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# Effects of Soybean Gums and Soybean Soapstocks on Weanling Pig Growth Performance, Fecal Dry Matter, and Apparent Total Tract Digestibility of Dry Matter[1]

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## Summary

Soybean processing by-products, such as gums and soapstocks, may be added back to soybean meal during processing, but it is unclear how they may impact pig growth performance. There is potential for these by-products to serve as an affordable energy source for swine due to their residual oil content. A total of 350 pigs (Line 241 × 600, DNA; initially 11.7 ± 0.05 lb) were weaned at approximately 19 d of age and used in a 42-d experiment. At weaning, pigs were randomly assigned to pens and pens were allotted to one of five dietary treatments. There were five pigs per pen and 14 pens per treatment. Diets were fed in three phases: phase 1 from weaning to d 11, phase 2 from d 11 to 23, and phase 3 from d 23 to 42. Treatments included a control diet containing soybean meal with no added soybean by-products. Two additional diets contained gums or soapstocks at 4% of the soybean meal level in the diet. Another treatment diet contained soybean meal with 2% added soybean gums and 2% added soybean soapstocks. Lastly, a negative control contained 4% less soybean meal with no added by-products to have equal protein from soybean meal as the diets with added gums or soapstocks. Feces were collected on d 11 and d 23 from three pigs per pen to determine fecal dry matter (DM). Fecal samples on d 23 were used to determine apparent total tract digestibility (ATTD) of DM. From d 0 to 11 (phase 1) and d 11 to 23 (phase 2), there was no evidence of differences ($P > 0.10$) for any growth response criteria. From d 23 to 42 (phase 3), feeding soybean meal with added gums increased ($P = 0.053$) ADG. However, there was no evidence for differences ($P > 0.10$) in ADFI or F/G. For the overall experimental period (d 0 to 42), there was no evidence of differences ($P > 0.10$) due to dietary treatment for ADG, ADFI, or F/G. Fecal DM was approximately 19% on both d 11 and 23 and was not affected ($P > 0.10$) by treatment. There was an interaction ($P = 0.019$) between soybean gum and soapstocks for the ATTD of

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DM. When adding 4% gums to the diet, there was an improvement in the ATTD of DM; however, there was no evidence of difference when adding 4% soapstocks or 2% gums and 2% soapstocks to soybean meal compared to the control. These data suggest that adding soybean processing by-products had minimal effects on nursery pig growth performance. However, there is a potential for improved ADG in the late nursery period when soybean meal containing added gums is included in the diet.

## Introduction

Soybean meal is a fundamental amino acid source in swine diets, and as a result, soybean meal processing and its impacts on pig growth performance has been extensively outlined in past literature. Depending on the processing plant, soybean gums and soapstocks may be added back to soybean meal during processing. Soybean gums are produced through the degumming step of oil refining to remove phosphatides from crude soybean oil, while soybean soapstocks are produced during the caustic refining step utilizing sodium hydroxide in an effort to neutralize free fatty acids. There is potential for these by-products to serve as an affordable energy source for swine due to their residual oil content. However, they also may contain impurities removed from crude oil during refining, which might negatively impact growth performance. Little data is available to determine the impact of soybean by-products on pig performance. Therefore, the objective of this study was to investigate the effects of utilizing soybean meal containing added soybean gums and soybean soapstocks on the growth performance, fecal dry matter (DM), and apparent total tract digestibility (ATTD) of DM for nursery pigs.

## Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen contained a 4-hole, dry self-feeder and nipple waterer. Pigs were provided ab libitum access to feed and water throughout the trial.

A total of 350 pigs (DNA 241 × 600) were weaned at approximately 19 d of age and randomly assigned to pens, then pens were allotted to one of five dietary treatments. There were five pigs per pen (three barrows and two gilts or two barrows and three gilts) and 14 pens per treatment. Treatments included a control diet containing soybean meal with no added soybean by-products. Two additional diets contained gums or soapstocks at 4% of the soybean meal level in the diet. Another treatment diet contained soybean meal with 2% added soybean gums and 2% added soybean soapstocks. Lastly, a negative control contained 4% less soybean meal with no added by-products to have equal soybean protein as diets with added gums or soapstocks.

All soybean meal was sourced as a single batch for this trial and contained no added soybean by-products during manufacturing (Bunge North America, Emporia, KS). Similarly, a single batch of each by-product was sourced and utilized across all three dietary phases. Diets were manufactured at O.H. Kruse Feed Technology Innovation Center at Kansas State University, Manhattan, KS. Prior to mixing treatment diets, soybean meal was mixed with soybean by-products to create four batches of soybean meal: soybean meal containing no by-products, soybean meal containing 4% soybean gums, soybean meal containing 4% soybean soapstocks, and soybean meal containing

2% soybean gums and 2% soybean soapstocks. Treatment diets were then mixed utilizing the proper soybean meal sublots (Table 1). For diets containing soybean by-products and the diet containing 4% less soybean meal, increased quantities of feed-grade amino acids were added to maintain similar dietary amino acid levels across all treatment diets. During bagging, complete diet samples were collected from every fourth bag, pooled, ground to reduce particle size, and stored at -4°F. Samples of soybean gums and soapstocks were submitted for lipid quality analysis (Barrow-Agee, Eurofins, Memphis, TN; Table 2). Additionally, samples of soybean meal and complete diets were submitted for duplicate analysis of Ca and P (K-State Research and Extension Soil Testing Laboratory, Manhattan, KS), as well as complete proximate analysis and neutral detergent fiber (Midwest Laboratories Inc., Omaha, NE; Table 3).

Pig weights and feed disappearance were measured on d 0, 11, 18, 23, 32, and 42 to determine ADG, ADFI, and F/G. All diets were fed in meal form in three phases: phase 1 from weaning to d 11, phase 2 from d 11 to 23, and phase 3 from d 23 to 42. Feces were collected on d 11 and d 23 from three pigs per pen to determine percentage fecal dry matter. Additionally, titanium dioxide was included in phase 2 diets as an indigestible marker to determine ATTD of DM from samples collected on d 23.

## *Digestibility analysis*

At the conclusion of the study, fecal samples were dried at 130°F for 48 h. The loss of weight was used to calculate fecal DM percent. Following fecal DM determination, both ground feed and fecal samples were dried in a 275°F forced air drying oven for 2 h to determine percentage DM of the samples used for titanium analysis. Titanium dioxide concentration in both dried feed and fecal samples was determined utilizing procedures outlined by Leone (1973).[5] The ATTD of DM was determined using the index method described by Adeola (2001)[6] using the following equation:

$$\text{ATTD DM, \%} = \left[1 - \left[\left(\frac{DM,\ \%_{Fecals}}{DM,\ \%_{Feed}}\right) \times \left(\frac{TiO_2,\ \%_{Feed}}{TiO_2,\ \%_{Fecals}}\right)\right]\right] \times 100$$

## *Statistical analysis*

Data were analyzed as a completely randomized design for a one-way ANOVA using the GLIMMIX procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, NC). Pen served as the experimental unit and treatment served as the fixed effect. In addition to the evaluation of treatment effect, the control treatment and treatments containing added gums and/or soapstocks were evaluated as a 2 × 2 factorial to investigate the interaction between added gums and soapstocks, as well as main effect of the addition of each by-product. Similarly, a contrast statement was used to compare pigs fed the diet containing soybean meal without soybean by-products and the diet containing 4% less soybean meal. Furthermore, contrasts were used to test for the main effects of treatment, day, and interaction between treatment and day for fecal DM. Results were considered significant with $P \leq 0.05$ and marginally significant with $P \leq 0.10$.

[5] Leone, J. L. 1973. Collaborative study of the quantitative determination of titanium dioxide in cheese. AOAC. 56(3):535.

[6] Adeola, O. 2001. Digestion and balance techniques in pigs. pp. 903. Swine Nutrition, 2nd ed. A. J. Lewis and L. L. Southern ed. CRC Press, Washington, DC.

## Results and Discussion

Lipid quality analysis of soybean gums and soapstocks sourced for this trial showed considerable differences in acid hydrolyzed fat, moisture and volatile matter, free fatty acids (FFA), P concentrations, and viscosity between the two by-products on an as-is basis (Table 2). Soybean gums had a greater percentage of acid hydrolyzed fat (52.3% vs 6.5%) and FFA (12.8% vs 0.5%) compared to soybean soapstocks. Inversely, soapstocks had a greater moisture and volatile matter content (44% vs 20%), which was then reflected in the viscosity of the by-products with soybean soapstocks having a lower viscosity than soybean gums. Finally, soybean gums contained approximately 0.95% P compared to soapstocks that contained only 0.16% P.

From d 0 to 11 (phase 1) and d 11 to 23 (phase 2), there was no evidence of differences ($P > 0.10$) for any growth response criteria (Table 4). From d 23 to 42 (phase 3), feeding soybean meal with added gums increased ($P = 0.053$) ADG. However, there was no evidence of differences ($P > 0.10$) in ADFI or F/G. For the overall experimental period (d 0 to 42), there was no evidence of differences ($P > 0.10$) due to dietary treatment for ADG, ADFI, or F/G.

There was no evidence ($P = 0.775$) of an interaction between treatment and day for fecal DM. Furthermore, there was no evidence of a main effect of treatment ($P = 0.862$) or day ($P = 0.375$) with pigs exhibiting fecal DM of approximately 19% for both sampling timepoints.

There was an interaction ($P = 0.019$) between soybean gum and soapstocks for ATTD of DM. When adding 4% gums to the diet, there was an improvement in the ATTD of DM compared to the control diet; however, there was no evidence of differences when adding 4% soapstocks or 2% gums and 2% soapstocks to soybean meal compared to the control diet.

In summary, these data suggest that adding up to 4% soybean processing by-products, such as soybean gums or soybean soapstocks, to soybean meal had minimal effects on nursery pig growth performance. However, there is a potential for improved ADG in the late nursery period when soybean meal containing added gums are included in the diet. This also happens to coincide with when diets contained the greatest amount of soybean meal and therefore the greatest amounts of gums and soapstocks. Further research is needed to understand how soybean by-products would affect growth performance of pigs when added higher inclusion levels independent of soybean meal or at different phases of growth.

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

| | | Phase 1 | | | Phase 2 | | | Phase 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Treatment:** | **1** | **2-4** | **5** | **1** | **2-4** | **5** | **1** | **2-4** | **5** |
| Ingredient, % | | | | | | | | | | |
| Corn | | 50.05 | 49.96 | 50.72 | 55.71 | 55.66 | 56.78 | 65.55 | 65.40 | 66.64 |
| Soybean meal[2] | | 18.61 | 18.61 | 17.85 | 27.95 | 27.95 | 26.76 | 30.54 | 30.54 | 29.34 |
| Spray-dried whey | | 20.00 | 20.00 | 20.00 | 10.00 | 10.00 | 10.00 | --- | --- | --- |
| Enzymatically treated soybean meal[3] | | 3.75 | 3.75 | 3.75 | --- | --- | --- | --- | --- | --- |
| Fish meal, 60% CP | | 4.50 | 4.50 | 4.50 | 2.00 | 2.00 | 2.00 | --- | --- | --- |
| Monocalcium P, 21% P | | 0.60 | 0.60 | 0.60 | 1.05 | 1.05 | 1.05 | 0.95 | 0.95 | 0.95 |
| Calcium carbonate | | 0.30 | 0.30 | 0.30 | 0.53 | 0.53 | 0.53 | 0.85 | 0.85 | 0.85 |
| Zinc oxide | | 0.40 | 0.40 | 0.40 | 0.27 | 0.27 | 0.27 | --- | --- | --- |
| Salt | | 0.40 | 0.40 | 0.40 | 0.50 | 0.50 | 0.50 | 0.60 | 0.60 | 0.60 |
| Vitamin premix | | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Trace mineral premix | | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| L-Lys-HCl | | 0.39 | 0.42 | 0.42 | 0.44 | 0.48 | 0.48 | 0.48 | 0.52 | 0.52 |
| DL-Met | | 0.20 | 0.21 | 0.21 | 0.22 | 0.23 | 0.23 | 0.20 | 0.21 | 0.21 |
| L-Thr | | 0.18 | 0.19 | 0.19 | 0.20 | 0.22 | 0.22 | 0.22 | 0.23 | 0.23 |
| L-Trp | | 0.05 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 |
| L-Val | | 0.11 | 0.12 | 0.12 | 0.13 | 0.15 | 0.15 | 0.12 | 0.14 | 0.14 |
| L-Ile | | --- | 0.03 | 0.03 | --- | 0.03 | 0.03 | --- | 0.02 | 0.02 |
| Phytase[4] | | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| Titanium dioxide[5] | | --- | --- | --- | 0.50 | 0.50 | 0.50 | --- | --- | --- |
| Total | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*continued*

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

| | | Phase 1 | | | Phase 2 | | | Phase 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Treatment:** | **1** | **2-4** | **5** | **1** | **2-4** | **5** | **1** | **2-4** | **5** |
| Calculated analysis[6] | | | | | | | | | | |
| SID AA, % | | | | | | | | | | |
| Lys, % | | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.30 | 1.30 | 1.30 |
| Ile:Lys | | 58 | 58 | 58 | 57 | 57 | 57 | 56 | 56 | 56 |
| Leu:Lys | | 114 | 112 | 113 | 114 | 111 | 112 | 117 | 114 | 115 |
| Met:Lys | | 38 | 38 | 38 | 38 | 38 | 38 | 37 | 37 | 37 |
| Met and Cys:Lys | | 58 | 58 | 58 | 59 | 59 | 59 | 58 | 58 | 58 |
| Thr:Lys | | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| Trp:Lys | | 19.7 | 19.7 | 19.7 | 19.5 | 19.7 | 19.7 | 19.2 | 19.4 | 19.4 |
| Val:Lys | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| His:Lys | | 34 | 33 | 33 | 35 | 34 | 34 | 37 | 36 | 36 |
| NE, kcal/lb[7] | | 1,130 | 1,123 | 1,132 | 1,101 | 1,091 | 1,105 | 1,100 | 1,089 | 1,104 |
| SID Lys:NE, g/Mcal | | 5.42 | 5.45 | 5.41 | 5.56 | 5.61 | 5.55 | 5.36 | 5.41 | 5.35 |
| CP, % | | 21.0 | 20.7 | 20.8 | 21.2 | 20.7 | 20.8 | 20.8 | 20.3 | 20.4 |
| Ca, % | | 0.70 | 0.70 | 0.70 | 0.72 | 0.72 | 0.72 | 0.69 | 0.69 | 0.69 |
| STTD P, % | | 0.60 | 0.59 | 0.59 | 0.58 | 0.57 | 0.58 | 0.47 | 0.46 | 0.46 |

[1]Phase 1 diets were fed from weaning to d 11, phase 2 from d 11 to 23, and phase 3 from d 23 to 42.
[2]Treatment 1 served as a control diet containing soybean meal with no added soybean by-products. Treatments 2 through 4 contained soybean meal with 4% added by-products. This includes two diets containing gums or soapstocks added at 4% of the soybean meal level in the diet and a diet containing soybean meal with 2% added soybean gums and 2% added soybean soapstocks. Treatment 5 served as a negative control containing 4% less soybean meal with no added by-products to have equal soybean protein as diets with added gums or soapstocks.
[3]HP 300, Hamlet Protein, Findlay, OH.
[4]Ronozyme HiPhos 2700 GT, DSM Nutritional Products, Parsippany, NJ was included at 2,000 FTU/kg to provide an estimated release of 0.12% STTD P for all diets.
[5]Utilized as an indigestible marker for apparent total tract digestibility calculations.
[6]Calculated analysis is based off nutrient profiles for ingredients listed in the NRC (2012).
[7]Energy values of the soybean gums and soapstocks were unknown and therefore not included in the calculated energy values.

**Table 2. Analyzed soybean processing by-products (as-is)[1]**

| | Analysis[2] | |
|---|---|---|
| **Item** | **Soybean gums** | **Soybean soapstocks** |
| Moisture and volatile matter, % | 20.32 | 44.26 |
| Insoluble impurities, % | 2.32 | 1.87 |
| Unsaponifiable matter, % | 0.58 | 0.35 |
| P, % | 0.953 | 0.156 |
| Peroxide value, meq/kg | --- | 0.6 |
| p-Anisidine value, % | 3.6 | --- |
| Viscosity, cps | 14,250 | --- |
| Fat by acid hydrolysis, % | 52.29 | 6.53 |
| SFA, %[3] | | |
| C16:0 | 15.30 | 15.31 |
| C17:0 | 0.13 | --- |
| C18:0 | 3.93 | 4.60 |
| C20:0 | 0.20 | --- |
| C22:0 | 0.40 | 0.53 |
| C24:0 | 0.27 | 0.53 |
| Total SFA | 20.32 | 21.33 |
| MUFA, %[3] | | |
| C16:1 | 0.17 | --- |
| C18:1[4] | 12.81 | 22.12 |
| C20:1[4] | 0.15 | --- |
| Total MUFA | 13.23 | 22.65 |
| PUFA, %[3] | | |
| C18:2[4] | 58.00 | 48.94 |
| C18:3[4] | 8.29 | 7.26 |
| Total PUFA | 66.44 | 56.02 |
| Free Fatty acids, %[3] | 12.75 | 0.51 |

[1]All soybean gums and soapstocks utilized in the trial were sourced from a single batch of each by-product.
[2]Both soybean by-product samples were submitted to Eurofins Nutrition Analytical Center (Des Moines, IA) for lipid quality analysis. All analyses besides viscosity were run in quadruplet. Viscosity was analyzed in duplicate.
[3]Presented as a percentage of extracted lipid.
[4]Concentration includes isomers.
MUFA = monounsaturated fatty acids. PUFA = polyunsaturated fatty acids. SFA = saturated fatty acids.

**Table 3. Analyzed soybean meal and diet composition (as-fed basis)**

| | Analysis, %[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Dry matter | Ether extract | Crude protein | Ash | Crude fiber | NDF | Ca | P |
| Soybean meal | | | | | | | | |
| No by-products | 89.94 | 1.06 | 48.00 | 6.36 | 4.75 | 7.55 | 0.69 | 0.63 |
| 4% gums | 88.01 | 4.00 | 46.05 | 6.08 | 4.35 | 7.30 | 0.62 | 0.68 |
| 4% soapstocks | 85.75 | 1.39 | 45.40 | 6.08 | 4.85 | 7.10 | 0.65 | 0.61 |
| 2% gums + 2% soapstocks | 86.98 | 2.50 | 46.55 | 6.03 | 5.25 | 5.95 | 0.56 | 0.64 |
| Complete diets | | | | | | | | |
| Phase 1 | | | | | | | | |
| No by-products | 88.90 | 2.61 | 20.85 | 6.37 | 1.90 | 5.60 | 0.91 | 0.70 |
| 4% gums | 88.60 | 2.91 | 20.10 | 6.64 | 1.90 | 4.90 | 0.87 | 0.72 |
| 4% soapstocks | 88.51 | 2.36 | 20.35 | 6.30 | 1.85 | 5.05 | 0.86 | 0.73 |
| 2% gums + 2% soapstocks | 88.39 | 2.63 | 19.65 | 6.34 | 1.75 | 4.45 | 0.91 | 0.73 |
| 4% less soybean meal | 88.58 | 2.38 | 20.45 | 6.26 | 1.70 | 6.35 | 1.02 | 0.68 |
| Phase 2 | | | | | | | | |
| No by-products | 88.44 | 2.23 | 20.15 | 6.45 | 2.05 | 7.10 | 0.84 | 0.74 |
| 4% gums | 88.04 | 3.11 | 20.15 | 6.44 | 2.45 | 6.35 | 0.97 | 0.82 |
| 4% soapstocks | 87.69 | 3.20 | 19.60 | 6.34 | 2.15 | 7.80 | 0.88 | 0.76 |
| 2% gums + 2% soapstocks | 87.78 | 3.18 | 21.15 | 6.32 | 2.65 | 6.90 | 0.98 | 0.75 |
| 4% less soybean meal | 88.40 | 2.37 | 20.10 | 6.42 | 2.35 | 5.80 | 0.66 | 0.69 |
| Phase 3 | | | | | | | | |
| No by-products | 87.66 | 2.41 | 20.65 | 4.78 | 2.30 | 5.20 | 1.16 | 0.66 |
| 4% gums | 87.46 | 3.26 | 18.65 | 4.64 | 2.65 | 5.40 | 1.09 | 0.63 |
| 4% soapstocks | 86.77 | 2.41 | 19.20 | 4.71 | 2.60 | 4.60 | 1.06 | 0.61 |
| 2% gums + 2% soapstocks | 87.14 | 2.85 | 20.20 | 4.70 | 2.45 | 6.15 | 0.89 | 0.63 |
| 4% less soybean meal | 87.64 | 2.39 | 19.40 | 4.61 | 2.80 | 7.45 | 1.01 | 0.64 |

[1] All soybean meal and complete diet samples were submitted for duplicate analysis of Ca and P at the K-State Research and Extension Soil Testing Laboratory in Manhattan, KS. All samples were also submitted to Midwest Laboratories Inc., Omaha, NE for duplicate analysis of proximate composition and neutral detergent fiber.

**Table 4. Effects of soybean gums and soapstocks added to soybean meal (SBM) on growth performance, fecal DM, and ATTD of DM for nursery pigs[1]**

| | | By-products, % of SBM | | | | | *P* = | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | 4% Gums | 4% Soap-stocks | 2% Gums + 2% Soap-stocks | 4% Less SBM | SEM | Treat-ment | Gums × Soap-stocks | Gums | Soap-stocks | Control v. 4% less SBM |
| Initial BW, lb | | | | | | | | | | | |
| d 0 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 0.05 | 1.000 | 0.873 | 0.986 | 0.975 | 0.933 |
| d 11 | 16.2 | 16.1 | 15.8 | 16.0 | 15.8 | 0.24 | 0.588 | 0.472 | 0.758 | 0.246 | 0.204 |
| d 23 | 28.9 | 28.6 | 28.3 | 28.4 | 28.1 | 0.47 | 0.725 | 0.623 | 0.918 | 0.353 | 0.196 |
| d 42 | 53.7 | 54.6 | 53.6 | 54.8 | 52.7 | 0.83 | 0.382 | 0.817 | 0.220 | 0.958 | 0.378 |
| d 0 to 11 (Phase 1) | | | | | | | | | | | |
| ADG, lb | 0.41 | 0.40 | 0.37 | 0.39 | 0.37 | 0.022 | 0.444 | 0.448 | 0.757 | 0.238 | 0.115 |
| ADFI, lb | 0.46 | 0.47 | 0.44 | 0.45 | 0.42 | 0.023 | 0.531 | 0.770 | 0.582 | 0.315 | 0.120 |
| F/G | 1.13 | 1.17 | 1.18 | 1.15 | 1.18 | 0.032 | 0.784 | 0.296 | 0.851 | 0.530 | 0.304 |
| d 11 to 23 (Phase 2) | | | | | | | | | | | |
| ADG, lb | 1.07 | 1.05 | 1.05 | 1.04 | 1.04 | 0.030 | 0.932 | 0.833 | 0.685 | 0.540 | 0.402 |
| ADFI, lb | 1.45 | 1.48 | 1.44 | 1.44 | 1.43 | 0.045 | 0.953 | 0.723 | 0.808 | 0.620 | 0.735 |
| F/G | 1.35 | 1.40 | 1.38 | 1.38 | 1.38 | 0.022 | 0.640 | 0.279 | 0.252 | 0.863 | 0.478 |
| d 23 to 42 (Phase 3) | | | | | | | | | | | |
| ADG, lb | 1.29 | 1.34 | 1.32 | 1.37 | 1.28 | 0.028 | 0.133 | 0.885 | 0.053 | 0.348 | 0.868 |
| ADFI, lb | 1.94 | 2.01 | 1.98 | 2.04 | 1.95 | 0.049 | 0.531 | 0.911 | 0.174 | 0.394 | 0.818 |
| F/G | 1.51 | 1.49 | 1.51 | 1.49 | 1.53 | 0.023 | 0.778 | 0.936 | 0.509 | 0.966 | 0.523 |
| d 0 to 42 (Overall) | | | | | | | | | | | |
| ADG, lb | 1.00 | 1.02 | 1.00 | 1.02 | 0.97 | 0.020 | 0.352 | 0.878 | 0.255 | 0.939 | 0.297 |
| ADFI, lb | 1.42 | 1.46 | 1.42 | 1.45 | 1.40 | 0.036 | 0.744 | 0.864 | 0.351 | 0.944 | 0.772 |
| F/G | 1.41 | 1.43 | 1.43 | 1.42 | 1.44 | 0.015 | 0.803 | 0.535 | 0.845 | 0.783 | 0.227 |
| Fecal DM, %[2] | | | | | | | | | | | |
| d 11 | 20.19 | 19.69 | 19.41 | 19.32 | 20.20 | 0.649 | 0.800 | 0.771 | 0.670 | 0.404 | 0.992 |
| d 24 | 18.86 | 19.87 | 19.20 | 19.42 | 19.63 | 0.649 | 0.839 | 0.518 | 0.313 | 0.933 | 0.372 |
| ATTD of DM[3] | 76.22[b] | 79.77[a] | 76.35[b] | 75.78[b] | 78.50[ab] | 0.901 | 0.004 | 0.019 | 0.085 | 0.027 | 0.069 |

[1]A total of 350 weanling pigs (DNA 241 × 600; initially 11.7 ± 0.05 lb) approximately 19 d of age were used in a 42-d experiment with five pigs per pen and 14 pens per treatment.

[2]Feces from three piglets from each pen were pooled, weighed, and dried to measure fecal dry matter. Treatment × day, *P* = 0.775; Treatment, *P* = 0.862; Day, *P* = 0.375.

[3]Both ground feed and fecal samples were dried in a 275°F forced air drying oven for 2 h to determine DM percentage of the samples used for titanium determination. Titanium dioxide concentration in both dried feed and fecal samples were analyzed in duplicate.

DM = dry matter. ATTD = apparent total tract digestibility.