Effects of Compound Enzymes in Nursery Pig Diets of Different Nutrient Density

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Summary
A total of 355 nursery pigs (DNA 241 × 600, initially 29.3 ± 0.52 lb BW) were used in a 35-d growth study to determine the effects of compound enzymes (Sunzyme; Wuhan Sunhy Biology Co., Ltd., Wuhan, P.R. China) on growth performance, intestinal morphology, and nutrient digestibility in nursery pigs fed diets of different nutrient density. At approximately 19 d of age, pigs were weaned, randomly allotted to pens, and fed common phase 1 and 2 diets. On d 24 post-weaning, considered d 0 of the study, pigs were blocked by average pen BW and allotted to one of six dietary treatments in a randomized complete block design with four or five pigs per pen and 12 pens per treatment. Treatment diets were formulated in two dietary phases and fed from d 0 to 22 and d 22 to 35, respectively. The six treatments included two corn-soybean meal-based diets (Corn-SBM; CS) with either 0 (CS + 0) or 0.01% (CS + 0.01) enzyme and four corn-soybean meal-wheat middling-low oil DDGS-based diets (Corn-SBM-By-product; CSBP) with lower dietary energy/CP with 0 (CSBP + 0), 0.01 (CSBP + 0.01), 0.02 (CSBP + 0.02), or 0.03% (CSBP + 0.03) enzyme. At the conclusion of the study, fecal samples were collected from six pigs per treatment to determine ATTD of DM, CP, ADF, and NDF. The same pigs were then euthanized, and ileal digesta and tissue samples were collected to determine AID of AA and small intestine morphology. Overall, pigs fed CS diets had increased ($P < 0.05$) ADG and improved ($P < 0.05$) F/G compared to pigs fed CSBP diets, but there were no treatment effects ($P > 0.05$) on ADFI. Pigs fed CSBP diets had increased ($P < 0.05$) duodenal villus height compared to pigs fed CS diets, but added enzyme decreased ($P < 0.05$) the duodenal villus height in CS diets and decreased (linear, $P < 0.05$) duodenal villus height and VH:CD in CSBP diets. There were no effects ($P > 0.05$) on jejunal or ileal morphology. Pigs fed CS diets had increased ($P < 0.05$) ATTD of DM, CP, and ADF, AID of Arg, Asp, and Trp compared to pigs fed CSBP diets. There was a quadratic reduction ($P = 0.015$) in AID of Met as enzyme increased in CSBP diets. In summary, pigs fed CS diets had improved growth performance, ATTD of DM, CP, and ADF, and AID of Arg, Asp, and Trp compared to pigs fed CSBP diets. The addition of a compound enzyme had no effect

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on overall growth performance but had a negative impact on duodenal morphology, ATTD of DM and CP, and AID of Met in CSBP diets.

Introduction

Swine diets contain plant-based ingredients, which contain fibrous components that are not readily digested by pigs. Including enzymes in the diet is one option to help break down these components and increase digestion and absorption. Enzymes can be included to degrade feed components resistant to endogenous enzymes, inactivate antinutritional factors, or supplement endogenous enzymes that may be present in insufficient amounts.[4]

Enzymes are substrate-specific, meaning enzyme inclusion must match the substrate present in the diet to be effective.[5] Sunzyme is comprised of non-starch polysaccharide (NSP) enzymes, such as xylanase, glucanase, mannanase, and cellulase, which break down complex carbohydrates in the cell walls of plant-derived ingredients.[5] In addition to NSP enzymes, Sunzyme contains digestive enzymes, such as protease and amylase, which break down protein and starch into simpler structures.[5] Little data were available describing the effect of these enzymes when added at the same time. Additionally, the independent use of these enzymes in swine diets has provided inconsistent results. As a result, new enzyme products, such as Sunzyme, must be evaluated to determine their efficacy. Therefore, the objective of this study was to determine the effects of Sunzyme on growth performance, gut health, and nutrient digestibility in nursery pigs fed diets of different nutrient density.

Materials and Methods

The protocol used in this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen contained a four-hole, dry self-feeder and nipple waterer for *ad libitum* access to feed and water.

Prior to diet formulation, representative samples of corn, SBM, and DDGS were submitted for analysis of CP, crude fat, ADF, ash, and NDF in duplicate (Midwest Laboratories, Omaha, NE) and for total AA profile analysis in duplicate (Ajinomoto Health and Nutrition, Inc., Eddyville, IA; Table 1). Analyzed values were used in diet formulation. Wheat middling samples were not available for analysis prior to diet formulation, so NRC (2012)[6] loading values were used. Nutrient loading values and standardized ileal digestibility coefficients from NRC (2012) were used for all nutrients where analytical values were not available.

A total of 355 nursery pigs (DNA 241 × 600) were weaned at approximately 19 d of age, randomly allotted to pens, and fed common phase 1 and 2 diets. On d 24 post-weaning, considered d 0 of the study, pigs were blocked by average pen BW (initially 29.3 ± 0.52 lb) and allotted to one of six dietary treatments in a randomized complete

[4] Thacker, P. A. 2013. Alternatives to antibiotics as growth promoters for use in swine production: A review. Journal of Animal Science and Biotechnology. 4:35-47. doi:10.1186/2049- 1891-4-35.
[5] Jacela, J Y.; DeRouchey, Joel M.; Tokach, Michael D.; Goodband, Robert D.; Nelssen, Jim L.; Renter, David G.; and Dritz, Steven S. 2009. "Feed additives for swine: Fact sheets – carcass modifiers, carbohydrate-degrading enzymes and proteases, and anthelmintics," Kansas Agricultural Experiment Station Research Reports: Vol. 0: Iss. 10. doi:10.4148/2378-5977.7070.
[6] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington D.C.

block design. There were four or five pigs per pen and 12 pens per treatment. Treatment diets were formulated in two dietary phases and fed from d 0 to 22 and d 22 to 35, respectively (Tables 2 and 3). The six treatments included two corn-soybean meal-based diets (Corn-SBM; CS) with either 0 (CS + 0) or 0.01% (CS + 0.01) compound enzyme and four corn-soybean meal-wheat middling-low oil DDGS based diets (Corn-SBM-By-product; CSBP) with 0 (CSBP + 0), 0.01 (CSBP + 0.01), 0.02 (CSBP + 0.02), or 0.03% (CSBP + 0.03) compound enzyme.

The CSBP diets were formulated to achieve a targeted 35 kcal/lb reduction in NE and a 1% reduction in CP compared to the CS diets. The two CS diets (CS + 0 and CS + 0.01) were formulated to 22.4% CP and 1,088 kcal/lb NE in phase 1 and 20.5% CP and 1,098 kcal/lb NE in phase 2. The four CSBP diets (CSBP + 0, CSBP + 0.01, CSBP + 0.02, and CSBP + 0.03) were formulated to 21.3% CP and 1,053 kcal/lb NE in phase 1 and 19.5% CP and 1,063 kcal/lb NE in phase 2. Phase 2 diets included 0.5% titanium dioxide as an indigestible marker. During bagging, complete diet samples were collected from every fourth bag, pooled, ground to reduce particle size, and stored at -4°F.

Throughout the experiment, pig and feeder weights were collected every 7 d to determine ADG, ADFI, and F/G. Feed delivered was recorded for each pen.

Fecal samples were collected from six pigs (three barrows and three gilts) per treatment on d 35 of the study for determination of apparent total tract digestibility (ATTD) of DM, CP, ADF, and NDF. The pigs selected for collection were the closest to the mean BW of each pen from the middle six weight blocks. After collection, fecal samples were dried at 131°F in a forced-air oven for 48 h, and fecal DM was determined as the ratio of dried to wet fecal weight.

On d 36, following the completion of the growth study, the same six pigs per treatment (36 pigs total) were euthanized via penetrating captive bolt for the collection of ileal digesta and duodenal, jejunal, and ileal tissue samples. Ileal digesta samples were stored at -112°F until freeze dried. Tissue samples were collected and fixed in formalin and submitted to the Kansas State University Veterinary Diagnostic Laboratory for analysis of villus height (VH), crypt depth (CD), and villus height to crypt depth ratio (VH:CD) by a board-certified anatomic pathologist. A total of 10 measurements were taken on each section of small intestine from each pig.

Ground feed, fecal, and ileal digesta samples were dried in a 275°F drying oven for 2 h to determine percentage DM of the samples used for titanium analysis (Method 985.01).[7] Titanium dioxide concentration in dried feed, fecal, and ileal digesta samples were determined utilizing procedures outlined by Leone (1973).[8] Fecal, ileal digesta, and feed samples were analyzed for ADF (fecal and phase 1 and 2 feed), NDF (fecal and phase 1 and 2 feed), and complete AA profile (ileal digesta and phase 2 feed; University of Missouri Agricultural Experiment Station Chemical Laboratory). Feed and fecal samples were analyzed for DM and CP (Kansas State University Swine Laboratory).

[7] AOAC. 2007. Official methods of analysis AOAC international. 18th ed. Association of Official Analytical Chemists, Washington, DC.
[8] Leone, J. L. 1973. Collaborative study of the quantitative determination of titanium dioxide in cheese. AOAC. 56(3):535.

The ATTD of DM, CP, ADF, and NDF, and AID of AAs were determined using the index method described by Adeola (2001)[9] using the following equation:

Statistical analysis

Growth and digestibility data were analyzed as a randomized complete block design with pen as the experimental unit, treatment as a fixed effect, and weight block as a random effect. Gut morphology data were analyzed as a randomized complete block design with pen as the experimental unit, treatment as a fixed effect, and weight block and pen as random effects to account for 10 observations for each section of small intestine per pig. Linear and quadratic contrasts were constructed with increasing levels of the compound enzyme in the CSBP diets. A pairwise comparison was conducted between the treatments with or without added enzyme within the CS diets. A contrast was constructed to determine the effect of formulation strategy by comparing the CS and CSBP diets with the same enzyme inclusion rates (CS + 0 and CS + 0.01 vs. CSBP + 0 and CSBP + 0.01). Data were analyzed using the lmer package of R (version 4.2.2 (2022-10-31)). Results were considered significant with $P \leq 0.05$ and were considered marginally significant with $P \leq 0.10$.

Results and Discussion

From d 0 to 22 (phase 1), pigs fed CS diets had increased ($P < 0.05$) ADG and improved ($P < 0.05$) F/G compared to pigs fed CSBP diets, but there were no treatment effects ($P > 0.05$) on ADFI. From d 22 to 35 (phase 2), pigs fed CS diets tended to have improved ($P < 0.10$) F/G compared to pigs fed CSBP diets, but no treatment effects were observed ($P > 0.05$) for ADG or ADFI. Feed efficiency worsened (linear, $P < 0.05$) as enzyme increased in the CSBP diets. From d 0 to 35 (overall), pigs fed CS diets had increased ($P < 0.05$) ADG and improved ($P < 0.05$) F/G compared to pigs fed CSBP diets, but there were no treatment effects ($P > 0.05$) on ADFI.

For intestinal morphology (Table 5), pigs fed CSBP diets had increased ($P < 0.05$) duodenal villus height compared to pigs fed CS diets, but there was no difference ($P > 0.05$) in duodenal crypt depth or VH:CD. There was also a linear decrease ($P < 0.05$) in duodenal villus height and VH:CD as enzyme increased in the CSBP diets, but enzyme addition had no effect ($P > 0.05$) on duodenal crypt depth in the CSBP diets. There was a decrease ($P < 0.05$) in duodenal villus height with added enzyme in the CS diets, but enzyme addition had no effect ($P > 0.05$) on duodenal crypt depth or VH:CD in the CS diets. No treatment effects were observed ($P > 0.05$) for jejunal or ileal morphology measures.

For ATTD measures (Table 6), pigs fed CS diets had increased ($P < 0.05$) ATTD of DM, CP, and ADF and tended to have increased ($P < 0.10$) ATTD of NDF compared to pigs fed CSBP diets. Enzyme addition had no effect ($P > 0.05$) on ATTD of DM, CP, ADF, or NDF in the CS diets. There was a tendency for a quadratic reduction ($P < 0.10$) in ATTD of DM and CP as enzyme increased in the CSBP diets, but no effect ($P > 0.05$) on ATTD of ADF and NDF.

For AID measures, pigs fed CS diets had increased ($P < 0.05$) AID of Arg, Asp, and Trp and tended to have increased ($P < 0.10$) AID of Gly, His, and Ser compared to pigs fed CSBP diets. There was a tendency ($P < 0.10$) for a reduction in AID of Glu when

[9] 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.

enzyme was included in the CS diets, but enzyme inclusion in the CS diets had no effect ($P > 0.05$) on AID of the other AAs. There was a quadratic reduction ($P < 0.05$) in AID of Met in the CSBP diets where AID decreased from 0 to 0.02% enzyme but increased from 0.02% to 0.03% enzyme, but enzyme inclusion had no effect ($P > 0.05$) on AID of the other AAs in the CSBP diets. There were no treatment effects on AID of Ala, Cys, Glu, Ile, Leu, Lys, Phe, Pro, Thr, Tyr, or Val.

In summary, pigs fed CS diets had increased ADG, ATTD of DM, CP, and ADF, AID of Trp and some non-essential AA, and improved F/G compared to pigs fed CSBP diets. The inclusion of compound enzymes had no effect on overall growth performance but had a negative impact on duodenal morphology, ATTD of DM and CP, and AID of Met in CSBP diets.

Acknowledgments
Appreciation is expressed to Wuhan Sunhy Biology Co., Ltd. (Wuhan, P. R. China) for partial financial support of this project.

Table 1. Analyzed ingredient composition (as-fed basis)[1]

Nutrient, %	Corn	Soybean meal	DDGS	Wheat middlings
Crude protein	7.86	47.75	28.35	17.30
Crude fat	3.30	1.01	4.18	3.93
Acid detergent fiber	1.55	---	8.75	11.40
Ash	1.04	6.11	5.08	4.89
Neutral detergent fiber	6.70	5.80	24.50	36.10
Essential AAs				
Arginine	0.35	3.37	1.18	---
Cysteine	0.16	0.62	0.52	---
Histidine	0.20	1.20	0.70	---
Isoleucine	0.25	2.03	1.06	---
Leucine	0.83	3.51	3.06	---
Lysine	0.24	2.88	0.83	---
Methionine	0.18	0.66	0.57	---
Phenylalanine	0.36	2.48	1.40	---
Threonine	0.27	1.88	1.04	---
Tryptophan	0.05	0.62	0.25	---
Valine	0.35	2.15	1.36	---
Non-essential AAs				
Alanine	0.52	2.04	1.92	---
Aspartic acid	0.51	5.42	1.79	---
Glutamic acid	1.32	8.74	4.64	---
Glycine	0.31	1.98	1.10	---
Proline	0.47	1.45	2.58	---
Serine	0.36	2.42	1.34	---
Tyrosine	0.14	1.50	1.01	---

[1]Ingredient samples were pooled and submitted for complete proximate analysis in duplicate (Midwest Laboratories, Omaha, NE) and for complete amino acid profile analysis in duplicate (Ajinomoto Health and Nutrition, Inc., Eddyville, IA). Analyzed values for corn, SBM, and DDGS were used in diet formulation. Values from NRC (2012) were used for wheat middlings.

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

	Phase 1		Phase 2	
Ingredient, %	**CS**	**CSBP**	**CS**	**CSBP**
Corn	60.81	46.59	65.40	51.02
Soybean meal	35.73	23.58	30.97	18.99
Wheat middlings	---	16.00	---	16.00
DDGS	---	10.00	---	10.00
Calcium carbonate	0.92	1.28	0.85	1.21
Monocalcium phosphate	0.79	0.28	0.60	0.10
Sodium chloride	0.60	0.55	0.55	0.50
L-Lys-HCl	0.33	0.59	0.33	0.59
DL-Met	0.18	0.19	0.16	0.17
L-Thr	0.13	0.22	0.12	0.21
L-Trp	0.04	0.07	0.04	0.07
L-Val	0.09	0.16	0.08	0.15
L-Ile	---	0.10	---	0.10
Trace mineral premix	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25
Phytase[2]	0.01	0.01	0.01	0.01
Compound enzyme[3]	+/-	+/-	+/-	+/-
Titanium dioxide[4]	---	---	0.50	0.50
Total	100.00	100.00	100.00	100.00

continued

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

	Phase 1		Phase 2	
Ingredient, %	**CS**	**CSBP**	**CS**	**CSBP**
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lys	1.28	1.28	1.17	1.17
Ile:Lys	60	60	59	59
Leu:Lys	121	114	122	115
Met:Lys	37	37	37	37
Met and Cys:Lys	58	58	58	58
Thr:Lys	64	64	64	64
Trp:Lys	20	20	20	20
Val:Lys	72	72	72	72
His:Lys	38	35	38	35
Total Lys, %	1.43	1.44	1.31	1.32
NE, kcal/lb	1,088	1,053	1,098	1,063
DE, kcal/lb	1,556	1,521	1,549	1,514
SID Lys:NE, g/Mcal	5.34	5.51	4.83	4.99
CP, %	22.4	21.3	20.5	19.5
Ca, %	0.70	0.72	0.62	0.65
STTD P, %	0.43	0.43	0.39	0.39
Ca:P	1.20	1.20	1.20	1.20
ADF, %	3.63	4.42	3.52	4.30
NDF, %	6.1	12.5	6.2	12.6
Diet cost, $/ton	226.41	221.37	216.53	211.47

[1]Phase 1 diets were fed from d 0 to 22, and phase 2 diets were fed from d 22 to 35 of the study.
[2]Sunphase HT (Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China) included at 1,227 FTU/kg provided an estimated release of 0.11% STTD P.
[3]Sunzyme (Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China) was included at 0 or 0.01% in the corn-SBM diets (CS) and 0, 0.01, 0.02, or 0.03% in the corn-SBM-by-product diets (CSBP).
[4]Titanium dioxide was included at 0.50% of the phase 2 diets as an indigestible marker.

Table 3. Analyzed composition of experimental diets (as-fed basis)[1]

Formulation strategy:	Corn-SBM		Corn-SBM-By-product			
Nutrient, % Enzyme, %[2]:	0	0.01	0	0.01	0.02	0.03
Phase 1						
DM	88.5	88.5	88.6	88.5	88.3	88.5
CP	21.6	24.2	21.1	21.1	21.2	21.6
Acid detergent fiber	3.9	3.8	6.2	5.9	5.5	5.8
Neutral detergent fiber	6.1	6.2	12.1	12.7	13.2	13.3
Phase 2						
DM	88.3	88.3	88.5	88.6	88.7	88.8
CP	19.8	20.3	19.5	19.2	19.7	19.5
Acid detergent fiber	3.9	4.0	5.5	6.4	6.9	6.8
Neutral detergent fiber	6.9	8.3	12.7	13.4	14.4	13.9
Essential AAs						
Arginine	1.33	1.30	1.13	1.14	1.07	1.16
Cysteine	0.33	0.35	0.35	0.33	0.31	0.37
Histidine	0.54	0.52	0.50	0.50	0.48	0.50
Isoleucine	0.92	0.90	0.87	0.87	0.84	0.88
Leucine	1.74	1.67	1.64	1.64	1.58	1.63
Lysine	1.33	1.36	1.37	1.33	1.27	1.35
Methionine	0.38	0.45	0.51	0.45	0.38	0.54
Phenylalanine	1.00	0.97	0.88	0.89	0.85	0.89
Threonine	0.86	0.81	0.90	0.80	0.85	0.82
Tryptophan	0.26	0.23	0.23	0.23	0.23	0.26
Valine	1.09	1.08	1.11	1.11	1.06	1.10
Non-essential AAs						
Alanine	1.04	1.00	1.02	1.02	0.99	1.01
Aspartic acid	2.04	1.98	1.65	1.65	1.55	1.67
Glutamic acid	3.81	3.68	3.46	3.47	3.35	3.44
Glycine	0.85	0.84	0.81	0.81	0.76	0.81
Proline	1.18	1.16	1.20	1.23	1.22	1.22
Serine	0.82	0.80	0.73	0.75	0.73	0.75
Tyrosine	0.66	0.63	0.58	0.59	0.56	0.60

[1]Complete diet samples were taken during bagging of experimental diets from every fourth bag and pooled into one homogenized sample per dietary treatment. Samples were stored at -4°F until analysis. Phase 1 and 2 samples were analyzed for ADF and NDF, and phase 2 samples were analyzed for complete AA profile (University of Missouri Agricultural Experiment Station Chemical Laboratory). Phase 1 and 2 samples were analyzed for DM and CP in the Kansas State University Swine Laboratory.
[2]Sunzyme (Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China).

Table 4. Effect of compound enzymes in diets of different nutrient density on nursery pig growth performance[1]

	Treatment[2]							*P* =			
Formulation strategy:	Corn-SBM		Corn-SBM-By-product							Enzyme in CSBP	
Item Enzyme, %[3]:	0	0.01	0	0.01	0.02	0.03	SEM	CS vs. CSBP[4]	Enzyme in CS	Linear	Quadratic
BW, lb											
d 0	29.3	29.3	29.3	29.3	29.3	29.3	0.52	0.983	0.882	0.953	0.811
d 22	63.5	62.8	61.7	61.3	60.8	61.5	0.87	0.005	0.426	0.728	0.324
d 35	88.8	88.1	86.4	85.9	84.8	85.9	0.91	0.002	0.448	0.345	0.251
d 0 to 22 (Phase 1)											
ADG, lb	1.55	1.52	1.46	1.45	1.43	1.47	0.026	0.004	0.339	0.978	0.395
ADFI, lb	2.30	2.26	2.31	2.28	2.24	2.31	0.041	0.641	0.487	0.800	0.129
F/G	1.49	1.50	1.59	1.57	1.56	1.58	0.015	< 0.001	0.616	0.741	0.281
d 22 to 35 (Phase 2)											
ADG, lb	1.95	1.91	1.90	1.87	1.84	1.87	0.032	0.175	0.394	0.397	0.304
ADFI, lb	3.60	3.46	3.57	3.58	3.51	3.75	0.075	0.570	0.186	0.153	0.134
F/G	1.86	1.81	1.88	1.92	1.91	2.01	0.041	0.087	0.455	0.047	0.457
d 0 to 35 (Overall)											
ADG, lb	1.70	1.65	1.62	1.61	1.58	1.62	0.023	0.010	0.206	0.683	0.279
ADFI, lb	2.78	2.69	2.77	2.76	2.71	2.85	0.047	0.489	0.199	0.422	0.111
F/G	1.64	1.63	1.71	1.72	1.71	1.76	0.021	< 0.001	0.665	0.152	0.291

[1]A total of 355 nursery pigs (DNA 241 × 600, initially 29.3 ± 0.52 lb BW) were used in a 35-d growth trial with four to five pigs per pen and 12 replications per treatment.
[2]Corn-SBM diets (CS) were corn-soybean meal based and formulated to 22.4% crude protein and 1,088 kcal/lb NE in phase 1 and 20.5% crude protein and 1,098 kcal/lb NE in phase 2. Corn-SBM-by-product diets (CSBP) were corn-soybean meal-wheat middling-low oil DDGS based and formulated to 21.3% crude protein and 1,053 kcal/lb NE in phase 1 and 19.5% crude protein and 1,063 kcal/lb NE in phase 2.
[3]Sunzyme, Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China.
[4]Corn-SBM vs. Corn-SBM-by-product diets with the same enzyme inclusion rates (CS + 0 and CS + 0.01 vs. CSBP + 0 and CSBP + 0.01).

Table 5. Effect of compound enzymes in diets of different nutrient density on nursery pig intestinal morphology[1]

Formulation strategy:	Treatment[2]							*P* =			
	Corn-SBM		Corn-SBM-By-product					CS vs.	Enzyme	Enzyme in CSBP	
Item Enzyme, %[3]:	0	0.01	0	0.01	0.02	0.03	SEM	CSBP[4]	in CS	Linear	Quadratic
Duodenum											
Villus height, µm	622	528	715	604	633	567	33.9	0.003	0.017	0.001	0.403
Crypt depth, µm	566	517	548	536	540	570	29.3	0.998	0.231	0.576	0.466
VH:CD[5]	1.16	1.13	1.33	1.17	1.22	1.03	0.106	0.197	0.813	0.028	0.888
Jejunum											
Villus height, µm	667	636	694	682	665	652	52.1	0.490	0.675	0.547	0.987
Crypt depth, µm	369	380	402	353	390	393	24.4	0.892	0.725	0.920	0.229
VH:CD	1.88	1.75	1.79	2.14	1.76	1.74	0.196	0.400	0.588	0.494	0.302
Ileum											
Villus height, µm	473	429	453	379	428	415	23.7	0.151	0.192	0.538	0.212
Crypt depth, µm	236	228	224	238	239	234	16.7	0.962	0.730	0.675	0.599
VH:CD	2.29	1.98	2.09	1.72	1.91	1.85	0.167	0.171	0.188	0.478	0.363

[1]A total of 355 nursery pigs (DNA 241 × 600, initially 29.3 ± 0.52 lb BW) were used in a 35-d growth trial with four to five pigs per pen and 12 replications per treatment. Tissue samples were collected from the duodenum, jejunum, and ileum from six pigs per treatment.
[2]Corn-SBM diets (CS) were corn-soybean meal based and formulated to 22.4% CP and 1,088 kcal/lb NE in phase 1 and 20.5% CP and 1,098 kcal/lb NE in phase 2. Corn-SBM-by-product diets (CSBP) were corn-soybean meal-wheat middling-low oil DDGS based and formulated to 21.3% CP and 1,053 kcal/lb NE in phase 1 and 19.5% CP and 1,063 kcal/lb NE in phase 2.
[3]Sunzyme, Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China.
[4]Corn-SBM vs. Corn-SBM-by-product diets with the same enzyme inclusion rates (CS + 0 and CS + 0.01 vs. CSBP + 0 and CSBP + 0.01).
[5]VH:CD = villus height to crypt depth ratio.

Table 6. Effect of compound enzymes in diets of different nutrient density on nursery pig nutrient digestibility[1]

	Formulation strategy:	Treatment[2]							*P* =			
		Corn-SBM		Corn-SBM-By-product					CS vs. CSBP[4]	Enzyme in CS	Enzyme in CSBP	
Item	Enzyme, %[3]:	0	0.01	0	0.01	0.02	0.03	SEM			Linear	Quadratic
ATTD, %												
DM		87.6	86.5	81.8	78.7	79.0	79.6	0.97	< 0.001	0.426	0.132	0.054
CP		84.7	84.3	82.6	80.4	80.4	82.5	1.22	0.012	0.763	0.959	0.065
ADF		52.0	50.1	37.0	38.2	41.0	38.2	5.48	0.020	0.809	0.792	0.717
NDF		43.3	46.2	39.3	28.8	36.1	30.7	5.50	0.060	0.709	0.452	0.643
AID, %												
Essential AAs												
Arg		93.9	92.8	91.0	90.8	89.6	90.5	0.95	0.012	0.394	0.508	0.581
His		90.9	89.0	87.8	87.2	85.8	86.4	1.43	0.073	0.307	0.360	0.657
Ile		89.3	87.9	87.5	87.5	85.6	86.6	1.32	0.380	0.428	0.396	0.714
Leu		88.7	87.5	87.2	87.5	84.7	86.4	1.55	0.633	0.566	0.427	0.621
Lys		91.2	90.0	89.9	89.5	88.2	89.2	1.20	0.400	0.458	0.520	0.510
Met		91.7	92.9	93.4	92.8	89.3	93.1	0.93	0.324	0.303	0.264	0.015
Phe		89.4	87.7	86.8	86.7	84.4	85.8	1.50	0.202	0.388	0.413	0.593
Thr		86.6	83.7	85.0	82.6	82.2	81.7	1.87	0.467	0.252	0.195	0.572
Trp		92.1	90.2	88.1	87.9	88.0	88.9	1.58	0.050	0.407	0.695	0.726
Val		88.2	86.7	86.4	86.2	84.5	85.1	1.51	0.434	0.465	0.383	0.750
Non-essential AAs												
Ala		86.3	84.0	84.6	85.1	81.6	83.0	1.89	0.869	0.377	0.305	0.804
Asp		89.6	86.4	84.9	85.1	82.5	83.9	1.51	0.048	0.132	0.407	0.689
Cys		83.1	79.9	79.5	78.1	73.7	78.5	2.43	0.265	0.343	0.499	0.204
Glu		92.1	89.2	89.5	90.2	87.6	89.0	1.21	0.507	0.082	0.433	0.739
Gly		85.5	81.2	79.4	78.1	75.4	76.8	3.20	0.082	0.248	0.371	0.596
Pro		88.4	86.7	86.4	87.3	84.5	85.3	1.68	0.662	0.445	0.396	0.982
Ser		88.6	87.2	84.9	84.9	83.5	84.1	1.63	0.058	0.499	0.572	0.818
Tyr		90.4	88.2	87.3	87.3	85.4	86.8	1.41	0.153	0.245	0.561	0.617

[1]A total of 355 nursery pigs (DNA 241 × 600, initially 29.3 ± 0.52 lb BW) were used in a 35-d growth trial with four to five pigs per pen and 12 replications per treatment. Fecal and ileal digesta samples were collected from six pigs per treatment.
[2]Corn-SBM diets (CS) were corn-soybean meal based and formulated to 22.4% CP and 1,088 kcal/lb NE in phase 1 and 20.5% CP and 1,098 kcal/lb NE in phase 2. Corn-SBM-by-product diets (CSBP) were corn-soybean meal-wheat middling-low oil DDGS based and formulated to 21.3% CP and 1,053 kcal/lb NE in phase 1 and 19.5% CP and 1,063 kcal/lb NE in phase 2.
[3]Sunzyme, Wuhan Sunhy Biology Co., Ltd., Wuhan, P. R. China.
[4]Corn-SBM vs. Corn-SBM-by-product diets with the same enzyme inclusion rates (CS + 0 and CS + 0.01 vs. CSBP + 0 and CSBP + 0.01).