Kansas Agricultural Experiment Station Research Reports

Volume 4
Issue 9 *Swine Day*

Article 22

2018

Effects of Sodium Metabisulfite Additives on Nursery Pig Growth

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Recommended Citation

Shawk, D. J.; Dritz, S. S.; Goodband, R. D.; Tokach, M. D.; Woodworth, J. C.; and DeRouchey, J. M. (2018) "Effects of Sodium Metabisulfite Additives on Nursery Pig Growth," *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7670

Effects of Sodium Metabisulfite Additives on Nursery Pig Growth

Abstract

Sodium metabisulfite (SMB)-based feed additive efficacy was evaluated in 3 nursery pig growth experiments where pigs were fed diets containing low deoxynivalenol (< 1.5 ppm; DON) concentrations. Pigs were weaned at approximately 22 d of age and randomly allotted to pens with one pen of 27 gilts and one pen of 27 barrows per fence line feeder, thus feeder was the experimental unit. In experiment 1, 2,268 pigs were used in a 35-d trial with 21 feeders per treatment. Experimental treatments included a control diet or the control with 0.50% SMB-based Product 1 (Defusion; Provimi, Brooksville, OH) fed in phase 1 and 0.25% fed in phases 2 and 3, then all pigs were fed a control diet for the last week of the study. Pigs fed Product 1 had greater ($P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), and feed/gain ratio (F/G) compared to pigs fed the control diet from d 0 to 28. However, from d 28 to 35, the opposite response was observed, with pigs fed the control diet having greater ADG and improved F/G than pigs previously fed Product 1. Despite this response, pigs fed Product 1 were heavier ($P < 0.05$) on d 35 than control-fed pigs. In experiment 2, 4,320 pigs were used in a 42-d trial with 8 or 16 feeders per treatment. Pigs were fed a control diet or diets with either SMB-based Product 1 or Product 2 (Nutriquest, Mason City, IA) at different concentrations and durations. Among the various treatments, Product 1 or Product 2 concentrations ranged from 0.50% initially to 0.25%, 0.15%, or none the last week of the study. Overall, pigs fed either of the additives at the highest concentrations and for the longest period of time had greater ($P < 0.05$) ADG and ADFI compared to pigs fed the control diet, with those fed lower concentrations or shorter durations intermediate. In experiment 3, 2,808 pigs were used in a 28-d trial with 13 feeders per treatment. All pigs were fed a common diet for 7 d after weaning. Pigs were then either fed a control diet or diets containing Product 1 (0.50 and 0.25% from d 0 to 21 and 21 to 28 respectively), SMB (0.50 and 0.25% from day 0 to 21 and 21 to 28 respectively) or 0.25% SMB from day 0 to 28. Overall, pigs fed Product 1 or high SMB diets had greater ($P < 0.05$) ADG compared to pigs fed low SMB or control diets. Collectively, these studies suggest that in diets with low DON concentrations, these SMB-based products increased ADG compared to pigs fed control diets.

Keywords

deoxynivalenol, nursery pig, preservative, sodium metabisulfite

Cover Page Footnote

We wish to express appreciation to Kayla Nelson and Hord Family Farms (Bucyrus, OH) for assistance with this trial.

Authors

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Effects of Sodium Metabisulfite Additives on Nursery Pig Growth

D.J. Shawk, S.S. Dritz,[1] R.D. Goodband, M.D. Tokach, J.C. Woodworth, and J.M. DeRouchey

Summary

Sodium metabisulfite (SMB)-based feed additive efficacy was evaluated in 3 nursery pig growth experiments where pigs were fed diets containing low deoxynivalenol (< 1.5 ppm; DON) concentrations. Pigs were weaned at approximately 22 d of age and randomly allotted to pens with one pen of 27 gilts and one pen of 27 barrows per fence line feeder, thus feeder was the experimental unit. In experiment 1, 2,268 pigs were used in a 35-d trial with 21 feeders per treatment. Experimental treatments included a control diet or the control with 0.50% SMB-based Product 1 (Defusion; Provimi, Brooksville, OH) fed in phase 1 and 0.25% fed in phases 2 and 3, then all pigs were fed a control diet for the last week of the study. Pigs fed Product 1 had greater ($P <$ 0.05) average daily gain (ADG), average daily feed intake (ADFI), and feed/gain ratio (F/G) compared to pigs fed the control diet from d 0 to 28. However, from d 28 to 35, the opposite response was observed, with pigs fed the control diet having greater ADG and improved F/G than pigs previously fed Product 1. Despite this response, pigs fed Product 1 were heavier ($P < 0.05$) on d 35 than control-fed pigs. In experiment 2, 4,320 pigs were used in a 42-d trial with 8 or 16 feeders per treatment. Pigs were fed a control diet or diets with either SMB-based Product 1 or Product 2 (Nutriquest, Mason City, IA) at different concentrations and durations. Among the various treatments, Product 1 or Product 2 concentrations ranged from 0.50% initially to 0.25%, 0.15%, or none the last week of the study. Overall, pigs fed either of the additives at the highest concentrations and for the longest period of time had greater ($P < 0.05$) ADG and ADFI compared to pigs fed the control diet, with those fed lower concentrations or shorter durations intermediate. In experiment 3, 2,808 pigs were used in a 28-d trial with 13 feeders per treatment. All pigs were fed a common diet for 7 d after weaning. Pigs were then either fed a control diet or diets containing Product 1 (0.50 and 0.25% from d 0 to 21 and 21 to 28 respectively), SMB (0.50 and 0.25% from day 0 to 21 and 21 to 28 respectively) or 0.25% SMB from day 0 to 28. Overall, pigs fed Product 1 or high SMB diets had greater ($P < 0.05$) ADG compared to pigs fed low SMB or control diets. Collectively, these studies suggest that in diets with low DON concentrations, these SMB-based products increased ADG compared to pigs fed control diets.

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We wish to express appreciation to Kayla Nelson and Hord Family Farms (Bucyrus, OH) for assistance with this trial.

Introduction

Deoxynivalenol (DON), or vomitoxin, is a mycotoxin found in cereal grains and is produced by the *Fusarium* genus. The DON concentration of cereal grains can vary from year to year, based on the degree of stress the plant is exposed to during the growing season, such as poor soil fertility, harsh weather conditions, and insect damage. Swine are sensitive to DON with exposure to concentrations greater than 1 ppm resulting in decreased feed intake and growth, while exposure to higher concentrations can result in complete feed refusal and vomiting. Although not approved by U.S. Food and Drug Administration as DON detoxifying agents, sodium metabisufite (SMB)-based feed additives have been used in diets with high DON concentrations with positive results. There is a positive relationship between growth performance and the addition of SMB-containing feed additives in swine diets with greater than 3 ppm of DON.[2,3,4] However, there is limited research available to document the effects of SMB-based feed additives on growth performance of nursery pigs fed diets with relatively little to no DON. Therefore, the objective of these experiments was to determine the effects of SMB-based feed additives in low-DON containing diets on the growth performance of nursery pigs weighing approximately 13 to 33 lb.

Procedures

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these studies. The experiments were conducted at a commercial research facility located in north central Ohio. Each pen (8.5 × 9 ft) contained approximately 27 barrows or gilts and a double-sided 5-hole stainless steel fence line feeder. Therefore, the experimental unit was the feeder. Each pen also contained a cup-waterer, and feed and water were provided *ad libitum*. Feed additions to each individual pen were made and recorded by an electronic feeding system (Dry Exact; Big Dutchman, Inc. Holland, MI). Experimental diets were manufactured at the Hord Elevator (Bucyrus, OH). Feed samples were collected from 6 feeders per treatment per phase, pooled, and subsampled for chemical analysis. Pens of pigs were weighed and feed disappearance was recorded every 7 days to determine ADG, ADFI, and F/G.

Experiment 1

A total of 2,268 pigs (PIC 337 × 1050; initial body weight (BW) 15 lb) were used in a 35-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into 1 of 84 pens (42 pens of barrows, 42 pens of gilts) with 1 pen of gilts and 1 pen of barrows per fence line feeder. A pair of pens (1 adjoining feeder) were blocked

[2]Mahan, D. 2010. Evaluation of three commercial mycotoxin inhibitors added to vomitoxin (DON) contaminated corn diets for weanling pigs: A report from the NCCC-042, S-1044, and NCERA-89 regional committees on swine nutrition and management. www.ddgs.umn.edu/prod/groups/cfans/@pub/@cfans/@ansci/documents/asset/cfans _asset_413775.pdf (Accessed 10 January 2018).

[3]Patience, J. F., A. J. Myers, S. Ensley, B. M. Jacobs, and D. Madson. 2014. Evaluation of two mycotoxin mitigation strategies in grow-finish swine diets containing corn dried distillers grains with solubles naturally contaminated with deoxynivalenol. J. Anim. Sci. 92:620-626. doi:10.2527/jas.2013-6238.

[4]Frobose, H. L., E. D. Fruge, M. D. Tokach, E. L. Hansen, J. M. DeRouchey, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2015. The effects of deoxynivalenol-contaminated corn dried distillers grains with solubles in nursery pig diets and potential for mitigation by commercially available feed additives. J. Anim. Sci. 93:1074-1088. doi:10.2527/jas.2013-6883

by body weight and weaning date and then randomly assigned to 1 of 2 dietary treatments in a randomized complete block design with 21 feeders per treatment. Dietary treatments included a control diet or the control with 0.50% Product 1 in phase 1 and 0.25% in phases 2 and 3 (Table 1). From day 28 to 35, all pigs were fed a common diet without Product 1. Product 1 (Defusion; Provimi, Brooksville, OH) is a commercially available preservative that is a blend of SMB (92%), organic acids, fermentation products, and supplemental vitamins and amino acids. For phase 1, pigs were offered 1.50 lb of feed, which lasted from day 0 to approximately day 5. Then phase 2 diets were provided until day 21, phase 3 diets were fed from day 21 to 28, with all pigs receiving a control diet without preservative from day 28 to 35.

Experiment 2
A total of 4,320 pigs (PIC 337 × 1050; initial weight 14 lb) were used in a 42-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into 1 of 160 pens (80 pens of barrows, 80 pens of gilts) with 1 pen of gilts and 1 pen of barrows per fence line feeder. A pair of pens (1 adjoining feeder) were blocked by body weight and weaning date and then randomly assigned to 1 of 5 dietary treatments that were fed for 35 d in a randomized complete block design. Dietary treatments included: 1) a control diet; 2) the control diets with 0.50% Product 1 fed for 7 days followed by 0.25% Product 1 from day 7 to 35; 3) control diet containing 0.50% Product 2 from day 0 to 7, 0.25% from day 7 to 28, and 0.15% from day 28 to 35; 4) control diet containing 0.50% Product 2 from day 0 to 7 and 0.25% from day 7 to 35; and 5) control diet containing 0.50% Product 2 from day 0 to 28 and 0.25% from day 28 to 35 (Table 2). Then on day 35, half of the pens receiving either Product 1 or Product 2 remained on those treatments and the other half were switched to the control diet. These combinations resulted in a total of 9 treatments. There were 16 replications (feeders) for all treatments from day 0 to 35 and 8 replications per treatment from day 35 to 42 for all treatments except for the control, which continued to have 16 replications per treatment. Product 2 (NutriQuest, Mason City, IA) is a custom-made preservative and anticaking agent that contains SMB (92%), bentonite, and mineral oil.

Experiment 3
A total of 2,808 pigs (PIC 337 × 1050; initial weight 15 lb) were used in a 28-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into 1 of 104 pens (52 pens of barrows, 52 pens of gilts) with 1 pen of gilts and 1 pen of barrows per fence line feeder. All pigs were fed a common phase 1 diet for 7 days, then 7 days after weaning, considered d 0 of the trial, a pair of pens (1 adjoining feeder) were blocked by weight and randomly assigned to one of four dietary treatments with 13 feeders per treatment. Dietary treatments were fed for 28 d. The four treatments were: 1) a control diet; 2) control diet with 0.50% Product 1 from day 0 to 21 followed by 0.25% Product 1 from day 21 to 28; 3) control diet with 0.25% SMB from day 0 to 28; and 4) control diet with 0.5% SMB from day 0 to 21 followed by 0.25% SMB from day 21 to 28 (Table 3).

Chemical analysis
Feed samples for all three experiments were submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for DON analysis. Dietary DON concentrations for experiment 1 were determined by the RIDASCREEN FAST DON SC ELISA test kit

(R-Biopharm AG, Darmstadt, Germany). Dietary DON concentration for experiments 2 and 3 were determined by ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA). North Dakota Grain Inspection Service, Inc., follows the Federal Grain Inspection Service guidelines that considers the standard certification limits for these assays to be 0.5 to 5 ppm.[5] Thus, the minimum detection limit for both assays was 0.5 ppm.

Statistical analysis

Feeder was considered the experimental unit (1 pen of barrows and 1 pen of gilts) for all experiments. Means are reported as least square means with pooled standard error of the means. For experiments 2 and 3, individual treatment means were separated using the Tukey-Kramer multiple comparison test. Data for all experiments were analyzed as a randomized complete block design using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Chemical Analysis

Chemical analysis of experiments 1 and 3 diets indicated that dietary DON concentrations of all diets, regardless of phase, were less than 0.5 ppm or below the detectable limit (Table 4 and 6). For experiment 2 (Table 5), the control diet had DON concentrations ranging from 1.1 to 1.5 ppm. Both the Product 1-based diets had DON concentrations equal to or less than 1.3 ppm. Diets containing Product 2 had DON concentrations equal to or less than 1.1 ppm.

Experiment 1

From d 0 to 28, pigs fed diets containing Product 1 had greater ($P < 0.05$) ADG, ADFI, d 28 body weight, and improved ($P < 0.05$) F/G compared to those fed the control diet (Table 7). However, from d 28 to 35, when all pigs were fed a control diet, the opposite effect was observed. Pigs previously fed the diets containing Product 1 had decreased ($P < 0.05$) ADG and ADFI and increased F/G compared to pigs fed the control diet. Regardless, overall (day 0 to 35) ADG, ADFI, and d 35 body weight were greater ($P < 0.05$) and F/G lower for those pigs fed diets containing Product 1.

Experiment 2

From d 0 to 35, pigs fed the control diet had decreased ($P < 0.05$) ADG, ADFI, and d 35 body weight compared to pigs fed the Product 1 or Product 2 combinations (Table 8). The response to SMB products (Product 1 or Product 2) was in a dose-dependent manner, with pigs fed the highest level of Product 2 having greater ($P < 0.05$) performance than the other Product 2 diets. There was no evidence for difference between pigs fed similar levels of Product 1 and Product 2. Feed efficiency was improved ($P < 0.05$) for pigs fed the highest levels of Product 2 compared with pigs fed diets with the lowest levels of Product 2, with pigs fed other diets intermediate.

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[5]USDA, Grain Inspection, Packers and Stockyards Administration, Federal Grain Inspection Service, Washington D.C. 2015. Mycotoxin Handbook. https://www.gipsa.usda.gov/fgis/handbook/MycotoxinHB/MycotoxinHandbook_2016-07-12.pdf (Accessed 18 January 2018.).

On d 35, pigs either remained on their respective Product 1 or 2 diets or were switched to a diet without feed preservative. During this period, those pigs switched to a diet without feed preservative had decreased ($P < 0.05$) ADG and ADFI compared with the pigs remaining on their respective feed preservative, with those fed the control diet intermediate.

Overall, pigs fed the Product 1 at the highest level had greater ($P < 0.05$) ADG and ADFI compared to pigs fed the control diet, with pigs fed the other diets intermediate. There was no evidence to indicate dietary treatment influenced F/G. Pigs fed the control diet had lower ($P < 0.05$) d 42 body weight compared to the other dietary treatments. Pigs fed Product 1 at the highest level had greater ($P < 0.05$) d 42 body weight compared to pigs fed the two lowest levels of Product 1, with pigs fed the other preservative-containing diets intermediate.

Experiment 3

From d 0 to 21, pigs fed 0.25% SMB had decreased ($P < 0.05$) ADG compared to pigs fed the other diets (Table 9). Pigs fed Product 1 or 0.50% SMB had greater ($P < 0.05$) ADG compared to pigs fed the other diets. Pigs fed Product 1 or 0.50% SMB had greater ($P < 0.05$) ADFI compared to pigs fed the control, with pigs fed 0.25% SMB intermediate. Pigs fed 0.25% SMB had poorer ($P < 0.05$) F/G than pigs fed the other dietary treatments. Pigs fed 0.50% SMB had improved ($P < 0.05$) F/G compared with pigs fed the control, with pigs fed Product 1 intermediate.

From d 21 to 28, pigs fed 0.25% SMB for the entire experiment had greater ($P < 0.05$) ADG compared to pigs fed the other diets. Pigs fed Product 1 had greater ($P < 0.05$) ADG compared to pigs fed the control diet, with pigs fed 0.50% SMB intermediate followed by 0.25% SMB. Pigs fed Product 1 had increased ($P < 0.05$) ADFI compared to pigs fed the control, with others intermediate. Pigs fed 0.25% SMB for the entire trial had improved ($P < 0.05$) F/G compared with pigs fed other diets.

From d 0 to 28, pigs fed Product 1 or 0.50% SMB had greater ($P < 0.05$) ADG compared to pigs fed 0.25% SMB or the control diet. Pigs fed Product 1 or 0.50% SMB had increased ($P < 0.05$) ADFI compared to pigs fed the control, with pigs fed the 0.25% SMB intermediate. Pigs fed 0.50% SMB had improved ($P < 0.05$) F/G compared with pigs fed the control diet, with those fed Product 1 intermediate. Pigs fed 0.25% SMB had poorer ($P < 0.05$) F/G compared to pigs fed the other treatments. Pigs fed 0.50% SMB or Product 1 had greater ($P < 0.05$) d 28 BW than pigs fed the other dietary treatments.

In conclusion, in diets relatively low in DON, pigs fed SMB-based preservatives had improved ADG compared to pigs fed a control diet. At the dietary concentrations of the product tested, the greater inclusion and longer feeding duration resulted in the greatest benefit. The mode of action for the improvement in performance is unclear. In high DON diets, the biological mechanism of SMB is suggested to be the chemical alteration of DON to a nontoxic DON-sulfonate adduct form.[6,7] However, in low DON diets the biological mechanism of SMB is unclear. Sodium metabisulfite is commonly used in the food industry as an antioxidant and antimicrobial agent. Previous research has indicated improvements in energy and protein utilization in broilers fed sorghum-based diets that were steam pelleted with SMB.[8,9,10] The biological mechanism of this improvement in protein and energy utilization is suggested to be the oxidative-reductive depolymerization of starch polysaccharides and the reduction of disulfide cross linkages in proteins, thus improving protein and starch availability. A portion of the response to SMB appears to be lost after pigs are switched from diets containing SMB additives to diets without. The reason that part of the growth response is lost when pigs are switched to a diet without SMB is also not clear and needs further investigation. Further research should be conducted to determine the biological mechanism of SMB in low DON diets.

[6]Frobose, H. L., E. D. Fruge, M. D. Tokach, E. L. Hansen, J. M. DeRouchey, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2015. The effects of deoxynivalenol-contaminated corn dried distillers grains with solubles in nursery pig diets and potential for mitigation by commercially available feed additives. J. Anim. Sci. 93:1074-1088. doi:10.2527/jas.2013-6883

[7]Frobose, H. L., E. W. Stephenson, M.D. Tokach, J. M. DeRouchey, J. C. Woodworth, S. S. Dritz, R. D. Goodband. 2017. Effects of potential detoxifying agents on growth performance and deoxynivalenol (DON) urinary balance characteristics of nursery pigs fed DON-contaminated wheat. J. Anim. Sci. 93:1074–1088 doi:10.2527/jas2013-6883

[8]Selle, P. H., S. Y. Liu, J. Cai, R. A. Caldwell, and A. J. Cowieson. 2013. Preliminary assessment of including a reducing agent (sodium metabisulphite) in 'all-sorghum' diets for broiler chickens. Anim. Feed Sci. Technol. 186:81-90. doi:10.1016/j.anifeedsci.2013.09.004.

[9]Selle, P. H., S. Y. Liu, J. Cai, R. A. Caldwell, and A. J. Cowieson. 2014. Graded inclusions of sodium metabisulphite in sorghum-based diets: I. Reduction of disulphide cross-linkages in vitro and enhancement of energy utilisation and feed conversion efficiency in broiler chickens. Anim. Feed Sci. Technol. 190:59-67. doi:10.1016/j.anifeedsci.2013.12.015.

[10]Truong, H. H., D. J. Cadogan, S. Y. Liu, and P. H. Selle. 2015. Addition of sodium metabisulfite and microbial phytase, individually and in combination, to a sorghum-based diet for broiler chickens from 7 to 28 days post-hatch. Animal Prod. Sci. 56:1484-1491. doi: 10.1071/AN14841

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	35.8	50.77	48.27
Soybean meal	20.87	31.57	33.06
Wheat	3.00	---	---
Bakery meal	---	---	12.50
Milk, whey powder	25.00	---	---
Dairylac 80[2]	---	9.00	---
HP 300[3]	7.50	2.50	---
Corn oil	4.00	1.50	2.50
Limestone	0.85	0.85	1.00
Monocalcium phosphate, 21%	0.73	1.50	0.85
Sodium chloride	0.50	0.60	0.50
L-Lysine HCl	0.45	0.48	0.45
DL-Methionine	0.30	0.31	0.25
L-Threonine	0.21	0.27	0.22
L-Tryptophan	0.06	0.04	0.01
L-Valine	0.12	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.15	0.18
Zinc oxide	0.38	0.25	---
Copper sulfate	---	0.03	0.03
Choline chloride, 60%	0.04	---	---
Quantum 5000 L[5]	0.05	0.05	---
Quantum Blue 2G[6]	---	---	0.10
Product 1[7]	---	---	---
TOTAL	100	100	100

continued

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Calculated analysis			
Standardized ileal digestible (SID) AA, %			
Lysine	1.40	1.42	1.38
Isoleucine:lysine	58	58	60
Leucine:lysine	107	109	113
Methionine:lysine	40	41	38
Methionine and cystine:lysine	58	59	57
Threonine:lysine	63	63	62
Tryptophan:lysine	21.2	20.4	18.5
Valine:lysine	67	70	68
Total lysine, %	1.56	1.57	1.53
Net energy, kcal/lb	1,098	1,122	1,128
Crude protein, %	21.0	21.4	21.3
Calcium, %	0.74	0.77	0.67
Phosphorus, %	0.66	0.76	0.59
Available phosphorus, %	0.55	0.59	0.40

[1]Experimental diet were fed in three phases with dietary phases formulated for BW ranges of 11 to 15, 15 to 24, and 24 to 44 lb.
[2]International Ingredients, Inc. (St. Louis, MO).
[3]Hamlet Protein (Findlay, OH).
[4]Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D_3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.
[5]Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[6]Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[7]Product 1 (Defusion; Provimi, Brooksville, OH).

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	35.80	50.77	48.27
Soybean meal	20.87	31.57	33.06
Wheat	3.00	---	---
Bakery meal	---	---	12.50
Milk, whey powder	25.00	---	---
Dairylac 80[2]	---	9.00	---
HP 300[3]	7.50	2.50	---
Corn oil	4.00	1.50	2.50
Limestone	0.85	0.85	1.00
Monocalcium phosphate, 21%	0.73	1.50	0.85
Sodium chloride	0.50	0.60	0.50
L-Lysine HCl	0.45	0.48	0.45
DL-Methionine	0.30	0.31	0.25
L-Threonine	0.21	0.27	0.22
L-Tryptophan	0.06	0.04	0.01
L-Valine	0.12	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.15	0.18
Zinc oxide	0.38	0.25	---
Copper sulfate	---	0.03	0.03
Choline chloride, 60%	0.04	---	---
Quantum 5000 L[5]	0.05	0.05	---
Quantum Blue 2G[6]	---	---	0.10
Product 1[7]	-/+	-/+	-/+
Product 2[8]	-/+	-/+	-/+
TOTAL	100	100	100

continued

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Calculated analysis			
Standardized ileal digestible (SID) AA, %			
Lysine	1.40	1.42	1.38
Isoleucine:lysine	58	58	60
Leucine:lysine	107	109	113
Methionine:lysine	40	41	38
Methionine and cystine:lysine	58	59	57
Threonine:lysine	63	63	62
Tryptophan:lysine	21.2	20.4	18.5
Valine:lysine	67	70	68
Total lysine, %	1.56	1.57	1.53
Net energy, kcal/lb	1,098	1,122	1,128
Crude protein, %	21.0	21.4	21.3
Calcium, %	0.74	0.77	0.67
Phosphorus, %	0.66	0.76	0.59
Available phosphorus, %	0.55	0.59	0.40

[1]Experimental diet were fed in three phases with dietary phases formulated for 11 to 15, 15 to 24, and 24 to 44 lb BW ranges.
[2]International Ingredients, Inc. (St. Louis, MO).
[3]Hamlet Protein, (Findlay, OH).
[4]Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D_3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.
[5]Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[6]Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[7]Product 1 (Defusion; Provimi, Brooksville, OH) was included at the expense of corn.
[8]Product 2 (NutriQuest, Mason City, IA) was included at the expense of corn.

Table 3. Diet composition, Experiment 3 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2
Corn	50.77	57.43
Soybean meal	31.57	33.10
Dairylac 80[2]	9.00	---
HP 300[3]	2.50	---
Corn oil	1.50	1.50
Limestone	0.85	1.05
Monocalcium phosphate, 21%	1.50	0.85
Sodium chloride	0.60	0.50
L-Lysine HCl	0.48	0.43
DL-Methionine	0.31	0.26
L-Threonine	0.27	0.22
L-Tryptophan	0.04	0.01
L-Valine	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.18
Zinc oxide	0.25	0.25
Copper sulfate	0.03	0.03
Quantum 5000 L[5]	0.05	---
Quantum Blue 2G[6]	---	0.10
Product 1[7]	-/+	-/+
Sodium metabisulfite[8]	-/+	-/+
TOTAL	100	96

continued

Table 3. Diet composition, Experiment 3 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2
Calculated analysis		
Standardized ileal digestible (SID) AA, %		
Lysine	1.42	1.37
Isoleucine:lysine	58	60
Leucine:lysine	109	115
Methionine:lysine	41	39
Methionine and cystine:lysine	59	58
Threonine:lysine	63	62
Tryptophan:lysine	20.4	18.6
Valine:lysine	70	68
Total lysine, %	1.57	1.53
Net energy, kcal/lb	1,082	1,099
Crude protein, %	21.4	21.2
Calcium, %	0.77	0.68
Phosphorus, %	0.76	0.62
Available phosphorus, %	0.59	0.41

[1]Experimental diet were fed in three phases with dietary phases formulated for 15 to 24, and 24 to 44 lb BW ranges.
[2]International Ingredients, Inc., St. Louis, MO.
[3]Hamlet Protein, Findlay, OH.
[4]Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D_3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.
[5]Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[6]Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.
[7]Product 1 (Defusion; Provimi, Brooksville, OH) was included at the expense of corn.
[8]Sodium metabisulfite was included at the expense of corn.

Table 4. Deoxynivalenol analysis of experimental diets, Experiment 1 (as-fed basis)[1]

Item	Control	Product 1[2]
DON, ppm		
Phase 1 diets	< 0.5	< 0.5
Phase 2 diets	< 0.5	< 0.5
Phase 3 diets	< 0.5	< 0.5

[1]Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of deoxynivalenol (DON) as determined by the RIDASCREEN FAST DON SC ELISA test kit (R-Biopharm AG, Darmstadt, Germany).
[2]Product 1 (Defusion; Provimi, Brooksville, OH).

Table 5. Deoxynivalenol analysis of experimental diets (as-fed basis), Experiment 2[1]

		Product added, %			
	Control	Product 1[2]	Product 2[3]		
Day 0 to 7[4]	---	0.50	0.50	0.50	0.50
Day 7 to 21	---	0.25	0.25	0.25	0.50
Day 21 to 28	---	0.25	0.25	0.25	0.50
Day 28 to 35	---	0.25	0.15	0.25	0.25
Day 35 to 42	---	--- 0.25	--- 0.15	--- 0.25	--- 0.25
DON, ppm					
Day 0 to 7	---[4]	< 0.5	< 0.5	< 0.5	< 0.5
Day 7 to 21	1.4	< 0.5	0.5	< 0.5	< 0.5
Day 21 to 28	1.1	0.9	1.0	0.9	1.1
Day 28 to 35	1.5	0.9	1.0	0.9	1.0
Day 35 to 42	1.3	1.3 1.3	1.3 1.0	1.3 0.8	1.3 0.9

[1]Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of deoxynivalenol (DON) as determined by the ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA).
[2]Product 1 (Defusion; Provimi, Brooksville, OH).
[3]Product 2 (NutriQuest, Mason City, IA).
[4]Missing sample.

Table 6. Deoxynivalenol analysis of experimental diets, Experiment 3 (as-fed basis)[1]

		Product added, %		
	Control	Product 1[2]	Sodium metabisulfite	
Day 0 to 14	---	0.50	0.25	0.50
Day 14 to 21	---	0.50	0.25	0.50
Day 21 to 28	---	0.25	0.25	0.25
DON, ppm				
Day 0 to 14	< 0.5	<0.5	< 0.5	< 0.5
Day 14 to 21	< 0.5	< 0.5	< 0.5	< 0.5
Day 21 to 28	< 0.5	<0.5	< 0.5	< 0.5

[1]Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of deoxynivalenol (DON) as determined by ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA).
[2]Product 1 (Defusion; Provimi, Brooksville, OH).

Table 7. Effects of Product 1 on growth of nursery pigs, Experiment 1[1]

Item	Control	Product 1[2]	SEM	Probability, *P* <
Day 0 to 28				
ADG, lb	.67	.81	0.010	0.001
ADFI, lb	.89	.98	0.011	0.001
F/G[3]	1.33	1.21	0.167	0.001
Day 28 to 35 (post test)				
ADG, lb	1.42	1.21	0.029	0.001
ADFI, lb	1.88	1.80	0.025	0.002
F/G	1.32	1.49	0.085	0.001
Day 0 to 35				
ADG, lb	0.82	0.88	0.011	0.001
ADFI, lb	1.09	1.14	0.012	0.001
F/G	1.33	1.29	0.189	0.001
BW, lb				
Day 0	15.0	15.0	0.09	0.921
Day 28	34.0	37.7	0.35	0.001
Day 35	44.1	46.1	0.44	0.001

[1]A total of 2,268 pigs (Line 337 × 1050; PIC) were used in a 35-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 84 pens (42 pens of barrows, 42 pens of gilts), with 1 pen of gilts and 1 pen of barrows per fence line feeder. Pigs were blocked by BW and then randomly assigned to 1 of 2 dietary treatments in a completely randomized block design with 21 feeders per treatment. Experimental diets were fed from d 0 to 28 and a common diet was then fed from d 28 to 35.
[2]Product 1 (Defusion; Provimi, Brooksville, OH).
[3]Analyzed as Gain to Feed (G:F). Mean and SEM reported are 1/G:F values.

Table 8. Effects of added Product 1 or 2 on growth of nursery pigs, Experiment 2[1]

		Product added, %								
	Control	Product 1[2]		Product 2[3]						
Day 0 to 7	---	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Day 7 to 21	---	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.50	
Day 21 to 28	---	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.50	
Day 28 to 35	---	0.25	0.25	0.15	0.15	0.25	0.25	0.25	0.25	
Day 35 to 42	---	---	0.25	---	0.15	---	0.25	---	0.25	SEM
Day 0 to 35										
ADG, lb	.75[d]	.84[ab]		.81[c]		.82[bc]		.87[a]		0.018
ADFI, lb	.98[c]	1.08[ab]		1.05[b]		1.07[b]		1.11[a]		0.024
F/G[4]	1.30[ab]	1.28[ab]		1.31[b]		1.30[ab]		1.27[a]		0.175
Day 35 to 42										
ADG, lb	1.61[abcd]	1.46[d]	1.72[ab]	1.48[cd]	1.70[abc]	1.51[bcd]	1.71[ab]	1.43[d]	1.75[a]	0.054
ADFI, lb	2.26[bcd]	2.15[d]	2.40[ab]	2.14[d]	2.34[abc]	2.17[cd]	2.05[ab]	2.17[d]	2.49[a]	0.050
F/G	1.41	1.47	1.40	1.44	1.38	1.44	1.19	1.51	1.42	0.049
Day 0 to 42										
ADG, lb	.89[d]	.95[bc]	.99[ab]	.92[cd]	.95[bc]	.93[bcd]	.96[abc]	.96[abc]	1.01[a]	0.020
ADFI, lb	1.19[d]	1.25[bcd]	1.31[ab]	1.23[cd]	1.25[bc]	1.25[bcd]	1.28[abc]	1.28[abc]	1.34[a]	0.027
F/G	1.34	1.32	1.32	1.34	1.32	1.34	1.33	1.33	1.32	0.125
BW, lb										
Day 0	13.7	13.7		13.7		13.7		13.7		0.20
Day 35	40.3[d]	43.4[ab]		42.1[c]		42.6[bc]		44.3[a]		0.73
Day 42	51.8[f]	53.6[de]	55.6[ab]	53.1[e]	53.8[de]	53.1[e]	54.9[bc]	54.5[cd]	56.4[a]	0.75

[abcde]Means within a row with different superscripts differ $P < 0.05$.

[1]A total of 4,320 pigs (Line 337 × 1050; PIC) were used in a 35-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 160 pens (80 pens of barrows, 80 pens of gilts), with 1 pen of gilts and 1 pen of barrows per fence line feeder. A pair of pens (feeders) were blocked by weight and then randomly assigned to 1 of 5 dietary treatments that were fed for 35 d in a completely randomized block design. Then on d 35, half of the pens receiving either Product 1 or 2 remained on those treatments and the other half were switched to the control diet. These combinations resulted in a total of 9 treatments. There were 16 replications (feeders) for all treatments from day 0 to 35 and 8 replications per treatment from day 35 to 42 for all treatments except for the control, which continued to have 16 replications per treatment.

[2]Product 1 (Defusion; Provimi, Brooksville, OH).

[3]Product 2 (NutriQuest, Mason City, IA).

[4]Analyzed as Gain to Feed (G:F). Mean and SEM reported are 1/G:F values.

Table 9. Effects of added sodium metabisulfite or Product 1 on growth of nursery pigs, Experiment 3[1]

		Product added, %			
	Control	Product 1[2]	Sodium metabisulfite		
Day 0 to 21	---	0.50	0.25	0.50	
Day 21 to 28	---	0.25	0.25	0.25	SEM
Day 0 to 21					
ADG, lb	1.01[b]	1.06[a]	.95[c]	1.07[a]	0.012
ADFI, lb	1.30[b]	1.34[a]	1.31[ab]	1.34[a]	0.015
F/G[3]	1.29[b]	1.26[ab]	1.37[c]	1.26[a]	0.185
Day 21 to 28					
ADG, lb	1.50[c]	1.54[b]	1.61[a]	1.54[bc]	0.013
ADFI, lb	2.14[b]	2.21[a]	2.20[ab]	2.19[ab]	0.018
F/G	1.43[b]	1.43[b]	1.37[a]	1.43[b]	0.204
Day 0 to 28					
ADG, lb	1.13[b]	1.18[a]	1.11[b]	1.18[a]	0.010
ADFI, lb	1.51[b]	1.56[a]	1.53[ab]	1.52[a]	0.014
F/G	1.34[b]	1.32[ab]	1.37[c]	1.31[a]	0.303
BW, lb					
Day 0	15.4	15.4	15.4	15.4	0.15
Day 21	37.0[b]	38.1[a]	35.7[c]	38.1[a]	0.31
Day 28	47.6[b]	48.9[a]	47.0[b]	48.9[a]	0.35

[abc]Means within a row with different superscripts differ $P < 0.05$.
[1]A total of 2,808 pigs (Line 337 × 1050; PIC) were used in a 28-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 104 pens (52 pens of barrows, 52 pens of gilts), with 1 pen of gilts and 1 pen of barrows per fence line feeder. Pigs were blocked by BW and then randomly assigned to 1 of 4 dietary treatments in a completely randomized block design with 13 feeders per treatment. Experimental diets were fed from d 0 to 28.
[2]Product 1 (Defusion; Provimi Brooksville, OH).
[3]Analyzed as Gain to Feed (GF). Mean and SEM reported are 1/G:F values.