treatment 3 in pellet form. The remaining 6 diets contained 30% DDGS. Diets 5 to 10 consisted of: (5) corn and

DDGS ground to ~638 and 580 μ, in meal form, (6) diet 5 in pellet form, (7) corn and DDGS ground to ~638 and 391 μ, in meal form, (8) diet 7 in pellet form, (9) corn and DDGS ground to ~325 and 391 μ, in meal form, and (10) diet 9 in pellet form.

Statistical Analysis

For both experiments, data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatment means were analyzed using the LSMEANS statement and pre-planned CONTRAST statements in SAS, with barn location as a random effect. The pre-planned contrasts in Exp. 1 included the interactive effects of pelleting × diet formulation, pelleting × grinding corn or the complete diet, and corn particle size × diet formulation. The main effects included, diet form (meal vs. pellet), corn grinding (650 μ vs. 320 μ), diet formulation (corn-soybean meal vs. corn-soybean meal-by-product), and complete diet grinding. In Exp. 2, the pre-planned contrasts included the interactive effects of pelleting × diet formulation, pelleting × corn μ, and pelleting × DDGS μ. Contrasts also included the main effects of diet form (pelleting vs. meal), corn particle size (638 vs. 325 μ), DDGS particle size (580 vs. 391 μ), and diet formulation (corn-soybean meal vs. corn-soybean meal-by-product). In both 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

Nutrient chemical analysis of corn, soybean meal, DDGS and midds used were verified to be similar to those used in formulation (Tables 3.3 and 3.4). The minor differences would not be expected to influence the results of the experiment. Nutrient analysis of treatment diets showed that the concentrations were similar to formulated values (Table 3.5). The only exception was ADF and NDF which on average were all slightly lower than formulated values.

For diet characteristics, as expected, as the portion of the diet that was ground increased, the particle size of the diet decreased, which led to an increase in the diet angle of repose. Bulk densities of meal diets were all relatively similar across treatments in both experiments; however, when midds were added to the diet, bulk density decreased (Exp. 1). Diets that were pelleted were higher in bulk density when compared to the meal diets. Across all treatments of both experiments PDI and modified PDI, % fines, mill throughput, and hot pellet temperature were all similar (Tables 3.6 and 3.7).

Experiment 1

Overall (d 0 to 21), a grinding × diet form interaction was observed ($P < 0.02$) for ADG as pelleting significantly increased ADG when only the corn was ground but only slightly increased ADG when the complete diet was ground. Grinding the complete diet improved G:F and caloric efficiency on an ME and NE basis when fed in meal form but worsened both when fed in pelleted form resulting in another grinding × diet form interaction. Also, pigs fed pelleted diets had improved ($P < 0.03$) ADG, G:F, and caloric efficiency when measured on an ME or NE basis (Table 3.8, 3.9). Reducing corn particle size in meal form diets did not influence G:F or caloric efficiency, but tended ($P < 0.08$) to reduce ADFI, which led to a reduction ($P < 0.02$) in ADG. Pigs fed the high-by-product diet had reduced ($P < 0.001$) ADG, ADFI, and final BW and poorer ($P < 0.01$) G:F, but caloric efficiency was similar to pigs fed the corn-soybean meal–based diet. Grinding the by-products to a finer particle size further reduced ($P < 0.05$) ADG, ADFI, and final BW but did not influence G:F.

Experiment 2

Overall (d 0 to 21), a corn particle size (regardless of DDGS addition) × diet form interaction was observed ($P < 0.01$) as a result of increased ADFI when corn was ground and fed in pellet form but decreased intake when corn was finely ground and fed in meal form (Table 3.10, 3.11). Pelleting the diets decreased ($P < 0.0001$) ADG, ADFI, and final BW and increased ($P < 0.0001$) G:F and caloric efficiency on both an ME and NE basis. Fine grinding corn decreased ($P < 0.04$) ADG as a result of numerically decreased ADFI. Also, feeding 30% DDGS decreased ($P < 0.01$) ADG, ADFI, and NE caloric efficiency, and tended to decrease ($P < 0.07$) final BW.

DISCUSSION

Pelleting has been shown to consistently improve both ADG and G:F in many finishing studies (Skoch et al., 1983; Potter et al., 2010; and Paulk et al., 2011). However, responses have been more variable when feeding pelleted diets to nursery pigs. Medel et al. (2003) showed similar results when pigs fed diets that were pelleted had improved) G:F from d 22 to 42 post-weaning, but had no differences in ADG as a result of numerically reduced ADFI. The improved G:F was most likely a result of the improved digestibility of GE, DM, organic matter, and CP. Traylor et al. (1996) conducted a similar experiment feeding meal and pelleted diets to nursery pigs. They also observed improved G:F when pigs were fed pelleted feed; however, there were no differences in ADG. Hansen et al. (1992) also showed improved G:F of nursery pigs when fed a pelleted diet compared to the same diet in meal form immediately following weaning with no changes in ADG. This held true in the current nursery experiments as there was an improvement in G:F for both experiments, but pigs in the first experiment had improved ADG and pigs in the second experiment had decreased ADG as a result of decreased feed intake.

Work done by Skoch et al. (1983) and Steidinger et al. (2000) both showed that when weanling pigs were fed similar diets in both meal and pellet form, pelleting the diet had no effect on pig performance from d 0 to 14. Skoch et al. (1983) did show that when similar diet forms as those fed to the weanling pigs were fed to finishing pigs, improved G:F was realized. This might suggest that finishing pigs may respond more consistently with improved performance when fed high quality pellets.

In Exp. 2 of the current trials, the reduction in ADG from feeding pellets was caused by a decrease in ADFI which may have been a result of increased pellet hardness as shown by high PDI values. This would support work done by Mavromichalis et al. (2002) who conducted 2 experiments to determine the effects of pellet hardness on nursery pig growth performance. In their first experiment, raw starch was replaced with gelatinized starch in formulation to increase pellet hardness. Harder pellets decreased ADFI and ADG but had no effect on G:F. In a second experiment, ADFI tended to decrease and led to numerically decreased ADG. Pellet durability index values increased as gelatinized starch replaced more of the diet (67, 93, 92, 97% respectively) and were reported for the second experiment only. It should be noted that gelatinized starch is not as digestible to the weaned pig when compared to regular starch and may have led to some of the decreased performance; however, since G:F was not changed results are more likely a result of pellet hardness and not diet formulation. In a trial conducted by Ford (1977) mice and rats were fed 6 diets with increasing pellet hardness measured by a tablet hardness tester and grinding the pellets through a coffee grinder and measuring the remaining particles not able to pass through a 20 mesh sieve. They concluded that mice or rats fed pellets with increased hardness had significantly reduced ADG and ADFI.

In contrast, other literature would suggest that pelleting may be beneficial for nursery pig growth rate, specifically ADG. Zhu et al. (2010) conducted two experiments investigating the effects of feeding 30% DDGS in both meal and pellet form on performance of 11.8 and 18.4 kg BW nursery pigs. Diets used in the experiment were both iso-caloric and iso-nitrogenous to ensure differences were from diet form and not diet formulation. They determined that for both experiments feeding a pelleted diet improved both ADG and G:F. Stark et al. (1994) conducted two similar experiments feeding both meal and pelleted diets with increasing percentages of fines to nursery pigs. Fines were increased to 25% which was well above values in the present studies of <10%. They determined in the first experiment that feeding pelleted diets improved G:F and numerically increased ADG. There was also a trend for increasing the percentage fines of the diet to decrease G:F. In their second experiment pelleting tended to increase ADG and improved G:F while increasing the amount of fines in the complete pelleted feed numerically worsened G:F. More recently Nemechek et al. (2013) conducted two experiments to determine the effect of feeder adjustment and pellet quality on nursery pig growth performance. Pigs were fed a similar diet in either meal form, or a poor or high quality pellet. Pigs in both experiments who were fed the high quality pellet had improved G:F when compared to pigs fed the poor quality pellets or meal diet. This would suggest that pellet quality may influence the effectiveness of pelleting nursery diets.

The true mode of action leading to improved performance of pigs fed pelleted diets may not be confined to a single criterion. Instead, factors including feed wastage, nutrient digestibility, starch gelatinization, pellet hardness and animal behavior may explain the improved growth rate and feed efficiency when feeding pelleted diets. Hanrahan et al. (1984) suggested that two main reasons exist for the improved performance exists: reduced feed wastage and improved digestibility of the pelleted diet. In the current experiment, the caloric efficiencies of the diets were improved by pelleting which would suggest that the digestibility of the diet was greater when pelleted. Moritz et al. (2005) suggested that gelatinized starch in pellets may improve broiler performance. In the experiment, corn was unprocessed, pelleted, or extruded and fed to broilers. Corn that was pelleted or extruded was ground post-pelleting and before mixing to ensure similar diet forms were utilized for broilers fed the diets. Pelleted corn and extruded corn were fed at levels of 1/3, 2/3, and 3/3 in the diets replacing unprocessed corn on a 1:1 basis. Pelleted corn and extruded corn had improvements in gelatinization of 29 and 92% respectively compared to the unprocessed corn. Broilers fed the pelleted corn had improved G:F compared to birds fed unprocessed corn. Extruded corn had no effect on broiler performance possibly as a result of nutrient destruction from thermal processing. However, corn particle size was confounded and may partially influenced the performance of the 3 diet types fed as the corn had particle sizes of 364, 256, and 487 μ, respectively for the unprocessed corn, processed corn, and extruded corn. This may explain improved performance for the processed corn with decreased particle size.

In the current experiments, reducing particle size appeared to have no positive effects on growth rate. This is contrast to other literature that suggests a reduction in cereal grain particle size can improve nursery ADG and feed efficiency. Healy et al. (1994) fed decreasing particle sizes of both corn and sorghum to weanling pigs in a 35 day study. Grains were fed at particle sizes of 900, 700, 500, and 300 μ. From d 0 to 14, ADG and G:F increased as either grain was ground to 300 μ. However, from d 0 to 35, G:F improved as grain was ground finer with maximum G:F observed at 500 μ. It should also be noted that all diets were fed in pelleted form in their study and may have mitigated some effects of fine grinding the grains. Choct et al.

(2004) conducted a similar study feeding varying particle sizes of wheat either ground through a roller-mill at three different corrugations or through a hammer-mill with three different screen sizes to adjust particle size. Pigs fed hammer-mill ground wheat had a tendency for increased ADG and improved G:F compared with pigs fed roller-mill ground wheat. The improved performance was most likely a result of the significantly smaller particle sizes of the wheat ground through the hammer-mill, although actual particle sizes were not reported for any of the treatments. Mavromichalis et al. (2000) fed decreasing particle sizes of wheat to nursery pigs in a 35 d study. Wheat was ground to 1,300, 600, or 400 µ and all diets were fed in meal form. Fine grinding the wheat resulted in improved G:F with the greatest G:F occurring at 600 µ. This supports work done by Healy et al. (1994) showing that an optimum particle size of cereal grains for nursery pigs may be at an intermediate micron size and improvements in growth don't continue in a linear fashion as grain is ground finer.

In the current experiments not only was the corn finely ground but other ingredients including midds, DDGS, and soybean meal were also finely ground. Other work evaluating fine grinding major ingredients is limited. However, Berrocoso et al. (2013) studied the effects of micronized soybean meal (60 µ) on nursery pig performance. They found that feeding micronized soybean meal to nursery pigs from d 0 to 7 improved G:F, but from d 0 to 21 had no effect on performance. Fastinger and Mahan (2003) found that decreasing soybean meal particle sizes (949, 600, 389, 185 µ) for grow-finish pigs tended to increase apparent ilieal digestibility of essential amino acids, and numerically improved digestibility of non-essential amino acids. Energy digestibility improved by 1% as particle size decreased but was not significant. However, Lawrence et al. (2003) observed that grinding the soybean meal in the diet had no effect on any growth performance.

For DDGS grinding, Liu et al. (2012) fed decreasing particle sizes of DDGS to grow-finish pigs (40 kg BW) in a digestibility study. Pigs were fed dietary DDGS ground to 818, 595, or 308 µ at an inclusion level of 30% to a basal corn-soybean meal based control diet. Grinding DDGS to 308 µ improved ATTD of DM, as well as GE, DE, and ME compared with the coarse ground DDGS. They reported a decrease in 25 µ resulted in an improvement of 13.5 kcal/kg of ME for the DDGS. However, while digestibility studies have shown improvements when DDGS and soybean meal are finely ground, pigs have not responded with improved growth as demonstrated by previous research and the current research. The difference may be too small to elicit a growth rate response.

In the current experiments, it was also shown that feeding diets containing high levels of by-products were detrimental to performance. The main reason for decreased performance was most likely a cause of the decreased energy concentration of the diets containing by-products, specifically midds. De Jong et al. (2012) showed increasing dietary midds were detrimental to performance at inclusion levels above 15%. In the present study, 20% midds was used. Another reason for decreased performance may have been caused by the increased bulkiness and fiber content of the diets as shown by the low bulk density and increased crude fiber of diets containing by-products. Ndou et al. (2012) observed that bulk density of the diet is an accurate predictor of intake when scaled per unit of BW. It also appears that weaned pigs will consume increasing amounts of high fiber diets in order to meet their energy requirements up to a point at which their intake may be affected as gut capacity is reached. Moore et al. (1988) conducted a similar trial to determine the effects of feeding high-fiber diets to weaned pigs. Pigs were fed diets containing: 1) corn-soybean control, 2) 15% oat hulls, 3) 15% soy hulls, and 4) 20% alfalfa meal. Diets 2 to 4 replaced corn and soybean meal with the ingredient listed. All sources of fiber decreased the apparent digestibility of N, energy, and dry matter, but did not affect N retention. This supports work done by Le Gall et al. (2008) who also showed that increasing dietary fiber decreased the digestibility of energy, organic matter, and all nutrients at the rate of 1% decrease with every 1% increase in NDF in the diet. This would correspond with Exp. 2 in the current trials where pigs fed 30% DDGS had decreased caloric efficiency possibly as a result of decreased digestibility of the diets due to increased NDF.

Though it is not clearly understood why pelleting and fine grinding had few positive, and even negative, effects on nursery pig performance in the current experiments, some possible explanations may exist. Reasons could include decreased palatability of finely ground ingredients, limited or no benefit to grinding grain finer than 600 μ for nursery pigs, or limited biological benefits of fine grinding other ingredients for nursery pigs. The lack of improvement to pelleting in Exp. 2 may have been a result of increased pellet hardness. It is clear; however, that more research needs to be conducted to determine the optimum particle size of cereal grains and complete diets when fed to nursery pigs as well as the effects of pellet hardness on nursery pig performance.

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TABLES AND FIGURES

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

Item	DDGS[2], %: / Midds[3], %:	0 / 0	30 / 20
Ingredient, %			
Corn		63.69	24.59
Soybean meal (46.5% CP)		32.80	22.43
DDGS		---	30.00
Wheat middlings		---	20.00
Monocalcium phosphate (21% P)		1.05	0.05
Limestone		1.00	1.50
Salt		0.35	0.35
Vitamin premix[4]		0.25	0.25
Trace mineral premix[5]		0.15	0.15
L-Lys HCl		0.33	0.48
DL-Met		0.14	0.01
L-Thr		0.13	0.08
Phytase[6]		0.13	0.13
Total		100.00	100.00
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lys		1.28	1.28
Iso:Lys		61	64
Leu:Lys		129	152
Met:Lys		34	28
Met & Cys:Lys		58	58
Thr:Lys		63	63
Trp:Lys		17.5	17.5
Val:Lys		68	76
Total Lys, %		1.42	1.46
ME,[7] kcal/kg		3,308	3,249
NE,[8] kcal/kg		2,359	2,280
SID Lys:ME, g/Mcal		3.86	3.93
CP, %		21.1	24.4
Crude fiber, %		2.7	2.8
NDF, %		9.3	22.1
ADF, %		3.6	8.9
Ca, %		0.70	0.70
P, %		0.63	0.63
Available P, %		0.42	0.42

[1] Experimental diets were fed from d 0 to 21.
[2] Dried distillers grains with solubles.

[3] Wheat middlings.
[4] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[5] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[6] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units (FTU)/kg, with a release of 0.12% available P.
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Table 3-2 Diet composition, Exp. 2 (as-fed basis)[1]

	DDGS[2]	
Item	0	30
Ingredient, %		
Corn	63.23	39.14
Soybean meal (46.5% CP)	32.83	27.39
DDGS	---	30.00
Monocalcium phosphate (21% P)	1.63	0.93
Limestone	0.98	1.35
Salt	0.35	0.35
Vitamin premix[3]	0.25	0.25
Trace mineral premix[4]	0.15	0.15
L-Lys HCl	0.33	0.40
DL-Met	0.14	---
L-Thr	0.13	0.05
Phytase[5]	0.13	0.13
Total	100.00	100.00
Calculated analysis		
Standard ileal digestible (SID) amino acids, %		
Lys	1.28	1.28
Iso:Lys	61	66
Leu:Lys	129	160
Met:Lys	34	28
Met & Cys:Lys	58	58
Thr:Lys	63	63
Trp:Lys	17.5	17.5
Val:Lys	68	77
Total Lys, %	1.42	1.47
ME,[6] kcal/kg	3,293	3,304
NE,[7] kcal/kg	2,349	2,391
SID Lys:ME, g/Mcal	3.88	3.87
CP, %	21.1	24.6
Crude fiber, %	2.7	1.9
NDF, %	10	17.6
ADF, %	3.9	7.5
Ca, %	0.80	0.80
P, %	0.74	0.71
Available P, %	0.42	0.42

[1] Experimental diets were fed from d 0 to 21.
[2] Dried distillers grains with solubles.
[3] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units (FTU)/kg, with a release of 0.12% available P.
[6] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
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Table 3-3 Chemical analysis of ingredients, Exp. 1 (as-fed basis)[1,2]

Item	Wheat middlings	DDGS	Soybean meal	Corn
DM, %	89.73[3]	90.34	89.89	88.22
CP, %	15.7(15.9)	29.3(27.2)	44.8(46.5)	9.3(8.50)
ADF, %	10.7	13.0	7.0	3.7
NDF, %	32.0	27.8	10.9	11.7
Crude fiber, %	6.6(7.0)	7.7(7.3)	4.2(3.9)	2.3(2.2)
NFE, %	56.6	43.5	34.2	71.0
Ca, %	0.14(0.12)	0.06(0.03)	0.28(0.03)	0.09(0.03)
P, %	1.08(0.93)	0.85(0.71)	0.79(0.69)	0.37(0.28)
Fat, %	3.8	9.9	1.5	3.3
Ash, %	5.1	4.3	6.6	1.7
Particle size, µ	534;357[4]	701;377	889;421	620;352
Particle size, SD	2.06;2.29[5]	1.75;1.90	1.91;2.03	2.39;2.47
Bulk density,[6] g/L	324	634	685	615

[1] Values in parentheses from NRC (1998).
[2] Values in parenthesis for DDGS are taken from Stein (2007).
[3] All values are averages of the ingredients used for the two groups used in this experiment.
[4] Values listed first are initial particle sizes, values listed second are particle sizes post hammer-mill grinding.
[5] Values listed first are roller-mill ground SD, values listed second are hammer-mill ground SD.
[6] Bulk density was determined from hammer-mill ground samples.

Table 3-4 Chemical analysis of ingredients Exp. 2 (as-fed basis)[1,2]

Item	DDGS	Soybean meal	Corn
DM, %	91.16[3]	89.34	89.06
CP, %	31.2(27.2)	44.8(46.5)	9.3(8.50)
ADF, %	10.6	6.1	2.5
NDF, %	25.4	7.5	5.9
Crude fiber, %	7.3(7.3)	3.5(3.9)	2(2.2)
NFE, %	38.3	33	73.2
Ca, %	0.09(0.03)	0.51(0.03)	0.06(0.03)
P, %	0.91(0.71)	0.66(0.69)	0.26(0.28)
Fat, %	9.4	1.6	3.2
Ash, %	4.87	6.5	1.39
Starch	3.1	4.3	61.9
Particle size, µ	580;391[4]	780	638;325
Particle size, SD	1.90;1.86[5]	2.13	2.18;2.21
Bulk density,[6] g/L	620	709	638

[1] Values in parentheses from NRC (1998).

[2] Values in parenthesis for DDGS are taken from Stein (2007).

[3] All values are averages of the ingredients used for the two groups used in this experiment.

[4] Values listed first are initial particle sizes, values listed second are particle sizes post hammer-mill grinding.

[5] Values listed first are roller-mill ground SD, values listed second are hammer-mill ground SD.

[6] Bulk density was determined from hammer-mill ground samples.

Table 3-5 Chemical analysis of diets[1]

	Exp.1		Exp. 2	
Diet:[2]	Control	HBP	Control	HBP
DM, %	89.38	90.54	90.81	91.93
CP, %	21.5	25.8	21.3	25.6
ADF, %	3.8	8.5	3.8	6.2
NDF, %	7.0	19.3	6.3	12.9
Crude fiber, %	2.0	5.2	2.1	3.5
NFE, %	57.5	47.4	59.5	52.5
Ca, %	0.72	0.70	0.97	1.04
P, %	0.62	0.72	0.71	0.75
Fat, %	1.9	4.6	2.3	4.0
Ash, %	5.6	6.1	5.8	6.4

[1] A composite sample consisting of 6 subsamples from each of two groups within each experiment.

[2] Control diet was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings in Exp. 1 and corn-soybean meal base with 30% DDGS in Exp. 1.

Table 3-6 Analysis of diets, Exp. 1

Item	Diet[1]:	Control	Control	Control	HBP	HBP	HBP	HBP	HBP
	Ingredient processed[2]:	---	Corn	Corn	---	Corn	Corn	Diet	Diet
	Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet
Particle size, μ		696[3]	517	---	679	551	---	397	---
Bulk density, g/L		718	750	774	551	583	679	581	699
Angle of repose, °		47.4	53.0	---	48.1	52.3	---	54.9	---
Standard pellet durability index		---	---	93.6	---	---	95.4	---	96.8
Modified pellet durability index		---	---	90.4	---	---	93.7	---	95.7
Fines, %		---	---	1.2	---	---	1.1	---	0.7
Production rate, kg/h		---	---	1451	---	---	1266	---	1264
Hot pellet temperature, °C		---	---	81	---	---	81	---	83

[1] Control diet was a corn-soybean meal–based diet. High-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings.
[2] Corn was fine ground to 352 μ, soybean meal to 421 μ, DDGS to 377 μ, and midds to 357 μ.
[3] All values are averages of the two groups.

Table 3-7 Analysis of diets Exp. 2

	Treatment:	1	2	3	4	5	6	7	8	9	10
	Diet[1]:	C	C	C	C	HBP	HBP	HBP	HBP	HBP	HBP
	Ingredient processed[2]:	---	---	Corn	Corn	---	---	DDGS	DDGS	Both	Both
Item	Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet
Particle size, µ		724[3]	---	619	---	709	---	703	---	550	---
Bulk density, g/L		695	715	631	739	661	691	670	694	687	685
Angle of repose, °		50.1	---	52.8	---	50.9	---	51.0	---	55.3	---
Standard pellet durability index		---	96.0	---	94.6	---	93.3	---	96.9	---	95.4
Modified pellet durability index		---	91.2	---	92.3	---	90.3	---	92.5	---	92.8
Fines, %		---	6.4	---	8.0	---	4.5	---	5.0	---	1.2
Production rate, kg/h		---	1165	---	1290	---	1100	---	1265	---	1285
Hot pellet temperature, °C		---	88	---	89	---	88	---	88	---	88

[1] Control diet was a corn-soybean meal–based diet. High-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS.
[2] Corn was fine ground to approximately 325 µ and dried distillers grains with solubles were ground to approximately 391 µ.
[3] All values are averages of the two groups.

Table 3-8 Effects of feeding varying particle sizes and diet forms on 11- to 24-kg nursery pig performance Exp. 1[1]

	Treatment:	1	2	3	4	5	6	7	8	
	Diet:[2]	Control	Control	Control	HBP	HBP	HBP	HBP	HBP	
	Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet	
Item	Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet	SEM
d 0 to 21										
ADG, g		648	621	618	585	564	599	548	573	24
ADFI, g		1001	963	948	935	917	909	861	890	41
G:F		0.648	0.647	0.652	0.626	0.615	0.659	0.637	0.644	0.013
Caloric efficiency[4]										
ME		5.12	5.14	5.09	5.20	5.31	4.95	5.11	5.07	0.08
NE		3.66	3.67	3.63	3.65	3.73	3.48	3.59	3.56	0.05
Wt, kg										
d 0		11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	0.2
d 21		24.8	24.2	24.7	23.4	23.3	23.8	22.4	23.1	0.6

[1] A total of 675 pigs (1050 barrows; initially 11.1 kg BW and 37 d of age) were used in a 21-d growth trial with 5 pigs per pen and 17 pens per treatment.

[2] Control was a corn-soybean meal–based diet. High-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings (midds).

[3] Corn was fine ground to 352 μ, soybean meal to 421 μ, DDGS to 377 μ, and midds to 357 μ.

[4] Caloric efficiency is expressed as mcal/kg gain.

Table 3-9 Effects of feeding varying particle sizes and diet forms on 11- to 24-kg nursery pig performance Exp. 1

		Probability, *P* <				
Item	Contrast:	Grinding × diet form[1,2,3]	Diet form[4]	Corn μ[5]	Diet[6]	Grinding[7]
d 0 to 21						
ADG, g		0.02	0.03	0.02	0.01	0.05
ADFI, g		0.70	0.89	0.08	0.01	0.02
G:F		0.002	0.01	0.32	0.01	0.51
Caloric efficiency[8]						
ME		0.001	0.004	0.33	0.44	0.51
NE		0.001	0.004	0.33	0.38	0.51
Wt, kg						
d 0		0.93	0.95	0.99	0.99	0.93
d 21		0.32	0.06	0.37	0.01	0.03

[1] No interactive effects ($P < 0.07$) of diet formulation × diet form.
[2] No interactive effects ($P > 0.46$) of corn particle size × diet formulation.
[3] Interactive effects of grinding corn or the complete diet × diet form.
[4] Treatments 2, 5, and 7 vs. 3, 6, and 8.
[5] Treatments 1 and 4 vs. 2 and 5.
[6] Treatments 1, 2, and 3 vs. 4, 5, and 6.
[7] Treatments 5 and 6 vs. 7 and 8.
[8] Caloric efficiency is expressed as mcal/kg gain.

Table 3-10 Effects of feeding varying ingredient particle sizes and diet forms on 11- to 24-kg nursery pig performance Exp. 2[1]

Item	Treatment:	1	2	3	4	5	6	7	8	9	10	
	Diet:[2]	Control	Control	Control	Control	HBP	HBP	HBP	HBP	HBP	HBP	
	Ingredient processed:[3]	---	---	Corn	Corn	---	---	DDGS	DDGS	Both	Both	
	Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM
d 0 to 21												
ADG, g		621	596	589	557	588	546	595	537	576	565	22
ADFI, g		989	898	932	875	958	835	955	836	926	876	35
G:F		0.631	0.664	0.633	0.635	0.616	0.654	0.625	0.643	0.62	0.646	0.012
Caloric efficiency[4]												
ME		5.26	4.97	5.22	5.20	5.39	5.07	5.32	5.16	5.33	5.13	0.08
NE		3.75	3.55	3.72	3.71	3.90	3.67	3.85	3.74	3.86	3.71	0.05
Wt, kg												
d 0		11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	0.3
d 21		24.3	23.8	23.7	23.0	23.7	23.1	23.8	22.7	23.4	23.1	0.5

[1] A total of 687 pigs (1050 barrows; initially 11.6 kg BW and 37 d of age) were used in a 21-d study with 5 pigs/pen and 14 pens/treatment.

[2] Control was a corn-soybean meal–based diet. High-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS).

[3] Corn was fine ground to approximately 325 μ, DDGS were ground to approximately 391 μ.

[4] Caloric efficiency is expressed as mcal/kg gain.

Table 3-11 Effects of feeding varying ingredient particle sizes and diet forms on 11- to 24-kg nursery pig performance Exp. 2

		Probability, *P* <				
Item	Contrast:	Corn μ × diet form[1,2]	Diet form[3]	Corn μ[4]	DDGS μ[5]	Diet[6]
d 0 to 21						
ADG, g		0.15	0.0001	0.04	0.95	0.01
ADFI, g		0.01	0.0001	0.16	0.95	0.01
G:F		0.13	0.0001	0.30	0.88	0.16
Caloric efficiency[7]						
ME		0.14	0.0001	0.42	0.88	0.13
NE		0.14	0.0001	0.44	0.87	0.01
Wt, kg						
d 21		0.62	0.008	0.21	0.64	0.07

[1] Interactive effects of corn μ and diet form.
[2] No interactive effects (*P* > 0.20) of diet × diet form, or DDGS μ × diet form.
[3] Treatments 1,3,5,7, and 9 vs. 2,4,6,8, and 10.
[4] Treatments 1,2,7,8 vs. 3,4, 9, and 10.
[5] Treatments 5 and 6 vs. 7 and 8.
[6] Treatments 1 and 2 vs. 5 and 6.
[7] Caloric efficiency is expressed as mcal/kg gain.