*Translational Animal Science*, 2022, **6**, 1–6
https://doi.org/10.1093/tas/txac058
Advance access publication 6 May 2022
**Non Ruminant Nutrition**



# Evaluation of increasing digestible threonine to lysine ratio in corn–soybean meal diets without and with distillers dried grains with solubles on growth performance of growing-finishing pigs

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## ABSTRACT

Corn distillers dried grains with solubles (DDGS) is commonly available and often can lower diet cost for swine diets. This corn co-product is recognized to be a source of dietary insoluble fiber, which can not only increase the villous length of the gut mucosa but also increase intestinal production of mucin. Mucin structure, functions, and synthesis are correlated to Thr intake; consequently, the dietary Thr level may need to be increased when feeding an insoluble fiber source such as corn–DDGS. Thus, the objective of this study was to evaluate if feeding standardized ileal digestible (SID) Thr:Lys ratio at or above the estimated requirement in diets without and with DDGS would influence growth performance in finishing pigs. A total of 2,160 pigs (PIC 337 × 1,050; initially 35.1 ± 0.5 kg) were used in a 112-d growth trial. Pigs were randomly assigned to pens (27 pigs per pen) in a randomized complete block design by body weight (BW) with 20 replications per treatment. Pens of pigs were allotted to one of four dietary treatments that were arranged in a 2 × 2 factorial with main effects of dietary Thr level (normal vs. high) and DDGS (without or with). Treatment diets were formulated in four phases from 34 to 57, 57 to 79, 79 to 104, and 104 to 130 kg BW. Diets with high DDGS were formulated to include 40% DDGS in phases 1 and 2, 30% in phase 3, and 15% in phase 4. The normal Thr diets were formulated to contain 61%, 62%, 63%, and 65% SID Thr:Lys ratios for the four dietary phases, respectively. High Thr diets had SID Thr:Lys ratios of 67%, 68%, 69%, and 72%, respectively. There were no interactions ($P > 0.10$) observed in any phase or overall between Thr level and added DDGS. For the overall period (day 0 to 112), pigs fed diets without DDGS had increased ($P < 0.001$) average daily gain (ADG) but reduced ($P < 0.001$) average daily feed intake (ADFI), leading to increased ($P < 0.001$) feed efficiency (gain-to-feed ratio [G:F]). There was no evidence for difference ($P > 0.10$) between pigs fed diets formulated at normal or high SID Thr:Lys ratio. In summary, feeding high levels of DDGS decreased ADG and increased ADFI, which resulted in decreased G:F and lower final BW, regardless of the dietary SID Thr:Lys ratio level. In the current study, increasing the level of digestible Thr in a diet that contained a highly insoluble fiber source did not increase the growth performance of grow-finish pigs.

**Key words:** DDGS, grow-finish pigs, growth, insoluble fiber, threonine

## INTRODUCTION

Early research by Wang and Fuller (1989) categorized Thr as the first limiting amino acid for maintenance, which suggests that the utilization of Thr for protein deposition is less than that for other body needs. The primary reason for this may be the extensive use of Thr by splanchnic tissues, resulting in some inefficiency of Thr conversion to body protein and greater utilization of Thr by intestinal tissue (Le Floc′h and Seve, 2005). These authors noted that labeled enrichments of Thr-bound protein were quite high in the pancreas and the mucosa compared with that of the liver, which led to the conclusion that Thr incorporation in mucosa protein and the pancreas would be very important (Le Floc′h and Seve, 2005). Similarly, Myrie et al. (2003) suggested that an increase in mucin production reduced body Thr retention. As intestinal tissue increases in size as the pig grows, mucin production could increase, and thus, the requirement for Thr would also increase to support the intestinal tract and growth of the pig. The NRC (2012) suggests that the dietary requirement for standardized ileal digestible (SID) Thr is 60% to 65% of that of SID Lys for pigs from 25 to 135 kg body weight (BW). However, these minimum requirements may change depending on diet formulation and fiber type of the diet (Zhu et al., 2005).

Furthermore, the abundant availability and lower cost of corn distillers dried grains with solubles (DDGS) have allowed nutritionists to partially replace corn, soybean meal, and supplemental phosphorus, reducing diet cost for grow-finish pigs. However, high concentrations of insoluble fiber in DDGS result in an increased passage rate of chyme and increased endogenous losses of digestive enzymes, enterocytes, and mucin (Dilger et al., 2004). Therefore, greater inclusion of DDGS in diets may potentially influence mucin secretion and secretion, which, in part, may impact gastrointestinal epithelial cells, digestive enzymes, and mucosal secretions of which Thr is a major component (Montagne et al., 2003).

Received March 2, 2022 Accepted May 3, 2022.

In a recent study, Mathai et al. (2016) fed pigs (25 to 50 kg) diets with or without 15% soybean hulls, which is a source of both soluble and insoluble fibers. Their SID Thr:Lys ratios ranged from 45% to 90% of the Lys requirement. Results from that study showed a quadratic increase in average daily gain (ADG) and feed efficiency (gain-to-feed ratio [G:F]) of pigs fed both low- and high-fiber diets. When combining the broken line and quadratic polynomial models, the estimated optimum SID Thr:Lys ratio for ADG was 63% and 66% and for G:F was 61% and 71% for pigs fed low- or high-fiber diets, respectively. This compares with a requirement estimate for SID Thr of 60% of Lys for the pigs in this weight range (NRC (2012). It was concluded that, in order to maximize growth performance, the level of digestible Thr may need to be increased in diets containing soybean hulls as a source of fiber. However, it is unclear if increased Thr is also needed when diets contain DDGS as opposed to soybean hulls. Therefore, the objective of the study herein was to test whether high levels of DDGS, as an insoluble fiber source, increased the Thr:Lys ratio needed to maximize the growth performance of finishing pigs.

## MATERIALS AND METHODS

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

### Animals and Diets

This experiment was conducted in two barns at a commercial research grow-finishing site in southwest Minnesota (New Horizon Farms, Pipestone, MN). Each barn was naturally ventilated and double-curtain-sided with a slatted concrete floor and deep manure storage. Each pen (3.05 × 5.49 m) was equipped with a 5-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer for ad libitum access to feed and water. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions.

Two groups of 1,080 pigs (2,160 total pigs; PIC 337 × 1,050; initially 35.1 ± 0.5 kg) were used in a 112-d growth trial. The two groups of pigs were started in two identical barns at the same initial weight and approximately 1 mo apart. In both barns, pens of pigs (27 pigs per pen) were randomly assigned to one of four dietary treatments in a randomized complete block design with BW serving as the blocking factor resulting in 20 observations (pens) per treatment. Dietary treatments were arranged in a 2 × 2 factorial with main effects of SID Thr:Lys ratio (normal vs. high) and DDGS (without or with). Diets were fed in four phases from 34 to 57, 57 to 79, 79 to 104, and 104 to 130 kg BW (Tables 1 and 2). Diets with DDGS were formulated to contain 40% DDGS in phases 1 and 2, 30% in phase 3, and 15% in phase 4. The diets with normal Thr level were formulated to meet the NRC's (2012) requirement estimates and contained SID Thr:Lys ratios of 61%, 62%, 63%, and 65%, whereas the high Thr diets had SID Thr:Lys ratios of 67%, 68%, 69%, and 72%, for the four dietary phases, respectively. Diets were formulated using NRC (2012) ingredient amino acid (AA) values and SID coefficients. All treatment diets were manufactured at New Horizon Farms Feed Mill in Pipestone, MN, and were formulated to meet or exceed NRC (2012) requirement estimates for growing-finishing pigs for their respective weight ranges.

Pens of pigs were weighed, and feed disappearance was determined every 2 wk to determine ADG, average daily feed intake (ADFI), and G:F. Two weeks before the end of the experiment, three pigs per pen were removed and marketed. The remaining pigs in the pen were weighed and marketed at the completion of the experiment. No carcass data were collected because of packing plant restrictions due to COVID-19.

### Statistical Analysis

Data from both barns were combined following a nonsignificant barn × treatment comparison. Pens of pigs were the experimental units for all data. Data were analyzed using the nlme package of R (Version 4.0.0, R Foundation for Statistical Computing, Vienna, Austria) as a randomized complete block design with BW as the blocking factor and pen as the experimental unit. The main effects and interactions of DDGS and Thr level were tested. Model assumptions were checked and considered to be appropriately met. Differences between treatments were considered significant at $P \le 0.05$.

## RESULTS

There were no interactions observed between SID Thr:Lys ratio and DDGS for any response criteria (Table 3). Furthermore, no differences were detected ($P > 0.10$) for ADG, ADFI, G:F or BW for pigs fed diets at the normal Thr:Lys ratios compared with pigs fed high Thr:Lys ratio throughout the study.

From day 0 to 56, pigs fed diets without DDGS had increased ($P < 0.001$) ADG, increased day 56 BW, and improved ($P < 0.001$) G:F compared with pigs fed diets without DDGS (Table 4). Interestingly, from day 56 to 112, pigs fed DDGS had increased ($P = 0.019$) ADG compared with pigs fed diets without DDGS, which could be explained by the reduction in DDGS level from 40% to 30% and 15% in the third and fourth dietary phases, respectively. Pigs fed diets without DDGS had decreased ($P = 0.004$) ADFI and improved ($P = 0.004$) G:F compared with those pigs fed diets with DDGS.

Overall (day 0 to 112), pigs fed diets without DDGS had increased ($P < 0.001$) ADG and BW, reduced ($P < 0.001$) ADFI, and improved ($P < 0.001$) G:F compared with pigs that were fed diets with DDGS.

## DISCUSSION

The fiber content of a feed ingredient is normally measured using various methods, which include crude fiber, neutral detergent fiber, acid detergent fiber, and total dietary fiber (TDF). The total dietary fiber includes insoluble dietary fiber and soluble dietary fiber and is designed to characterize types of indigestible carbohydrates in feedstuffs (Kerr et al., 2013). Corn DDGS is predominantly considered an insoluble fiber source because most of the TDF in DDGS is insoluble, ranging from 31.8% to 37.3%, whereas the soluble fiber component ranges from 0.0% to 1.8% (Urriola et al., 2010). The high insoluble fiber content of corn DDGS may influence not only pig performance but also intestinal health. Insoluble fibers can act in the intestinal tract by increasing water holding capacity, which increases digesta viscosity and increases fecal bulkiness as well as digesta passage rate (McRorie and McKeown, 2017). In addition, mucus in the intestinal tract of pigs is characterized by its high level of serine, proline, and particularly Thr (Święch et al., 2019). Mucins form intestinal mucus, are secreted by goblet cells, and are resistant to digestion

**Table 1.** Composition of phases 1 and 2 diets (as-fed basis)[†]

| | Phase 1 | | | | Phase 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | No DDGS | | DDGS | | No DDGS | | DDGS | |
| Item | Normal Thr | High Thr | Normal Thr | High Thr | Normal Thr | High Thr | Normal Thr | High Thr |
| Ingredients, % | | | | | | | | |
| Corn | 72.67 | 72.60 | 50.34 | 50.27 | 78.90 | 78.84 | 55.75 | 55.70 |
| Soybean meal | 24.64 | 24.65 | 6.82 | 6.82 | 18.51 | 18.51 | 1.49 | 1.49 |
| Corn DDGS | — | — | 40.00 | 40.00 | — | — | 40.00 | 40.00 |
| Limestone | 0.95 | 0.95 | 1.35 | 1.35 | 0.95 | 0.95 | 1.35 | 1.35 |
| Monocalcium P (21% P) | 0.60 | 0.60 | — | — | 0.55 | 0.55 | — | — |
| Salt | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| L-Lys-HCl | 0.30 | 0.30 | 0.60 | 0.60 | 0.30 | 0.30 | 0.58 | 0.58 |
| DL-Met | 0.08 | 0.08 | 0.03 | 0.03 | 0.05 | 0.05 | — | — |
| L-Thr | 0.08 | 0.14 | 0.12 | 0.19 | 0.08 | 0.13 | 0.11 | 0.17 |
| L-Trp | 0.01 | 0.01 | 0.07 | 0.07 | 0.02 | 0.02 | 0.07 | 0.07 |
| Mineral–vitamin premix[‡] | 0.15 | 0.15 | 0.15 | 0.15 | 0.13 | 0.13 | 0.13 | 0.13 |
| Phytase[‖] | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Calculated analysis | | | | | | | | |
| SID amino acids, % | | | | | | | | |
| Lys | 1.02 | 1.02 | 1.02 | 1.02 | 0.87 | 0.87 | 0.87 | 0.87 |
| Ile:Lys | 62 | 62 | 55 | 55 | 61 | 61 | 55 | 55 |
| Leu:Lys | 136 | 136 | 169 | 169 | 144 | 143 | 184 | 184 |
| Met:Lys | 33 | 33 | 32 | 32 | 32 | 32 | 32 | 32 |
| Met and Cys:Lys | 58 | 58 | 58 | 58 | 58 | 58 | 60 | 60 |
| Thr:Lys | 61 | 67 | 61 | 67 | 62 | 68 | 62 | 68 |
| Trp:Lys | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 |
| Val:Lys | 69 | 69 | 69 | 69 | 70 | 70 | 71 | 71 |
| SID Lys:NE, g/Mcal | 4.13 | 4.13 | 4.14 | 4.14 | 3.47 | 3.47 | 3.49 | 3.49 |
| NE, kcal/kg | 2,472 | 2,472 | 2,461 | 2,461 | 2,509 | 2,509 | 2,492 | 2,494 |
| CP, % | 18.14 | 18.19 | 19.39 | 19.43 | 15.72 | 15.76 | 17.25 | 17.28 |
| Ca, % | 0.58 | 0.58 | 0.61 | 0.61 | 0.55 | 0.55 | 0.59 | 0.59 |
| P, % | 0.49 | 0.49 | 0.47 | 0.47 | 0.46 | 0.45 | 0.45 | 0.45 |
| STTD P, % | 0.37 | 0.37 | 0.37 | 0.37 | 0.35 | 0.35 | 0.36 | 0.36 |
| NDF, % | 8.64 | 8.64 | 18.55 | 18.54 | 8.71 | 8.70 | 18.60 | 18.60 |
| IDF, %[$] | 11.90 | 11.89 | 20.28 | 20.28 | 11.54 | 11.54 | 19.97 | 19.97 |

IDF, insoluble dietary fiber; NDF, neutral detergent fiber; STTD, standard total tract digestibility.
[†]Phases 1 and 2 were fed from 34.9 to 57.4, and 57.4 to 82.5 kg, respectively.
[‡]Provided per kilogram of diet: 110 mg Zn, 110 mg Fe, 0.30 mg I, 0.30 mg Se, 5,290 IU vitamin A, 1,323 IU vitamin D, 26.5 IU vitamin E, 1.2 mg vitamin K, 22.5 mg niacin, 7.5 mg pantothenic acid, 2.25 mg riboflavin, and 11 µg vitamin B12.
[‖]Optiphos 2000 (Huvepharma Inc. Peachtree City, GA) provided 858.7 units of phytase/kg of diet with an assumed release of 0.12% STTD P.
[$]Insoluble digestible fiber. Matrix loading values are derived from Navarro (2018).

(Święch et al., 2019). Consequently, an increase in goblet cell numbers in the villi or crypts may result in an increase in intestinal mucus and, therefore, greater ileal endogenous losses of Thr (Święch et al., 2019).

Schaart et al. (2005) observed that 40% to 60% of dietary Thr was absorbed by the portal-drained viscera in the pig. In addition, Law et al. (2007) observed that dietary deficiency of Thr reduced the number of goblet cells and mucin content in the small intestine, which was not restored by intravenous administration of Thr, concluding that the intestinal tract of the pig uses considerable amounts of Thr from the lumen rather than from arterial blood. Degradation of Thr by gut bacteria from the *Clostridium* family results in volatile fatty acid production, which is important in modulating immunological response and in maintaining intestinal function (Neis et al., 2015; Tang et al., 2021; Zhang et al., 2016). Furthermore, studies in fish have reported that dietary Thr deficiency reduces the activity of intestinal enzymes, such as trypsin, alpha-amylase, chymotrypsin, and lipase (Hong et al., 2015). Thus, Thr appears to be involved in significant roles, including intestinal barrier function, immune response, and absorptive capacity. As the pig grows, the requirement for amino acids that are used for maintenance, such as Thr, increases, and the NRC (2012) estimates that the dietary requirement for SID Thr is 60% to 65% of SID Lys for pigs from 25 to 135 kg BW. However, research suggests that these

**Table 2.** Composition of phases 3 and 4 diets (as-fed basis)†

| | Phase 3 | | | | Phase 4 | | | |
|---|---|---|---|---|---|---|---|---|
| | No DDGS | | DDGS | | No DDGS | | DDGS | |
| Item | Normal Thr | High Thr | Normal Thr | High Thr | Normal Thr | High Thr | Normal Thr | High Thr |
| Ingredients, % | | | | | | | | |
| Corn | 83.54 | 83.49 | 66.02 | 65.97 | 85.82 | 85.77 | 77.09 | 77.04 |
| Soybean meal | 14.01 | 14.01 | 1.44 | 1.45 | 11.95 | 11.95 | 5.67 | 5.67 |
| Corn DDGS | — | — | 30.00 | 30.00 | — | — | 15.00 | 15.00 |
| Limestone | 0.95 | 0.95 | 1.25 | 1.25 | 0.90 | 0.90 | 1.05 | 1.05 |
| Monocalcium P (21% P) | 0.45 | 0.45 | — | — | 0.25 | 0.25 | — | — |
| Salt | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| L-Lys-HCl | 0.30 | 0.30 | 0.50 | 0.50 | 0.30 | 0.30 | 0.40 | 0.40 |
| DL-Met | 0.03 | 0.03 | — | — | 0.02 | 0.02 | — | — |
| L-Thr | 0.08 | 0.13 | 0.10 | 0.15 | 0.09 | 0.14 | 0.10 | 0.15 |
| L-Trp | 0.02 | 0.02 | 0.06 | 0.06 | 0.02 | 0.02 | 0.04 | 0.04 |
| Mineral–vitamin premix‡ | 0.10 | 0.10 | 0.10 | 0.10 | 0.08 | 0.08 | 0.08 | 0.08 |
| Phytase‖ | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Calculated analysis | | | | | | | | |
| SID amino acids, % | | | | | | | | |
| Lys | 0.76 | 0.76 | 0.76 | 0.76 | 0.71 | 0.71 | 0.71 | 0.71 |
| Ile:Lys | 60 | 60 | 55 | 55 | 60 | 60 | 57 | 57 |
| Leu:Lys | 151 | 150 | 186 | 186 | 155 | 155 | 173 | 173 |
| Met:Lys | 31 | 31 | 32 | 32 | 30 | 30 | 31 | 31 |
| Met and Cys:Lys | 58 | 58 | 62 | 62 | 58 | 58 | 60 | 60 |
| Thr:Lys | 63 | 69 | 63 | 69 | 65 | 72 | 65 | 72 |
| Trp:Lys | 19.2 | 19.2 | 19.1 | 19.1 | 19.0 | 19.0 | 19.1 | 19.1 |
| Val:Lys | 70 | 70 | 72 | 72 | 70 | 70 | 71 | 71 |
| SID Lys:NE, g/Mcal | 2.99 | 2.99 | 3.01 | 3.01 | 2.78 | 2.78 | 2.78 | 2.78 |
| NE, kcal/kg | 2,540 | 2,540 | 2,527 | 2,527 | 2,558 | 2,558 | 2,551 | 2,551 |
| CP, % | 13.94 | 13.98 | 15.17 | 15.20 | 13.15 | 13.19 | 13.76 | 13.80 |
| Ca, % | 0.52 | 0.52 | 0.54 | 0.54 | 0.45 | 0.45 | 0.46 | 0.46 |
| P, % | 0.41 | 0.41 | 0.40 | 0.40 | 0.36 | 0.36 | 0.35 | 0.35 |
| STTD P, % | 0.32 | 0.32 | 0.32 | 0.32 | 0.28 | 0.28 | 0.27 | 0.27 |
| NDF, % | 8.76 | 8.76 | 16.18 | 16.18 | 8.80 | 8.79 | 12.51 | 12.51 |
| IDF, %$ | 11.29 | 11.28 | 17.63 | 17.62 | 11.19 | 11.18 | 14.36 | 14.36 |

IDF, insoluble dietary fiber; NDF, neutral detergent fiber; STTD, standard total tract digestibility.
†Phases 3 and 4 were fed from 82.5 to 108.2, and 108.2 kg to market, respectively.
‡Provided per kilogram of diet: 110 mg Zn, 110 mg Fe, 0.30 mg I, 0.30 mg Se, 5,290 IU vitamin A, 1,323 IU vitamin D, 26.5 IU vitamin E, 1.2 mg vitamin K, 22.5 mg niacin, 7.5 mg pantothenic acid, 2.25 mg riboflavin, and 11 µg vitamin B12.
‖Optiphos 2000 (Huvepharma Inc. Peachtree City, GA) provided 858.7 units of phytase/kg of diet with an assumed release of 0.12% STTD P.
$Insoluble digestible fiber. Matrix loading values are derived from Navarro (2018).

minimum requirement estimates may change depending on ingredients used in diet formulation, especially ingredients affecting the fiber content of the diet (Zhu et al., 2005).

While data from the current study did not show an influence of increasing the SID Thr:Lys ratio on pig performance, Mathai et al. (2016) observed improved performance of growing pigs when increased SID Thr:Lys ratio was included in high-fiber diets compared with pigs fed a low-fiber diet. The diets used were formulated to contain high and low fibers by including soybean hulls (15% or 0% soybean hulls, respectively), which is both an insoluble and soluble fiber source. Mathai et al. (2016) included 45%, 54%, 63%, 72%, 81%, and 90% SID Thr:Lys ratios for pigs from 25 to 50 kg BW. The quadratic curve estimation for maximum ADG when feeding a low-fibrous diet compared with a high-fibrous diet increased from 76% to 80% SID Thr:Lys ratio. Using Mathai et al. (2016) quadratic equation, the increase in gain when going from 76% to 80% SID Thr:Lys ratio resulted in 1.8 g/d improved gain. Over a 112-d period, this would result in a 202-g heavier pig. Even though the findings suggested an increase in the requirement, the response was small and almost impossible to measure. Furthermore, Zhu et al. (2005) fed growing pigs increasing levels of dietary pectin from 0% to 12% and an additional treatment that provided 8% cellulose. A linear decrease in ileal digestible Thr utilization for protein deposition was observed as pectin increased in the diet; however, the cellulose level of the diet did not influence the utilization of Thr, suggesting that fiber

**Table 3.** Interactive effects of DDGS and Thr on grow-finish pig performance†

| Item | No DDGS | | DDGS‡ | | SEM | P = | | |
|---|---|---|---|---|---|---|---|---|
| | Normal Thr‖ | High Thr$ | Normal Thr‖ | High Thr$ | | Thr × DDGS | Thr | DDGS |
| Initial BW, kg | | | | | | | | |
| Day 0 | 35.1 | 35.1 | 35.1 | 34.9 | 0.47 | 0.384 | 0.503 | 0.259 |
| Day 56 | 84.1 | 84.8 | 80.9 | 80.5 | 0.67 | 0.222 | 0.755 | <0.001 |
| Day 112 | 136.6 | 136.9 | 133.6 | 133.3 | 0.80 | 0.655 | 0.972 | <0.001 |
| Day 0 to 56 | | | | | | | | |
| ADG, kg | 0.90 | 0.90 | 0.84 | 0.84 | 0.011 | 0.635 | 0.986 | <0.001 |
| ADFI, kg | 2.10 | 2.14 | 2.18 | 2.15 | 0.029 | 0.168 | 0.651 | 0.081 |
| G:F | 0.429 | 0.421 | 0.387 | 0.389 | 0.0039 | 0.133 | 0.379 | <0.001 |
| Day 56 to 112 | | | | | | | | |
| ADG, kg | 0.94 | 0.94 | 0.96 | 0.97 | 0.016 | 0.597 | 0.926 | 0.019 |
| ADFI, kg | 3.12 | 3.15 | 3.29 | 3.29 | 0.044 | 0.488 | 0.572 | 0.004 |
| G:F | 0.304 | 0.299 | 0.292 | 0.293 | 0.0037 | 0.294 | 0.547 | 0.004 |
| Day 0 to 112 | | | | | | | | |
| ADG, kg | 0.92 | 0.92 | 0.89 | 0.89 | 0.006 | 0.989 | 0.973 | <0.001 |
| ADFI, kg | 2.59 | 2.64 | 2.72 | 2.71 | 0.027 | 0.252 | 0.556 | <0.001 |
| G:F | 0.356 | 0.350 | 0.331 | 0.332 | 0.0030 | 0.164 | 0.408 | <0.001 |

†A total of 2,160 pigs were used in two groups with 27 pigs per pen and 10 replicates per treatment. Phase 1 was fed from day 0 to 28, phase 2 from day 28 to 56, phase 3 from day 56 to 84, and phase 4 from day 84 to 112.
‡DDGS included at 40% in phases 1 and 2, 30% in phase 3, and 15% in phase 4.
‖SID Thr:Lys was 61%, 62%, 63%, and 65% in phases 1, 2, 3, and 4, respectively.
$SID Thr:Lys was 67%, 68%, 69%, and 72% in phases 1, 2, 3, and 4, respectively.

**Table 4.** Main effects of DDGS and Thr on grow-finish pig performance†

| | DDGS‡ | | SEM | P = | Thr | | SEM | P = |
|---|---|---|---|---|---|---|---|---|
| | No DDGS | High DDGS | | | Normal Thr‖ | High Thr$ | | |
| Initial BW, lb | | | | | | | | |
| Day 0 | 35.1 | 34.9 | 0.46 | 0.259 | 35.1 | 35.0 | 0.46 | 0.503 |
| Day 56 | 84.4 | 80.7 | 0.59 | <0.001 | 82.5 | 82.6 | 0.59 | 0.755 |
| Day 112 | 136.7 | 133.4 | 0.63 | <0.001 | 135.1 | 135.1 | 0.63 | 0.972 |
| Day 0 to 56 | | | | | | | | |
| ADG, l kg | 0.90 | 0.84 | 0.010 | <0.001 | 0.87 | 0.87 | 0.010 | 0.986 |
| ADFI, kg | 2.12 | 2.16 | 0.023 | 0.081 | 2.14 | 2.15 | 0.023 | 0.651 |
| G:F | 0.425 | 0.388 | 0.0032 | <0.001 | 0.408 | 0.405 | 0.0032 | 0.379 |
| Day 56 to 112 | | | | | | | | |
| ADG, kg | 0.95 | 0.96 | 0.014 | 0.019 | 0.96 | 0.95 | 0.014 | 0.926 |
| ADFI, kg | 3.14 | 3.29 | 0.038 | <0.001 | 3.21 | 3.22 | 0.038 | 0.572 |
| G:F | 0.302 | 0.293 | 0.0029 | 0.004 | 0.298 | 0.296 | 0.0029 | 0.547 |
| Day 0 to 112 | | | | | | | | |
| ADG, kg | 0.92 | 0.89 | 0.004 | <0.001 | 0.91 | 0.91 | 0.004 | 0.973 |
| ADFI, kg | 2.61 | 2.71 | 0.019 | <0.001 | 2.66 | 2.67 | 0.019 | 0.556 |
| G:F | 0.353 | 0.332 | 0.0024 | <0.001 | 0.343 | 0.341 | 0.0024 | 0.408 |

†A total of 2,160 pigs were used in two groups with 27 pigs per pen and 10 replicates per treatment. Phase 1 was fed from day 0 to 28, phase 2 from day 28 to 56, phase 3 from day 56 to 84, and phase 4 from day 84 to 112.
‡DDGS included at 40% in phases 1 and 2, 30% in phase 3, and 15% in phase 4.
‖SID Thr:Lys was 61%, 6%2, 63%, and 65% in phases 1, 2, 3, and 4, respectively.
$SID Thr:Lys was 67%, 68%, 69%, and 72% in phases 1, 2, 3, and 4, respectively.

type may have an impact on the Thr requirement. Soluble fiber includes pectins, gums, and β-glucans, whereas insoluble fiber includes cellulose and hemicellulose (Jha and Berrocoso, 2015). In the current study, only DDGS (a source of insoluble fiber) was used in the diet, and pig performance decreased with no ameliorating effect of increasing digestible Thr. Therefore, this presents the possibility that the greater insoluble fiber content of DDGS may not result in an increased need for digestible Thr:Lys ratio above the pigs' current estimated requirement.

The current study corroborated that the high inclusion (i.e., 40%) of corn co-products, such as DDGS, which is used in grow-finishing diets at the expense of corn and soybean meal, negatively impacts growth performance. Hardman (2013) observed that increasing DDGS inclusion from 0% to 40% in the diet for grow-finish pigs from 23 to 128 kg linearly reduced ADG and resulted in a 1.4-kg reduction in weight after 120 d compared with pigs fed the diet without DDGS. A cooperative study by Cromwell et al. (2011) included 560 pigs from nine university research stations and fed pigs from 32 to 120 kg diets with increasing levels of DDGS from 0% to 45% resulting in a linear decrease in ADG and in a 3-kg reduction in final BW. These results are in agreement with the current study where feeding a diet with DDGS to pigs from 35 to 136 kg decreased gain and feed efficiency, and reduced final BW by 3.2 kg compared with pigs fed diets without DDGS. We speculate that the bulkiness of the 40% DDGS diets may have limited feed intake by gut fill in the early portions of the study. But then, as DDGS levels decreased, pigs were able to consume more feed resulting in increased ADG in late finishing. However, this almost compensatory growth effect was not of a magnitude to offset the poor performance early in the study and resulted in a 3-kg decrease in the final weight.

In conclusion, the current study demonstrated that feeding diets with high levels of insoluble fiber from DDGS decreased growth performance. In this study, increasing the digestible Thr concentration in DDGS-containing diets did not improve growth performance. Further research should explore whether fiber type influences the SID Thr:Lys ratio requirement of growing and finishing pigs.

## Acknowledgments

We would like to thank the team at New Horizon Farms, Pipestone, MN, for providing the animals and technical support for this project. The contribution no. is 22-250-J from the Kansas Agricultural Station, Manhattan, KS.

## Conflict of interest statement

The authors declare no conflicts of interest.

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