EFFECTS OF AMINO ACID INCLUSION, OIL SOURCE OR MINERAL SUPPLEMENTATION OF SWINE DIETS ON FINISHING OR NURSERY PIG PERFORMANCE

by

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Abstract

In 6 experiments, a total of 1,802 pigs were used to determine: 1) effects of increasing crystalline amino acids in sorghum- or corn-based diets on nursery or finishing pig growth performance; 2) effects of different Zn sources on nursery pig performance; and 3) effects of different corn oil sources on nursery pig performance. In the first set of experiments, corn or sorghum-based diets were supplemented with increasing levels of synthetic amino acids up to the 5^{th} limiting amino acid. For nursery pigs, there were no main or interactive effects ($P>0.05$) of grain source or added amino acids which suggests that balancing up to the fifth limiting amino acid is possible in both sorghum- and corn-based diets with the use of crystalline amino acids without detrimental effects on nursery pig growth performance. For finishing pigs, balancing to the 5^{th} limiting AA using NRC (2012) suggested amino acid ratios in corn- or sorghum-based diets resulted in decreased ADG and G:F and pigs fed corn-based diets had greater G:F and IV than those fed sorghum. The second set of studies compared two new zinc sources to a diet containing pharmacological levels of ZnO on nursery pig growth performance. These studies demonstrated that increasing Zn up to 3,000 ppm Zn increased ADG and ADFI. Lower levels of the new zinc sources did not elicit similar growth performance as the high level of ZnO. The third set of studies compared increasing levels of different sources of corn oil to diets containing soy oil. In the first study, an oil source × level interaction was observed ($P<0.05$) for ADG, G:F and caloric efficiency; however in the second study that compared a different corn oil source there were no interactions observed. Overall, increasing the level of oil from either corn- or soy-oil improved feed efficiency similar to expectations. However, the data suggests that differences in performance can be observed between different corn oil sources derived from different locations. These studies show the benefits of adding either corn or soybean oil in late-phase

nursery diets to improve performance, and cost and availability should dictate which source to use.

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Dedication

I would like to dedicate this to my family for the sacrifices they have made to get me to this point in my life and the support to continue even when times were hard. To Baylee for all the support you have given me, I hope I can return it tenfold in the years to come. Lastly to my grandfather Gerald Jordan, this was one of the hardest things to do without having you here 09/26/2013.

Chapter 1 - Effects of zinc source and level on nursery pig performance.

ABSTRACT

Two experiments were conducted to determine the effects of dietary Zn source and level on nursery pig growth performance. In Exp. 1, 294 pigs (initially 6.4 ± 0.02 kg BW) were used in a 31-d study with 6 dietary treatments arranged in a 2 × 2 + 2 factorial with 7 pigs per pen and 7 pens per treatment. Treatments included a control diet with 110 ppm Zn from $ZnSO_4$ from the trace mineral premix or the control with 390 or 1,390 ppm from a lipid encapsulated Zn source (LEZ; Zinco+, Jefo, Quebec, Canada); or 390, 1,390, or 2,890 ppm added Zn from ZnO to provide 500, 1,500, or 3,000 ppm total dietary Zn. Dietary treatments were fed in 3 phases. No Zn source or source × level interactions were observed. Increasing Zn improved (linear; $P < 0.01$) ADG, ADFI, and G:F from d 7 to 21 and increasing Zn improved (linear; $P < 0.01$) ADG, and ADFI for the overall study. In Exp. 2, 360 pigs (initially 5.9 ± 0.14 kg BW) were used in a 28-d study with 9 dietary treatments arranged in a 2 × 4 + 1 factorial with 5 pigs per pen and 8 pens per treatment. Diets included: a control with 110 ppm Zn from $ZnSO_4$ from the trace mineral premix or the control with 500, 1,000, 2,000, or 3,000 ppm added Zn from either tetrabasic zinc chloride (TBZC; Intellibond Z; Micronutrients, Indianapolis, IN) or ZnO. Dietary treatments were fed in 3 phases. There were no Zn source differences or Zn source × level interactions observed for growth performance. From d 7 to 14, 14 to 21 and 0 to 28, increasing Zn increased (linear; $P \leq 0.05$) ADG and ADFI. From d 21 to 28, pigs fed increasing Zn had increased (linear, $P = 0.018$) ADFI but poorer G:F (quadratic, $P = 0.041$). On d 28, fecal samples were collected from 3 pigs in each pen and analyzed for DM content. There was a tendency ($P = 0.081$) for a Zn source by level interaction as increasing Zn from TBZC decreased fecal DM whereas no difference in fecal DM was observed for increasing Zn from ZnO. In conclusion, these studies demonstrate that increasing dietary Zn up to 3,000 ppm increased ADG and ADFI but no differences existed among the Zn sources that were evaluated. Finally, lower added levels of Zn from LEZ or TBZC did not have similar growth performance as pharmacological levels of Zn from ZnO.

Key Words: growth performance, nursery pig, zinc

INTRODUCTION

Zinc is a trace mineral that is essential for optimal protein and energy metabolism. While the NRC (2012) suggests that the Zn requirement for a newly weaned pig is 100 ppm, other research has shown that pharmacological levels (3,000 ppm) of dietary Zn from ZnO fed for the first 2 to 4 wk after weaning can increase growth rates (Hill et al., 2001) and decrease the incidence of diarrhea (Tokach et al., 2002). Typically ZnO is the preferred source of Zn added to achieve growth-promotional benefits, due to its consistency in response and low cost.

Research has shown ZnO sources vary in bioavailability (Edwards and Baker, 1999) and the usage of high levels of dietary Zn are associated with increased Zn concentrations in swine waste (Meyer et al., 2002). Wedekind et al. (1994) reviewed the bioavailability of Zn methionine, Zn sulfate, Zn lysine, and Zn oxide and found that Zn methionine and Zn sulfate were more bioavailable Zn sources; however, these sources provided the same growth performance as ZnO when fed at the same level.

A lipid encapsulated form of ZnO (LEZ, Zinco+, Jefo, Quebec, Canada) and Tetrabasic zinc chloride (TBZC, Intellibond Z®, Micronutrients Indianapolis, IN) are unique sources of Zn that may be more bioavailable than ZnO (Zhang et al., 2006; Jang et al., 2014). These sources could potentially be fed at low concentrations to achieve growth benefits similar to higher concentrations of ZnO. Batal et al. (2001) found no significant difference in Relative Bioavailability Value (RBV) between TBZC and $ZnSO_4$. Some research has been conducted to compare the performance of pigs fed either Zn from ZnO or TBZC (Mavromichalis et al. 2001 and Zhang et al. 2006) and found linear improvements in ADG and ADFI with increasing Zn from either source. Due to this limited research, more experiments are needed to determine the true effects of these unique Zn sources.

Therefore, the objective of these experiments was to compare the effects of different dietary levels of Zn from LEZ, TBZC, and ZnO on the growth performance and fecal DM of nursery pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

In Exp. 1, a total of 294 pigs (Line 327 × 1050; PIC, Hendersonville, TN) initially 6.4 ± 0.02 kg were used in 31-d trial. This experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility consists of 3 totally enclosed, environmentally controlled, mechanically ventilated rooms. Each pen (1.52 ×

1.83 m; wire mesh flooring) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

In Exp. 2, a total of 360 pigs (Line 400 × 200; DNA Genetics, Columbus, NE) initially 5.9 ± 0.14 kg BW were used in a 28-d trial. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility consists of 2 completely enclosed, environmentally controlled, and mechanically ventilated barns. Each barn has 40 pens. 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. Pens (1.22 × 1.22 m) had wire-mesh floors and deep pits for manure storage. All diets for both experiments were manufactured at the K-State O.H. Kruse Feed Mill (Tables 1-1 Exp.1 and 1-2 Exp. 2).

Feed samples were taken during each dietary phase. Feed samples were analyzed for DM (934.01; AOAC International, 2006), CP (990.03; AOAC International, 2006), Ca and P (Campbell and Plank, 1991), and Zn (Kover, 2003) at Ward Laboratories, Inc. (Kearney, NE) for both experiments.

Experiment 1

A 31-d trial was conducted to determine the effects of Zn source (ZnO or LEZ; Zinco+, Jefo, Quebec, Canada) and level on the growth performance of nursery pigs. Pigs were weaned at 21-d of age and were then randomly allotted to pens based on initial BW. Pens were then randomly allotted to 1 of 6 dietary treatments using initial average BW as a blocking factor. Each treatment had 7 replicate pens with 7 pigs per pen with gender with either 3 or 4 barrows or gilts per pen. The 6 dietary treatments were arranged as 2 × 2 + 2 factorial and were: a control with 110 ppm Zn from $ZnSO_4$ from the trace mineral premix or the control with 390 or 1,390 ppm added Zn from LEZ; or 390, 1,390, or 2,890 ppm added Zn from ZnO, to provide 500, 1,500 or 3,000 ppm added Zn. The treatments with the 390 or 1390 ppm from either source were considered the 2 x 2 factorial treatment arrangement. Diets were fed in 3 phases from d 0 to 7, 7 to 21, and 21 to 31. Diets within phase were formulated to contain equal amounts of standardized ileal digestible (SID) Lys with 1.40, 1.35, and 1.22% SID Lys for phases 1, 2, and 3, respectively.

Pig weight and feed disappearance were measured on d 7, 14, 21, and 31 of the trial to determine ADG, ADFI, and G:F.

Experiment 2

A 28-d trial was conducted to determine the effects of ZnO and TBZC (Intellibond Z; Micronutrients, Indianapolis, IN) level on the growth performance of nursery pigs. Pigs were randomly allotted to pens based on weight. The treatments were then assigned to pen in a completely randomized design. Each treatment had 8 replicate pens (4 replicate pens in each barn) with 5 pigs per pen. The 9 dietary treatments were arranged as 2 × 4 + 1 factorial and consisted of a control diet that contained 110 ppm Zn from $ZnSO_4$ from the trace mineral premix or the control diet with 390, 890, 1,890, or 2,890 ppm added Zn from either TBZC or ZnO. This provided diets with a total of 500, 1,000, 2,000, or 3,000 ppm added Zn. Diets were fed in 3 phases from d 0 to 7, 7 to 21, and 21 to 28. Diets within phase were formulated to contain 1.40, 1.35, and 1.22% SID Lys for phases 1, 2, and 3, respectively.

Pig weight and feed disappearance were measured on d 0, 7, 14, 21, and 28 of the trial to determine ADG, ADFI, and G:F. On d 28 of the study, feces were collected to determine fecal

DM. Feces were collected from 3 pigs per pen for a total of 8 replications per treatment. Fecal samples were then frozen at -20°C until they were analyzed for DM (Undersander et al., 1993).

Statistical Analysis

Data for Exp. 1 and 2 was analyzed using PROC MIXED of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. For Exp. 1, weight block was included in the model as a random effect. Contrasts were used to evaluate the main effects and Zn level by source interactions for the 2 x 2 factorial treatment arrangement. Linear and quadratic Zn level contrast coefficients for each source were determined for unequally spaced treatments using the IML procedure of SAS and the treatment without supplemental Zn was used as the first dose for each of the sources.

For Exp. 2, barn was used as a blocking factor and was included in the model as a random effect. Source × by level interactions were evaluated using contrasts. The effects of increasing Zn level within source and main effects of Zn level were determined by linear and quadratic polynomial contrasts. Contrast coefficients were determined for unequally spaced treatments using the IML procedure of SAS.

Results from both experiments were considered significant at $P < 0.05$ and a tendency between $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

Chemical Analysis

Analysis of dietary Zn levels for all three phases in both Exp. 1 and 2 showed some variation compared to formulated levels in some phases (Table 1-3, Exp. 1 and Table 1-4, Exp. 2). However, most diets were in the acceptable range for analytic variation for Zn of 20% (AAFCO,

2015) considering that the targeted level did not account for Zn contributed from the feed ingredients only that which was supplemented. Thus, some of the variation could be due to different concentrations of Zn in ingredients used across feed manufacturing dates.

Growth Performance

Added Zn effects. In Exp. 1 (Table 1-5), for the 2 x 2 factorial treatments there were no Zn source by level interactions or Zn source differences observed throughout the entire 28 d study. From d 0 to 7, no differences were detected among pigs fed either Zn from LEZ or ZnO (P > 0.10). From d 7 to 21, pigs fed increasing Zn from LEZ tended to have increased (linear, P = 0.069) ADG and had improved G:F (linear, P = 0.011). Pigs fed increasing Zn from ZnO had greater ADG and ADFI (linear, P < 0.01) and improved G:F (quadratic, P = 0.022). Day-21 BW increased with increasing Zn from LEZ (linear, P = 0.039) and ZnO (linear; P < 0.01). From d 21 to 31, ADG and ADFI were not influenced by treatment; however, G:F tended to worsen (linear, P = 0.085) when pigs were fed increasing Zn from LEZ and worsened (linear, P = 0.022) when pigs were fed increasing Zn from ZnO. Overall, from d 0 to 31, increasing Zn from LEZ did not affect growth performance, but increasing Zn from ZnO increased (linear; P < 0.01) ADG and ADFI.

In Exp. 2, (Tables 1-6 and 1-7) there were no Zn source by level interactions or Zn source differences observed throughout the entire 28 d study. From d 0 to 7, 7 to 14, 14 to 21 and from d 0 to 28 increasing Zn increased ($P \leq 0.05$) ADG and ADFI. From d 0 to 7, increasing Zn from ZnO tended to increase (linear, P = 0.060) ADG and increased (linear, P = 0.022) ADFI. When increasing Zn from TBZC tended to improve (linear, P = 0.074) G:F. From d 7 to 14, increasing Zn from TBZC increased (linear, $P \leq 0.05$) ADG and ADFI and pigs fed increasing Zn from ZnO tended to have increased (linear, P = 0.087) ADFI. From d 14 to 21, Increasing Zn from either TBZC or ZnO increased (linear, $P \leq 0.05$) ADG, ADFI, and d 21 BW. From d 21 to 28, increasing Zn from TBZC increased (linear, $P = 0.030$) ADFI and tended to worsen (linear, $P = 0.092$) G:F. Increasing Zn from ZnO tended to increase (linear, $P = 0.099$) ADFI and worsened (linear, $P = 0.058$) G:F. From d 21 to 28, ADG was not influenced by Zn level; however, pigs fed increasing Zn from either Zn source had increased (linear, $P = 0.030$) ADFI, resulting in decreased G:F (quadratic, $P = 0.041$). Overall, from d 0 to 28, increasing Zn from TBZC increased (linear, $P \leq 0.05$) ADG, ADFI, and d 28 BW and pigs fed increasing Zn from ZnO had increased (linear, $P = 0.017$) ADFI and tended to have increased (linear, $P \geq 0.10$) ADG and d 28 BW.

The use of pharmacological levels of added Zn from various Zn sources has been shown to improve ADG and ADFI, with generally no improvement in G:F (Hill et al., 2001, Hollis et al., 2004, Williams et al. 2005). Williams et al. (2005) fed a control diet containing no added Zn, 1,000 or 2,000 ppm of added Zn from ZnO to 5.7 kg pigs that were weaned on d 19 for 21 d and observed a linear increase in ADG and ADFI for the overall study. When feeding pigs (19 d of age and weighing 6.0 kg) diets containing 0, 500, 1,000, 2,000 or 3,000 ppm of added Zn from ZnO, Hill et al. (2001) observed that ADG and ADFI from d 0 to 28 was increased with increasing Zn. When feeding 0, 50, 100, 200, 400, 800, 1,600, 2,400 or 3,200 ppm of added Zn from ZnO to pigs initially 12 d of age and 3.85 kg for 35 d, Woodworth et al. (1999) found that increasing Zn tended to increase ADG (linear; $P = 0.07$) and increased ADFI (linear; $P < 0.01$) with the greatest response observed from d 0 to 21. In addition, Hahn and Baker (1993) fed 250, 3,000 or 5,000 ppm of added Zn from ZnO and observed increased ADG and ADFI with increasing Zn for the overall (0 to 21 d) performance. Mavromichalis et al. (2000), fed 1,500 ppm of added Zn from 2 different ZnO sources, one with a low relative bioavailability (39%) and another with a high relative bioavailability (93%), and as well as diet that was free of added Zn. These diets were fed for 17 d to pigs that were weaned on d 21 and they observed increased (P = 0.05) ADG and improved (P = 0.05) G:F for pigs fed either ZnO source in comparison to the diet that contained no added Zn. They also observed no differences in performance for pigs fed added Zn from either ZnO. The responses observed in these experiments would agree with what we observed in both Exp. 1 and 2 when supplementing increasing levels of Zn.

Because pharmacological doses of added ZnO result in increased excretion of Zn in swine waste, it has been proposed that other sources of Zn, specifically organic sources of Zn, or inorganic sources with greater Zn availability, might be fed at lower concentrations and provide the same growth promoting effects. In previous studies various Zn sources such as Zn-methionine, Zn polysaccharide complex, Zn proteinate, Zn AA complex, and Zn AA chelate have been tested and in most cases have failed to perform similarly to the pharmacological levels of ZnO (Schell et al., 1996, Buff et al., 2005, and Hollis et al., 2005). Hollis et al. (2005) observed when replacing 2,500 ppm of added Zn from ZnO with 125, 250, or 500 ppm of added Zn from Zn methionine, that there were no differences for growth performance for pigs fed the three levels of Zn methionine but pigs had increased ADG compared to the control diet (no added Zn). However, they also observed that pigs fed 2,500 ppm of added Zn from ZnO had increased ADG compared to the three diets with added Zn from Zn methionine or the control. This response was driven by an increase in ADFI for the pigs fed 2,500 ppm of added Zn from ZnO from d 0 to 28. This response would agree with increased ADG and ADFI we observed in both Exp. 1 and 2 for pigs fed increasing Zn from ZnO.

Lipid encapsulated forms of ZnO have shown varied results. Park et al. (2015) reported no differences in growth performance of pigs fed either ZnO or the lipid encapsulated ZnO source at

100 ppm of added Zn over the duration of a 14 d study. Similarly, in our Exp. 1 there were no differences between ZnO or LEZ when added at levels of 500 and 1,500 ppm of Zn. Additionally, Park et al. reported that the 2,500 ppm of added Zn from ZnO had improved ADG and ADFI compared to the 100 ppm added Zn from ZnO or the lipid encapsulated ZnO. Likewise, in Exp. 1, optimal performance was obtained with 3,000 ppm of added Zn from ZnO compared to any other level of Zn from either source. Shen et al. (2014) fed diets containing 250 or 2,250 ppm of added Zn from ZnO, as well as 250, 380, 570, 760, or 1,140 ppm of added Zn from coated Zinc (CZ) in a 14 d trial. There were no significant differences between CZ and ZnO for ADG, ADFI, and G:F. Similarly, in Exp. 1 from d 0 to 7 there were no significant differences among dietary treatments. In Exp. 1, we observed from d 7 to 21, and 0 to 31 increasing Zn from ZnO increased (linear; $P < 0.01$) ADG and ADFI and from d 7 to 21 tended (linear; $P = 0.069$) to improve ADG for pigs fed increase Zn from LEZ. An additional study using a lipid encapsulated ZnO source resulted in no differences in ADG, ADFI, and G:F from d 0 to 14 (Jang et al., 2014) when comparing 125 or 2,500 ppm of added Zn from ZnO or diets containing 100 or 200 ppm of added Zn from LEZ. Kwon et al. (2014) used a lipid encapsulated Zn source and compared its efficacy to ZnO with a bacterial challenge from E. coli. During this 7 d study, ADG was similar for pigs fed 2,500 ppm added Zn from ZnO and 100 ppm of added Zn from the LEZ; while 100 ppm of added Zn from ZnO reduced pig performance compared to the other treatments. The length of the experiment conducted by Kwon et al. (2014) could have been the primary reason why they observed the responses in their study since they only conducted the experiment for 7 d.

In three experiments ranging from 19 to 21 d, Mavromichalis et al. (2001) evaluated the growth promoting efficacy of 1,500 and 3,000 ppm of Zn from TBZC in diets for nursery pigs. In Exp. 1 they observed that increasing Zn from TBZC tended to increase and then decrease ADG (quadratic; $P < 0.07$). Feeding the same levels of ZnO they observed a tendency for increased ADG (linear; $P = 0.06$). Contrary to the response in our experiments for G:F, Mavromichalis et al. (2001) also observed an improvement in feed efficiency (linear; $P < 0.01$) with increasing Zn. In the second experiment of the series, Mavromichalis et al. (2001) observed no differences for ADG or ADFI when pigs were fed added Zn at 1,500 ppm from either ZnO or TBZC when carbadox was also included in the diet. Again, they observed improved feed efficiency for pigs fed TBZC, while pigs fed ZnO showed no improvement for G:F. In the third experiment from Mavromichalis et al. (2001) increasing Zn from either ZnO or TBZC increased ADG and improved G:F. Mavromichalis et al. (2001) suggested that, when feeding 1,500 ppm or higher of added Zn from TBZC, ADG and G:F were improved and also suggested that any level fed higher than 1,500 ppm of added Zn from TBZC was not any more effective than the 1,500 ppm of added Zn from TBZC. This response would have been similar to our Exp. 2 were we observed improvements in ADG but we also observed increased ADFI with no differences in G:F. Additionally, Zhang et al. (2007) conducted a 28 d study on pigs weaned on d 27 and fed 2,250 or 3,000 ppm of added Zn from ZnO as well as 1,500, 2,250, or 3,000 ppm of added Zn from TBZC. They reported linear improvements for ADG and ADFI from d 0 to 14 for pigs fed either TBZC or ZnO. Similarly, from d 0 to 28, they reported a tendency for increased ADG at 2,250 ppm of added Zn from ZnO and then a decrease in ADG for pigs fed 3,000 ppm of Zn from ZnO. This response was driven by ADFI, with increased ADFI for pigs fed 2,250 ppm of added Zn from ZnO but decreased ADFI for pigs fed 3,000 ppm of added Zn from ZnO. The responses were similar for pigs fed equivalent levels of added Zn from TBZC. This would agree with the response we observed in Exp. 2 with increased ADG and ADFI from d 0 to 28 with increasing Zn from TBZC.

Fecal Dry Matter. For fecal DM (Tables 1-8 and 1-9) content on d 28 in Exp. 2, there was a tendency ($P = 0.081$) for a Zn source × level interaction. As Zn from TBZC increased, fecal DM decreased, but for pigs fed increased Zn from ZnO there was no difference in fecal DM. Zhang et al. (2007) evaluated fecal consistency and fecal scores on a daily basis for 28 d. They observed that added Zn from TBZC reduced fecal scores and improved fecal consistency (linear; $P < 0.01$). Zhang et al. (2007) also observed a similar response for pigs fed added Zn from ZnO to have reduced fecal scores and fecal consistency. Shen et al. (2014) also observed an improvement in diarrhea index for pigs fed added Zn from CZ. An additional study using a LEZ ZnO source resulted in no differences in fecal scores from d 0 to 14 (Jang et al., 2014). The results of these experiments would contrast to what was observed in Exp. 2 for pigs to have decreased fecal DM as added Zn from TBZC increased and that pigs fed increasing Zn from ZnO had no differences in fecal DM. This could be due to the event of toxicity issues that arise when using increased levels of added Zn for an extended period of time.

In summary, the LEZ source used in our study elicited the same performance as equal concentrations of ZnO. In our second study, increasing Zn from either TBZC or ZnO improved ADG and ADFI. In both studies, G:F worsened as Zn level increased. In both studies, the best growth performance occurred by including 3,000 ppm of Zn from ZnO in diets fed to weanling pigs for approximately 21 d. Our studies suggest that the alternative Zn sources (LEZ or TBZC) performed similar to equal levels of ZnO, and therefore cost and availability should determine their use.

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TABLES

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

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	37.53	54.60	63.69
Soybean meal (47.5% CP)	19.86	29.54	32.86
Blood meal	1.25	1.25	---
Blood plasma	4.00	---	---
Dried distillers grains with solubles	5.00	---	---
Fish meal	1.25	1.25	---
Spray-dried whey	25.00	10.00	---
Choice white grease	3.00	---	---
Monocalcium phosphate	0.90	0.80	1.00
Limestone	1.00	1.10	1.03
Salt	0.30	0.30	0.35
L-Lys-HCL	0.23	0.30	0.30
DL-Met	0.15	0.18	0.12
L-Thr	0.09	0.15	0.12
Vitamin premix [2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Choline chloride 60%	0.04	---	---
Phytase[4]	---	0.13	0.13
Zinc source[5]	---	---	---
TOTAL	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lys	1.40	1.35	1.22
Ile:lys	56	58	63
Leu:lys	128	125	129
Met:lys	32	35	33
Met & Cys:lys	57	58	57
Thr:lys	63	64	63
Trp:lys	19.0	18.1	18.7
Val:lys	71	69	69
Total lys, %	1.56	1.50	1.37
ME, kcal/kg	3,471	3,287	3,272
NE, kcal/kg	2,601	2,426	2,407
SID Lys:ME, g/Mcal	4.04	4.11	3.73
CP, %	22.2	22.1	21.4
Ca, %	0.85	0.80	0.70
P, %	0.73	0.63	0.61

Available P, %	0.51	0.47	0.41

[1] Experimental diets were fed in 3 phases, with phases 1, 2, and 3 fed from d 0 to 7, 7 to 21, and 21 to 31, respectively. All diets contained 110 ppm of Zn from ZnSO4 from the trace mineral premix.
[2] Provided per kilogram 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 kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, 198 mg Se from sodium selenite and 110 g Zn from zinc sulfate.
[4] Natuphos 600 (BASF, Florham Park, NJ) provided 154 phytase units (FTU)/kg, with a release of 0.09% available P.
[5] Diets contained added Zn from either LEZ or ZnO at 390, or 1,390 or ZnO at 2,890 ppm with the addition of 110 ppm added Zn from $ZnSO_4$ in the trace mineral premix to provide a total of 500, 1,500 and 3,000 ppm added Zn. Zinc was added at the expense of corn in the basal diet to form the experimental treatments.

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

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	36.55	52.74	63.28
Soybean meal (47.5% CP)	20.01	30.12	32.89
Spray-dried whey	25.00	10.00	---
Blood plasma	4.00	---	---
Dried distillers grains with solubles	5.00	---	---
Fish meal	3.75	4.00	---
Choice white grease	3.00	---	---
Monocalcium phosphate	0.93	1.03	1.60
Limestone	0.60	0.88	0.95
Salt	0.30	0.30	0.35
L-Lys-HCL	0.23	0.28	0.30
DL-Met	0.13	0.14	0.12
L-Thr	0.08	0.12	0.12
Vitamin premix[2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Choline chloride 60%	0.04	---	---
Zinc source[4]	---	---	---
TOTAL	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lys	1.40	1.35	1.22
Ile:lys	59	62	63
Leu:lys	125	123	129
Met:lys	32	35	33
Met & Cys:lys	57	57	57
Thr:lys	63	63	63
Trp:lys	18.8	18.1	18.7
Val:lys	69	67	68
Total lys, %	1.57	1.51	1.37
ME, kcal/g	3,479	3,290	3,257
NE, kcal/g	2,606	2,421	2,397
SID Lys:ME, g/Mcal	4.02	4.10	3.75
CP, %	22.6	22.8	21.3
Ca, %	0.90	0.90	0.80
P, %	0.73	0.76	0.74
Available P, %	0.52	0.47	0.42

[1] Experimental diets were fed in 3 phases with phase 1, 2, and 3 fed from day 0 to 7, 7 to 21, and 21 to 28; respectively. All diets contained 110 ppm of Zn from ZnSO4; from the trace mineral premix.

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

[4] Diets contained added Zn from either TBZC : (Intellibond Z®, Micronutrients, Indianapolis, IN) or ZnO at 390, 890, 1,890, and 2,890 ppm with the addition of 110 ppm added Zn from $ZnSO_4$ in the trace mineral premix to provide a total of 500, 1,000, 2,000 and 3,000 ppm added Zn. Zinc was added at the expense of corn in the basal diet to form the experimental treatments.

Table 1-3. Chemical analysis of experimental diets (Exp. 1)[1]

		Added Zn[2], ppm				
	Control[2]	LEZ[3]		ZnO		
Item	110	500	1,500	500	1,500	3,000
d 0 to 7						
DM, %	91.82	92.08	92.38	92.67	92.60	92.59
CP, %	21.70	23.00	22.50	22.70	22.80	22.70
Ca, %	0.99	0.93	1.00	0.96	0.98	1.05
P, %	0.66	0.76	0.78	0.82	0.77	0.85
Zn, ppm	122	488	1,533	1,010	1,279	2,881
d 7 to 21						
DM, %	91.06	91.00	91.62	91.29	91.09	91.48
CP, %	23.10	22.40	21.20	23.20	23.80	21.60
Ca, %	1.02	1.19	1.19	1.07	0.98	1.18
P, %	0.62	0.60	0.59	0.61	0.60	0.63
Zn, ppm	114	532	1,590	369	898	3,099
d 21 to 31						
DM, %	89.86	89.72	89.96	90.30	90.57	90.40
CP, %	21.30	22.50	22.50	22.40	21.40	22.00
Ca, %	0.96	0.89	0.88	0.89	0.95	0.91
P, %	0.56	0.66	0.60	0.65	0.66	0.64
Zn, ppm	273	354	1,604	434	1,612	2,690

[1] Means represent a composite of sub-samples per phase. Multiple samples of each diet were collected, blended and subsampled, and analyzed (Ward Laboratories, Inc., Kearney, NE)

[2] All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.

[3] Lipid encapsulated Zinc: Zinco +(Jefo, Quebec, Canada)

Table 1-4. Chemical analysis of experimental diets (Exp. 2) [1]

		Total added dietary Zn[2], ppm							
	Control[2]	TBZC[3]				ZnO			
Item	110	500	1,000	2,000	3,000	500	1,000	2,000	3,000
d 0 to 7									
DM, %	90.84	90.99	90.51	90.41	90.15	90.25	90.20	90.13	90.18
CP, %	22.70	22.80	21.90	21.60	21.40	21.40	22.20	22.60	22.70
Ca, %	1.02	1.00	1.09	1.10	1.21	1.18	0.96	1.23	1.09
P, %	0.85	0.79	0.81	0.81	0.80	0.78	0.78	0.86	0.82
Zn, ppm	120	528	1,023	2,173	3,596	644	862	2,375	3,050
d 7 to 21									
DM, %	89.53	89.88	89.73	89.37	89.50	89.48	89.80	89.75	89.42
CP, %	23.10	22.40	22.50	22.70	21.70	23.20	23.40	23.20	23.10
Ca, %	0.99	1.00	1.16	1.15	1.11	1.05	0.99	1.17	0.99
P, %	0.78	0.83	0.83	0.79	0.79	0.78	0.83	0.86	0.78
Zn, ppm	212	502	1,278	2,143	3,065	558	742	1,765	2,480
d 21 to 28									
DM, %	88.52	88.64	88.48	88.52	88.58	88.65	88.44	88.61	88.65
CP, %	21.30	21.30	21.00	21.40	21.80	21.50	21.90	21.30	22.70
Ca, %	0.73	0.87	0.84	0.70	0.76	0.82	0.79	0.86	0.77
P, %	0.72	0.78	0.69	0.67	0.73	0.73	0.72	0.78	0.73
Zn, ppm	243	522	1,565	2,030	2,479	725	731	1,547	2,449

[1] Multiple samples of each diet were collected, blended and subsampled, and analyzed (Ward Laboratories, Inc., (Kearney, NE)

[2] All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.

[3] Tetrabasic zinc chloride; IntelliBond® Z, (Micronutrients, Indianapolis, IN).

Table 1-5. Evaluation of different Zn sources and levels on nursery pig performance, (Exp. 1)[1]

	Control[2]	Added Zn[2], ppm						Probability[3], $P <$			
		LEZ[4]		ZnO				LEZ[4]		ZnO	
Item	110	500	1,500	500	1,500	3,000	SEM	Linear	Quadratic	Linear	Quadratic
d 0 to 7											
ADG, g	81	89	92	108	93	110	10.0	0.411	0.660	0.105	0.813
ADFI, g	182	179	175	193	190	197	11.1	0689	0.959	0.405	0.873
G:F	0.438	0.488	0.553	0.573	0.492	0.557	0.0534	0.109	0.853	0.296	0.755
d 7 to 21											
ADG, g	267	280	308	277	321	352	15.8	0.069	0.978	< 0.001	0.6092
ADFI, g	434	424	452	419	458	508	21.9	0.464	0.541	0.005	0.516
G:F	0.617	0.660	0.683	0.657	0.703	0.696	0.0164	0.011	0.316	0.002	0.022
d 21 to 31											
ADG, g	509	511	499	532	514	510	15.6	0.579	0.773	0.663	0.600
ADFI, g	790	799	810	822	825	836	19.3	0.435	0.914	0.124	0.484
G:F	0.644	0.640	0.615	0.646	0.624	0.610	0.0122	0.085	0.721	0.022	0.990
d 0 to 31											
ADG, g	303	311	319	319	332	348	10.5	0.292	0.822	0.005	0.539
ADFI, g	492	490	503	495	516	542	13.5	0.502	0.721	0.006	0.906
G:F	0.617	0.636	0.634	0.643	0.644	0.642	0.0110	0.364	0.328	0.236	0.187
BW, kg											
d 0	6.5	6.5	6.5	6.5	6.5	6.5	0.02	0.202	0.268	0.483	0.338
d 7	7.1	7.10	7.2	7.3	7.1	7.3	0.07	0.298	0.831	0.088	0.963
d 21	10.7	11.0	11.5	11.2	11.6	12.2	0.25	0.039	0.967	< 0.001	0.661
d 31	15.9	16.1	16.5	16.6	16.8	17.4	0.31	0.160	0.920	0.003	0.559

[1]A total of 294 pigs (PIC 327 × 1050) were used with 7 pigs per pen and 7 pens per treatment.

[2] Treatments were arranged in a 2 x 2 factorial of source or dose (500 vs 1500 ppm Zn) + the control and 3000 ppm Zn0 treatments.
All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.

[3]For the factorial there were no source × by dose interactions or effects of source $P \geq 0.10$. For dose there was a main effect ($P < 0.05$) of dose for ADG and GF from d 7 to 21.

[4] Lipid encapsulated Zn: Zinco +(Jefo, Quebec, Canada)

Table 1-6. Evaluation of different Zn sources and levels on nursery pig performance, (Exp. 2)[1]

	Total added dietary Zn[2], ppm										Probability[3,4], $P <$			
	Control[2]	TBZC[5]				ZnO					TBZC[5]		ZnO	
Item	110	500	1,000	2,000	3,000	500	1,000	2,000	3,000	SEM	Linear	Quadratic	Linear	Quadratic
d 0 to 7														
ADG, g	103	128	114	135	134	112	85	133	130	16.1	0.140	0.585	0.060	0.636
ADFI, g	109	135	125	130	128	117	104	135	134	9.8	0.367	0.271	0.022	0.912
G:F	0.907	0.938	0.911	1.026	1.039	0.954	0.805	0.964	0.934	0.0808	0.074	0.962	0.615	0.649
d 7 to 14														
ADG, g	197	199	202	215	232	210	171	221	215	14.2	0.049	0.692	0.190	0.569
ADFI, g	263	294	298	302	318	286	256	306	298	23.4	0.047	0.529	0.087	0.894
G:F	0.749	0.673	0.693	0.714	0.727	0.734	0.673	0.723	0.729	0.0471	0.818	0.200	0.812	0.190
d 14 to 21														
ADG, g	393	384	398	391	476	423	385	439	462	27.2	0.008	0.072	0.018	0.569
ADFI, g	507	508	523	521	583	579	489	561	603	34.5	0.015	0.307	0.007	0.290
G:F	0.772	0.753	0.763	0.746	0.817	0.728	0.791	0.782	0.768	0.0242	0.203	0.095	0.615	0.631
d 21 to 28														
ADG, g	453	441	444	458	456	429	454	479	431	20.5	0.680	0.846	0.999	0.299
ADFI, g	686	676	676	682	756	678	684	734	719	30.8	0.030	0.085	0.099	0.822
G:F	0.657	0.652	0.657	0.671	0.604	0.634	0.664	0.653	0.599	0.0197	0.092	0.078	0.058	0.130
d 0 to 28														
ADG, g	285	288	289	300	323	294	273	318	307	13.4	0.030	0.470	0.083	0.990
ADFI, g	389	403	406	409	444	415	383	434	434	15.6	0.016	0.577	0.017	0.934
G:F	0.728	0.712	0.716	0.731	0.729	0.706	0.717	0.733	0.707	0.0144	0.567	0.693	0.756	0.708
BW, kg														
d 0	5.9	5.9	6.0	5.9	5.9	5.9	5.9	5.9	5.9	0.14	0.707	0.418	0.887	0.813
d 7	6.6	6.8	6.8	6.9	6.8	6.7	6.5	6.8	6.8	0.12	0.186	0.401	0.070	0.560
d 14	8.0	8.2	8.2	8.4	8.5	8.2	7.7	8.4	8.3	0.18	0.061	0.781	0.076	0.546
d 21	10.8	10.9	11.0	11.1	11.8	11.1	10.4	11.5	11.6	0.32	0.009	0.415	0.011	0.416
d 28	13.9	14.0	14.1	14.3	15.1	14.1	13.5	14.8	14.6	0.43	0.024	0.433	0.055	0.823

[1]A total of 360 pigs (DNA Genetics Line 400 × 200) were used with 5 pigs per pen and 8 pens per treatment.
[2]All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.
[3]Significance was determined by $P \leq 0.05$.
[4]There were no source × dose interactions $P \geq 0.10$.
[5] Tetrabasic zinc chloride; IntelliBond® Z, (Micronutrients, Indianapolis, IN).

Table 1-7. Main effects of different Zn sources on nursery pig performance (Exp. 2)[1]

	Zn Source				Total added dietary Zn[2], ppm					Probability[3], $P <$		
Item	Control[2]	TBZC[4]	ZnO	SEM	500	1,000	2,000	3,000	SEM	TBZC vs ZnO	Linear	Quadratic
d 0 to 7												
ADG, g	103	128	115	10.3	120	99	134	132	12.6	0.210	0.038	0.964
ADFI, g	109	129	122	5.1	126	115	132	131	7.0	0.312	0.047	0.537
G:F	0.907	0.979	0.914	0.0582	0.946	0.858	0.995	0.987	0.0666	0.163	0.109	0.756
d 7 to 14												
ADG, g	197	212	204	7.1	204	186	218	223	10.0	0.458	0.042	0.549
ADFI, g	263	303	286	18.0	290	277	304	308	19.9	0.181	0.022	0.635
G:F	0.749	0.702	0.715	0.0393	0.704	0.683	0.718	0.728	0.0420	0.538	0.987	0.124
d 14 to 21												
ADG, g	393	412	427	19.3	403	391	415	469	22.3	0.346	0.002	0.141
ADFI, g	507	534	558	28.7	544	506	541	593	30.8	0.122	0.002	0.198
G:F	0.772	0.770	0.767	0.0121	0.740	0.777	0.764	0.792	0.0171	0.884	0.349	0.462
d 21 to 28												
ADG, g	453	450	448	10.3	435	449	468	443	14.5	0.915	0.798	0.598
ADFI, g	686	698	704	22.7	677	680	708	738	25.7	0.717	0.018	0.348
G:F	0.657	0.646	0.638	0.0116	0.643	0.661	0.662	0.602	0.0148	0.510	0.024	0.041
d 0 to 28												
ADG, g	285	300	298	6.7	291	281	309	315	9.5	0.820	0.016	0.659
ADFI, g	389	415	417	8.6	409	394	421	439	11.4	0.896	0.003	0.690
G:F	0.728	0.722	0.715	0.0072	0.709	0.716	0.732	0.718	0.0101	0.529	0.820	0.975
BW, kg												
d 0	5.9	5.9	5.9	0.13	5.9	5.9	5.9	5.9	0.13	0.343	0.747	0.721
d 7	6.6	6.8	6.7	0.08	6.7	6.6	6.8	6.8	0.09	0.138	0.052	0.872
d 14	8.0	8.3	8.1	0.09	8.2	7.9	8.4	8.4	0.13	0.202	0.024	0.839
d 21	10.8	11.2	11.1	0.21	11.0	10.7	11.3	11.7	0.25	0.796	0.001	0.313
d 28	13.9	14.4	14.3	0.27	14.0	13.8	14.6	14.8	0.33	0.762	0.010	0.531

[1]A total of 360 pigs (DNA Genetics Line 400 × 200) were used with 5 pigs per pen and 32 pens for source and 16 pens for dose per treatment.
[2]All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.
[3]Significance was determined by $P \leq 0.05$.
[4] Tetrabasic zinc chloride; IntelliBond® Z, (Micronutrients, Indianapolis, IN).

Table 1-8. Evaluation of zinc sources and levels on nursery pig fecal DM (Exp. 2)[1]

		Added dietary Zn[2], ppm									Probability[3,4], $P <$					
	Control[2]	TBZC[5]				ZnO					Source × level		TBZC[5]		ZnO	
Item	0	500	1,000	2,000	3,000	500	1,000	2,000	3,000	SEM	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Fecal, DM	27.9	29.8	27.4	27.6	24.2	27.6	28.0	27.9	25.9	0.93	0.081	0.568	0.001	0.087	0.179	0.294

[1]A total of 216 samples were collected on d 28of the study with 3 samples per pen and 8 pens per treatment.
[2]All diets contained an additional 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.
[3]Significance was determined by $P \leq 0.05$.
[4]There was no significant difference for TBZC vs ZnO.
[5] Tetrabasic zinc chloride; IntelliBond® Z, (Micronutrients, Indianapolis, IN).

Table 1-9. Main effects of zinc sources on nursery pig fecal DM (Exp. 2)[1]

	Zn Source				Added dietary Zn[2], ppm					Probability[3], $P <$		
Item	Control[2]	TBZC[4]	ZnO	SEM	500	1,000	2,000	3,000	SEM	TBZC vs ZnO	Linear	Quadratic
Fecal, DM	27.9	27.3	27.3	0.46	28.7	27.7	27.7	25.1	0.66	0.134	0.004	0.087

[1] A total of 216 samples were collected on d 28 of the study with 3 samples per pen and 32 pens for source and 16 pens for dose per treatment.
[2]All diets contained an additional 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.
[3]Significance was determined by $P \leq 0.05$.
[4] Tetrabasic zinc chloride; IntelliBond® Z, (Micronutrients, Indianapolis, IN).

Chapter 2 - Effects of vegetable oil type and level on nursery pig performance

ABSTRACT

Two experiments were conducted to determine the effects of vegetable oil type and level on nursery pig growth performance. In both experiments, diets were formulated to a constant standardized ileal digestible Lys:ME of 3.78 g/Mcal. In Exp. 1, 350 pigs (PIC 1050; initially 12.0 ± 0.37 kg and 45 d of age) were used in a 21-d study with 5 pigs per pen and 10 replications per treatment. The 3 vegetable oil sources included a commercially available of soybean oil (Grain States Soya Inc., West Point, NE), and two sources of corn oil derived from ethanol production (source 1: Poet, Sioux Falls, SD; and source 2: Green Plains Renewable Energy, Shenandoah, IA). The 7 dietary treatments consisted of a corn and soybean meal-based control diet with either no added oil or with 2.5 or 5% soybean oil or corn oil from either source. The energy values for oil sources were based off the NRC (2012) for corn oil (8,579 kcal/kg) and soybean oil (8,574 kcal/kg).Overall, an oil source × level interaction was observed ($P < 0.05$) for ADG, G:F and caloric efficiency (CE; caloric intake/total BW gain). For ADG, increasing soy oil or corn oil source 1 increased ADG while increasing corn oil source 2 decreased ADG. Gain:feed increased at a greater rate for pigs fed corn oil source 1 compared to the other oil sources which led to improved CE for this source. This suggests that the energy value is greater for corn oil source 1 than the other oil sources. In Exp. 2, a total of 210 pigs (PIC 327 × 1050, initially 13.1 kg BW ± 0.53 kg and 46 days of age) were used in a 21-d trial with 6 pens per treatment and 7 pigs per pen to evaluate a commercial source of soybean oil (Grain States Soya Inc., West Point, NE), and a proprietary source of refined corn oil originating from the ethanol industry (Corn Oil ONE®, Feed

Energy LLC Pleasant Hill, IA). The 5 experimental diets included: a control diet without added oil, diets with 2.5 or 5% added soybean oil or corn oil. The same energy values for oil sources in Exp. 1 were used. Overall, from d 0 to 21, there were no oil source × level interactions observed, or differences between oil sources. Increasing corn or soybean oil had no effect on ADG or final BW; however, increasing corn oil or soybean oil decreased (linear; $P < 0.05$) ADFI and improved (linear; $P < 0.01$) G:F. Caloric efficiency on an ME or NE basis was not affected by either corn or soybean oil source or level indicating the formulated energy values assigned to the oil sources (8,579 and 8,574 kcal/kg for corn oil and soybean oil) were accurate. Overall, these studies showed improvements in G:F when adding either corn source 1 or soybean oil in nursery pig diets ranging from 12 to 26 kg. However there exists differences in corn oil sources that affect growth performance.

Key words: corn oil, growth, nursery pig, soybean oil

INTRODUCTION

Soybean oil can be added to nursery pig diets as a highly digestible source of energy (Cervantes-Pahm, and Stein, 2008), but feed manufactures often choose to include other sources of dietary fat based on economics. However, when feeding vegetable oil to swine, Cera at el. (1990) showed no differences in nursery growth performance for pigs fed either corn oil or soybean oil and both improved G:F when compared to a no added oil control diet. Tokach et al. (1995) reported a similar response in which G:F was improved post-weaning for pigs fed either corn oil, soybean oil, or tallow.

More recently, corn oil has become a more economical dietary added lipid source compared to soybean oil because of increased oil extraction during the ethanol manufacturing process. Ethanol production facilities utilize different oil extraction techniques (Hojilla-Evangelista et al., 1992; Feng et al. 2002; Moreau et al., 2005). Some methods used would be fraction of the corn germ before fermentation and various post fermentation methods in order to collect corn oil. Currently, no data is available comparing corn oil fed to nursery pigs from the different corn oil extraction methods. These methods can have influence the FFA, peroxide values, moisture, insolubles, and unsaponifiables (MIU) for the resulting corn oil (Moreau et al., 2010; Winkler-Mosler and Breyer, 2010). It is not uncommon for corn oil to a have a FFA level up to 15% and a range of wax content from 15 ppm to 50 ppm (Moreau et al., 2010). Due to the high wax and FFA levels in these oils, a refined corn oil with reduced FFA and wax concentrations is now being produced (Feed Energy LLC., Pleasant Hill, IA), but no data is available on its performance in nursery pigs. Thus, the objective of these experiments was to compare different corn oil sources and commercially available soybean oil on growth performance of nursery pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

In Exp. 1, a total of 350 pigs (PIC 1050; initially 12.0 ± 0.37 kg and 45-d of age) were used in a 21-d study. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility consists of two completely enclosed, environmentally controlled, and mechanically ventilated barns. Pens in each barn were equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Pens (1.22 × 1.22 m) had wire floors and deep pits for manure storage.

In Exp. 2, a total of 210 pigs (PIC 327 × 1050, initially 13.1 ± 0.53 kg BW and 46-d of age) were used in a 21-d trial. This experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen (1.52 × 1.83 m) had wire-mesh floors that contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

Samples of each oil source were collected at feed manufacturing and were analyzed for moisture (2c-25; AOCS Ca, 2013), insoluble impurities (3a-46; AOCS Ca, 2013) and unsaponifiables (6a-40; AOCS Ca, 2013), FFAs (5a-40; AOCS Ca, 2013), and peroxide value (12-57; AOCS Ca, 2013) at Novus Laboratories, (St. Charles, MO); (Table 2-1). For Exp. 2, samples of each oil source were collected at feed manufacturing and were analyzed for tha same criteria as Exp. 1 at Midwest Laboratories, (Omaha, NE; Table 2-2). Feed samples of each dietary treatment were taken at multiple times from multiple feeders, blended and sub-sampled for analysis. Feed samples were analyzed for DM (934.01; AOAC International, 2006), CP (990.03; AOAC International, 2006), Ca and P (Campbell and Plank, 1991), and ether extract (920.39 A; AOAC International, 2006) at Ward Laboratories, Inc. (Kearney, NE).

Experiment 1

The 7 dietary treatments were arranged in 2 × 3 +1 factorial, with 5 pigs per pen and 10 pens per treatment and consisted of a no added oil control diet, diets with 2.5 or 5% added soybean oil, and diets with 2.5 or 5% added corn oil from 2 different sources. Pigs were weaned at approximately 21 d of age and fed a common diet before the start of the experiment. The commercially available oil sources were: soybean oil (Grain States Soya Inc., West Point, NE), corn oil source 1 (Poet, Sioux Falls, SD), and corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA). Diets were formulated to same standardized ileal digestible (SID**)** Lys:ME, ratio of 3.78 g/Mcal which resulted in SID Lys of 1.23, 1.28, and 1.33% for the 0, 2.5%, and 5% added oil diets, respectively (Table 2-3). The energy values for oil sources were based from NRC (2012) for corn oil (8,579 kcal/kg) and soybean oil (8,574 kcal/kg).

Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, G:F, and caloric efficiency (CE; caloric intake/total BW gain).

Experiment 2

Pigs were weaned at 18 or 25 d of age with weaning age used as a blocking factor. Pigs within wean age were randomly allotted to pens so average pen weight was balanced across pens. Pens were then assigned 1 of 5 dietary treatments in a completely randomized manner with 6 pens per treatment with 7 pigs per pen. Pigs were fed a common diet before the start of the experiment. The 5 dietary treatments were arranged in 2 × 2 + 1 factorial with a no added oil control diet, diets with 2.5 or 5% added soybean oil (Grain States Soya Inc., West Point, NE), and diets with 2.5 or 5% added corn oil (Corn Oil ONE®, Feed Energy LLC., Pleasant Hill, IA). Similar to Exp. 1, diets were formulated to have a balanced Lys:ME ratio, of 3.78 g/Mcal with SID Lys of 1.23, 1.28, and 1.33 for the 0, 2.5%, and 5% added oil diets, respectively (Table 2-3). The same energy values of oil sources (NRC, 2012) were used, in diet formulation.

Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, G:F, and caloric efficiency.

Statistical Analysis

Data for Exp. 1 and 2 were analyzed using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Barn and weight block within barn were included in the model as random effects in Exp. 1. Weaning age was included in the model as a random effect in Exp. 2.

Source by dose interactions were evaluated using contrasts. The dose effects of oil source were tested using linear and quadratic polynomial contrasts. Treatment differences were considered significant at $P \leq 0.05$ and a tendency from $P > 0.05$ to $P \leq 0.10$.

RESULTS

Chemical analysis

Experiment 1 and 2. Quality characteristics of the oil sources (Table 2-1 and 2-2 for Exp. 1 and 2, respectively) differed for FFA, peroxide value, and MIU. In Exp. 1, the FFA for soybean oil was 0.16%, 4.10% for corn oil source 1, and 11.80 for corn oil source 2. The initial peroxide values were 47.60, 1.00, and 5.60 meq/kg for soybean oil, corn oil source 1, and corn oil source 2, respectively. In Exp. 2, the FFA for soybean oil was 0.46%, and the corn oil was 1.29%. The peroxide values value were 14.0 and 16.9 for soybean oil and corn oil used in Exp. 2. The diet analysis results (Table 2-4 and 2-5 for Exp. 1 and 2, respectively) were similar to expectations from diet formulation.

Growth performance

Experiment 1. For overall growth performance (d 0 to 21; Table 2-6), an oil source × level interactions were observed (P < 0.05) for ADG, G:F and caloric efficiency. For ADG, increasing soybean oil or corn oil source 1 increased ADG while increasing corn oil source 2 decreased ADG. The interaction for G:F was due to feed efficiency improving at a greater rate for pigs fed increasing corn oil source 1 compared to the other oil sources. Caloric efficiency did not change as soy oil or corn oil source 2 level increased, whereas pigs fed increasing corn oil source 1 had improved CE.

Experiment 2. Overall (d 0 to 21; Table 2-7), no oil source × level interactions were observed. Increasing soybean or corn oil had no effect on ADG or final BW. Average daily feed intake decreased (linear, P = 0.003) with increasing oil level, which resulted in an improvement (linear, P < 0.001) in G:F. Caloric efficiency was not influenced by oil source or level, indicating that the energy values assigned to each oil source (ME = 8,574 kcal/kg and ME = 8,579 kcal/kg for soybean oil and corn oil, respectively: NRC, 2012) were accurate.

DISCUSSION

Vegetable oil sources commonly used in nursery pig diets (12 to 26 kg) could be corn, soybean, and blended vegetable oils (Cera et al., 1989; 1990); while commonly used animal-based fats are tallow or choice white grease. Cera et al. (1989; 1990) observed improved growth performance when pigs were fed diets containing vegetable oils, when compared to those fed animal-based fats. Several other researchers (Tokach et al., 1995; Adeola et al., 2013; Mendoza et al., 2014) have noted few differences among pigs fed, different fat or oil sources; however the level of added fat or oil has been more important in dictating the level of improvement of growth performance. These studies show the benefit of added fat to nursery pig diets in order to improve G:F and in some instances increase ADG.

Cera et al. (1988a) observed the addition of 6% corn oil had no effect on ADG in the first 3 wk after weaning; but during the 4th week after weaning, an increase in ADG was observed compared to pigs fed no added fat. In Exp. 1, pigs fed corn oil source 1 had improved ADG in comparison to pigs fed no added fat with pigs that were approximately 45 d of age at the beginning of the study. This apparently age dependent response to added oil is still not fully understood. In addition, Li et al. (1990) evaluated the use of soybean oil, coconut oil, or multiple combinations of soybean and coconut oil. They observed increased ADG and ADFI from d 0 to 35, but no improvements in G:F. This is similar to results of Cera et al. (1990) who evaluated the use of corn oil, soybean oil, and coconut oil. This would agree with the improvements observed in G:F for pigs fed either corn-oil or soybean-oil added to diets in Exp. 1. In, Tokach et al. (1995) evaluated the addition of 6% added fat from either corn oil, soybean oil, or tallow, and observed an improvement in G:F which was driven by reduced ADFI with no differences in overall ADG due to fat source. Likewise, Adeola et al. (2013) reported no differences in ADG for pigs fed either soybean oil or tallow but observed an improvement in G:F (0 to 35 d) as level of either soybean oil or tallow were increased in the diet. The response they observed was primarily driven by reduced feed intake. The responses observed in these experiments would be similar to what was observed in Exp. 1 and 2 for G:F with increasing oil concentration in the diet.

In contrast, Kil et al. (2013) evaluated the addition of soybean oil at 5, 8, and 10% of the diet in 27 kg grower pigs and found no differences in ADG, ADFI, and G:F in comparison to the control diet over a 28-d period. Kil et al. (2011) observed a tendency (linear, *P* = 0.08) for improved G:F with increasing soybean oil; while they also observed no difference in ADG for pigs fed either 10% added soybean oil or choice white grease. Likewise, Cera et al (1988b), observed no differences in ADG, ADFI, and G:F for nursery pigs fed corn oil, lard, or tallow. The variability in response in ADG in the literature is consistent with the results of our experiments, where ADG was improved by two of the oil sources in Exp. 1, but not by the third source or by either oil source in Exp. 2. The reduced ADFI with increasing dietary energy and resulting improved G:F is more consistent as demonstrated in both Exp. 1 and 2 with all oil sources. The reasoning for increased ADG needs further investigation in order to determine what factor is truly impacting this response.

The energy value of the corn oil source 1 used in Exp. 1 must be greater than ME and NE in comparison to the NRC (2012) to the improvement in CE. However, for the soybean oil and corn oil source 2, the caloric values for ME and NE based upon the NRC (2012) were accurate due to the similar CE for pigs fed either these oil sources in comparison to diet with no added oil. Likewise for Exp. 2, the values estimated by the NRC (2012) for ME and NE these oil sources were fairly accurate due to similar CE.

The observations of feeding nursery pigs diets containing fats or oils that have various FFA profiles, peroxide values, and MIU are very limited. The ideal quality characteristics of oils needs to be further evaluated in order to improve fat quality standards and in turn improve growth performance of pigs. In Exp. 1, the FFA profile of soybean oil was lower than corn oil but neither oil source had a FFA concentration of concern based on work conducted by DeRouchey et al. (2004) or Shurson et al. (2015). DeRouchey et al. (2004) observed that FFA content could be as high as 53% in choice white grease and not affect growth performance of weanling pigs. However, that research generated FFAs with a lipase without thermal heating. Shurson et al. (2015) reviewed various oil and fat sources for lipid peroxidation by using quality indicating criteria such as active oxygen method, oil stability index, and oxygen bomb method. Results indicated that these quality indicators vary in their ability to determine peroxidation of lipids. The authors suggested that more emphasis should be placed on FFA as a measure of fat quality.

In Exp. 1 the soybean oil source had a peroxide value of 47.60 mEq/kg which did not reduce growth performance of nursery pigs. However, this value is slightly greater than the suggested maximum peroxide value of 40 mEq/kg for choice white grease suggested by DeRouchey et al. (2004). In addition in Exp. 1, pigs fed the soybean oil had improved growth performance in comparison to pigs fed the two corn oil sources which had PVs of 1.00 and 5.60 mEq/kg. Furthermore, pigs had increased growth ADG in comparison to pigs fed an oil free diet. A better understanding of peroxide value and the impact on growth performance could be better determined with further experimentation. In Exp. 2, using the same source of soybean oil but from a different batch, we observed a peroxide value of 14.6 mEq/kg and the corn oil used had a peroxide value of 16.9 mEq/kg. In Exp. 2, no differences in performance was observed for pigs fed either soybean or corn oil. Due to the lack of knowledge of how these measurements affect growth performance, as well as the limited number of experiments evaluating these measurements and their application to diet formulation, more work is needed in order to have a better understanding of how theses fat quality indicators influence growth performance of weanling pigs.

Our data suggests that there may be differences in corn oil sources and additional research should be conducted to further define the impact of corn oil source on growth performance of pigs. Overall, these experiments confirm the benefits of adding dietary vegetable oil in 12 to 26 kg pig diets to improve G:F.

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TABLES

Table 2-1. Chemical analysis of oil sources (Exp. 1)[1]

Item	Soybean oil[2]	Corn oil 1[3]	Corn oil 2[4]
FFA, %	0.16	4.10	11.80
Initial peroxide value, meq/kg	47.60	1.00	5.60
Moisture, %	0.05	0.55	0.45
Insoluble impurities, %	0.03	0.07	0.02
Unsaponifiables, %	0.53	1.76	1.86

[1] Samples were analyzed by NOVUS Laboratories, Inc. (St. Louis, MO).
[2] Soybean oil (Grain States Soya Inc., West Point, NE).
[3] Corn oil source 1 (Poet, Sioux Falls, SD).
[4] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).

Table 2-2. Chemical analysis of oil sources (Exp. 2)[1]

Item	Soybean oil[2]	Corn oil [3]
FFA, %	0.46	1.29
Initial peroxide value, meq/kg	14.0	16.9
Moisture, %	0.32	0.64
Insoluble impurities, %	0.18	0.04
Unsaponifiables, %	0.41	1.52

[1]Samples were analyzed by Midwest Laboratories, Inc. of Omaha, NE.
[2] Soybean oil (Grain States Soya Inc., West Point, NE).
[3] Corn Oil ONE®, (Feed Energy LLC., Pleasant Hill, IA).

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

Ingredient, %	Control	2.5% oil	5% oil
Corn	63.58	58.56	53.52
Soybean meal (46.5% CP)	32.65	35.20	37.75
Oil source[2]	---	2.50	5.00
Monocalcium phosphate (21% P)	1.30	1.28	1.28
Limestone	1.08	1.08	1.05
Salt	0.35	0.35	0.35
L-Lys-HCL	0.32	0.31	0.30
DL-Met	0.13	0.14	0.15
L-Thr	0.12	0.12	0.13
Vitamin premix[3]	0.25	0.25	0.25
Trace mineral premix[4]	0.15	0.15	0.15
Phytase[5]	0.08	0.08	0.08
TOTAL	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) Lys:ME, g/Mcal	3.78	3.78	3.78
SID amino acids, %			
Lys	1.23	1.28	1.33
Ile:lys	62	63	63
Leu:lys	128	126	124
Met:lys	34	34	34
Met & Cys:lys	57	57	57
Thr:lys	63	63	63
Trp:lys	18.4	18.7	19.0
Val:lys	68	68	68
Total lys, %	1.38	1.43	1.49
ME, kcal/kg	3,259	3,387	3,515
NE, kcal/kg	2,401	2,507	2,615
CP, %	21.3	22.1	22.9
Ca, %	0.73	0.73	0.73
P, %	0.68	0.68	0.68
Available P, %	0.45	0.45	0.45

[1] Experimental diets were fed for 21 d.

[2] Corn oil source 1 (Poet, Sioux Falls, SD), Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA), and soybean oil (Grain States Soya Inc., West Point, NE) were obtained commercially for Exp. 1. Corn Oil ONE™, (Feed Energy, Des Moines, Iowa) and soybean oil (Grain States Soya Inc., West Point, NE) for Exp. 2.

[3] Provided per kilogram 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.

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

[5] Natuphos 600 (BASF, Florham Park, NJ) provided 448.7 phytase units (FTU)/kg, with a release of 0.09% available P.

Table 2-4. Chemical analysis of experimental diets (Exp. 1)[1]

	Control	Soybean oil,[2]%		Corn oil 1,[3]%		Corn oil 2,[4]%	
Item, %	0	2.5	5	2.5	5	2.5	5
DM	89.87	90.38	90.59	90.38	90.62	90.64	90.57
CP	21.90	22.80	23.70	21.60	23.40	22.50	23.20
Ca	1.05	0.90	0.89	1.03	1.06	0.92	0.98
P	0.69	0.64	0.70	0.67	0.71	0.65	0.65
Crude fat	2.8	4.9	7.2	4.9	7.7	4.4	5.7

[1] Multiple samples were collected from each diet throughout the study, homogenized, then subsampled and analyzed (Ward Laboratories, Kearney, NE).
[2] Soybean oil (Grain States Soya Inc., West Point, NE).
[3] Corn oil source 1 (Poet, Sioux Falls, SD).
[4] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).

Table 2-5. Chemical analysis of experimental diets (Exp. 2)[1]

	Control	Soybean oil,[2]%		Corn oil,[3]%	
Item, %	0	2.5	5	2.5	5
DM	89.59	89.64	90.52	89.97	90.05
CP	23.7	23.9	25.1	24.1	24.5
Ca	0.91	0.96	0.91	0.83	0.91
P	0.78	0.73	0.73	0.69	0.71
Oil	2.9	5.1	7.4	4.6	7.1

[1] Samples were collected, homogenized, sub-sampled, and analyzed (Ward Laboratories, Kearney, NE).
[2] Soybean oil (Grain States Soya Inc., West Point, NE).
[3] Corn Oil ONE®, (Feed Energy LLC., Pleasant Hill, IA).

Table 2-6. Comparison of source and level of vegetable oil on nursery pig performance (Exp. 1)[1]

										Probability, P[5] <	
	Source	None	Soybean oil[2]		Corn oil 1[3]		Corn oil 2[4]			Soybean oil	Corn oil 1	Corn oil 2
Item	level, %	0	2.5	5.0	2.5	5.0	2.5	5.0	SEM	Linear	Linear	Linear
d 0 to 21												
ADG, g[a]		633	682	693	662	673	661	655	12.8	0.001	0.020	0.199
ADFI, g[a,b]		1,011	1,026	1,008	978	943	981	946	20.5	0.939	0.020	0.025
G:F[b]		0.627	0.666	0.689	0.677	0.714	0.675	0.693	0.0118	< 0.001	< 0.001	< 0.001
ME[6bc]		5,211	5,101	5,115	5,008	4,928	5,029	5,078	86.3	0.292	0.003	0.144
NE[7bc]		3,837	3,776	3,806	3,708	3,666	3,723	3,778	63.9	0.645	0.013	0.381
BW, kg												
d 0		12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.37	0.832	0.678	0.692
d 21[a]		25.3	26.5	26.6	25.9	26.2	25.9	25.7	0.37	0.005	0.045	0.330

[1] A total of 350 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment.
[2] Soybean oil (Grain States Soya Inc., West Point, NE)
[3] Corn oil source 1 (Poet, Sioux Falls, SD).
[4] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).
[5] No significant differences were observed for quadratic effects.
[6] Caloric efficiency = Kcal of7ME per kg of gain (ADFI × ME/kg) /ADG).
[7] Caloric efficiency = Kcal of NE per kg of gain (ADFI × NE/kg) /ADG).
[a] Source × level interaction (soybean oil × corn oil 1); $P < 0.05$.
[b] Source × level interaction (soybean oil × corn oil 2); $P < 0.05$.
[c] Source × level interaction (corn oil 1 × corn oil 2); $P < 0.10$.

Table 2-7. Comparison of vegetable oil sources on nursery pig performance (Exp. 2)[1]

	Added oil, %						Probability, $P <$ [4]		
	Control	Soybean oil		Corn oil			Level		Soybean oil vs
Item	0	2.5	5.0	2.5	5.0	SEM	Linear	Quadratic	Corn oil
d 0 to 21									
ADG, g	643	655	634	645	642	12.8	0.727	0.437	0.965
ADFI, g	989	981	889	945	913	23.7	0.006	0.430	0.805
G:F	0.651	0.668	0.714	0.684	0.704	0.0092	< 0.001	0.592	0.711
ME[2]	5,006	5,075	4,930	4,963	4,997	66.0	0.605	0.580	0.737
NE[3]	3,686	3,757	3,668	3,674	3,717	48.9	0.912	0.570	0.929
BW, kg									
d 0	13.2	13.2	13.2	13.2	13.2	0.53	0.966	0.989	0.965
d 21	26.7	26.9	26.5	26.7	26.7	0.64	0.901	0.736	0.735

[1] A total of 210 pigs (PIC 327 × 1050) were used in a 21-d study with 7 pigs per pen and 6 pens per treatment.
[2] Caloric efficiency = Kcal of ME per kg of gain ((ADFI × ME/kg) /ADG).
[3] Caloric efficiency = Kcal of NE per kg of gain ((ADFI × NE/kg) /ADG).
[4] No source × level interactions.

Chapter 3 - Effects of increasing crystalline amino acids in sorghum- or corn-based diets on nursery and finishing pig growth performance

ABSTRACT

Two experiments were conducted to determine the effects of increasing crystalline AA in sorghum- or corn-based diets on nursery and finishing pig growth performance. In Exp. 1, a total of 300 pigs (PIC 1050; initially 10.6 ± 0.36 kg BW) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of grain source (sorghum vs. corn) and crystalline AA supplementation (low, medium, or high). Amino acids ratios to Lys as well as standardized ileal digestibility coefficients used were based on those estimated by NRC (2012). All diets were formulated to the same Lys:NE ratio and at 95% of the pig's estimated Lys requirement to ensure that AA were not above the pigs requirement. The grain sources and soybean meal were analyzed for AA profile and diets were formulated based on these values. In Exp. 1 the low AA fortification contained L-Lys and DL-Met. The medium AA fortification contained L-Lys, DL-Met and L-Thr, and the high AA fortification contained L-Lys, DL-Met, L-Thr, and L-Val. Overall, no grain source × crystalline AA interactions were observed. There were no differences among treatments for ADG or ADFI; however G:F tended to increase then decrease (quadratic; $P = 0.078$) as AA fortification increased. In Exp. 2, a total of 288 pigs (PIC 327 × 1050; initially 45.9 ± 0.79 kg) were used in a 90-d study with 8 pigs per pen and 6 pens per treatment. Diets used the same batch of sorghum, corn, and soybean meal and formulated on the same principles as Exp. 1 with the exception that the high AA fortification contained L-Val in sorghum- and L-Trp in corn-based diets. Pigs fed corn-based diets tended to have greater ADG ($P < 0.072$) and had greater G:F ($P < 0.01$) than those fed sorghum-based diets. As crystalline AA increased, ADG tended to increase then decrease (quadratic; $P = 0.057$), and ADFI decreased (linear; $P = 0.019$). Pigs fed sorghum had decreased ($P < 0.01$) jowl iodine value in comparison to those fed corn-based diets. In conclusion, there were no grain source or AA fortification differences observed for ADG and ADFI in nursery pigs, but increasing amounts of crystalline AA increased and then decreased G:F. In finishing diets increasing AA resulted in decreased ADG and G:F. In the finishing study, grain sorghum had approximately 97% of the feeding value relative to corn based on G:F. Crystalline AA can replace soybean meal in times when it would be advantageous to reduce diet cost and not hinder growth performance.

Key words: corn, crystalline AA, finishing pig, nursery pig, sorghum

INTRODUCTION

In order to lower feed costs, crystalline AA are used routinely in swine diets to replace a portion of dietary soybean meal. The AA that are commonly added to swine diets would include Lys, Thr, Met, Trp, and Val. The increased availability of crystalline AA sources has created the opportunity to formulate grain-based diets to the fifth or sixth limiting AA. If this can be accomplished without negatively affecting pig growth performance and reduce N excretion in swine waste (Shriver et al., 2003). However, in some cases, low-protein, AA–fortified diets have not provided similar growth performance as those fed high CP diets without crystalline AA (Kerr et al. 2003), thus further investigation in this type of diet is needed.

The use of a grain sorghum in diets as the primary energy source in nursery and finishing diets has been used in experiments in the past by Brudevold and Southern (1994), Ward and Southern (1995), and De la Llata et al. (2002). These studies have also examined the effects of using low-protein sorghum-based diets with added crystalline AA. The addition of crystalline AA to nursery and finishing diets in some experiments has resulted in no impact on growth performance (Page et al., 1993; and Brudevold and Southern, 1994). However, in some experiments the addition of crystalline AA has been shown to reduce ADG as crystalline AA level increased (Ward and Southern, 1995; and De la Llata et al., 2002). These differences are likely due to formulation method, use of total vs. digestible AA coefficients, and ratios of other AA to Lys. It could also be due to the energy assigned to each grain source and due to the AA requirements of those pigs.

Because AA requirement estimates are now routinely based on standardized ileal digestible (SID) AA ratios relative to Lys, the objective of these studies were to determine the effects of feeding increasing concentrations of crystalline AA as a replacement for soybean meal in sorghum- or corn-based diets on growth performance of nursery and finishing pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

In Exp. 1, a total of 300 pigs (PIC 1050; initially 10.6 ± 0.36 kg and 39 d of age) were used in a 21-d study. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility consists of two completely enclosed, environmentally controlled, and mechanically ventilated barns. Each pen (1.22 m × 1.22 m) was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. In Exp. 2, a total of 288 pigs (PIC 327 × 1050, initially 45.9 ± 0.74 kg BW) were used in a 90-d trial. This experiment was conducted in the finishing facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen contained a 2-hole, dry self-feeder and a cup waterer to provide ad libitum access to feed and water. Pens (2.44 m × 3.05 m) were located over a completely slatted concrete floor with a 1.20-m pit underneath for manure storage.

The grain sources and soybean meal were analyzed for AA profile and diets were formulated from these concentrations (Table 3-1). Feed samples for each dietary treatment were taken at multiple times during the experiment, and sub-sampled for chemical analysis. Feed and ingredient samples were analyzed for DM (934.01; AOAC International, 2006), Ca and P (Campbell and Plank, 1991), at Ward Laboratories, Inc. (Kearney, NE). Total AA (method 994.12;

AOAC Int., 2012), and CP (method 990.03; AOAC Int., 2012) were analyzed by Ajinomoto Heartland, Inc. (Eddyville, IA). Diets were formulated on analyzed AA values and NRC (2012) SID coefficients.

Experiment 1

A 21-d trial was conducted with 5 pigs per pen and 10 replications per treatment. Pigs were randomly assigned to pens and then pens were randomly assigned to treatment in a complete randomized block design based on weight blocks within barn. Dietary treatments were arranged in a 2 × 3 factorial with main effects of grain source (grain sorghum vs. corn) and crystalline AA concentration (low, medium, or high). The low AA fortification diet contained L-Lys HCl and DL-Met. The medium AA fortification contained L-Lys HCl, DL-Met, and L-Thr; and the high AA fortification contained L-Lys HCl, DL-Met, L-Thr, and L-Val (Table 3-2). Amino acid to Lys ratios, as well as standardized ileal digestibility (SID) coefficients used were those estimated by NRC (2012). The diets were formulated at 95% of the pig's estimated Lys requirement (Nemechek et al., 2014) to ensure that all AA were not above the pig's requirement. Furthermore, because replacing soybean meal with crystalline AA increased the dietary NE content, with all diets were formulated to a constant Lys:NE ratio. The NE concentration of grain sorghum was assumed to be 96% that of corn (NRC, 1998) as the 2012 NRC reports the NE content of grain sorghum greater than that of corn. Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and G:F.

Experiment 2

The experiment was 90 d in duration and used 8 pigs per pen and 6 pens per treatment. Pigs were randomly assigned to pens and the treatments randomly assigned to treatments in a completely randomized manner. The 6 dietary treatments were arranged in 2 × 3 factorial with main effects of grain source (grain sorghum vs. corn) and crystalline AA level (low, medium, or high). The low and medium AA diets were similar in limiting order as in Exp. 1, but in the high AA fortification, sorghum-based diets contained L-valine and corn-based diets contained L-tryptophan (Tables 3-3 to 3-6). The grain sources and soybean meal were from the same batches as used in Exp. 1. Diets were fed in 4 dietary phases in meal form, and in each phase diets were balanced to have the same Lys:NE ratio.

Pig weight and feed disappearance were measured approximately every 2 wk, throughout the trial to determine ADG, ADFI, and G:F.

On d 90, all pigs were individually weighed and tattooed for carcass data collection and transported 210 km to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for collection of standard carcass data and jowl fat iodine value (IV). Jowl fat IV was calculated using Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) using the equation of Cocciardi et al. (2009). Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage carcass yield, backfat, loin depth, and percentage lean. Fat depth and loin depth were measured with an optical probe inserted approximately 7cm from the dorsal midline between the 3rd and 4th last rib (counting from the ham end of the carcass). Percentage yield was calculated by dividing HCW at the plant by live weight at the farm.

Statistical Analysis

Data were analyzed using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1 barn and weight block within barn were included in the model as random effects. Treatments were arranged in a 2 × 3 factorial with interactive and main effects of grain source and AA fortification. Contrasts were used to evaluate the linear and quadratic dose effects of increasing AA concentrations. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

RESULTS

Chemical Anlaysis

Dietary analysis for Exp. 1 and 2 showed that nutrients in the experimental diets were similar to those calculated from diet formulation (Table 3-7, 3-8 and 3-9).

Growth Performance.

Experiment 1 Overall, no main or interactive effects ($P > 0.05$) of grain source or added crystalline AA were detected for ADG and ADFI (Tables 3-10 and 3-11). Increasing crystalline AA concentrations at the expense of soybean meal did not influence ADG or ADFI; however, there was a tendency (quadratic; $P = 0.079$) for G:F was similar then decreased at the high crystalline AA fortification diet.

Experiment 2 Overall, no grain source × crystalline AA interactions were observed ($P > 0.05$; Table 3-12). Pigs fed corn-based diets tended to have greater ADG ($P < 0.072$) and had greater G:F ($P < 0.01$) than those fed sorghum-based diets (Table 3-13). As crystalline AA concentrations increased, ADG tended to increase then decrease (quadratic; $P = 0.057$), and ADFI decreased (linear; P= 0.019) but there was no effect no G:F. Pigs fed corn-based diets tended to have greater loin depth ($P = 0.088$) and increased ($P < 0.01$) jowl IV compared to pigs fed sorghum-based diets. Increasing crystalline AA fortification did not influence any carcass characteristic.

DISCUSSION

The use of sorghum in swine diets has increased because of increased production in Midwestern states with semi-arid climates where sorghum is agronomically more advantageous in yield compared to corn (Carter et al., 1989). The relative energy value of sorghum is often reported as approximately 96% of corn when used as the primary grain in swine diets but it can completely replace corn without affecting growth performance (Shelton et al., 2004; Benz et al., 2011).

The sorghum used in these experiments had lower percentages of total AA in comparison to estimates of the NRC (2012) as well as lower DM, CP, crude fiber, ADF, and NDF values. The corn used in formulation was relatively similar to the estimates of the NRC (2012) for total percentages of total AA and for the previously specifications that were mentioned for sorghum.

Previous research has evaluated the effects of increasing crystalline AA in corn-or sorghum-based diets for both nursery and finishing pigs (Page et al., 1993; Brudevold and Southern, 1994; Ward and Southern, 1995). Page et al. (1993) evaluated Thr supplementation of low-protein, Lys supplemented, sorghum-soybean meal diets for growing-finishing pigs (30 to 100 kg). They observed no effect on ADG or ADFI for pigs supplemented with Thr, and observed reduced G:F for pigs fed a low protein diet without Thr supplementation. However, the diets were formulated on total AA-basis which could result in formulating above the estimated SID AA values. Brudevold and Southern (1994) added the crystalline AA Met, His, Ile, Trp, and Val in sorghum-based diets for 10 to 20 kg nursery pigs and reported no differences in performance for nursery pigs fed various crystalline AA or various levels of crystalline AA in comparison to a positive control containing minimum amounts of additional crystalline AA. Again, these diets were formulated on total AA-basis which would likely result in over formulation. Ward and Southern (1995) added crystalline AA (Lys, Thr, Met, and Trp) to sorghum-based diets on a total AA basis for finishing pigs. They observed reduced ADG for pigs supplemented with high levels of AA in comparison to finishing pigs fed a positive control sorghum-soybean meal based diet formulated to 110% of the lysine requirement (NRC, 1988) with no effects on ADFI or G:F. This would agree with the present data where ADG of finishing pigs fed increasing crystalline AA levels had a ADG that tended to increase and then decrease (quadratic; $P = 0.057$). However, Hansen et al. (1993) conducted a series of experiments evaluating the AA supplementation (total-basis) of low-protein sorghum-soybean meal diets for 5- to 20-kg pigs. They observed that diets supplemented with crystalline Thr and Met and containing 17% CP had equal performance compared to pigs fed a 21% CP diet without crystalline AA. Variability in results of these experiments might be due to differences in AA formulation. Nutritionist currently formulate to a digestible or SID basis compared to a total diet level which could account for differences in AA digestibility. Formulating on a NE basis has given nutritionists a better utilization of crystalline AA net energy values and provide added energy when using higher concentrations of crystalline AA.

De la Llata et al. (2002) made a comparison of sorghum-based diets or corn-based diets with the addition of increasing Lysine HCl for growing-finishing pigs (29 to 120 kg). They observed in sorghum-based diets that increasing Lys HCL decreased (linear, $P < 0.01$) ADG and G:F. However, the decrease in ADG and G:F was most prominent in diets containing greater than 0.15% L-Lys. Based on 2012 NRC ratios, all other AA should not have been limiting on a SID basis until 0.30% L-lysine was added (Met & Cys, and Thr). This would suggest that the required minimum AA ratios related to Lys were different than what is predicted by the NRC (2012). A second possibility was that the sorghum used by De la Llata et al. (2002), was different in AA profile compared to the book values used in formulation, similar to what was observed in our chemical analysis of sorghum. In corn-based diets in relation to 2012 NRC SID ratio requirements, Met, Thr, and Trp should have been limiting in diets containing 0.225% L-lysine which corresponded with decreased ADG and G:F.

Roux et al. (2011) conducted a study to evaluate the limiting AA beyond Lys, Thr, Trp, and Met in corn-soybean meal based diets in growing pigs (20 to 45 kg). They formulated on a SID basis using 1998 NRC nutrient values. They observed decreased ADG, and G:F for pigs fed a diet supplemented with crystalline Lys, Thr, Trp, and Met. They concluded other AA other than Lys, Thr, Trp, and Met were likely limiting. This study would contrast from our Exp. 1 were we observed no differences in corn or sorghum diets regardless of level of crystalline AA inclusion but agrees with results observed in Exp. 2 where another AA or nutrient could have been limiting which caused the reduction in performance we observed. Nemechek et al. (2014) evaluated the addition of crystalline AA replacing fish meal, meat and bone meal, or poultry meal in nursery pig diets. From d 0 to 28 they observed that there were no differences in growth performance for pigs supplemented with crystalline AA in replace of any of the intact protein sources. The AA ratios relative to Lys used by Nemechek et al., (2014) were: Ile:Lys, 52%:, Met and Cys:Lys, 58%: Thr:Lys, 62%: Trp:Lys, 16.5%: and Val:Lys, 65%. Our minimum ratios in the nursery study were Ile:Lys, 51.2%: Met and Cys:Lys, 55.3%: Thr:Lys, 59.5%: Trp:Lys, 16.3%: and Val:Lys, 63.4%. Although some AA ratios were slightly lower than Nemechek et al. (2014) we also did not see a change in ADG in Exp. 1. In Exp. 1, grain source or AA inclusion level did not have a detrimental effect on nursery pig growth performance which confirms the response of Nemechek et al. (2014).

Waguespack et al. (2012) evaluated the addition of Val in 25 to 45 kg pigs. They titrated Val levels from 0.61, 0.63, 0.65, 0.67 and 0.69 for a Val:Lys ratio in their experiment and formulated diets on SID to range from 0.51 to 0.61 Val. They observed increased ADG, and ADFI and improved G:F with increasing Val:Lys ratio. They used a broken line analysis to determine that the SID requirement for ADG was 0.58 and 0.56 for G:F. They also concluded that SID Val:Lys ratio does not change as BW increases for the pig and that the SID Val:Lys ratio is 0.71 from complied data and analysis that they performed. In Exp. 2, through all four phases could have been lower than the value, of 0.71 for the Val:Lys ratio based upon Waguespack et al. (2012). Which, in Exp. 2 based on the order of AA, Ile or Val (sorghum) and Ile (corn) could have been below their estimated requirement.

Sotak et al. (2014) fed either corn- or sorghum-based diets to nursery pigs (11 to 20 kg) and, similar to our Exp. 1, observed no differences in pig growth between the two cereal grain sources. Benz et al. (2011) observed the effects of increasing choice white grease (CWG) in corn- and sorghum-based diets in finishing pigs for 83 d and observed that pigs fed sorghum-based diets had increased ADG (P = 0.01) in comparison to pigs fed corn-based diets. This would contrast to what we observed in Exp. 2 where pigs fed corn-based diets tended to have increased ADG (P = 0.076) in comparison to pigs fed sorghum-based diets. This difference could have been due to the energy values assigned to the grain sources when diets were formulated. Pigs fed sorghum-based diets had reduced NE in comparison to pigs fed corn-based diets. Furthermore Benz et al., (2011) observed that finishing pigs fed sorghum-based diets with added CWG had decreased jowl fat IV in comparison to pigs fed corn-based diets with added CWG. This would agree with the reduced jowl fat IV we observed in pigs fed sorghum-based diets in comparison to pigs fed corn-based diets. Sotak et al. (2015) observed the effects of adding 30% corn or sorghum dried distiller grains to either sorghum-based diets or corn-based diets in finishing pigs over 73 d and they observed no grain source difference for ADG, ADFI, or G:F. Likewise they observed a tendency (P = 0.10) for pigs fed sorghum-based diets to have reduced jowl IV compared to pigs fed corn-based diets.

Again this would agree with the decrease jowl IV we observed in Exp. 2 for pigs fed sorghum-based diets in comparison to pigs fed corn-based diets.

In summary, our results suggest that corn or sorghum elicit similar performance when used in nursery pig diets. However, when sorghum was fed in finishing pig diets, an energy value of 97% that of corn, based on ADG and G:F was observed. This coincides with the differences in energy (NRC, 1998) concentration between the two grains. Potential explanations for the decrease in ADG and G:F in the high AA fortified diets could possibly be due to greater AA requirements for Ile and Val. We speculate this as a possibility because their ratios were lower than those used in the medium formulations where ADG and G:F were the greatest among the three AA regimens. Also, when formulating diets to the 5th or 6th limiting AA, it is likely that an AA, most likely Val, was limited and should be further investigated. A second possibility is that nutrients other than AA are possible limiting in low-protein, AA-fortified diets.

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TABLES

Table 3-1. Analyzed concentration of sorghum, corn, and soybean meal (%, as-fed basis)[1] used in Exp. 1 and 2.

Item, %	Sorghum	Corn	Soybean meal
DM	87.03	84.01	89.47
CP	7.5	8.4	48.9
Crude Fiber	1.6	1.5	2.9
Ca	0.04	0.03	0.34
P	0.24	0.24	0.69
AA			
Arg	0.29	0.36	3.33
His	0.16	0.23	1.19
Ile	0.26	0.28	2.12
Leu	0.82	0.98	3.47
Lys	0.17	0.23	2.86
Met	0.13	0.17	0.65
Phe	0.34	0.37	2.33
Thr	0.23	0.28	1.82
Trp	0.08	0.06	0.68
Val	0.33	0.36	2.13

[1] Multiple samples were collected from each grain source prior to the study, homogenized, and then subsampled for analysis at Ward Laboratories, Kearney, NE and Ajinomoto Heartland, Inc., Chicago, IL..

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

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	61.59	67.36	70.72
Sorghum	61.10	67.10	72.66	--	--	--
Soybean meal (46.5% CP)	35.86	29.41	23.24	35.33	29.07	25.36
Monocalcium phosphate (21% P)	1.10	1.15	1.23	1.18	1.25	1.3
Limestone	1.03	1.05	1.08	1.00	1.04	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys-HCl	0.16	0.37	0.59	0.18	0.39	0.52
DL-Met	0.08	0.15	0.22	0.05	0.12	0.16
L-Thr	--	0.10	0.20	--	0.10	0.15
L-Val	--	--	0.11	--	--	0.07
Vitamin premix [2]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	5.04	5.04	5.04	5.04	5.04	5.04
SID AA, %						
Lys	1.11	1.13	1.14	1.15	1.16	1.17
Ile:lys	72	61	51.2	71	60	55
Leu:lys	136	120	105	140	126	117
Met:lys	31.7	34.8	37.7	30.4	33.2	34.8
Met & Cys:lys	55.3	55.3	55.3	55.3	55.3	55.3
Thr:lys	59.4	59.4	59.4	59.4	59.4	59.4
Trp:lys	23.2	19.7	16.3	21.7	18.2	16.3
Val:lys	73.7	63.4	63.4	73.1	63.4	63.4
Total lysine, %	1.25	1.25	1.25	1.29	1.29	1.30
NE NRC, kcal/kg	2,324	2,357	2,390	2,392	2,428	2,452
CP, %	22.3	19.9	17.7	22.7	20.4	19.1
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.63	0.61	0.60	0.64	0.63	0.62
Available P, %	0.43	0.43	0.44	0.43	0.44	0.45

[1] Experimental diets were fed for 21 d beginning approximately 18 d after weaning.
[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] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.3 phytase units (FTU)/kg with a release of 0.10% available P.

Table 3-3. Phase 1 diet composition(as-fed basis), Exp. 2[1]

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	74.25	77.80	83.79
Sorghum	73.73	78.87	79.91	--	--	--
Soybean meal (46.5% CP)	23.65	18.16	17.01	23.05	19.29	13.75
Monocalcium phosphate (21% P)	0.75	0.80	0.82	0.82	0.84	0.51
Limestone	1.03	1.00	1.00	1.07	1.04	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.15
L-Lys-HCl	0.15	0.33	0.37	0.16	0.29	0.36
DL-Met	0.04	0.10	0.12	--	0.04	0.05
L-Thr	--	0.09	0.10	--	0.05	0.08
L-Trp	--	--	--	--	--	0.01
L-Val	--	--	0.02	--	--	--
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	3.64	3.64	3.64	3.64	3.64	3.64
SID AA, %						
Lys	0.81	0.82	0.83	0.84	0.85	0.85
Ile:lys	73.3	61.1	58.5	72.1	64.0	59.7
Leu:lys	150.5	132.6	128.9	159.2	147.7	141.6
Met:lys	31.6	35.1	35.8	29.0	31.2	32.4
Met & Cys:lys	56.7	56.7	56.7	56.7	56.7	56.7
Thr:lys	61	61	61	62	61	61
Trp:lys	23.4	19.3	18.5	21.2	18.5	18.5
Val:lys	77.0	65.2	65.2	76.9	69.2	65.2
Total lys, %	0.92	0.91	0.91	0.96	0.96	0.96
NE NRC, kcal/kg	2,391	2,420	2,426	2,470	2,494	2,507
CP, %	17.3	15.2	14.8	17.7	16.3	15.6
Ca, %	0.61	0.59	0.59	0.62	0.60	0.60
P, %	0.50	0.49	0.48	0.51	0.50	0.49
Available P, %	0.34	0.34	0.34	0.34	0.34	0.34

[1] Experimental diets were fed for 20 d from 46 to 66 kg

[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] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.28 phytase units (FTU)/kg with a release of 0.10% available P.

Table 3-4. Phase 2 diet composition (as-fed basis), Exp. 2[1]

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	79.16	81.97	83.79
Sorghum	77.28	82.67	84.06	--	--	--
Soybean meal (46.5% CP)	20.55	14.75	13.2	18.53	15.51	13.75
Monocalcium phosphate (21% P)	0.34	0.38	0.42	0.45	0.48	0.51
Limestone	1.00	1.03	1.03	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.15
L-Lys-HCl	0.15	0.34	0.39	0.2	0.3	0.36
DL-Met	0.03	0.09	0.11	--	0.03	0.05
L-Thr	--	0.09	0.11	0.01	0.06	0.08
L-Trp	--	--	--	--	--	0.01
L-Val	--	--	0.03	--	--	--
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	3.22	3.22	3.22	3.22	3.22	3.22
SID AA, %						
Lys	0.74	0.75	0.75	0.76	0.77	0.78
Ile:lys	73.9	59.7	56.1	69.6	62.5	58.2
Leu:lys	156.5	135.7	130.5	162.4	152.3	146.1
Met:lys	30.8	35.0	36.0	28.8	30.7	31.8
Met & Cys:lys	56.6	56.7	56.6	56.8	56.6	56.6
Thr:lys	61.2	61.2	61.2	61.2	61.2	61.2
Trp:lys	23.5	18.8	17.6	20.0	17.6	17.6
Val:lys	78.3	64.7	64.7	75.5	68.8	64.7
Total lys, %	0.84	0.83	0.83	0.87	0.87	0.87
NE NRC, kcal/kg	2,417	2,446	2,454	2,509	2,527	2,543
CP, %	16.0	13.8	13.3	15.9	14.8	14.2
Ca, %	0.52	0.52	0.52	0.52	0.52	0.52
P, %	0.40	0.38	0.38	0.41	0.41	0.41
Available P, %	0.25	0.25	0.26	0.25	0.26	0.26

[1] Experimental diets were fed for 22 d from 66 to 86 kg.

[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] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.28 phytase units (FTU)/kg with a release of 0.10% available P.

Table 3-5. Phase 3 diet composition (as-fed basis), Exp. 2[1]

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	83.26	84.35	83.79
Sorghum	79.89	85.46	86.44	--	--	--
Soybean meal (46.5% CP)	18.21	12.22	11.12	14.61	13.42	13.75
Monocalcium phosphate (21% P)	0.20	0.25	0.28	0.34	0.35	0.51
Limestone	0.90	0.93	0.93	0.88	0.90	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.15
L-Lys-HCl	0.13	0.32	0.36	0.23	0.27	0.36
DL-Met	0.02	0.08	0.09	--	0.01	0.05
L-Thr	--	0.09	0.11	0.03	0.05	0.08
L-Trp	--	--	--	--	--	0.01
L-Val	--	--	0.02	--	--	--
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	2.88	2.88	2.88	2.88	2.88	2.88
SID AA, %						
Lys	0.67	0.67	0.68	0.70	0.70	0.70
Ile:lys	76	60	57	67	64	58
Leu:lys	165	142	137	166	162	154
Met:lys	31	35	36	29	30	32
Met & Cys:lys	57.5	57.5	57.5	57.5	57.5	57.5
Thr:lys	63.0	63.0	63.0	63.0	63.0	63.0
Trp:lys	24.0	18.7	17.8	18.8	17.8	17.8
Val:lys	81.2	65.8	65.8	74.3	71.6	65.8
Total lysine, %	0.76	0.75	0.75	0.79	0.79	0.79
NE NRC, kcal/kg	2,434	2,464	2,469	2,538	2,545	2,560
CP, %	15.0	12.8	12.4	14.4	13.9	13.1
Ca, %	0.45	0.45	0.45	0.45	0.45	0.45
P, %	0.36	0.34	0.34	0.37	0.37	0.36
Available P, %	0.22	0.22	0.22	0.23	0.23	0.22

[1] Experimental diets were fed for 21 d from 86 to 106 kg.
[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] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.28 phytase units (FTU)/kg with a release of 0.10% available P.

Table 3-6. Phase 4 diet composition (as-fed basis), Exp. 2[1]

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	86.56	87.03	89.29
Sorghum	82.26	88.06	88.68	--	--	--
Soybean meal (46.5% CP)	16.06	9.81	9.13	11.47	10.95	8.48
Monocalcium phosphate (21% P)	0.05	0.12	0.15	0.20	0.20	0.25
Limestone	0.85	0.87	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys-HCl	0.11	0.31	0.33	0.23	0.25	0.33
DL-Met	0.004	0.07	0.08	--	--	0.02
L-Thr	--	0.09	0.10	0.04	0.05	0.09
L-Trp	--	--	--	--	0.004	0.02
L-Val	--	--	0.01	--	--	--
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	2.56	2.56	2.56	2.56	2.56	2.56
SID AA, %						
Lys	0.60	0.60	0.60	0.62	0.62	0.63
Ile:lys	79.0	60.4	58.4	66.7	65.2	58.3
Leu:lys	176.5	149.2	146.3	174.9	172.8	162.9
Met:lys	30.7	36.0	36.6	30.4	30.0	31.8
Met & Cys:lys	59.0	59.0	59.0	59.9	59.0	59.0
Thr:lys	65.6	65.6	65.6	65.6	65.6	65.6
Trp:lys	24.9	18.7	18.1	18.1	18.1	18.1
Val:lys	85.1	67.3	67.2	75.2	73.8	67.2
Total lys, %	0.68	0.67	0.67	0.71	0.71	0.71
NE NRC, kcal/kg	2,449	2,480	2,484	2,561	2,565	2,579
CP, %	14.1	11.8	11.6	13.1	12.9	12.1
Ca, %	0.40	0.40	0.40	0.40	0.40	0.40
P, %	0.32	0.30	0.31	0.33	0.33	0.33
Available P, %	0.18	0.19	0.19	0.19	0.19	0.20

[1] Experimental diets were fed for 27 d from 106 to 128 kg.

[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] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 478.26 phytase units (FTU)/kg with a release of 0.10% available P.

Table 3-7. Chemical analysis of experimental diets (as-fed basis) for Exp. 1[1]

		Grain source					
		Sorghum			Corn		
Item, %	Crystalline AA	Low	Medium	High	Low	Medium	High
DM		89.15	89.34	89.26	89.99	89.72	89.71
CP		23.3	20.5	18.1	23.3	21.5	20.0
Ca		0.66	0.82	0.70	0.83	0.74	0.76
P		0.53	0.68	0.54	0.62	0.71	0.62
AA							
Arg		1.43	1.26	1.07	1.51	1.39	1.28
His		0.55	0.49	0.43	0.59	0.55	0.52
Ile		0.95	0.87	0.70	0.98	0.91	0.79
Leu		1.89	1.75	1.50	1.98	1.86	1.74
Lys		1.30	1.33	1.34	1.40	1.44	1.46
Met		0.39	0.42	0.47	0.40	0.42	0.44
Thr		0.83	0.80	0.85	0.89	0.90	0.88
Trp		0.27	0.25	0.21	0.28	0.23	0.21
Val		1.01	0.95	0.92	1.06	1.00	0.94

[1] Multiple samples were collected from each diet throughout the study, homogenized, and then subsampled for analysis at Ward Laboratories, Kearney, NE and Ajinomoto Heartland, Inc., Chicago, IL.

Table 3-8. Chemical analysis of experimental diets Phase 1 and 2 (as-fed basis), Exp. 2[1]

		Grain source[2]						Grain source[3]					
		Sorghum			Corn			Sorghum			Corn		
Item, %	Crystalline AA	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
DM		86.79	86.68	86.52	87.22	87.20	86.75	86.46	86.40	86.43	86.60	86.83	86.51
CP		17.3	15.4	14.7	17.7	16.6	16.2	16.8	13.4	13.0	16.2	15.0	14.5
Ca		0.84	0.73	0.56	0.66	0.60	0.57	0.71	0.85	0.63	0.62	0.58	0.71
P		0.47	0.43	0.45	0.57	0.59	0.51	0.43	0.36	0.34	0.43	0.45	0.42
AA													
Arg		1.05	0.87	0.84	1.12	0.98	0.93	0.99	0.73	0.65	0.92	0.85	0.80
His		0.42	0.36	0.35	0.46	0.41	0.40	0.40	0.31	0.28	0.40	0.38	0.36
Ile		0.77	0.67	0.69	0.72	0.68	0.62	0.68	0.54	0.48	0.62	0.58	0.55
Leu		1.57	1.42	1.36	1.62	1.52	1.48	1.47	1.28	1.18	1.46	1.42	1.38
Lys		0.98	0.94	0.97	1.01	0.98	0.96	0.91	0.82	0.79	0.90	0.85	0.90
Met		0.30	0.32	0.34	0.30	0.30	0.30	0.28	0.28	0.29	0.28	0.27	0.28
Thr		0.64	0.65	0.60	0.68	0.67	0.69	0.61	0.55	0.54	0.58	0.57	0.60
Trp		0.20	0.18	0.17	0.20	0.17	0.17	0.20	0.17	0.15	0.17	0.16	0.16
Val		0.83	0.73	0.72	0.82	0.76	0.70	0.75	0.61	0.60	0.69	0.65	0.63

[1] Multiple samples were collected from each diet throughout the study, homogenized, and then subsampled for analysis at Ward Laboratories, Kearney, NE and Ajinomoto Heartland, Inc., Chicago, IL.
[2] Analyzed values for Phase 1 finishing pig diets.
[3] Analyzed values for Phase 2 finishing pig diets.

Table 3-9. Chemical analysis of experimental diets Phase 3 and 4 (as-fed basis), Exp. 2[1]

		Grain source[2]						Grain source[3]					
		Sorghum			Corn			Sorghum			Corn		
Item,%	Crystalline AA	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
DM		87.31	86.63	86.72	85.76	86.26	86.24	86.76	86.59	86.44	86.89	86.54	86.94
CP		15.5	12.2	12.0	15.0	13.7	13.2	14.1	12.0	11.6	13.5	13.0	11.9
Ca		0.6	0.7	0.55	0.43	0.57	0.55	0.52	0.52	0.49	0.48	0.41	0.58
P		0.47	0.36	0.32	0.45	0.42	0.39	0.32	0.33	0.30	0.31	0.31	0.36
AA													
Arg		0.95	0.65	0.61	0.87	0.80	0.69	0.79	0.61	0.56	0.73	0.70	0.62
His		0.38	0.29	0.28	0.39	0.36	0.32	0.33	0.27	0.26	0.34	0.33	0.34
Ile		0.64	0.49	0.48	0.59	0.54	0.48	0.56	0.49	0.43	0.50	0.52	0.47
Leu		1.39	1.20	1.18	1.45	1.35	1.27	1.27	1.11	1.09	1.32	1.32	1.23
Lys		0.84	0.73	0.72	0.82	0.82	0.76	0.71	0.68	0.65	0.71	0.72	0.72
Met		0.26	0.26	0.27	0.26	0.25	0.25	0.23	0.24	0.25	0.23	0.22	0.23
Thr		0.58	0.47	0.49	0.56	0.56	0.51	0.51	0.50	0.45	0.50	0.48	0.48
Trp		0.20	0.15	0.14	0.15	0.14	0.13	0.17	0.13	0.13	0.13	0.12	0.12
Val		0.72	0.56	0.56	0.68	0.62	0.57	0.63	0.58	0.52	0.59	0.63	0.55

[1] Multiple samples were collected from each diet throughout the study, homogenized, and then subsampled for analysis at Ward Laboratories, Kearney, NE and Ajinomoto Heartland, Inc., Chicago, IL.
[2] Analyzed values for Phase 3 finishing pig diets.
[3] Analyzed values for Phase 4 finishing pig diets.

Table 3-10. Interactive effects of grain source and crystalline AA level on growth performance of nursery pigs, Exp. 1[1]

	Grain source							Probability, $P <$ [3]		
	Sorghum			Corn					AA level	
Crystalline AA[2]:	Low	Medium	High	Low	Medium	High	SEM	Grain source	Linear	Quadratic
d 0 to 21										
ADG, g	486	473	469	473	479	478	19.8	0.973	0.633	0.994
ADFI, g	744	722	741	729	729	738	33.8	0.803	0.871	0.410
G:F	0.658	0.660	0.638	0.654	0.664	0.651	0.0102	0.460	0.124	0.079
BW, kg										
d 0	10.6	10.6	10.6	10.6	10.6	10.6	0.36	0.939	0.967	0.870
d 21	20.8	20.6	20.5	20.6	20.7	20.7	0.77	0.952	0.706	0.942

[1]A total of 300 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment.
[2] The low AA fortification contained L-lysi HCl and DL-met. The medium AA fortification contained L-lys HCl, DL-met, and L-thr, and the high AA fortification contained L-lys HCl, DL-met, L-thr, and L-val.
[3] No grain source × AA level interactions were detected ($P > 0.10$).

Table 3-11. Main effects of grain source and crystalline AA on growth performance of nursery pigs, Exp. 1[1]

								Probability, $P <$		
	Grain source			Added crystalline AA[2]					Crystalline AA	
Item	Sorghum	Corn	SEM	Low	Medium	High	SEM	Grain source	Linear	Quadratic
d 0 to 21										
ADG, g	476	477	16.5	480	476	473	17.4	0.973	0.633	0.994
ADFI, g	736	732	30.7	737	726	740	31.5	0.803	0.871	0.410
G:F	0.652	0.657	0.0082	0.656	0.662	0.645	0.0087	0.460	0.124	0.079
BW, kg										
d 0	10.6	10.6	0.34	10.6	10.6	10.6	0.35	0.939	0.967	0.870
d 21	20.6	20.7	0.72	20.7	20.7	20.6	0.73	0.952	0.706	0.942

[1]A total of 300 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 30 pens for grain source or 20 pens for added crystalline AA.
[2] The low AA fortification contained L-lys HCl and DL-met. The medium AA fortification contained L-lys HCl, DL-met, and L-thr, and the high AA fortification contained L-lys HCl, DL-met, L-thr, and L-val.

Table 3-12. Interactive effects of grain source and crystalline AA level on growth performance of finishing pigs[1] (Exp. 2)

		Grain source							Probability, $P <$ [3]		
		Sorghum			Corn					Crystalline AA	
Item	Crystalline AA[2]:	Low	Medium	High	Low	Medium	High	SEM	Grain source	Linear	Quadratic
d 0 to 90											
ADG, kg		0.90	0.91	0.87	0.92	0.93	0.90	0.0126	0.072	0.055	0.072
ADFI, kg		2.66	2.63	2.55	2.62	2.63	2.54	0.0373	0.696	0.019	0.696
G:F		0.340	0.347	0.342	0.350	0.353	0.353	0.0025	0.001	0.315	0.001
BW, kg											
d 0		45.9	45.9	46.0	45.8	45.9	45.9	0.74	0.891	0.967	0.891
d 90		127.3	127.3	124.6	128.4	129.6	126.6	1.59	0.218	0.167	0.218
Carcass characteristics											
HCW, kg		92.8	93.1	92.4	93.9	93.9	92.5	1.13	0.486	0.454	0.486
Yield, %[4]		73.2	73.0	73.3	73.3	73.0	73.2	0.01	1.000	1.000	1.000
Loin Depth, mm		57.8	58.9	58.1	60.9	60.4	57.8	1.00	0.088	0.166	0.088
BF, mm.		19.3	19.6	19.9	19.5	19.0	20.6	0.86	0.869	0.318	0.869
FFLI, %[5]		52.2	52.3	52.2	52.5	52.8	52.0	0.01	0.583	0.614	0.583
Jowl iodine value		67.9	67.9	67.3	68.8	68.9	69.6	0.59	0.006	0.875	0.006

[1] A total of 288 pigs (PIC 1050) were used in a 90-d study with 8 pigs per pen and 6 pens per treatment.
[2] The low AA fortification contained L-lys HCl and DL-met. The medium AA fortification contained L-lys HCl, DL-met, and L-thr, and the high AA fortification contained L-lys HCl, DL-met, L-thr, and L-trp or L-val.
[3] No grain source × AA level interactions were detected ($P > 0.10$).
[4] Yield percentage was calculated by dividing HCW by live weight before transport to the packing plant (Triumph Foods, LLC., St Joseph, MO).
[5] Fat-free lean index.

Table 3-13. Main effects of grain source and crystalline AA on growth performance and carcass characteristics of finishing pigs[1] (Exp. 2)

	Grain source			Added crystalline AA[2]				Probability, $P <$		
									Crystalline AA	
Item	Sorghum	Corn	SEM	Low	Medium	High	SEM	Grain source	Linear	Quadratic
d 0 to 90										
ADG, kg	0.896	0.915	0.0073	0.911	0.920	0.886	0.0089	0.072	0.055	0.057
ADFI, kg	2.612	2.600	0.0215	2.641	2.630	2.548	0.0264	0.696	0.019	0.289
G:F	0.343	0.352	0.0014	0.345	0.350	0.348	0.0018	0.001	0.315	0.107
BW, kg										
d 0	45.9	45.9	0.44	45.9	45.9	45.9	0.52	0.891	0.967	0.972
d 90	126.6	128.2	0.92	127.8	128.7	125.6	1.13	0.218	0.167	0.162
Carcass characteristics										
HCW, kg	92.8	93.4	0.65	93.3	93.5	92.5	0.80	0.486	0.454	0.567
Yield, %[3]	73.2	73.2	0.002	73.3	73.0	73.3	0.002	1.000	1.000	0.279
Loin Depth, mm.	58.3	59.7	0.58	59.4	59.6	58.0	0.71	0.088	0.166	0.288
BF, mm.	19.6	19.7	0.50	19.4	19.3	20.3	0.61	0.869	0.318	0.488
FFLI, %[4]	52.2	52.4	0.003	52.3	52.6	52.1	0.002	0.583	0.614	0.385
Jowl iodine value	67.7	69.10	0.34	68.4	68.4	68.5	0.42	0.006	0.875	0.955

[1] A total of 288 pigs (PIC 327 × 1050) were used in a 90-d study with 8 pigs per pen and 18 pens for grain source or 12 pens for added crystalline AA.

[2] The low AA fortification contained L-lys HCl and DL-met. The medium AA fortification contained L-lys HCl, DL-met, and L-thr, and the high AA fortification contained L-lys HCl, DL-met, L-thr, and L-trp or L-val.

[3] Yield percentage was calculated by dividing HCW by live weight before transport to the packing plant (Triumph Foods, LLC., St Joseph, MO).

[4] Fat-free lean index.