The influence of particle size of Enogen Feed corn and conventional yellow dent corn on nursery and finishing pig performance, carcass characteristics and stomach morphology

by

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Abstract

Enogen Feed corn is a corn hybrid developed by Syngenta Seeds that has been genetically modified to contain an α-amylase enzyme trait (SYT-EFC). Several approaches to compare Enogen Feed corn and conventional yellow dent corn were evaluated including interventions within the feed manufacturing process to maximize animal performance. A total of 2,513 pigs were used in a total of 4 experiments structured in 3 chapters. Chapter 1 evaluated the influence of particle size and Enogen Feed corn and conventional yellow dent corn on nursery and finishing pig performance, carcass characteristics and stomach morphology. The six experimental treatments included Enogen Feed corn and conventional yellow dent corn ground to 3 different particle sizes: 300, 600, and 900 microns. For nursery pigs there was a corn source × particle size interaction for gain to feed (G:F) ratio. There was no difference due to particle size when pigs were fed conventional yellow dent corn, but in pigs fed Enogen Feed corn, G:F decreased with increasing particle size. Neither corn source nor particle size affected average daily gain (ADG) or average daily feed intake (ADFI). For finishing pigs, there were no differences observed among pigs fed either corn source for ADG, ADFI or G:F while G:F increased linearly as corn particle size decreased. Chapter 2 evaluated the influence of particle size of Enogen Feed corn and conventional yellow dent corn on lactating sow and their offspring performance. We observed no differences when comparing Enogen Feed corn and conventional yellow dent corn on lactating sow and litter performance. Litter ADG and overall litter gain tended to be greater in sows fed 600-micron corn compared to sows fed diets with 900 microns. Chapter 3 evaluated the influence of Enogen Feed corn and conventional yellow dent corn in pelleted- or meal- based diets on finishing pig performance and carcass characteristics. Feeding

pelleted diets to pigs increased ADG and improved G:F with no major differences between corn sources on growth performance.

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Dedication

This thesis is dedicated to my parents Noel and Jacque Williams.

Chapter 1 - The influence of Enogen Feed corn and conventional yellow dent corn and particle size on nursery and finishing pig performance, carcass characteristics and stomach morphology

Abstract

Enogen Feed corn is a corn variety developed by Syngenta Seeds (Downers Grove, IL) that has been genetically modified to contain an α-amylase enzyme trait (SYT-EFC). Originally, Enogen feed corn was developed for the ethanol industry due to its reduction in viscosity of the corn mash, thus eliminating the need to add a liquid form of the α-amylase enzyme. However, there is potential application for Enogen Feed corn to be used in livestock diets due to the increase in α-amylase enzyme potential to increase starch digestibility. Another way to improve starch digestibility is to reduce the corn particle size. Pigs fed Enogen feed corn potentially could achieve similar gain:feed ratio (G:F) at larger particle sizes than conventional corn because of the differences in starch digestibility. Therefor the objective of these studies were to evaluate the effects of corn source and particle size in nursery and finishing pig diets. In Exp. 1, 360 pigs (DNA 200 × 400, Columbus, NE; initially 6.6 ± 0.1 kg BW) were used. There were 5 pigs per pen and 12 pens per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of corn source (Enogen Feed corn or conventional yellow dent corn) and ground corn particle size (300, 600, or 900 µm). Overall, there was a corn source × particle size interaction (linear, P = 0.027) for G:F ratio. Although unexpected, there was no difference due to particle size when pigs were fed conventional yellow dent corn, but in pigs fed Enogen Feed corn, G:F increased with decreasing particle size. Neither corn source nor particle size affected (P > 0.05) average daily gain (ADG) or average daily feed intake (ADFI). In Exp. 2, a total of 323 pigs (241 × 600; DNA, Columbus, NE; initially 50.0 ± 1.3 kg) were used with 9 pigs per pen and 6 pens per treatment. Treatments were arranged identical as Exp. 1 with main effects of corn source (Enogen Feed corn or conventional yellow dent corn) and ground corn particle size (300, 600, and 900 µm). Overall, corn source did not elicit differences among finishing pigs for ADG, ADFI or G:F. For corn particle size, ADG and G:F increased (linear, $P < 0.014$) and ADFI decreased ($P = 0.043$) as particle size decreased. For carcass characteristics, there was a tendency (linear, $P = 0.093$) for increased HCW and increased carcass yield (linear, $P = 0.023$) as corn particle size decreased. For stomach morphology, there was a tendency for a corn source × particle size interaction ($P = 0.055$) for keratinization score with keratinization increasing linearly ($P = 0.001$) as particle size of the corn decreased for yellow dent corn with no change in keratinization score as particle size decreased for Enogen Feed corn. In summary, there were no corn source by particle size interactions observed. Reducing corn particle size improved G:F with no major differences observed between corn sources for overall pig performance.

Key words: α-amylase, Enogen Feed corn, finishing pigs, growth performance, nursery pigs, particle size

Introduction

Cereal grains such as corn, grain sorghum, wheat, and barley typically provide most of the dietary energy in swine diets. Due to the elevated energy density and availability when compared to other cereal grains, corn is the most commonly used cereal grain among pork production systems in the United States. Corn can contain up to 65% starch (NRC, 2012) with apparent total tract digestibility around 90 to 96% (Rojas and Stein, 2015). Genetic modification of corn varieties has enhanced the nutrient profile of the corn product. Genetically modified corn varieties such as NutriDense and low-phytate corn, have been evaluated in growing-finishing pigs (Hastad et al., 2005, Spencer et al., 2000). A new corn hybrid, developed by Syngenta Seeds (Downers Grove, IL), Enogen Feed corn, which was originally intended to be used in the ethanol industry, has been genetically enhanced to contain a thermotolerant α-amylase enzyme trait. This increase in α-amylase in the corn helps increase the conversion of corn starch to sugar, providing more energy available to ruminants (Brinton, 2019). However, there is limited literature available to evaluate the influence of corn hybrid varieties on swine growth performance. However, a recent trial conducted by Ochonski et al. (2019) determined that utilizing Enogen Feed corn in finishing pig diets tended to increase average daily gain compared to pigs that were fed diets with conventional corn, but there was no influence on feed efficiency.

Although corn varieties can influence growth performance, reducing its particle size can influence performance as well. Grinding corn to reduce particle size increases the surface area, allowing more enzymatic activity to occur and increase the digestibility of both energy and other nutrients (Kim et al., 2002). Research in finishing pigs has shown that reducing corn particle size from 1,000 to 400 µm improves feed efficiency (Wondra et al., 1995). However, decreasing particle size below 700 µm is not always beneficial. Wondra et al. (1995) suggested reducing particle size causes more lesions and greater keratinization of the esophageal region due to the lack of protective mucus in this region of the stomach. We hypothesized that feeding coarser Enogen Feed corn will have the same response as feeding finer particle size conventional corn due to the higher availability of starch. Therefore, the objective of this study was to determine the effects of feeding Enogen Feed corn compared to conventional yellow dent corn at different particle sizes on nursery and finishing pig growth performance, carcass characteristics and stomach morphology.

Materials and methods

The Kansas State University and Institutional Animal Care and Use Committee approved the protocols used in these experiments.

Ingredients and chemical analysis

All diets for experiment 1 and 2 were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS.

Conventional U.S. No. 2 dent corn and Enogen Feed corn were ground to approximately 300, 600 or 900 µm using a roller mill (Model 924, RMS Roller Grinder, Harrisburg, SD) equipped with 3 roll pairs. The top, middle, and bottom roll pairs had 2.36 and 2.36 corrugations/cm, 4.72 and 5.51 corrugations/cm, and 6.30 and 7.09 corrugations/cm, respectively. Adjustments were made to the roll gap setting to achieve the desired particle sizes. Samples of ground corn were obtained during each feed manufacturing event for each experiment and analyzed (Table 1; Ward Laboratories, Inc., Kearney, NE) for dry matter (method 935.29; AOAC Inc., 2019), starch (Application #322. 2000), crude protein (method 990.03; AOAC Inc., 2019), ether extract (ANKOM Technology, 2004), acid detergent fiber and neutral detergent fiber (ANKOM Technology, 2005), calcium (method 6.3; Kovar, 2003) and phosphorus (method 6.3; Kovar, 2003).

Particle size analysis was conducted on ground corn samples (100 g) in duplicate according to the ANSI/ASAE S319.2 (1995) standard method. Samples were analyzed both with (5 g) and without dispersing agent (Gilson Company, Inc., Lewis Center, OH) using 2 separate stainless-steel sieve stacks (13 sieves each) to prevent residual dispersing agent from affecting results. Both sieve stacks contained agitators and were placed in the Ro-Tap (Model RX-29, W. S. Tyler Industrial Group, Mentor, OH) machine for 15 min, using the same sieve and agitator configurations as Gebhardt et al. (2018).

Representative diet samples from each manufacturing event were obtained from each treatment within experiment and stored at -20°C until analysis. Diet samples were analyzed (Ward Laboratories, Inc., Kearney, NE) for dry matter, crude protein, acid detergent fiber, neutral detergent fiber, Ca, and P using the same procedures as used for ground grain samples.

Animals and diets

In both experiments, treatments were arranged in a 2 × 3 factorial with main effects of corn source (conventional yellow dent corn or Enogen Feed corn) and ground corn particle size (300, 600 or 900 µm). Diets were similar between all treatments, and Enogen Feed corn replaced conventional yellow dent corn on an equal weight basis (Tables 2 and 3).

Experiment 1 was conducted at the Kansas State University Segregated Early Weaning facility (Manhattan, KS). A total of 360 barrows (DNA 200 × 400, Columbus, NE; initially 6.6 ± 0.01 kg) were placed in pens with 5 pigs per pen. Pens (1.22 × 1.22 m) had metal slatted floors and were equipped with a four-hole stainless steel dry feeder and a water cup. Pigs were weaned at approximately 21 d of age and placed in pens based on initial body weight (**BW**), and fed a common pelleted started diet for approximately 7-d. On d 7, which was considered d 0 of the trial, pens of pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with BW as the blocking factor. There were 12 replications (pens) per treatment. Diets were provided ad libitum in mash form and split into 2 separate phases. Phase 1 was fed from d 0 to 14 and phase 2 was fed from d 14 to 35. Pens of pigs were weighed, and feed disappearance was measured weekly to calculate average daily gain (**ADG**), average daily feed intake (**ADFI**), and gain to feed ratio (**G:F**).

Experiment 2 was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). A total of 323 pigs (241 × 600; DNA, Columbus, NE; initially 50.0 ± 1.3 kg) were used in an 83-d trial. Pens of pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with BW as the blocking factor with 9 pigs per pen and 6 pens per treatment. Diets were fed in mash form in 3 separate phases. The facility was totally enclosed and environmentally regulated, containing 36 pens. Each pen (3.00 × 2.44 m) was equipped with a 1-cup waterer and a dry, single-sided feeder (Farmweld, Teutopolis, IL) with two feeder spaces. Pens were located over a completely slatted concrete floor with a 1.22-m deep pit underneath for manure storage. A robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen. Pens were equipped with adjustable gates to allow space allowance per pig to be maintained if a pig died or was removed during the experiment. Growth performance was assessed by recording BW and feed disappearance every 2 weeks and at the conclusion of the study (d 83).

On d-79, 2 pigs per pen, 1 barrow and 1 gilt of equal weight based on average of the pen weight, were selected and transported to a USDA inspected packing facility (Natural Food Holdings, Sioux Center, IA) for slaughter and to collect stomachs. The stomachs were taken to the Kansas State University Veterinary Diagnostic Laboratory where a scoring system was used to determine the severity of ulceration and keratinization of the esophageal opening of the stomach (DeJong, 2016). Stomach ulceration score was based on a scale of 1 to 4, with 1 = no ulceration, 2 = < 25% ulceration, 3 = 25-75% ulceration and 4 = > 75% ulceration. This scoring criteria was the same for keratinization.

On d 83, the remaining pigs were individually tattooed with a unique ID number, and a radio frequency identification (**RFID**) transponder was inserted into the right ear to allow carcass measurements to be recorded on an individual pig basis. Final individual pig weights were taken, and pigs were transported approximately 2.5 h to a commercial packing plant (Triumph Foods, St. Joseph, MO) and held in lairage for approximately 7 h before slaughter. At the plant, hot carcass weight (**HCW**) was determined immediately after evisceration. Backfat and loin depth were measured with an optical probe (Fat-O-Meter, SFK, Herlev, Denamrk) inserted between the third and fourth rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Percentage lean was calculated using proprietary equations from the packing plant. Carcass yield was calculated by dividing the individual HCW obtained from the packing plant by the individual final live weight obtained at the farm.

Statistical analysis

Treatments were analyzed as a randomized complete block design for two-way ANOVA using the *lmer* function from the *lme4* package in R (version 3.5.1 (2018-07-.2)) with pen considered the experimental unit, average pen body weight at allotment to treatment diets as blocking factor included in the model as a random effect, and treatment as fixed effect. The main effects of corn source and particle size, as well as their interactions, were tested. Differences between treatments were considered significant at $P \leq$ and marginally significant at $0.05 < P \leq 0.10$.

Results

Chemical and particle size analysis

The chemical analysis for ground corn was similar across sources for both Exp. 1 and 2. Samples analyzed with dispersing agent resulted in lower geometric mean diameter (dgw) and greater geometric standard deviation (sgw) than those analyzed without agent as expected (Table 4 and 5). Kalivoda et al. (2017) observed similar findings when comparing methods and suggested that the inclusion of a dispersing agent best facilitated the movement of fine material through sieves and reduced possible agglomerations due to forces such as static charge. Thus, particle size targets and roller mill settings for both trials were based on the analysis with the inclusion of dispersing agent. For Exp. 1, the target particle sizes were achieved and remained similar when comparing conventional to Enogen feed corn (Table 4). For Exp. 2, the particle size targets were again achieved and remained similar across corn source with the exception of a lower than expected dgw in phase 1 for the highest particle size for Enogen feed corn (785 µm) when compared to the closer to target conventional corn (911 µm; Table 5).

Complete diet nutrient analysis matched expected values for Exp. 1 and 2 (Table 6 and 7).

Experiment 1

Interactive and main effects are reported in Tables 8 and 9. During phase 1 (d 0 to 14), there was no evidence for interaction or main effect differences for ADG and ADFI. However, there was a corn source × particle size interaction (linear, P = 0.027) for G:F. There were no changes in G:F for pigs fed decreasing particle size of conventional yellow dent corn (P = 0.610), but a linear improvement in G:F was observed as particle size decreased for pigs fed Enogen Feed corn (P = < 0.001). During phase 2 (d 14 to 35), there was no evidence for differences in ADG among pigs fed either corn source or different particle sizes. There was a tendency for a corn source × particle size interaction (quadratic, P = 0.071) for ADFI, with no differences in ADFI for pigs fed conventional yellow dent corn as particle size changed (P = 0.540), but an increase then decrease in ADFI as particle size increased in pigs fed Enogen Feed corn ($P = 0.030$). There was also a tendency for a corn source × particle size interaction (linear, $P = 0.095$) for G:F. There was no difference among pigs fed conventional yellow dent corn, but G:F improved as particle size decreased in pigs fed Enogen Feed corn.

For overall performance (d 0 to 35), there was no evidence for differences in ADG due to corn source or particle size. There was a tendency for a corn source × particle size interaction (quadratic, $P = 0.086$) for ADFI. There was no change in ADFI in pigs fed conventional yellow dent corn regardless of corn particle size, whereas pigs fed Enogen Feed corn had an increase then decrease in ADFI as particle size increased. For overall G:F, there was also a corn source × particle size interaction (linear, $P = 0.027$). There was no difference in G:F when pigs were fed conventional yellow dent corn regardless of corn particle size, but for pigs fed Enogen Feed corn, G:F improved with decreasing particle size.

Experiment 2

There was no evidence for a corn source × particle size interaction for any growth response criteria (Table 10). There was no evidence for difference in growth performance or carcass characteristics between corn sources, except for a tendency for greater ($P = 0.064$) ADFI from d 56 to 83 of the experiment for pigs fed Enogen Feed corn compared with pigs fed conventional yellow dent corn. For BW, there was a tendency for greater ($P < 0.10$) BW on d 0 and 28 for pigs fed conventional yellow dent corn compared to pigs fed Enogen Feed corn. This small initial difference disappeared by d 56 with no differences in BW between pigs fed either corn source for the remainder of the experiment. As expected, G:F improved (linear, $P < 0.05$) during each phase and overall as corn particle size decreased. Overall, ADFI decreased (linear, $P = 0.043$) as corn particle size decreased (Table 11) while ADG increased (linear, $P = 0.014$) as particle size decreased. The improvement in ADG led to a tendency for increased (linear, P = 0.056) BW on d 83 as corn particle decreased.

For carcass characteristics, there was a tendency for an increase (linear, P = 0.093) in HCW as corn particle size decreased in the diet. Carcass yield also increased (linear, P = 0.023) as corn particle size decreased. For stomach morphology (Table 12), there was a tendency for a corn source × particle size interaction (P = 0.055) for keratinization score. This was caused by a lower incidence of keratinization in stomachs of pigs fed Enogen Feed corn when ground to 300 or 900 µm than pigs fed conventional yellow dent corn at these particle sizes with similar keratinization score when both corn sources were ground to 600 µm. Neither corn source nor particle size affected stomach ulceration.

Discussion

The United States is the world's largest producer of corn, with an annual production of approximately 13 billion bushels in 2019 (NCGA, 2020). Corn in the United States is generally grown for 3 major uses: food production, livestock use, and the ethanol industry. A new corn hybrid, developed by Syngenta Seeds, Enogen Feed corn, was originally developed with the intent to be used in the ethanol industry. Enogen Feed corn has the ability to reduce the viscosity of its corn mash, thus eliminating the need to add a liquid form of the α-amylase enzyme.

The chemical analysis of ground corn and complete experimental diets found an increase in starch concentration for Exp.1 for ground Enogen Feed corn and an increase in neutral detergent fiber (NDF) in both the Enogen Feed corn ground corn sample and complete experimental diets. Neutral detergent fiber is the general class of polysaccharides that includes most pentosans but do not include certain soluble fibers such as arabino-xylan. Neutral detergent fibers are resistant to digestion by endogenous enzymes and are slowly but incompletely fermented to volatile fatty acids in the large intestine. An increase in dietary NDF decreases energy availability, causing increased feed intake to meet the nutrient requirements for the pig (Sauber and Owens, 2000).

Starch is the major storage carbohydrate of cereal grains. Corn being the most prevalent of cereal grains has a starch content of 65% (NRC, 2012). The digestion of starch is first initiated when feed interacts with salivary amylase (Englyst and Hudson, 2000). Digestion by salivary amylase is short, due to the decrease of pH in the stomach as feed is ingested. Most of the starch digestion takes place in the small intestine, where the starch molecule is hydrolyzed into maltose, maltotriose, and isomaltose subunits by pancreatic α-amylase and isomaltase enzymes (Groff and Gropper, 2000). The digestion of starch is an efficient process, with approximately 95% of starch digestion occurring in the small intestine. Enogen Feed corn contains an α-amylase enzyme trait (SYT-EFC). The SYT-EFC α-amylase enzyme is thought to help with the starch degradation and improve the digestibility of corn by converting starch into fermentable sugars. Although there is limited research on starch digestion of Enogen Feed corn in monogastric, a study by Jolly-Breithaupt et al. (2016) observed when finishing cattle were feed corn with the SYT-EFC α-amylase enzyme, there was a numerical increase in post-ruminal starch digestibility compared to cattle fed conventional yellow dent corn.

One of the main drivers of improved feed efficiency is an increase in the ability to utilize energy in the diet (Patience et al., 2016). With the increase of α-amylase in Enogen Feed corn, starch can potentially be converted to sugar more readily, allowing more energy for the animal which in turn should improve feed efficiency. A study conducted by Ochonski et al. (2019) evaluated the use of Enogen Feed corn fed to finishing pigs. While they did not observe any difference in G:F, they observed a numerical increase in ADG when pigs were fed Enogen Feed corn compared to conventional yellow dent corn. In our study, we did not observe any significant differences for ADG, ADFI or G:F when comparing conventional yellow dent corn and Enogen Feed corn on overall finishing pig performance.

Feed processing of cereal grains also can influence feed efficiency. The main reason cereal grains, like corn, are ground to fine particle sizes is to increase particle surface area and energy utilization (Wondra et al., 1995). A study conducted by Rojas and Stein (2015) evaluated the apparent ileal digestibility (AID) of starch and confirmed that decreased corn particle size from 865 to 339 µm linearly increased AID of starch from 89.0% to 96.6%. This is likely due to increased access to the starch granules for α-amylase, which increases starch digestibility in the small intestine. As digestibility increases, feed intake may also decrease, since less feed is needed to meet the animal's nutrient requirements. Although not statistically significant, in both experiments, we observed a numerical decrease in feed intake as corn particle size decreased.

For nursery pigs in Exp. 1, as corn particle size was reduced from 900 to 300 µm for Enogen Feed corn, G:F improved linearly. Similarly, Bokelman et al. (2014) also observed improved G:F as diet particle size was reduced. However, a study conducted by DeJong et al. (2014) observed no improvement in G:F when the particle size of corn was reduced from approximately 900 µm to approximately 325 µm for nursery pigs. The reasons DeJong et al. (2014) observed no improvement in G:F was due to decreased ADG and ADFI when the corn was ground to very fine particle sizes. In our study we observed a tendency for a quadratic effect in ADG, with pigs fed 300 and 600 µm corn having increased gain compared to the 900 µm, resulting in a linear improvement in G:F as corn particle size was decreased.

When a pig is weaned, their enzyme activity is relatively low for enzymes like amylase and protease. Amylase is an endogenous enzyme that originates from saliva and brush border enzymes and is used to break down starch in the small intestine. In our study, we observed an improvement in ADG and G:F when pigs were fed Enogen Feed corn compared with pigs fed conventional yellow dent corn. The increase in gain with pigs fed Enogen Feed corn could have been related to the increase in α-amylase in the corn. A study conducted by Yi et al., (2013) found an increase in weight gain when supplementing an enzyme complex of amylase, protease and xylanase to wean pigs. In our study, the improvement in gain, however, was not maintained during the subsequent period from d 14 to35 after weaning.

Due to a large volume of feed consumed by finishing pigs over their life span, a small improvement in feed efficiency can result in large economic benefits. A study conducted by DeJong et al. (2013) with finishing pigs observed an improvement in G:F when reducing corn particle size from 596 to 320 µm. Other studies have shown that reducing the particle size of corn in the diet can decrease ADFI when fed to finishing pigs (DeJong et al., 2013, Nemechek et al., 2016). In Exp. 2, reducing corn particle size from 900 to 300 µm resulted in an increase in ADG, decrease in ADFI, and improvement in G:F. In the current study, a 1% improvement of G:F for every 100 µm decrease of ground corn was observed, which is consistent to the findings by Wondra et al. (1995) who saw an 8% improvement as corn particle size was reduced from 1,000 to 400 µm.

While reducing corn particle size for finishing pigs has been shown to improve G:F, grinding corn to a fine particle has been shown to cause gastric lesions (Maxwell et al., 1970). In Exp. 2, there was no evidence for difference in corn source or particle size on ulcer score. However, pigs fed Enogen Feed corn had decreased keratinization score compared to pigs fed conventional yellow dent corn. As corn particle size was decreased in the diet from 900 to 300 µm, keratinization score increased for pigs fed conventional yellow dent corn. Keratinization, the process of keratin forming around the esophageal opening of the stomach, occurs prior to ulceration. Once the keratinization is sloughed off, ulcerations are visible. Ulceration occurs with lower particle size due to reduced viscosity of the feed form in the stomach lowering the pH in the stomach. This difference in keratinization scores between corn sources warrants further investigation.

In summary, as new corn sources become available for use in swine diets, their influence on growth performance needs to be evaluated to accurately determine their effects on nursery and finishing pig performance. The present studies observed that Enogen Feed corn can be effectively used in nursery or finishing pig diets and result in less keratinization on stomach tissue than pigs fed conventional yellow dent corn. This data also confirms previous research that observed reducing particle size of corn improves G:F in both nursery and finishing pig diets. However, feeding Enogen Feed corn ground to coarser particle size did not yield the same response for G:F as conventional yellow dent corn at finer diet particle sizes as had been hypothesized.

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Table 1.1 Chemical analysis of corn varieties of Exp. 1 and 2 (as-fed basis)[1]

	Experiment 1		Experiment 2	
Item, %	Conventional[2]	Enogen Feed corn[3]	Conventional	Enogen Feed corn
Dry matter	87.38	87.73	87.72	87.80
Starch	59.68	64.15	60.60	59.76
Crude protein	7.74	7.45	7.68	7.40
Ether extract	4.10	4.10	3.88	4.16
Acid detergent fiber	1.70	1.91	1.55	1.73
Neutral detergent fiber	6.32	7.31	6.20	7.22
Ca	0.10	0.13	0.10	0.11
P	0.23	0.21	0.22	0.21

[1]Corn samples were collected at time of feed manufacturing and pooled for analysis (Ward Laboratories, Inc., Kearney, NE). Each value represents the mean of six analyses per sample.

[2]Yellow dent corn.

[3]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

Table 1.2 Diet composition, Exp. 1 (as-fed basis)

Item	Phase 1[1]	Phase 2[2]
Ingredient, %		
Corn[3]	56.40	66.45
Soybean meal, 46.5% CP	24.70	29.75
Dried whey	10.00	---
Enzymatically treated soybean meal[4]	5.00	---
Calcium carbonate	0.80	0.80
Monocalcium phosphate, 21% P	0.90	0.90
Sodium chloride	0.50	0.60
L-Lysine HCl	0.45	0.50
DL-Methionine	0.22	0.20
L-Threonine	0.18	0.23
L-Tryptophan	0.03	0.04
L-Valine	0.11	0.13
Trace mineral[5]	0.15	0.15
Vitamin premix[6]	0.25	0.25
Zinc oxide	0.25	---
Phytase[7]	0.04	0.04
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.35	1.30
Isoleucine:lysine	58	55
Leucine:lysine	116	115
Methionine:lysine	37	36
Methionine and cysteine:lysine	58	58
Threonine:lysine	63	64
Tryptophan:lysine	19.0	19.2
Valine:lysine	70	70
Histidine:lysine	36	37
Total lysine, %	1.49	1.44
NE, kcal/kg[8]	2,445	2,560
SID lysine:NE, g/Mcal	5.52	5.34
Crude protein, %	21.2	20.5
Ca, %	0.71	0.66
P, %	0.62	0.58
Analyzed Ca:analyzed P	1.14	1.13
STTD P, %[9]	0.50	0.45

[1]Phase 1 diets were fed from approximately 6.8 to 11.3 kg.

[2]Phase 2 diets were fed from approximately 11.3 to 24.9 kg.

[3]Enogen Feed corn replaced conventional yellow dent corn on an equal weight basis.

[4]HP300 (Hamlet Protein, Findlay, OH).

[5]Provided per kg of premix: 73g Zn from Zn sulfate; 73 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.2 g I from calcium iodate; 0.2 g Se from sodium selenite.

[6] Provided per kg of premix: 3,527,399 IU vitamin A; 881,850 IU vitamin D; 17,637 IU vitamin E; 1,764 mg vitamin K; 15.4 mg vitamin B12; 33,069 mg niacin; 11,023 mb pantothenic acid; 3,307 mg riboflavin.

[7]HiPhos 2700 (DSM Nutritional Products, Parisppany, NJ) provided an estimated release of 0.10% STTD P.

[8]NE = net energy.

[9]STTD P = standardized total tract digestible phosphorus.

Table 1.3 Diet composition, Exp. 2 (as-fed basis)

Item	Phase 1[1]	Phase 2[2]	Phase 3[3]
Ingredient, %			
Corn[4]	75.45	81.90	85.25
Soybean meal, 46.5 % CP	21.80	15.65	12.35
Calcium carbonate	0.93	0.85	0.85
Monocalcium phosphate, 21% P	0.55	0.40	0.35
Sodium chloride	0.50	0.50	0.50
L-Lysine HCl	0.30	0.30	0.30
DL-Methionine	0.07	0.03	0.02
L-Threonine	0.09	0.10	0.11
L-Tryptophan	0.01	0.02	0.02
Trace mineral	0.15	0.13	0.10
Vitamin premix	0.15	0.13	0.10
Phytase[5]	0.02	0.02	0.02
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.95	0.80	0.72
Isoleucine:lysine	62	61	60
Leucine:lysine	139	148	154
Methionine:lysine	32	31	30
Methionine and cysteine:lysine	58	58	58
Threonine:lysine	63	65	68
Tryptophan:lysine	18.6	18.5	18.7
Valine:lysine	69	70	70
Histidine:lysine	42	43	43
Total lysine, %	1.07	0.90	0.82
Net energy, kcal/kg	2,487	2,529	2,551
SID lysine:net energy, g/Mcal	3.83	3.16	2.82
Crude protein, %	18.4	14.6	13.3
Ca, %	0.60	0.51	0.48
P, %	0.47	0.41	0.38
Analyzed Ca:analyzed P	1.27	1.25	1.26
STTD P, %[6]	0.33	0.28	0.26

[1]Phase 1 diets were fed from d 0 to 14.

[2]Phase 2 diets were fed from d 14 to 42.

[3]Phase 3 diets were fed from d 42 to 83.

[4]Enogen Feed corn replaced conventional corn on an equal weight basis.

[5]HiPhos 2700 (DSM Nutritional Products, Parisppany, NJ) provided an estimated release of 0.10% STTD P.

[6]Standardized total tract digestible phosphorus.

Table 1.4 Particle size analysis of ground corn, Exp. 1[1,2]

	Conventional yellow dent corn		Enogen Feed corn	
Item	With flow agent	Without flow agent	With flow agent	Without flow agent
Particle size phase 1, µm				
300	345	407	345	403
600	576	675	554	564
900	954	1,058	883	972
Particle size phase 2, µm				
300	376	454	328	417
600	606	725	525	646
900	1,069	1,169	926	1,460

[1]Ground corn samples were collected the day of feed manufacturing, values represent the mean of 2 samples.

[2]Ground corn samples were split using a riffle splitter to produce 2, 100 g samples. A flow agent 5 g of powdered synthetic amorphous silicon dioxide (Gilson Company, Inc., Lewis Center, OH) was added to one of the samples.

Table 1.5 Particle size analysis of ground corn, Exp. 2[1,2]

Item	Conventional yellow dent corn		Enogen Feed corn	
	With flow agent	Without flow agent	With flow agent	Without flow agent
Particle size phase 1, µm				
300	343	423	287	419
600	510	673	414	577
900	911	975	785	931
Particle size phase 2, µm				
300	338	434	309	417
600	561	704	567	646
900	932	1,096	983	1,123
Particle size phase 3, µm				
300	374	469	350	476
600	602	743	618	750
900	974	1,167	975	1,202

[1]Ground corn samples were collected the day of feed manufacturing, values represent the mean of

[2]Ground corn samples were split using a riffle splitter to produce 2, 100 g samples. A flow agent (5 g of powdered synthetic amorphous silicon dioxide) was added to one of the samples.

Table 1.6 Chemical analysis of diets, Exp. 1, (as-fed basis)[1]

	Phase 1[2]		Phase 2	
Item, %	Conventional[3]	Enogen Feed corn[4]	Conventional	Enogen Feed corn
Dry matter	90.32	90.78	89.41	89.42
Crude protein	20.95	20.55	20.35	19.85
Acid detergent fiber	3.10	3.00	3.10	3.30
Neutral detergent fiber	6.50	6.80	5.70	6.60
Ca	0.76	0.81	0.73	0.78
P	0.54	0.52	0.48	0.51

[1]Feed samples were collected approximately 2 days after each feed delivery, pooled within corn source for each phase, and analyzed. (Ward Laboratories, Inc., Kearney, NE).

[2]The experimental diets were fed in 2 phases: d 0 to 14, and d 14 to 35.

[3]Yellow dent corn.

[4]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

Table 1.7 Chemical analysis of diets, Exp. 2, (as-fed basis)[1]

	Phase 1[2]		Phase 2		Phase 3	
Item, %	Conventional[3]	Enogen Feed corn[4]	Conventional	Enogen Feed corn	Conventional	Enogen Feed corn
Dry matter	89.15	88.62	88.22	88.53	88.04	88.69
Crude protein	17.25	16.3	14.35	13.65	12.3	12.6
Acid detergent fiber	2.55	2.75	2.65	2.45	2.15	2.35
Neutral detergent fiber	5.55	5.65	4.90	5.75	5.25	5.65
Ca	0.72	0.73	0.76	0.71	0.59	0.59
P	0.42	0.40	0.37	0.34	0.33	0.33

[1]Feed samples were collected approximately 2 days after each feed delivery, pooled within corn source for each phase, and analyzed. (Ward Laboratories, Inc., Kearney, NE).

[2]The experimental diets were fed in 3 phases: d 0 to 14, d 14 to 42, and d 42 to 83.

[3]Yellow dent corn.

[4]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

Table 1.8 Effects of corn source and particle size on growth performance of weanling pigs, Exp. 1[1]

	Conventional, µm[2]			Enogen Feed corn, µm[3]				Probability, P =	
Item	300	600	900	300	600	900	SEM	Source × particle size, linear	Source × particle size, quadratic
BW[4], kg									
d 0	6.6	6.6	6.6	6.6	6.6	6.6	0.05	0.754	0.856
d 14	11.7	11.7	11.7	12.1	12.3	12.0	0.20	0.911	0.467
d 35	23.9	23.8	23.5	23.9	24.2	23.3	0.33	0.749	0.283
d 0 to 14[5]									
ADG[6], g	366	363	356	394	405	386	12.3	0.939	0.497
ADFI, g	448	440	440	459	483	482	14.4	0.237	0.472
G:F, g/kg	818	825	810	860	841	800	11.6	0.027	0.945
d 14 to 35									
ADG, g	571	577	562	560	569	540	9.4	0.530	0.584
ADFI, g	907	898	900	882	939	902	19.3	0.408	0.071
G:F, g/kg	631	644	625	636	607	600	9.8	0.095	0.125
d 0 to 35									
ADG, g	489	490	477	494	503	478	8.9	0.801	0.462
ADFI[7], g	722	712	711	713	757	734	15.3	0.203	0.086
G:F[8], g/kg	677	689	672	693	666	652	8.0	0.027	0.127

[1]A total of 360 pigs (Line 200 × 400, DNA, Columbus, NE initially 6.6 kg) with 12 pens per treatment and 5 pigs per pen.
[2]Yellow dent corn.
[3]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.
[4]BW = body weight.
[5]The experimental diets were fed in 2 phases: d 0 to 14, and d 14 to 35.
[6]ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed.

[7]Conventional yellow dent corn when particle size of ground corn was reduced (linear, P = 0.640), Enogen Feed corn when particle size was reduced (quadratic, P = 0.030).

[8]Convetional yellow dent corn when particle size of ground corn was reduced (linear, P = 0.610), Enogen Feed corn when particle size was reduced (linear, P = <0.001).

Table 1.9 Main effects of corn source and particle size on growth performance of weanling pigs, Exp. 1[1]

Item	Source				Particle size, µm				Probability, P =	
	Conventional[2]	Enogen Feed corn[3]	SEM	Probability, P =	300	600	900	SEM	Linear	Quadratic
BW[4], kg										
d 0	6.6	6.6	0.05	0.778	6.6	6.6	6.6	0.05	0.531	0.612
d 14	11.7	12.1	0.15	0.001	11.9	12.0	11.8	0.17	0.498	0.394
d 35	23.7	23.8	0.25	0.731	23.9	24.0	23.4	0.27	0.091	0.131
d 0 to 14[5]										
ADG[6], g	362	395	7.9	0.001	380	384	371	9.2	0.424	0.391
ADFI, g	442	475	10.0	0.003	453	461	461	11.3	0.563	0.712
G:F, g/kg	818	834	6.7	0.094	839	833	805	8.2	0.006	0.268
d 14 to 35										
ADG, g	570	556	6.2	0.063	566	573	551	7.1	0.101	0.064
ADFI, g	902	908	11.4	0.641	895	919	901	15.3	0.708	0.160
G:F, g/kg	633	614	5.9	0.016	634	626	613	6.7	0.036	0.757
d 0 to 35										
ADG, g	485	492	6.3	0.309	491	497	478	7.1	0.090	0.074
ADFI, g	715	734	11.3	0.062	718	734	723	12.5	0.681	0.190
G:F, g/kg	679	671	4.6	0.143	685	678	662	5.7	0.005	0.573

[1]A total of 360 pigs (Line 200 × 400, DNA, Columbus, NE, initially 6.6 kg) with 12 pens per treatment and 5 pigs per pen.
[2]Yellow dent corn.
[3]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.
[4]BW = body weight.
[5]The experimental diets were fed in 2 phases: d 0 to 14, and d 14 to 35.
[6]ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed.

Table 1.10 Effects of corn source and particle size on growth performance and carcass characteristics of finishing pigs, Exp. 2[1]

	Conventional, μm[2]			Enogen Feed corn, μm[3]				Probability, P =	
Item	300	600	900	300	600	900	SEM	Source × particle size, linear	Source × particle size, quadratic
BW[4], kg									
d 0	50.6	50.3	49.8	49.8	48.7	49.7	1.00	0.554	0.228
d 28	78.9	78.6	77.8	78.1	78.3	77.9	0.31	0.314	0.339
d 56	107.1	106.4	104.9	106.6	107.4	105.4	0.63	0.380	0.849
d 83	134.7	132.0	133.1	135.4	134.2	132.1	1.33	0.669	0.600
d 0 to 28									
ADG[5], g	1,040	1,034	1,006	1,012	1,019	1,004	16.8	0.388	0.883
ADFI, g	2,217	2,250	2,294	2,199	2,323	2,288	41.4	0.731	0.484
G:F, g/kg	468	460	439	460	440	439	6.6	0.681	0.250
d 28 to 56									
ADG, g	1,004	994	967	1,020	1,039	981	21.2	0.960	0.366
ADFI, g	2,886	2,950	2,948	2,946	2,984	3,025	44.7	0.837	0.622
G:F, g/kg	348	337	328	346	348	324	5.2	0.821	0.140
d 56 to 83									
ADG, g	969	939	945	983	973	941	22.9	0.645	0.397
ADFI, g	2,965	2,965	3,079	3,048	3,118	3,090	55.0	0.485	0.248
G:F, g/kg	327	317	308	322	312	305	5.3	0.913	0.915
d 0 to 83									
ADG, g	1,006	990	974	1,006	1,011	976	11.7	0.922	0.327
ADFI, g	2,682	2,714	2,766	2,719	2,799	2,793	34.3	0.957	0.491
G:F, g/kg	375	365	352	370	361	350	3.4	0.895	0.801
Carcass characteristics									
HCW[6], kg	100.0	98.1	97.8	100.7	99.7	97.6	1.70	0.754	0.600
Carcass yield, %	74.1	74.2	73.6	74.3	74.1	73.8	0.002	0.960	0.259

Backfat depth, mm	16.3	16.3	16.4	16.2	16.4	16.5	0.498	0.871	0.930
Loin depth, mm	67.4	65.2	65.1	66.0	65.1	66.4	0.937	0.171	0.989
Lean, %	54.8	54.4	54.4	54.6	54.4	54.6	0.295	0.519	0.891

[1]A total of 323 mixed gender pigs (Line 241 × 600, DNA, Columbus, NE, initially 50.0 ± 0.3 kg) were used with 9 pigs per pen and 6 pens per treatment.

[2]Conventional yellow dent.

[3] Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

[4]BW = body weight.

[5]ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed.

[6]HCW = hot carcass weight.

Table 1.11 Main effects of corn source and particle size on growth performance and carcass characteristics of finishing pigs, Exp. 2[1]

	Source				Particle size, µm				Probability, P =	
Item	Conventional[2]	Enogen Feed corn[3]	SEM	Probability, P =	300	600	900	SEM	Linear	Quadratic
BW[4], kg										
d 0	50.2	49.4	0.90	0.091	50.2	49.5	49.8	0.93	0.457	0.324
d 28	78.9	77.7	1.04	0.064	78.9	78.1	77.9	1.09	0.164	0.702
d 56	106.6	106.1	1.01	0.494	107.2	106.6	105.1	1.08	0.031	0.564
d 83	133.6	133.5	1.17	0.933	135.4	132.8	132.6	1.32	0.057	0.328
d 0 to 28										
ADG[5], g	1,028	1,010	10.6	0.185	1,027	1,025	1,005	12.7	0.187	0.497
ADFI, g	2,266	2,260	32.8	0.875	2,220	2,279	2,290	38.2	0.133	0.541
G:F, g/kg	454	448	5.5	0.231	462	451	439	6.2	0.002	0.929
d 28 to 56										
ADG, g	988	1014	13.1	0.128	1,012	1,017	974	15.6	0.067	0.177
ADFI, g	2,929	2,984	25.9	0.131	2,917	2,966	2,987	32.0	0.125	0.702
G:F, g/kg	338	340	3.0	0.615	347	343	326	3.7	0.001	0.166
d 56 to 83										
ADG, g	949	967	13.4	0.349	975	957	943	16.7	0.187	0.932
ADFI, g	3,001	3,086	31.8	0.064	3,004	3,043	3,085	39.4	0.151	0.975
G:F, g/kg	317	313	3.1	0.512	324	315	306	3.9	0.003	0.979
d 0 to 83										
ADG, g	990	998	6.7	0.398	1,005	1,001	975	8.3	0.014	0.289
ADFI, g	2,724	2,767	20.4	0.145	2,701	2,756	2,779	39.4	0.043	0.691
G:F, g/kg	364	360	3.1	0.368	372	363	350	3.9	0.001	0.419
Carcass characteristics										
HCW[6], kg	98.6	99.3	1.233	0.576	100.3	98.9	97.7	1.355	0.093	0.919
Carcass yield, %	74.0	74.1	0.001	0.437	74.2	74.1	73.7	0.002	0.023	0.253
Backfat depth, mm	16.4	16.3	0.304	0.965	16.5	16.4	16.2	0.357	0.645	0.949
Loin depth, mm	65.9	65.8	0.615	0.921	66.7	65.7	65.2	0.728	0.317	0.193
Lean, %	54.5	54.5	0.175	0.955	54.7	54.4	54.5	0.213	0.509	0.482

[1]A total of 323 mixed gender pigs (Line 241 × 600, DNA, Columbus, NE, initially 50.0 ± 0.3 kg) with 9 pigs per pen and 6 pens per treatment.

[2]Yellow dent corn.
[3]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.
[4]BW = body weight.
[5]ADG = average daily gain; ADFI = average daily gain; G:F = gain to feed.
[6]HCW = hot carcass weight.

Table 1.12 Effects of particle size on stomach ulceration and keratinization for Exp. 2[1]

	Conventional[2]			Enogen Feed corn[3]			Probability		
Item	300	600	900	300	600	900	Source × particle size	Source	Particle size
Ulcer score[4]	1.42	1.42	1.67	1.92	1.50	1.42	0.178	0.438	0.840
Keratinization score	2.92	2.00	1.58	1.42	1.92	1.17	0.055	0.002	0.015

[1]On d 79, 2 pigs per pen, 1 barrow and 1 gilt of equal weight, were selected and transported to Natural Food Holdings, Sioux Center, Iowa to collect stomachs. The stomachs were taken to the Kansas State University diagnostic lab where a scoring system was used to determine the severity of ulceration and keratinization of the esophageal opening of the stomach.

[2]Yellow dent corn.

[3]Enogen Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

[4]Stomachs were scored on a scale of 1 to 4 with 1 = no ulceration, 2 = <25% ulceration, 3 = 25-75% ulceration and 4 > 75%. This scoring criteria used was the same for keratinization.

Chapter 2 - Influence of particle size of Enogen Feed corn and conventional yellow dent corn on lactating sow performance

Abstract

Enogen Feed corn is a variety developed by Syngenta Seeds (Downers Grove, IL) that has been genetically modified to contain an α-amylase enzyme trait (SYT-EFC). Originally, Enogen feed corn was developed for the ethanol industry, due to its properties for reducing the viscosity of its corn mash. There is potential application for Enogen Feed corn to be used in livestock diets due to the potential for the increase in α-amylase enzyme to increase the starch digestibility. Along with this, due to the increase of α-amylase in Enogen Feed corn, there is potential to not have to grind the corn as fine to reach the same starch digestibility as finely ground conventional yellow dent corn. Therefore, our hypothesis was that an interaction between corn source and particle size would exist, such that performance of sows fed fine ground conventional yellow dent corn would be similar to sows fed coarse ground Enogen Feed corn. Thus, a total of 107 sows (Line 241; DNA, Columbus, NE) across 4 batch farrowing groups were used to evaluate sow and litter performance. Treatments were arranged in a 2 × 2 factorial with main effects of corn source (Enogen Feed corn or conventional yellow dent corn) and ground corn particle size (600 or 900 µm). From farrowing to weaning, there was a tendency for a source × particle size interaction ($P = 0.065$) for sow body weight change. Sows fed 900 µm Enogen Feed corn had decreased body weight loss compared to sows fed other treatments which were similar in body weight loss. For sow ADFI from farrowing to weaning, there was a source × particle size interaction ($P = 0.048$) with sows fed 900 µm conventional yellow dent corn having lower feed intake than the sows fed 600 µm conventional yellow dent corn, whereas sows fed 900 µm Enogen Feed corn had greater feed intake compared to the sows fed 600 µm Enogen Feed corn. There was a tendency for a particle size main effect ($P < 0.10$) for litter ADG and total litter gain, with sows fed corn ground to 600 µm having increased litter ADG and total litter gain compared to sows fed corn ground to 900 µm. In summary, there were few differences in sow or litter characteristics among those fed Enogen Feed corn or conventional yellow dent corn. Reducing particle size of both corn sources tended to increase litter ADG and weaning weights.

Key words: Corn, Enogen Feed corn, lactating sows, litter growth, particle size

Introduction

Genetic modification of corn varieties has enhanced nutrient profiles or traits that can potentially improve their utilization in swine diets. A new corn hybrid, Syngenta Enogen Feed corn, has been genetically enhanced to contain a thermotolerant α-amylase enzyme trait, was originally intended to be used in the ethanol industry. With increased availability of α-amylase in Enogen Feed corn, ruminant trials have shown increased activity of converting starch to sugar which provided more energy availability (Brinton, 2019). Research with Enogen Feed corn fed to nursery pigs showed increased ADFI compared to pigs fed conventional yellow dent corn with no differences when fed to finishing pigs (Williams et al., 2020). If these findings of increased feed intake associated with Enogen Feed corn could result in similar responses for lactating sows, improved sow and litter performance might be observed.

Reducing particle size of cereal grain in the diet can influence pig growth performance. Grinding corn to reduce particle size increases the surface area, allows more enzymatic activity to occur and therefore, increases the digestibility of both energy and nutrients (Kim et al., 2002).

Research in finishing pigs suggest for every 100 µm decrease in corn particle size in the diet, there is a 1.0% improvement in feed efficiency (DeJong, 2013; 2016; Nemecheck, 2016; Gebhardt, 2018). Wondra et al. (1995) reduced the particle size of corn in lactation diets and observed a linear increased in average daily feed intake and litter weight gain when particle size decreased from 1,200 to 400 µm. Because Enogen Feed corn has increased α-amylase, there is potential for an improvement in energy availability for the sow. Consequently, we hypothesized that feeding coarse ground Enogen Feed corn will have the same response as feeding more finely ground conventional corn due to the amylase in Enogen Feed corn improving the availability of starch, similar to the benefit of reduction in particle size. Therefore, the objective of this study was to determine the effects of feeding Enogen Feed corn instead of conventional yellow dent corn at different particle sizes on sow and litter performance.

Materials and methods

The Kansas State University and Institutional Animal Care and Use Committee approved the protocol used in this experiment.

Ingredients and chemical analysis

Conventional U.S. No. 2 yellow dent corn and Enogen Feed corn were ground to approximately 600 and 900 µm using a roller mill (Model 924, RMS Roller Grinder, Harrisburg, SD) equipped with 3 roll pairs. The top, middle, and bottom roll pairs had 2.36 and 2.36 corrugations/cm, 4.72 and 5.51 corrugations/cm, and 6.30 and 7.09 corrugations/cm, respectively. Adjustments were made to the roll gap setting to achieve desired particle sizes. Samples of ground corn were obtained during each feed manufacturing event and analyzed (Ward Laboratories, Inc., Kearney, NE) for dry matter (method 935.29; AOAC Inc., 2019), starch (Application #322. 2000), crude protein (method 990.03; AOAC Inc., 2019), ether extract

(ANKOM Technology, 2004), acid detergent fiber and neutral detergent fiber (ANKOM Technology, 2005), calcium (method 6.3; Kovar, 2003), and phosphorus (method 6.3; Kovar, 2003).

Particle size analysis was conducted on ground corn samples (100 g) in duplicate according to the ANSI/ASAE S319.2 (1995) standard method. Samples were analyzed both with (5 g) and without dispersing agent (Gilson Company, Inc., Lewis Center, OH) using 2 separate stainless-steel sieve stacks (13 sieves each) to prevent residual dispersing agent from affecting results. Both sieve stacks contained agitators and were placed in the Ro-Tap (Model RX-29, W. S. Tyler Industrial Group, Mentor, OH) machine for 15 min.

Animals and diets

The experiment was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). A total of 107 sows (Line 241; DNA, Columbus, NE) and litters (241 × 600, DNA Genetics, Columbus, NE) were used across four batch farrowing groups (July to September 2019). Sows were individually housed in an environmentally controlled and mechanically ventilated barn. Each farrowing crate was equipped with a nipple waterer and electronic feeding system (Gestal Solo Feeder, Jyga Technologies, St-Lambert-de-Lauzon, Quebec, Canada). On d 112 of gestation, sows were weighed and moved into the farrowing house. Females were blocked by initial body weight (**BW**) and parity and allotted to 1 of 4 dietary treatments within farrowing group. Dietary treatments were arranged in a 2 × 2 factorial and consisted of two corn sources (conventional yellow dent or Enogen Feed corn) and two ground corn particle sizes (600 or 900 µm; Table 1).

Diets were manufactured at the Kansas State University O.H. Kruse Feed Mill in Manhattan, KS. A new batch of each treatment diet (approximately 907 kg per treatment) was manufactured for each farrowing group and packaged in 22.7 kg bags. All diets were identical, with the only difference being the equal weight substitution of the source of corn ground to the two particle sizes.

Sows received 2 kg/d of a conventional yellow dent corn-soybean meal-based gestation diet until entry into the farrowing house (d 112). From d 112 of gestation until farrowing (approximately d 115), all sows were fed 2.47 kg/d of the gestation diet. Postpartum, sows were allowed *ad libitum* access to the treatment diets. Feed was weighed and added to a tub in front of each farrowing crate and used to feed each respective sow. Sow feed intake was recorded by weighing the amount of feed placed in a feed hopper and the amount of remaining every 7 d until weaning (d 18 ± 2). Sow BW was recorded at 24 h after farrowing and at weaning. Within 48 h postpartum, piglets were processed and cross-fostered, regardless of dietary treatment, in an attempt to equalize litter size (minimum of 12 pigs per litter). Litters were weighed on d 2, 7, 14 and at weaning. Litter average daily gain was calculated as: [(litter weaning weight – d 2 litter weight)/ (days from d 2 to weaning)].

Statistical analysis

Data were analyzed using the *lmer* function from the *lme4* package in R (version 3.5.2 (2018-1-20)) as a 2 × 2 factorial with main effects and their interactions tested. Sow was the experimental unit, dietary treatment was a fixed effect, and sow group and block were the random effects. Statistical models were fitted using RStudio7 (version 3.5.2, R core Team. Vienna, Austria). All results were considered significant at $P \leq 0.05$, and marginally significant at $0.05 \leq P \leq 0.10$.

Results and discussion

Chemical analysis

Chemical analysis of dry matter, starch, crude protein ether extract, acid detergent fiber, neutral detergent fiber, calcium, and phosphorus were similar across dietary treatments (Table 2). Samples analyzed with dispersing agent resulted in decreased geometric mean diameter (dgw) and increased geometric standard deviation (sgw) compared with those analyzed without agent as expected (Table 3). Kalivoda et al. (2017) found similar findings when comparing particle size analysis methods and suggest the inclusion of a dispersing agent best facilitates the movement of fine material through sieves and reduces possible buildup due to forces such as static charge. Thus, particle size targets and roller mill settings were based analysis with the inclusion of dispersing agent. Particle size spread was met, but the 900 µm corn was observed to be slightly greater than expected at 974 and 975 µms for the conventional yellow dent corn and Enogen Feed corn, respectively, when a flow agent was used.

Sow Performance

Corn is the most common cereal grain formulated into swine diets due to the availability in the US and the starch content being 65% (NRC, 2012). Starch is the major storage carbohydrate of cereal grains. The corn hybrid, Enogen Feed corn, contains an α-amylase enzyme trait (SYT-EFC). The SYT-EFC α-amylase enzyme is thought to help with the starch degradation in the animal. The increase in α-amylase improves the digestibility of the corn by converting starch into fermentable sugars which results in more energy for the animal. Although there is limited research on starch digestion of Enogen Feed corn in monogastric animals, a recent study by Jolly-Breithaupt et al. (2016) observed when finishing cattle were feed corn with the SYT-EFC α-amylase enzyme, there was numerically increased post ruminal starch digestibility compared to finishing cattle that were fed conventional yellow dent corn.

Reducing corn particle size of the diet for lactating sows can increase ADFI and litter weight gain. A study conducted by Wondra et al. (1995) observed that reducing corn particle size in the diet from 1,200 to 400 µm, resulted in a 6% increase in ADFI. Baudon et al. (2003) observed similar findings when reducing corn particle size from 1,500 µm to 600 µm. In our study, a corn source × particle size interaction (P = 0.048) was observed for sow ADFI from farrowing to weaning. Sows fed 900 µm conventional yellow dent corn had decreased feed intake compared with sows fed 600 µm conventional yellow dent corn similar to previous research, whereas, sows fed 900 µm Enogen Feed corn had greater feed intake compared to the sows fed 600 µm Enogen Feed corn (Table 4).

From farrow to wean, there was a tendency for a source × particle size interaction (P = 0.065) for sow body weight change. Sows fed 900-µm Enogen Feed corn had less body weight loss compared to sows fed other treatments which were similar in body weight loss. These findings were not consistent with other literature that has evaluated particle size of corn on lactating sow performance. Wondra et al. (1995) and Baudon et al. (2003) did not observe differences in sow body weight loss due to particle size of the diet. It is unclear why the sow body weight loss differences were observed in our study and additional research should be conducted to confirm our response.

The NRC (2012) model can be used to estimate nutrient requirements using the performance from sows on each treatment. After inputting the observed performance, the model estimates a 5.4% increase in ME for Enogen Feed corn compared to conventional yellow dent corn. Using the same procedures, comparing 600-µm ground corn to 900-µm ground corn, the

ME was increased 1.4% for 600 µm compared to 900 µm. The differences in predicted ME and feed intake would explain the differences in performance and sow weight loss between treatments.

Litter Performance

There was no evidence of treatment differences (*P* > 0.10) for litter size, pig weight, or litter weight on d 2 and at weaning. There was a tendency for a particle size main effect (*P* < 0.10) for litter ADG and total litter gain, with sows fed corn ground to 600 µm having increased litter ADG and total litter gain compared to sows fed corn ground to 900 µm. Wondra et al. (1995) observed similar findings for total litter gain, when particle size in the diet was reduced, total litter gain increased by 3.9% when particle size of the diet was reduced from 900 to 600 µm compared to 7.6% increase in our study as particle size of the diet was reduced from 975 to 600 µm. Our study saw a 2.0% increase in total litter gain for every 100-µm reduction in the diet, compared to 1.3% observed by Wondra et al. (1995). These findings are different from Baudon et al. (2003) who observed no difference in litter weight gain as particle size in the diet was reduced from 900 to 600 µm. The reported increase in gain in litter BW with reduced particle size resulted from increased intake of digestible nutrients (Wondra et al., 1995). Reducing grain particle size in the diet increases the surface area and utilization of dietary energy. Studies have demonstrated increasing the energy concentration of lactation diets from 12.8 to 13.4 MJ ME/kg improved energy intake which resulted in increased litter growth rate during lactation (Xue et al., 2012).

In summary, as new corn sources become available for use in swine diets, their influence on lactating sow and litter performance needs to be evaluated. The present research observed an increase in litter ADG and total litter gain as particle size was reduced in the diet regardless of the corn source. When evaluating Enogen Feed corn fed to sows, our study did not observe changes in performance on sow or litter performance compared to conventional yellow dent corn.

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Table 2.1 Composition of experimental diets (as-fed basis)

Ingredient	%
Corn[1]	66.10
Soybean meal, 46.5% CP	30.00
Calcium carbonate	1.20
Monocalcium phosphate, 21% P	1.15
Sodium chloride	0.50
L-Lysine-HCl	0.18
DL-Methionine	0.08
L-Threonine	0.12
Trace mineral premix[2]	0.15
Vitamin premix[3]	0.25
Sow add pack[4]	0.25
Phytase[5]	0.04
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.05
Isoleucine:lysine	69
Leucine:lysine	144
Methionine:lysine	33
Methionine & Cystine: lysine	60
Threonine:lysine	70
Tryptophan:lysine	20.2
Valine:lysine	75
Histidine:lysine	45
Total lysine, %	1.19
NE, kcal/kg[6]	2,405
SID lysine:net energy, g/Mcal	4.37
Crude protein, %	20.1
Ca, %	0.90
P, %	0.63
STTD P, %[7]	0.49
Analyzed Ca:analyzed P	1.42

[1]Enogen feed corn replaced conventional yellow dent corn on an equal weight basis

[2]Provided per kg of premix: 73 g from Zn sulfate; 73 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.2 mg from calcium iodate; 0.2 Se mg from sodium selenite.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D; 22,455 IU vitamin E; 1,764 mg vitamin K; 15 mg B12; 19,841 mg niacin; 11,023 mg pantothenic acid; 3,307 mg riboflavin.

[4]Provided per kg of premix: 80 mg chromium; 1,653,467 IU vitamin A; 8,818 IU vitamin E; 88 mg biotin; 880 mg folic acid; 396 mg pyridoxine; 220,000 mg choline; 19,800 mg carnitine.

[5]HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) added to give an approximate release value of 0.13%.

[6]NE = net energy.

[7]Standardized total tract digestible phosphorus.

Table 2.2 Chemical analysis of corn varieties, (as-fed basis)[1]

Item, %	Conventional yellow dent corn[2]	Enogen Feed corn[3]
Dry matter	87.8	87.9
Starch	59.2	61.0
Crude protein	7.90	7.50
Ether extract	4.20	4.30
Acid detergent fiber	1.70	1.70
Neutral detergent fiber	6.90	6.80
Ca	0.10	0.09
P	0.23	0.21

[1]Corn samples were collected at time of feed manufacturing and pooled for analysis (Ward Laboratories, INC., Kearney, NE). Each value represents the mean of six analyses per sample.

[2]Yellow dent corn.

[3]Enogen® Feed, Syngenta Seeds, LLC, Downers Grove, IL.

Table 2.3 Particle size analysis of ground corn samples[1,2]

	Conventional yellow dent[3]		Enogen Feed corn[4]	
Item	With flow agent[4]	Without flow agent	With flow agent	Without flow agent
Particle size, µm				
600	602	732	618	728
900	974	1,116	975	1,126

[1]Ground corn samples were collected the day of feed manufacturing, values represent the mean of 2 samples.
[2] Ground corn samples were split using a riffle splitter to produce 2, 100 g samples. A flow agent (5 g of powdered synthetic amorphous silicon dioxide) was added to one of the samples.
[3]Yellow dent corn.
[4]Enogen® Feed, Syngenta Seeds, LLC, Downers Grove, IL.

Table 2.4 Effect of corn source and particle size on lactating sow performance[1]

	Conventional yellow dent, µm[2]		Enogen Feed corn, µm[3]			Probability, $P <$		
Item	600	900	600	900	SEM	Corn source × particle size	Particle size	Corn source
Number of sows, n	28	27	25	27				
Parity	1.89	1.93	1.92	1.93	---	---	---	---
Lactation length, d	18.7	18.7	18.7	18.8	0.24	0.672	0.937	0.634
Sow body weight, kg								
Entry	251.8	251.7	246.6	250.7	---	---	---	---
After farrowing	234.2	235.8	235.8	234.0	5.44	0.560	0.969	0.971
Weaning (d 18)	219.8	219.6	219.8	223.1	4.95	0.532	0.589	0.558
Change (farrow to wean)	-14.3	-16.1	-15.6	-10.7	2.17	0.065	0.395	0.261
Sow ADFI[4], kg[5]								
Farrow to wean	4.97	4.35	4.70	4.94	0.21	0.048	0.390	0.460
Litter count, n								
d 2	13.1	13.0	13.0	13.3	0.28	0.447	0.807	0.773
Weaning (d 18)	12.5	12.3	12.7	12.6	0.28	0.913	0.504	0.407
Pig weight, kg								
d 2	1.52	1.54	1.53	1.50	0.05	0.576	0.881	0.822
Weaning (d 18)	5.26	5.07	5.32	5.15	0.16	0.930	0.228	0.647
Litter weight, kg								
d 2	20.9	21.3	20.6	21.1	0.55	0.908	0.397	0.681
Weaning (d 18)	65.6	62.0	67.2	64.9	2.15	0.747	0.173	0.301
Litter ADG[6], g	2,786	2,563	2,911	2,706	111.84	0.937	0.061	0.238
Total litter gain, kg	44.73	40.71	46.64	43.81	1.93	0.749	0.069	0.185

[1]A total of 107 sows (Line 241; DNA, Columbus, NE) were enrolled in a 21-d trial. There were 26 ± 2 sows per treatment across 4 batch farrow groups.
[2]Yellow dent corn.
[3]Enogen®, Syngenta Seeds, LLC, Downers Grove, IL.
[4]ADFI = average daily feed intake.
[5]The experimental diets were fed to sows from farrowing to weaning. Before farrowing, all sows were fed 2.47 kg/d of a corn-soybean meal-based gestation diet.

[6]ADG = average daily gain.

Chapter 3 - Influence of Enogen Feed corn and conventional yellow dent corn in pelleted or meal-based diets on finishing pig performance and carcass characteristics

Abstract

Genetic modification of corn has enhanced the use of different corn hybrids in animal agriculture. Enogen Feed corn, developed by Syngenta Seeds (Downers Grove, IL), has potential for use in livestock diets due to increase α-amylase enzyme in the corn thus improving starch digestibility. In addition, it is believed that the pelleting process increases the gelatinization of starch and increases its digestibility by the pig and increase growth rate and improve feed efficiency. Recent research observed an increase in starch gelatinization for Enogen Feed corn compared to conventional yellow dent corn as pellet conditioner temperature increased. Thus, the objective of this experiment was to determine the effects of corn source and diet form on growth performance and carcass characteristics of finishing pigs. A total of 288 pigs (53.0 ± 0.5 kg) were used with 8 pigs per pen and 9 pens per treatment in a 72-d study. Treatments were arranged in a 2 × 2 factorial with main effects of corn source (Enogen Feed corn or conventional yellow dent corn) and diet form (meal or pellet). For overall (d 0 to 72) performance, no interactions between corn source and diet form were observed. There was a tendency ($P < 0.10$) for slightly improved average daily gain (ADG) and gain:feed ratio (G:F) for pigs fed conventional yellow dent corn compared to those fed Enogen Feed corn. For feed form, pigs fed pelleted diets had increased ($P < 0.001$) ADG and G:F compared to pigs fed meal diets. For carcass characteristics, pigs fed pelleted diets had increased hot carcass weight compared to pigs fed meal diets ($P < 0.001$). In summary, feeding pelleted diets to finishing pigs increased ADG and improved feed efficiency compared to those fed meal-based diets. There were no major differences between observed corn sources or interactions between corn source and diet form on growth performance.

Key words: Carcass, Enogen Feed corn, finishing pigs, growth, meal, pellet

Introduction

Cereal grains provide most of the dietary energy in swine diets. Corn is a widely available energy source in the United States and is commonly used in swine diets. Along with ample availability, corn has increased energy density compared to other cereal grains. As genetic modification of corn improves, use of corn hybrids in the livestock industry has increased, and studies have observed increased in ADG and improved G:F when corn hybrids with specialized nutritional traits are fed compared to conventional yellow dent corn (O'Quinn et al., 2000; Hastad et al., 2005). Enogen Feed corn contains an α-amylase enzyme trait, which is used in the ethanol industry to reduce the viscosity of the corn mash. An increase of the α-amylase enzyme in the corn helps increase the conversion of corn starch to sugar to provide more available energy for beef cattle (Brinton, 2019). Ochonski et al. (2019) fed Enogen Feed corn to finishing pigs and observed a tendency for increased daily gain compared to pigs fed conventional yellow dent corn but did not find differences in feed efficiency. Conversely, Williams et al. (2020) observed no difference in growth performance when feeding Enogen Feed corn in the diets compared to conventional yellow dent corn. Diets were fed in meal form in both of these studies.

Research has proven that feeding pelleted diets increased ADG and G:F (Wondra et al., 1995; De Jong et al., 2013a,b; Nemechek et al., 2015). Pelleting pig diets improves performance by increasing nutrient digestibility and reducing feed wastage (Ball et al., 2015). During pelleting, starch gelatinization occurs which allows the pig to better utilize the starch. Truelock et al. (2020) evaluated pelleting Enogen Feed corn and conventional yellow dent corn with different pellet die length to diameter (L/D) ratios and conditioning temperatures on starch gelatinization. As conditioning temperature increased, starch gelatinization increased. Due to Enogen Feed corn having increased starch gelatinization when pelleted, we hypothesize that feeding Enogen Feed corn will improve growth performance when fed in a pellet form more than in a meal form when compared to diets with conventional yellow dent corn. Therefore, the objective of this study was to determine the effects of feeding Enogen Feed corn in meal or pellet form on finishing pig growth performance and carcass characteristics.

Materials and methods

The Kansas State University and Institutional Animal Care and Use committee approved the protocol used in these experiments.

Ingredients and chemical analysis

Conventional U.S. No. 2 dent corn and Enogen Feed corn (Syngenta Seeds; Downers Grove, IL) were ground to approximately 600 microns using a roller mill (Model DP 900-36, Roskamp, Waterloo, IA) equipped with 3 roll pairs. Samples of ground corn were taken directly from the roller mill during each feed manufacturing event for each experiment and analyzed (Table 1, Ward Laboratories, Inc., Kearney, NE) for dry matter (method 935.29; AOAC Inc., 2019), starch (Application #322. 2000), crude protein (method 990.03; AOAC Inc., 2019), ether extract (ANKOM Technology, 2004), acid detergent fiber and neutral detergent fiber (ANKOM Technology, 2005), calcium (method 6.3; Kovar, 2003), and phosphorus (method 6.3; Kovar, 2003).

Particle size analysis was conducted on ground corn samples (100 g) in duplicate according to the ANSI/ASAE S319.2 (1995) standard method. Samples were analyzed both with (5 g) and without dispersing agent (Gilson Company, Inc., Lewis Center, OH) using 2 separate stainless-steel sieve stacks (13 sieves each) to prevent residual dispersing agent from affecting results. Both sieve stacks contained agitators and were placed in the Ro-Tap (Model RX-29, W. S. Tyler Industrial Group, Mentor, OH) machine for 15 min.

Representative diet samples from each manufacturing event were obtained from each treatment within experiment and stored at -20°C until analysis. All manufacturing events occurred on the same days to use the same lots of corn for both the meal and pelleted diets. Samples were analyzed (Table 2, Ward Laboratories, Inc., Kearney, NE) for dry matter, crude protein, acid detergent fiber, neutral detergent fiber, Ca, and P using the same procedures as used for ground grain samples.

All experimental diets were manufactured at Hubbard Feeds (Columbus, NE). Target conditioner temperature was set at 82.2°C. Corn needed to be 13 to 14% moisture upon arrival to the feed mill to allow moisture rise required to achieve this temperature. Getting the conditioner temperature to 82.2°C is ideal to achieve maximum starch gelatinization of Enogen Feed corn. When pelleting the diets, the conditioning temperature averaged 68.4°C for conventional yellow dent corn and 67.7 °C for Enogen Feed corn. The hot pellet temperature averaged 75.1°C for conventional yellow dent corn averaged and 75.8°C for Enogen feed corn. Conditioned mash corn was taken directly from the conditioner (Model 18 × 120, Andritz Sprout Bauer, Muncy, PA) to determine the moisture of the conditioned mash. Conditioned mash moisture for conventional yellow dent corn averaged 19.3% and conditioned mash for Enogen Feed corn diets averaged 20.1%. Pellets were taken directly from the die (Model 26W – 300 HL, Sprout

Waldron, Tyler, TX) and analyzed for pellet durability index (PDI) using a NHP100 with a 30-sec run time and a 100-g sample with a filter. Pellets were sifted before and after analysis for separation of fines and pellets using a U.S. #6 standard sieve. Air temperature and pressure within the NHP100 were recorded throughout the analysis. During feed manufacturing, completed pellets were taken directly from the die to measure hot pellet temperature and chemical analysis (Table 4).

Animals and diets

Treatments were arranged in a 2 × 2 factorial with main effects of corn source (conventional yellow dent corn or Enogen Feed corn) and diet form (pellet or meal). Enogen Feed corn replaced conventional yellow dent corn on an equal weight basis (Table 3).

The experiment was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). Pens of pigs were allotted to 1 of 4 dietary treatments in a randomized complete block design with BW as the blocking factor with 8 pigs per pen and 9 pens per treatment. Diets were fed in either mash or pellet form for 72 d, split into 2 separate phases, grower and finisher phase. A total of 288 pigs (line 241 × 600; DNA, Columbus, NE; initially 53.43 ± 0.5 kg) were used in a 72-d trial. The facility was totally enclosed and environmentally regulated, containing 36 pens. Each pen (3.00 × 2.44 m) was equipped with a dry, single-sided feeder (Farmweld, Teutopolis, IL) with two feeder spaces and a 1-cup waterer. Pens were located over a completely slatted concrete floor with a 1.22-m deep pit underneath for manure storage. A robotic feeding system (FeedPro;Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen. Pens were equipped with adjustable gates to allow space allowance per pig to be maintained if a pig died or was removed during the experiment. All experimental pens of pigs were weighed, and feed disappearance was measured every two weeks to calculate average daily gain (**ADG**), average daily feed intake (**ADFI**), and gain to feed ratio (**G:F**).

On d 72, pigs were individually tattooed with a unique ID number, and a radio frequency identification transponder was inserted into the right ear to allow carcass measurements to be recorded on a pig basis. Final pen weights and individual pig weights were taken, and pigs were transported approximately 2.5 h to a commercial packing plant (Triumph Foods, St. Joseph, MO) and held in lairage for approximately 7 h before slaughter. At the plant, hot carcass weight (**HCW**) was determined immediately after evisceration. Backfat and loin depth were measured with an optical probe (Fat-O-Meter, SFK, Herley, Denmark) inserted between the third and fourth rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Percentage lean was calculated using proprietary equations from the packing plant. Carcass yield was calculated by dividing the individual HCW obtained from the packing plant by the individual final live weight measured at the farm.

Statistical analysis

Treatments were analyzed as randomized complete block design for two-way ANOVA using the *lmer* function from the *lme4* package in R version 3.5.1 (2018-07-2) with pen considered the experimental unit, body weight as the blocking factor, and treatment as fixed effect. The main effects of corn source and diet form, as well as their interactions, were tested. Differences between treatments were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results

Chemical analysis

The chemical analysis for ground corn was similar for both (Table 1). Corn particle size was analyzed with and without the inclusion of dispersing agent. In both the grower and finisher phases, Enogen Feed corn tended to have slightly greater particle size compared to the conventional yellow dent (Table 4).

Conditioning temperature for both corn sources was lower than targeted during the grower and finisher feed manufacturing process. This result could be because the moisture of the corn was higher than expected upon arrival to the feed mill as previously stated. The higher corn moisture content resulted in conditioner moisture to be higher than intended, resulting in hot pellet temperatures to be lower than planned. For PDI, there was no major differences between the corn sources. Also, complete pelleted diets were generally similar in chemical analysis within the grower and finisher phases, however, diets for the grower and finisher phases containing the Enogen Feed corn tended to have increased neutral detergent fiber and slightly higher crude fiber compared to the diets containing the conventional yellow dent corn (Table 4).

Growth performance

There was no evidence for interactions other than during the finisher phase, where there was a tendency for a corn source × diet form interaction ($P = 0.091$; Tables 5 and 6) for G:F. Pelleting did not improve G:F in pigs fed conventional corn but did in pigs fed Enogen Feed corn. For carcass characteristics interactions, there was a tendency for a corn source × diet form interaction ($P < 0.10$) for backfat depth and percentage lean with pigs fed Enogen Feed corn in meal diets having decreased backfat depth compared with pigs fed the other three diets and pelleting increasing percentage lean in pigs fed conventional corn diets, with pigs fed Enogen Feed corn diets having reduced percentage lean when pelleted.

For the overall experimental period, pigs fed the conventional yellow dent corn tended to have increased ($P = 0.077$) ADG compared to pigs fed Enogen Feed corn, which resulted in a tendency ($P = 0.101$) for improvement in G:F. There was no other evidence for difference in performance or carcass characteristics detected between corn sources.

For overall feed form effects, during the grower phase, pigs fed pelleted diets had increased ($P < 0.003$) ADG and G:F compared to those fed meal diets. During the finisher phase, pigs fed pelleted diets had increased ADG ($P = 0.049$) compared to pigs fed meal diets. Overall, pigs fed pelleted diets had improved ($P < 0.001$) ADG and G:F compared with pigs fed meal diets. For carcass characteristics, pigs fed pelleted diets had increased HCW ($P < 0.001$) compared to pigs fed meal diets with no differences found for other carcass parameters.

Discussion

Starch is the major storage carbohydrate of cereal grains with corn having a starch content of 65% (NRC, 2012). Enogen Feed corn contains an α-amylase enzyme trait (SYT-EFC). The SYT-EFC α-amylase enzyme is thought to improve starch digestibility by improving conversion of starch into fermentable sugars. Although research on starch digestion of Enogen Feed corn is limited in pigs, a recent study by Jolly-Breithaupt et al. (2016) observed when finishing cattle were fed corn with SYT-EFC α-amylase enzyme, there was numerically increased post ruminal starch digestibility compared to cattle fed conventional yellow dent corn.

Research dedicated to evaluating grain processing methods that increase starch digestibility, includes grinding and thermal processing. Starch availability during pelleting is increased through a process known as starch gelatinization. Gelatinization occurs during a fourstep process that irreversibly solubilizes raw starch granules through the application of heat and moisture. As mash feed passes through the conditioner, the feed is mixed with heat and moisture in the form of steam, allowing starch granules to swell. As the mash feed exits the conditioner, it passes through the pellet mill die, which generates frictional heat and drives starch gelatinization. Gelatinization of starch during the pelleting process increases the starch availability in the pig as shown by Rojas et al. (2016) which observed an increase in apparent ileal digestibility (AID) of starch from 93.4 in mash diets to 97.7% in pelleted diets. Lundblad et al. (2011) increased the steam temperature in the conditioner to 90°C which resulted in increased starch gelatinization and nursery pig G:F compared with mash diets or steam conditioning at 47°C (Lundblad et al., 2011). Truelock et al. (2020) observed that increasing the conditioner temperature from 74°C to 85°C, when pelleting Enogen Feed corn, increases starch gelatinization in the pellet compared to conventional yellow dent corn. In our study, we originally planned to pellet the diets for both conventional yellow dent corn and Enogen feed corn with a conditioner temperature of 85°C but were unable to reach the temperature because of the moisture content of both Enogen Feed corn and conventional yellow dent corn. Increased corn moisture content decreases steam uptake and consequently the conditioner cannot reach the desired temperatures.

In this study, pelleting diets resulted in increased ADG and G:F. This agrees with Wondra et al. (1995) who observed a 7% improvement in G:F when feeding pelleted diets compared with meal. De Jong et al. (2013a,b) and Nemechek et al. (2015) observed a 6% improvement in G:F when pelleted diets were fed during the finishing period. However, the benefits in G:F when feeding pellets are not always consistent. Meyers et al. (2013) observed no difference in G:F when feeding pelleted diets compared to meal. The authors suggest the PDI of the pellets could be the reason for the lack of differences. In the current study, overall G:F was improved by 3.9% for pigs fed pellets compared to pigs fed meal diets. During the grower stage, a 6.4% improvement in G:F was observed when pellets were fed compared to meal diets. During the finisher phase, no difference in G:F was observed when comparing pigs fed pelleted diets or meal diets. Reasons for lack of difference in G:F during the finishing period between pigs fed pelleted and meal diets is not fully understood. There did not appear to be any difference in PDI between the grower and finisher phases. Interestingly, the percentage fines for both the conventional yellow dent corn and Enogen Feed corn were higher during the grower phase compared to the finisher phase. The influence of pellet fines on G:F has also been inconsistent in previous research. Langdon (2015) found no impact on G:F when pellet fines ranged from 0 to 60%. However, these findings were different from Stark et al. (1993) who reported improved G:F as pellet fines were decreased from 60% to 0%.

In the current study, we observed a 6% improvement in ADG when pigs were fed pelleted diets compared to meal diets. These finding are similar to Ball et al. (2015) and Wondra et al. (1995) who observed a 5% improvement in daily gain when feeding pelleted diets compared to meal diets. Research has shown feeding pelleted swine diets compared to meal diets improves nutrient utilization with higher energy digestibility (Wondra et al., 1995; Lundblad et al., 2011; Ball et al., 2015).

Pigs fed pelleted diets had a 4.2% improvement in HCW compared to pigs fed meal diets. The increase in ADG and final body weight by pigs fed pelleted diets led to the increase in HCW. These results are consistent with Nemechek et al. (2015) who observed an increase in ADG and a numerical improvement in final BW and HCW when pigs were fed pelleted diets compared to meal diets. Similarly, Overholt et al. (2016) observed an increase in final BW and HCW when pigs were fed pelleted diets compared to meal diets. A study conducted by Potter et al. (2010) observed pigs fed pelleted diets had improved carcass yield and a tendency for decreased percentage lean and loin depth. The authors suggested the increase in carcass yield could be attributed to the increased weight gain of pigs fed the pelleted diets. However, in our study, we did not observe any difference on carcass yield, loin depth or lean percentage between pigs fed pelleted or meal diets.

In summary, this study did not find any advantages in finishing pig growth performance when feeding Enogen Feed corn compared to conventional yellow dent corn. The study confirmed previous research that observed feeding pelleted diets to finishing pigs improved ADG and G:F compared to feeding meal diets. However, feeding Enogen Feed corn did not improve growth performance when compared to conventional yellow dent corn whether fed in meal or pelleted diets.

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Table 3.1 Chemical analysis of ground corn[1,2]

Item	Conventional[3]	Enogen Feed corn[4]
Dry matter	88.20	87.50
Crude Protein	9.00	8.50
Ether extract	4.15	4.03
Ash	1.43	1.54
Acid detergent fiber	2.58	3.30
Neutral detergent fiber	8.25	8.38
Starch	71.85	71.93
Ca	0.05	0.05
P	0.24	0.25

[1]Ground corn samples were taken from the roller mill at time of feed manufacturing.
[2]All samples were sent to Ward Laboratories, (Kearney, NE), for chemical analysis.
[3]Yellow dent corn.
[4]Enogen® Feed corn, Syngenta Seeds, LLC, Downers Grove, IL.

Table 3.2 Chemical analysis of complete diets[1,2]

	Meal diets[3]		Pelleted diets	
Item, %	Conventional[4]	Enogen Feed corn[5]	Conventional	Enogen Feed corn
Grower				
Dry matter	88.2	90.1	88.1	87.9
Crude protein	14.9	14.8	15.0	15.2
Ether extract	4.1	4.1	5.9	4.8
Ash	3.8	3.4	3.4	3.4
Acid detergent fiber	2.5	3.4	3.0	3.6
Neutral detergent fiber	6.0	7.6	6.0	7.9
Starch	51.5	50.3	47.1	48.1
Finisher				
Dry matter	88.5	90.2	90.2	91.3
Crude protein	14.8	15.3	13.7	14.5
Ether extract	4.2	4.1	4.3	4.5
Ash	3.3	3.3	3.4	3.6
Acid detergent fiber	2.4	2.6	2.9	2.9
Neutral detergent fiber	6.8	7.7	7.2	6.7
Starch	51.5	49.7	52.6	50.4

[1]Pellets were collected directly from the die at time of feed manufacturing.

[2]Meal diets were taken directly from the feeder 3 days after each phase began. A composite diet was riffle divided and on sample of each treatment per phase was sent for analysis.

[3]Samples were sent to Ward Laboratories, Kearney, NE.

[4]Yellow dent corn.

[5]Enogen®, Syngenta Seeds, LLC, Downers Grove, IL.

[6]Grower diets were fed from d 0 to 28.

[7]Finisher diets were fed from d 28 to 72.

Table 3.3 Diet composition, (as-fed basis)

Ingredient, %	Grower[1]	Finisher[2]
Corn[3]	79.60	83.05
Soybean meal, 46.5% CP	16.50	13.10
Corn oil	1.50	1.50
Salt	0.50	0.50
Monocalcium phosphate, 21% P	0.40	0.35
Calcium carbonate	0.85	0.85
L-Lysine HCl	0.30	0.30
L-Threonine	0.10	0.11
L-Tryptophan	0.015	0.02
DL-Methionine	0.03	0.015
Phytase[4]	0.02	0.02
Selenium Premix	0.05	0.05
Trace mineral premix[5]	0.08	0.08
Vitamin premix[6]	0.05	0.05
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids %		
Lysine	0.84	0.76
Isoleucine:lysine	59	58
Leucine:lysine	142	148
Methionine:lysine	30	30
Threonine:lysine	64	67
Tryptophan:lysine	19	19
Valine:lysine	70	71
Total lysine, %	0.93	0.84
Net energy, kcal, kg	2,548	2,588
SID lysine:NE, g/Mcal	3.31	2.94
Crude protein, %	14.09	12.74
Ca, %	0.49	0.47
P, %	0.40	0.38
Analyzed Ca:analyzed P	1.21	1.25

[1]Grower diets were fed from d 0 to 28.

[2]Finisher diets were fed from d 28 to 72.

[3]Enogen Feed corn replaced conventional corn on an equal weight basis

[4]Axtra PHY 2500 TPT (DuPont, Wilmington, DE) provided an estimated release of 0.15% available P.

[5]Provided per kg of premix: 160,090 mg Zn from zinc oxide, 134,000 mg Fe of FeS Monohydrate, 40,000 mg Mn from Manganese sulfate, 13,340 mg Cu from copper sulfate, 666 mg I from EDDI 80% iodine.

[6]Provided per kg of premix: 24,255 IU vitamin A, 4,410 IU vitamin D, 132,268 IU vitamin E, 13,228 vitamin K, 110.2 mg vitamin B_{12}, 99,212 mg niacin, 90,390 mg pantothenic acid, 17,640 mg riboflavin.

Table 3.4 Pelleting parameters for conventional and Enogen Feed corn[1]

	Grower		Finisher	
Item	Conventional[2]	Enogen Feed corn	Conventional	Enogen Feed corn
Particle size, µm	690	771	605	632
Conditioner mash moisture, %	19.82	20.16	18.89	20.03
Conditioning temperature, °C	68.6	66.4	68.2	68.9
Hot pellet temperature, °C	75.4	76.7	74.8	74.8
Pellet durability index[2], %	53.1	63.5	56.2	53.1
Fines, %	46.55	54.42	36.03	22.04

[1]A double pass conditioner (Model 18 × 120, Andritz Sprout Bauer, Muncy, PA) was used, with a 4.8 mm die on the pellet mill (Model 26W – 300 HL, Sprout Waldron, Tyler, TX). Production rates were held constant for all 3 dietary phases at 6.5 ton/h.

[2]Yellow dent corn.

[3]Enogen®, Syngenta Seeds, LLC, Downers Grove, IL.

[4]All pellets were analyzed for PDI using the NHP100 with a 30-sec run time and a 100-g sample with a filter. Pellets were sifted before and after analysis for separation of fines and pellets using a U.S. #6 standard sieve. Air temperature and pressure within the NHP100 were recorded throughout the experiment.

Table 3.5 Interactive effects of diet form and corn source on finishing pig performance[1]

	Conventional[2]		Enogen Feed corn[3]			Probability, *P* =		
Item[4]	Meal	Pellet	Meal	Pellet	SEM	Source × Diet form	Source	Diet form
BW, kg								
d 0	53.4	53.4	53.0	53.5	0.63	0.534	0.726	0.535
d 28	85.5	89.8	85.7	89.0	0.87	0.536	0.715	<0.001
d 72	134.7	139.1	132.8	138.1	0.93	0.588	0.106	<0.001
Grower[5]								
ADG, g	1,148	1,294	1,157	1,272	27.2	0.576	0.809	<0.001
ADFI, g	2,744	2,807	2,734	2,863	60.2	0.585	0.705	0.123
G:F, g/kg	418	462	427	443	9.6	0.129	0.602	0.003
Finisher[6]								
ADG, g	1,108	1,116	1,059	1,117	16.7	0.133	0.152	0.049
ADFI, g	3,156	3,205	3,165	3,210	44.4	0.958	0.883	0.297
G:F, g/kg	351	348	334	350	5.2	0.091	0.170	0.276
Overall								
ADG, g	1,123	1,189	1,099	1,172	12.9	0.769	0.077	<0.001
ADFI, g	2,996	3,052	2,994	3,075	41.1	0.766	0.786	0.103
G:F, g/kg	375	389	368	382	4.4	0.973	0.100	0.001
Carcass characteristics								
HCW, kg	101.6	105.7	100.1	104.6	1.05	0.837	0.221	<0.001
Carcass yield, %	75.2	75.5	75.3	75.2	0.20	0.266	0.418	0.638
Backfat depth, mm	17.8	17.5	16.6	17.9	0.41	0.068	0.333	0.271
Loin depth, mm	65.3	67.5	66.3	66.4	0.66	0.120	0.963	0.109
Lean, %	53.60	54.01	54.13	53.76	0.20	0.061	0.492	0.927

[1]A total of 288 pigs (Line 241 × 600, DNA, Columbus, NE initially 53.0 ± .5 kg) were used in a 72-d trial. There were 9 pens per treatment with 8 pigs per pen.

[2]Yellow dent corn.

[3]Enogen Feed corn, a product of Syngenta, Downers Grove, IL.

[4]BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed ratio; HCW = got carcass weight

[5]Grower diets were fed from d 0 to 28.
[6]Finisher diets were fed from d 28 to 72.

Table 3.6 Main effects of diet form and corn source on finishing pig growth performance[1]

	Corn source				Diet form			
Item[4]	Conventional[2]	Enogen Feed corn[3]	SEM	Probability, *P* =	Meal	Pellet	SEM	Probability, *P* =
BW, kg								
d 0	53.4	53.3	0.55	0.726	53.2	53.5	0.55	0.535
d 28	87.6	87.3	0.63	0.715	85.6	89.4	0.62	<0.001
d 72	136.9	135.4	0.72	0.106	133.8	138.6	0.71	<0.001
Grower[5]								
ADG, g	1,221	1,214	19.2	0.809	1,153	1,283	19.2	<0.001
ADFI, g	2,775	2,798	42.8	0.705	2,739	2,835	42.7	0.123
G:F, g/kg	440	435	7.2	0.602	423	452	7.2	0.003
Finisher[6]								
ADG, g	1,112	1,088	12.2	0.152	1,083	1,116	12.1	0.049
ADFI, g	3,181	3,187	31.4	0.883	3,160	3,208	31.4	0.297
G:F, g/kg	349	342	3.7	0.170	343	349	3.7	0.276
Overall								
ADG, g	1,156	1,136	10.5	0.077	1,111	1,181	10.4	<0.001
ADFI, g	3,024	3,035	29.7	0.786	2,995	3,063	29.5	0.103
G:F, g/kg	382	375	3.5	0.101	371	386	3.4	0.001
Carcass characteristics								
HCW, kg	103.7	102.3	0.75	0.221	100.8	105.2	0.73	<0.001
Carcass yield, %	75.4	75.2	0.10	0.418	75.3	75.3	0.100	0.638
Backfat depth, mm	17.7	17.3	0.01	0.333	17.7	17.2	0.011	0.271
Loin depth, mm	66.4	66.4	0.02	0.963	67.0	65.9	0.018	0.109
Lean, %	53.80	53.95	0.14	0.492	53.87	53.88	0.142	0.927

[1]A total of 288 pigs (Line 241 × 600, DNA, Columbus, NE initially 53.0 ± 0.5 kg) were used in a 72-d trial. There were 9 pens per treatment with 8 pigs per pen.

[2]Yellow dent corn.

[3]Enogen Feed corn. A product of Syngenta, Downers Grove, IL.

[4]BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed ratio; HCW = hot carcass weight.

[5]Grower diets were fed from d 0 to 28.
[6]Finisher diets were fed from d 28 to 72.