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Effects of a Mycelium-derived β-glucan Feed Additive on Nursery Pig Growth Performance, Fecal Dry Matter, and Immune Response

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Summary

A study was conducted to evaluate the effects of increasing dietary inclusion of a mycelium-derived β-glucan feed additive on growth performance, fecal dry matter, and cytokine responses in nursery pigs. A total of 360 weanling pigs (initial BW = 12.4 ± 0.06 lb) were used in a 45-d study. At weaning, pigs were blocked by three BW categories (light, medium, and heavy) and within BW category pigs were randomly assigned to one of six dietary treatments in a generalized randomized block design. Each treatment consisted of 12 replicate pens with five pigs per pen. The dietary program was typical of commercially formulated diets and consisted of three feeding phases: phase 1 (d 0 to 10), phase 2 (d 10 to 24), and phase 3 (d 24 to 45). The six treatments were: Control (Ctrl): basal diet across all phases; Ctrl + Carbadox: basal diet supplemented with 55 ppm carbadox in all phases; Low β-glucan: basal diet supplemented with β-glucan at 750, 500, and 250 ppm in phases 1, 2, and 3, respectively; Medium-Low β-glucan: basal diet supplemented with β-glucan at 1,000, 750, and 500 ppm in phases 1, 2, and 3, respectively; Medium-High β-glucan: basal diet supplemented with β-glucan at 1,250, 1,000, and 750 ppm in phases 1, 2, and 3, respectively; and High β-glucan: basal diet supplemented with β-glucan at 1,500, 1,250, and 1,000 ppm in phases 1, 2, and 3, respectively. There was no evidence of treatment differences in BW on d 0 and 10; however, by d 24, pigs fed Carbadox had greater BW than Ctrl pigs ($P = 0.002$), and this response was maintained through d 45, at which time Carbadox-fed pigs had greater BW than Ctrl, Medium-Low, and Medium-High β-glucan pigs ($P < 0.05$) with the Low and High β-glucan pigs intermediate. From d 0 to 10, ADG, ADFI, and F/G were not affected by treatment. From d 10 to 24, ADG and ADFI were greater in Carbadox-fed pigs compared with Ctrl pigs ($P \leq 0.014$), with a tendency for improved F/G ($P = 0.078$) also observed; however, β-glucan level did not impact performance. From d 24 to 45, ADG and ADFI were improved ($P \leq 0.001$) when Carbadox was included in the diet. Although there were no linear or quadratic responses to β-glucan inclusion level, pigs fed the Low and High β-glucan treatments had intermediate ADG

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and ADFI compared with the Carbadox-fed pigs and the other treatments. Overall (d 0 to 45), Carbadox increased ($P \leq 0.002$) ADG, ADFI, and final BW compared with pigs fed the control diet. There were no linear or quadratic growth performance responses to increasing β-glucan in the diet. The Low β-glucan treatment had an intermediate ADG response compared with the Carbadox-fed pigs and the other treatments. For ADFI, all β-glucan treatments were intermediate compared with the Ctrl and Carbadox treatments and for F/G the Low and High β-glucan treatments were intermediate compared with the Carbadox treatment and all other treatments. Treatment affected fecal DM on d 24 and 45 ($P < 0.001$), with Carbadox-fed pigs having greater fecal DM than the Medium-Low β-glucan pigs on d 24 ($P < 0.05$) and greater than all other treatments on d 45 ($P < 0.05$). No linear or quadratic effects of β-glucan inclusion were observed for fecal DM. Carbadox-fed pigs also had lower CRP on d 24 compared with Ctrl and Medium-High β-glucan pigs ($P < 0.05$) and lower haptoglobin compared with Ctrl and all β-glucan treatments ($P < 0.05$), although these effects were not maintained on d 45. Treatment affected cytokine responses, including increased GM-CSF ($P < 0.05$) in pigs fed Medium-High β-glucan compared with Medium-Low and Low β-glucan on d 45. Interferon-γ (IFN-γ) was also affected by treatment on d 45 ($P = 0.035$), although no mean separation was detected. A linear effect of β-glucan inclusion was observed for IFN-γ ($P = 0.019$) and a quadratic effect for IL-12 ($P = 0.044$). No treatment effects were observed for other cytokines. In conclusion, carbadox improved growth performance, fecal DM, and reduced inflammatory markers, whereas mycelium-derived β-glucan supplementation influenced selected immune parameters with the low level of β-glucan resulting in overall ADG and ADFI similar to that of both the control and carbadox treatments in this high-health environment. Additional research in a commercial barn may be warranted, especially with the low β-glucan treatment to determine if the ADG and ADFI benefits can be repeated.

Introduction

In-feed antibiotics have traditionally been used to improve growth performance and health in nursery pigs, but increasing concerns about antimicrobial resistance have limited their use. This is particularly important during the weaning period, when physiological and environmental stressors impair intestinal health, immune function, and growth performance, highlighting the need for effective nutritional alternatives to support pig health in antibiotic-free systems.

One potential alternative to antibiotics is the inclusion of β-glucans in nursery pig diets. β-glucans are non-starch polysaccharides, naturally present in the cell walls of bacteria, fungi, yeast, and cereals. These compounds have garnered considerable attention in animal nutrition due to their immunomodulatory properties, being capable of interacting with immune cells such as macrophages, neutrophils, and dendritic cells, stimulating cytokine production and strengthening antimicrobial defense responses. In addition to their immunomodulatory effects, β-glucans have been shown to improve intestinal morphology and barrier function, reduce pathogen colonization, and enhance nutrient utilization, which may contribute to improved growth performance and

overall health in nursery pigs[3],[4],[5]. The biological activity of β-glucans is dependent on their source, purity, and structural characteristics, which influence their interaction with immune receptors and subsequent physiological responses3.

Mycelium-derived β-glucans represent a distinct source with unique structural properties and high purity, which may enhance immune recognition and bioavailability compared with more commonly studied yeast-derived β-glucans. These structural differences may influence their ability to modulate immune function and support intestinal health. Most of the β-glucans evaluated in nursery pigs come from yeast; however, limited information is available regarding the effects of mycelium-derived β-glucans in swine. Therefore, the objective of this study was to evaluate the effects of increasing levels of a mycelium-derived β-glucan feed additive on growth performance, fecal dry matter, and immune responses in nursery pigs during the post-weaning period.

Procedures

The protocol for 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. All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS.

Animals and diets

A total of 360 weanling pigs (Line 241 × 600, DNA, Columbus, NE), with an initial weight of 12.4 ± 0.06 lb, were used in a 45-d study. Pigs were weaned at approximately 21 d of age and divided into three body weight (BW) categories: light, medium, or heavy. Within the BW categories, pigs were randomly assigned to pens, and pens were allotted to one of six dietary treatments in a generalized randomized block design. Each treatment consisted of 12 replicate pens, with five pigs per pen. Each pen (5 × 5 ft) was equipped with a 6-hole dry feeder and a nipple drinker to provide *ad libitum* access to feed and water. The nursery facility was previously power-washed but not disinfected to generate a "dirty environment" condition.

The dietary program was based on diet formulations typical of commercial formulation and implemented in three feeding phases: phase 1 (Table 1), fed from d 0 to 10; phase 2 (Table 2), fed from d 10 to 24; and phase 3 (Table 3), fed from d 24 to 45. All diets were provided in mash form and were formulated to meet or exceed the nutrient requirements recommended by the NRC (2012). All pigs received a common basal diet, with treatments differing by the inclusion of carbadox or β-glucan supplementation. The six treatments were as follows: Control (Ctrl): basal diet across all phases; Ctrl + Carbadox: basal diet supplemented with 55 ppm carbadox in all phases; Low β-glucan: basal diet supplemented with β-glucan at 750, 500, and 250 ppm in phases 1, 2, and 3,

[3] Volman, J. J., J. D. Ramakers, and J. Plat. 2008. Dietary modulation of immune function by β-glucans. Physiol. Behav. 94(2):276–284. doi:10.1016/j.physbeh.2007.11.045.

[4] Sweeney, T., C. B. Collins, P. Reilly, K. M. Pierce, M. Ryan, and J. V. O'Doherty. 2012. Effect of purified β-glucans derived from Laminaria digitata, Laminaria hyperborea and Saccharomyces cerevisiae on piglet performance, selected bacterial populations, volatile fatty acids and pro-inflammatory cytokines in the gastrointestinal tract of pigs. Br. J. Nutr. 108(7):1226–1234. doi:10.1017/S0007114511006751.

[5] Lee, J. J., H. Kyoung, J. H. Cho, J. Choe, Y. Kim, Y. Liu, J. Kang, H. Lee, H. B. Kim, and M. Song. 2021. Dietary yeast cell wall improves growth performance and prevents diarrhea of weaned pigs by enhancing gut health and anti-inflammatory immune responses. Animals. 11(8):2269. doi:10.3390/ani11082269.

respectively; Medium-Low β-glucan: basal diet supplemented with β-glucan at 1,000, 750, and 500 ppm in phases 1, 2, and 3, respectively; Medium-High β-glucan: basal diet supplemented with β-glucan at 1,250, 1,000, and 750 ppm in phases 1, 2, and 3, respectively; and High β-glucan: basal diet supplemented with β-glucan at 1,500, 1,250, and 1,000 ppm in phases 1, 2, and 3, respectively. The β-glucan product used in this trial was provided by Primient, Schaumburg, IL.

Pigs and feeders were weighed on d 0, 10, 24, and 45 to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G). To assess fecal dry matter (DM), fecal samples were collected via rectal stimulation from the same three pigs per pen on d 24 and 45 of the study. Samples were stored at 39.2°F (4°C) until fecal DM analysis was conducted. Samples were dried in a forced-air oven at 131°F (55°C) for 48 h to determine fecal DM. Additionally, on d 24 and 45, blood samples were collected from the average weight pig in each pen via jugular venipuncture into 10-mL vacutainer tubes. Plasma was obtained by centrifugation, and samples were stored at −4°F (−20°C) until analysis. An aliquot of plasma was sent to Eve Technologies (Calgary, AB, Canada) and analyzed to quantify 13 cytokines, including granulocyte-macrophage colony-stimulating factor (GM-CSF), interferon-gamma (IFN-γ), 10 interleukins (IL-1α, IL-1β, IL-1RA, IL-2, IL-4, IL-6, IL-8, IL-10, IL-12, IL-18), and tumor necrosis factor-alpha (TNF-α), as well as two acute-phase proteins, haptoglobin and C-reactive protein (CRP).

Statistical analysis

Data were analyzed as a generalized randomized block design. Growth performance and fecal DM statistical analyses were performed using RStudio (Version 4.0.2, R Core Team, Vienna, Austria) with the lmer function from the lme4 package. The pen served as the experimental unit. For growth performance, the statistical model included dietary treatment and BW block as fixed effects. For fecal DM, the model included treatment, day of collection, and their interaction as fixed effects, with block included as a fixed effect. Pen was included as a random effect to account for subsampling, and pig was included as a random effect to account for repeated measures over time.

Plasma cytokines and acute-phase proteins were analyzed using the GLIMMIX procedure of SAS OnDemand for Academics (SAS Institute Inc., Cary, NC). An individual pig served as the observational unit, with one pig per pen sampled. The model included treatment and block as fixed effects and pen as a random effect. Cytokines and acute-phase proteins data were log-transformed to meet model assumptions and back-transformed for presentation of least squares means.

Contrast coefficients were constructed to evaluate the linear and quadratic effects of increasing β-glucan inclusion levels, and to compare specific treatments, including Control versus Carbadox. Statistical significance was declared at $P \leq 0.05$, and tendencies were declared at $0.05 < P \leq 0.10$.

Results and Discussion

From d 0 to 10, ADG, ADFI, F/G, and d 10 BW were not affected by dietary treatment. Additionally, no linear or quadratic effects of β-glucan inclusion were observed for any growth performance parameter during this phase.

From d 10 to 24, pigs fed Carbadox had greater ADG than pigs fed the Ctrl diet ($P < 0.05$) with those fed β-glucan being intermediate. However, ADFI and F/G were

not affected by dietary treatment during this period. No linear or quadratic effects of β-glucan inclusion were observed for ADG, ADFI, or F/G. There was a tendency ($P = 0.061$) for treatment effects on BW at d 24, with pigs fed Carbadox exhibiting the greatest BW.

From d 24 to 45, treatment affected ADG ($P < 0.001$) and ADFI ($P = 0.006$). Pigs fed Carbadox had greater ($P < 0.05$) ADG and ADFI than pigs fed the Ctrl, Medium-Low, and Medium-High β-glucan diets, with the Low and High β-glucan being intermediate. Feed efficiency was not affected by treatment. No linear or quadratic effects of β-glucan inclusion were observed for ADG, ADFI, or F/G. Final BW (d 45) was greater ($P < 0.05$) for the Carbadox group compared with the Control, Medium-Low, and Medium-High β-glucan groups with the Low and High β-glucan being intermediate. Despite no statistical difference, the Low β-glucan treatment showed an interesting numerical increase in BW (2.6 lb) compared with the Ctrl group. No linear or quadratic effects of increasing β-glucan inclusion were observed for final BW.

Overall (d 0 to 45), treatment affected ADG ($P = 0.001$), with pigs fed Carbadox having greater ($P < 0.05$) ADG than pigs fed the Ctrl, Medium-Low, Medium-High, and High β-glucan diets with the Low β-glucan intermediate. Treatment also affected ADFI ($P = 0.038$), with pigs fed Carbadox having greater ($P < 0.05$) ADFI than Ctrl pigs and all β-glucan treatments being intermediate. Feed efficiency was affected by treatment ($P = 0.026$), with pigs fed Carbadox showing improved ($P < 0.05$) F/G compared with pigs fed the Medium-Low and Medium-High β-glucan diets with other treatments intermediate. No linear or quadratic effects of β-glucan inclusion were observed for ADG, ADFI, or F/G.

Fecal DM on d 24 and 45 was affected by treatment ($P < 0.001$). On d 24, pigs fed Carbadox had greater ($P < 0.05$) fecal DM than pigs fed the Medium-Low β-glucan treatment with all other treatments being intermediate. When conducting a pairwise comparison, the Carbadox treatment also had greater fecal DM than the Ctrl ($P = 0.013$). On d 45, pigs fed Carbadox had greater fecal DM than pigs fed all other treatments ($P < 0.05$), with no linear or quadratic effects of β-glucan inclusion observed.

Plasma CRP was affected by the treatment on d 24 ($P = 0.019$), with pigs fed Carbadox having lower ($P < 0.05$) CRP concentrations than pigs fed the Ctrl and Medium-High β-glucan diets, with other treatments intermediate. However, no treatment effect was observed on d 45. No linear or quadratic effects of β-glucan inclusion on CRP were observed on either day. Treatment affected haptoglobin concentration on d 24 ($P < 0.001$), with pigs fed Carbadox having lower ($P < 0.05$) haptoglobin concentrations than the Ctrl and all four β-glucan treatments. However, no treatment effect was observed on d 45, showing that this response was not maintained throughout the trial.

Plasma GM-CSF concentration was affected by the treatment on d 45 ($P = 0.029$), but not on d 24. On d 45, pigs fed Medium-High β-glucan had greater ($P < 0.05$) GM-CSF concentrations than pigs fed Medium-Low and Low β-glucan with other treatments being intermediate. Treatment affected IFN-γ concentration without mean separation on d 45 ($P = 0.035$), but not on d 24. Increasing β-glucan inclusion increased (linear, $P = 0.019$) d 45 IFN-γ concentration.

No treatment effect was observed for IL-8 on d 24. However, there was a tendency ($P = 0.094$) for effect on d 45, with pigs fed Medium-High β-glucan showing numerically

greater IL-8 concentrations than pigs fed Medium-Low β-glucan and Carbadox. The concentration of IL-12 on d 24 was greater ($P < 0.05$) for pigs fed Carbadox than pigs fed Medium-Low β-glucan with other treatments being intermediate. No treatment effect was observed on d 45. A quadratic effect of β-glucan inclusion was observed on d 45 ($P = 0.044$), indicating a non-linear response to increasing β-glucan levels. No treatment effects were observed for IL-1α, IL-1ra, IL-1β, IL-2, IL-4, IL-6, IL-10, IL-18, or TNF-α on either day 24 or 45. On d 24, IL-12 concentration was greater ($P < 0.05$) in the Carbadox group compared with the Medium-Low β-glucan group. CRP concentrations were lower ($P < 0.05$) on d 24 in the Carbadox group compared to the control and Medium-High β-glucan groups, while Low, Medium-Low and High β-glucan groups were intermediate. Additionally, haptoglobin concentrations were lower ($P < 0.05$) in the Carbadox group compared with both the Ctrl and the β-glucan groups. These results indicate that β-glucans did not reduce systemic inflammation.

In conclusion, supplementation with carbadox improved growth performance, fecal DM, and reduced markers of systemic inflammation in nursery pigs, confirming its effectiveness in supporting pig health and performance during the post-weaning period. In contrast, increasing inclusion levels of mycelium-derived β-glucan did not consistently improve growth performance or fecal dry matter compared with the control diet. However, an interesting numerical difference was detected for the growth performance of pigs fed the Low β-glucan treatment compared with the control group at the end of the nursery period. Moreover, β-glucan supplementation influenced certain immune parameters, including increased GM-CSF and IFN-γ concentrations and a tendency to affect IL-8 and IL-12, suggesting modulation of immune function. These findings indicate that mycelium-derived β-glucan did not replicate the growth-promoting effects or the immunomodulatory activity observed with carbadox under the conditions of this study. Further research is needed to determine optimal inclusion levels, timing of supplementation, and potential benefits under different health or environmental challenge conditions.

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Table 1. Phase 1 diet composition (as-fed basis)[1]

	Dietary treatments					
Item	Control	Carbadox	Low β-glucan	Medium Low β-glucan	Medium High β-glucan	High β-glucan
Ingredient, %						
Corn	48.24	47.36	48.16	48.14	48.11	48.08
Soybean meal, 46.5% CP	15.03	15.09	15.04	15.04	15.04	15.04
Spray-dried bovine plasma	3.00	3.00	3.00	3.00	3.00	3.00
Whey powder	5.00	5.00	5.00	5.00	5.00	5.00
Whey permeate	14.25	14.25	14.25	14.25	14.25	14.25
Microbially enhanced soybean meal[2]	10.00	10.00	10.00	10.00	10.00	10.00
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	0.55	0.38	0.55	0.55	0.55	0.55
Monocalcium phosphate, 21% P	0.98	0.98	0.98	0.98	0.98	0.98
Salt	0.20	0.20	0.20	0.20	0.20	0.20
L-Lys-HCl	0.39	0.39	0.39	0.39	0.39	0.39
DL-Met	0.21	0.21	0.21	0.21	0.21	0.21
L-Thr	0.19	0.19	0.19	0.19	0.19	0.19
L-Trp	0.01	0.01	0.01	0.01	0.01	0.01
L-Val	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride, 60%	0.05	0.05	0.05	0.05	0.05	0.05
Phytase[3]	0.06	0.06	0.06	0.06	0.06	0.06
ZnO	0.40	0.40	0.40	0.40	0.40	0.40
Carbadox[4]	---	1.00	---	---	---	---
Beta-glucan	---	---	0.08	0.10	0.13	0.15
Calculated analysis						
SID amino acids, %						
Lys	1.40	1.40	1.40	1.40	1.40	1.40
Ile:Lys	59	59	59	59	59	59
Leu:Lys	119	118	119	119	119	119
Met:Lys	35	35	35	35	35	35
Met and Cys:Lys	59	59	59	59	59	59
Thr:Lys	65	65	65	65	65	65
Trp:Lys	20.1	20.1	20.1	20.1	20.1	20.1
Val:Lys	69	69	69	69	69	69
His:Lys	36	36	36	36	36	36
NE, kcal/lb	1,159	1,149	1,158	1,158	1,158	1,157
SID Lys:NE, g/Mcal	5.48	5.53	5.48	5.48	5.49	5.49
CP, %	22.2	22.2	22.2	22.2	22.2	22.2
Lactose, %	15.0	15.0	15.0	15.0	15.0	15.0

Ca, %	0.65	0.65	0.65	0.65	0.65	0.65
P, %	0.60	0.60	0.60	0.60	0.60	0.60
STTD P, %	0.55	0.55	0.55	0.55	0.55	0.55

[1] Phase 1 diet was fed from d 0 to 10.

[2] Access Starter Protein (Houdek, Volga, SD).

[3] HiPhorius 2400 (DSM, Parsippany, NJ), 1,500 FTU/kg, and assumed release of 0.12% STTD P.

[4] Mecadox 2.5 (Phibro Animal Health, Teaneck, NJ).

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

	Dietary treatments					
Item	Control	Carbadox	Low β-glucan	Medium Low β-glucan	Medium High β-glucan	High β-glucan
Ingredient, %						
Corn	56.20	55.34	56.17	56.20	56.13	56.15
Soybean meal, 46.5% CP	22.27	22.30	22.25	22.19	22.23	22.19
Whey permeate	10.00	10.00	10.00	10.00	10.00	10.00
Microbially enhanced soybean meal	7.50	7.50	7.50	7.50	7.50	7.50
Calcium carbonate	0.70	0.52	0.70	0.70	0.70	0.70
Monocalcium phosphate, 21% P	1.11	1.11	1.11	1.11	1.11	1.11
Salt	0.47	0.47	0.47	0.47	0.47	0.47
L-Lys-HCl	0.48	0.48	0.48	0.48	0.48	0.48
DL-Met	0.23	0.23	0.23	0.23	0.23	0.23
L-Thr	0.23	0.23	0.23	0.23	0.23	0.23
L-Trp	0.03	0.03	0.03	0.03	0.03	0.03
L-Val	0.09	0.09	0.09	0.09	0.09	0.09
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[3]	0.06	0.06	0.06	0.06	0.06	0.06
ZnO	0.26	0.26	0.26	0.26	0.26	0.26
Carbadox[4]	---	1.00	---	---	---	---
Beta-glucan	---	---	0.05	0.08	0.10	0.13
Calculated analysis						
SID amino acids, %						
Lys	1.35	1.35	1.35	1.35	1.35	1.35
Ile:Lys	59	59	59	59	59	59
Leu:Lys	117	116	117	117	117	117
Met:Lys	38	38	38	38	38	38
Met and Cys:Lys	59	59	59	59	59	59
Thr:Lys	65	65	65	65	65	65
Trp:Lys	20.1	20.1	20.1	20.1	20.1	20.1
Val:Lys	69	69	69	69	69	69
His:Lys	36	36	36	36	36	36
NE, kcal/lb	1,117	1,106	1,116	1,116	1,115	1,115
SID Lys:NE, g/Mcal	5.49	5.54	5.49	5.49	5.49	5.49
CP, %	21.7	21.6	21.7	21.6	21.7	21.6
Lactose, %	8.0	8.0	8.0	8.0	8.0	8.0
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.61	0.60	0.61	0.61	0.61	0.61
STTD P, %	0.52	0.52	0.52	0.52	0.52	0.52

[1] Phase 2 diet was fed from d 10 to 24.

[2] Access Starter Protein (Houdek, Volga, SD).

[3] HiPhorius 2400 (DSM, Parsippany, NJ), 1,500 FTU/kg, and assumed release of 0.12% STTD P.

[4] Mecadox 2.5 (Phibro Animal Health, Teaneck, NJ).

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

	Dietary treatments					
Item	Control	Carbadox	Low β-glucan	Medium Low β-glucan	Medium High β-glucan	High β-glucan
Ingredient, %						
Corn	64.23	63.34	64.21	64.18	64.15	64.13
Soybean meal, 46.5% CP	32.12	32.19	32.13	32.13	32.13	32.13
Calcium carbonate	0.72	0.56	0.72	0.72	0.72	0.72
Monocalcium phosphate, 21% P	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.60	0.60	0.60	0.60	0.60	0.60
L-Lys-HCl	0.43	0.43	0.43	0.43	0.43	0.43
DL-Met	0.20	0.20	0.20	0.20	0.20	0.20
L-Thr	0.20	0.20	0.20	0.20	0.20	0.20
L-Trp	0.04	0.04	0.04	0.04	0.04	0.04
L-Val	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[2]	0.06	0.06	0.06	0.06	0.06	0.06
$CuSO_4$	0.07	0.07	0.07	0.07	0.07	0.07
Carbadox[3]	---	1.00	---	---	---	---
Beta-glucan	---	---	0.03	0.05	0.08	0.10
Calculated analysis						
SID amino acids, %						
Lys	1.30	1.30	1.30	1.30	1.30	1.30
Ile:Lys	58	58	58	58	58	58
Leu:Lys	120	120	120	120	120	120
Met:Lys	37	37	37	37	37	37
Met and Cys:Lys	59	59	59	59	59	59
Thr:Lys	65	65	65	65	65	65
Trp:Lys	20.2	20.2	20.2	20.2	20.2	20.2
Val:Lys	69	69	69	69	69	69
His:Lys	38	38	38	38	38	38
NE, kcal/lb	1,098	1,088	1,098	1,097	1,097	1,097
SID Lys:NE, g/Mcal	5.37	5.42	5.37	5.37	5.38	5.38
CP, %	21.4	21.3	21.4	21.4	21.4	21.4
Ca, %	0.66	0.66	0.66	0.66	0.66	0.66
P, %	0.58	0.57	0.58	0.58	0.58	0.58
STTD P, %	0.45	0.45	0.45	0.45	0.45	0.45

[1] Phase 3 diet was fed from d 24 to 45.

[2] HiPhorius 2400 (DSM, Parsippany, NJ), 1,500 FTU/kg, and assumed release of 0.12% STTD P.

[3] Mecadox 2.5 (Phibro Animal Health, Teaneck, NJ).

Table 4. Effects of a mycelium β-glucan feed additive on nursery pig growth performance[1]

	Treatments, ppm										
	Control	Carbadox[2]	Low β-glucan	Medium Low β-glucan	Medium High β-glucan	High β-glucan		*P* =			
Phase 1:	0	55	750	1,000	1,250	1,500					
Phase 2:	0	55	500	750	1,000	1,250					
Phase 3:	0	55	250	500	750	1,000	SEM	Treatment	Linear β-glucan	Quadratic β-glucan	Control vs. Carbadox
BW, lb											
d 0	12.4	12.4	12.4	12.4	12.4	12.4	0.06	1.000	0.881	0.953	0.869
d 10	14.9	15.6	15.5	15.3	14.8	14.9	0.33	0.448	0.754	0.220	0.142
d 24	27.4	30.2	28.7	28.4	28.1	28.1	0.63	0.061	0.518	0.238	0.002
d 45	58.8[b]	65.1[a]	61.4[ab]	60.0[b]	59.0[b]	61.0[ab]	1.03	0.001	0.478	0.575	< 0.001
Phase 1 (d 0 to 10)											
ADG, lb	0.25	0.31	0.31	0.27	0.24	0.25	0.034	0.479	0.718	0.294	0.153
ADFI, lb	0.35	0.39	0.39	0.38	0.34	0.34	0.029	0.602	0.616	0.225	0.246
F/G	1.47	1.41	1.39	0.94	1.20	1.41	0.242	0.466	0.620	0.794	0.437
Phase 2 (d 10 to 24)											
ADG, lb	0.89[b]	1.05[a]	0.94[ab]	0.94[ab]	0.95[ab]	0.93[ab]	0.030	0.021	0.288	0.317	0.001
ADFI, lb	1.32	1.48	1.42	1.43	1.41	1.39	0.044	0.233	0.282	0.109	0.014
F/G	1.49	1.42	1.52	1.53	1.49	1.50	0.030	0.118	0.882	0.261	0.078
Phase 3 (d 24 to 45)											
ADG, lb	1.50[b]	1.66[a]	1.55[ab]	1.50[b]	1.47[b]	1.56[ab]	0.030	< 0.001	0.714	0.726	< 0.001
ADFI, lb	2.23[b]	2.48[a]	2.34[ab]	2.26[b]	2.23[b]	2.33[ab]	0.048	0.006	0.499	0.891	0.001
F/G	1.49	1.49	1.50	1.51	1.52	1.50	0.015	0.563	0.337	0.337	0.985
Overall performance (d 0 to 45)											
ADG, lb	1.02[b]	1.17[a]	1.10[ab]	1.05[b]	1.03[b]	1.06[b]	0.024	0.001	0.612	0.540	< 0.001
ADFI, lb	1.52[b]	1.69[a]	1.61[ab]	1.57[ab]	1.55[ab]	1.58[ab]	0.038	0.038	0.491	0.339	0.002
F/G	1.48[ab]	1.46[a]	1.49[ab]	1.50[b]	1.51[b]	1.49[ab]	0.012	0.026	0.417	0.164	0.109
Fecal dry matter[3]											
d 24	21.60[ab]	24.52[a]	21.40[ab]	20.34[b]	22.12[ab]	21.86[ab]	0.829	< 0.001	0.705	0.364	0.013
d 45	23.08[b]	27.85[a]	22.15[b]	22.68[b]	24.38[b]	23.63[b]	0.674	< 0.001	0.168	0.291	< 0.001

[1] A total of 360 weaned pigs (initially 12.4 ± 0.06 lb) were used with 5 pigs per pen and 12 replications per treatment. Treatment diets were fed during phase 1 (d 0 to 10), phase 2 (d 10 to 24), and phase 3 (d 24 to 45) in mash form.

[2] Mecadox 2.5 (Phibro Animal Health, Teaneck, NJ).

[3] Day: P < 0.001, Treatment: P < 0.001, Treatment × day: P = 0.423.

Table 5. Effects of a mycelium β-glucan feed additive on plasma acute-phase proteins and cytokines[1]

	Treatments, ppm										
	Control	Carbadox[2]	Low β-glucan	Medium Low β-glucan	Medium High β-glucan	High β-glucan		*P*[3] =			
Phase 1:	0	55	750	1,000	1,250	1,500					
Phase 2:	0	55	500	750	1,000	1,250					
Phase 3:	0	55	250	500	750	1,000	SEM	Treat-ment	Linear β-glucan	Quadratic β-glucan	Control vs. Carbadox
Acute-phase proteins											
CRP[4]											
d 24	1,306.7[a]	419.3[b]	891.3[ab]	871.0[ab]	1,142.4[a]	894.7[ab]	299.6	0.019	0.405	0.458	< 0.001
d 45	2,392.6	2,418.3	2,702.5	2,168.3	3,094.3	2,822.2	500.5	0.672	0.373	0.772	0.963
Haptoglobin[5]											
d 24	2,849.0[a]	712.9[b]	3,866.5[a]	2,683.9[a]	2,422.2[a]	2,752.4[a]	1,039.5	< 0.001	0.594	0.707	< 0.001
d 45	4,165.9	3,834.4	4,067.1	4,325.8	4,625.1	4,283.8	468.7	0.465	0.589	0.945	0.582
Cytokines											
GM-CSF[6]											
d 24	16.6	16.9	15.6	15.9	14.6	16.3	0.67	0.113	0.339	0.143	0.743
d 45	17.6[ab]	18.0[ab]	16.7[b]	16.8[b]	19.9[a]	18.1[ab]	0.80	0.029	0.088	0.269	0.691
IFN-γ											
d 24	32.2	26.4	23.0	33.1	30.7	38.0	5.50	0.203	0.267	0.114	0.343
d 45	18.7	21.5	18.3	25.6	20.9	24.1	2.13	0.035	0.019	0.846	0.249
IL-1α											
d 24	37.6	28.2	33.4	26.4	34.8	36.5	8.46	0.841	0.897	0.340	0.365
d 45	106.6	127.4	170.5	99.3	143.9	113.5	38.34	0.548	0.932	0.422	0.577
IL-1β											
d 24	69.3	45.0	59.4	47.1	56.6	54.4	13.52	0.659	0.345	0.452	0.120
d 45	99.3	108.5	166.3	90.9	141.0	103.9	32.46	0.226	0.944	0.283	0.749
IL-1ra											
d 24	145.7	99.4	123.5	113.2	125.8	123.8	24.89	0.738	0.507	0.469	0.115
d 45	229.1	206.7	274.3	205.7	275.8	225.9	47.11	0.709	0.982	0.715	0.671
IL-2											
d 24	30.5	20.5	27.0	21.7	26.4	26.5	6.85	0.822	0.612	0.486	0.215
d 45	81.5	90.3	139.1	72.9	105.4	82.8	31.26	0.383	0.865	0.352	0.748
IL-4											
d 24	31.7	31.4	37.9	29.1	36.8	36.6	5.28	0.695	0.546	0.881	0.958

d 45	115.4	125.1	186.0	99.1	147.1	109.5	43.09	0.444	0.760	0.388	0.807
IL-6											
d 24	36.0	33.3	42.3	37.2	38.4	37.1	7.80	0.971	0.995	0.674	0.773
d 45	106.4	111.1	167.7	98.6	136.6	111.4	30.94	0.345	0.986	0.347	0.870
IL-8											
d 24	24.3	23.7	19.1	22.9	21.2	22.0	2.50	0.608	0.643	0.331	0.861
d 45	20.0	18.2	19.1	17.8	22.5	18.7	1.34	0.094	0.965	0.703	0.278
IL-10											
d 24	47.6	33.9	51.1	33.8	41.7	45.4	11.02	0.654	0.647	0.562	0.267
d 45	91.3	95.4	157.9	83.7	112.0	109.8	34.07	0.373	0.847	0.558	0.888
IL-12											
d 24	1,501.3[ab]	1,666.4[a]	1,468.1[ab]	1,173.1[b]	1,440.1[ab]	1,470.5[ab]	121.68	0.037	0.680	0.099	0.315
d 45	1,647.9	1,448.9	1,528.2	1,294.3	1,606.9	1,640.1	120.33	0.157	0.965	0.044	0.215
IL-18											
d 24	93.9	96.9	78.3	60.8	71.4	76.8	17.01	0.434	0.311	0.223	0.900
d 45	108.3	112.2	144.5	93.0	131.7	103.1	25.38	0.516	0.817	0.532	0.889
TNFα											
d 24	29.4	29.3	23.9	32.8	32.8	33.7	3.39	0.162	0.111	0.122	0.981
d 45	25.8	25.8	24.7	29.5	33.1	28.7	3.34	0.321	0.337	0.824	0.995

[1] On d 24 and 45 of the trial, blood was collected from one pig per pen (12 pigs per treatment), and the plasma was analyzed for cytokines and acute-phase proteins. Values represent fluorescence intensity.

[2] Mecadox 2.5 (Phibro Animal Health, Teaneck, NJ).

[3] Day: $P < 0.001$ for acute-phase proteins (CRP and haptoglobin), and $P \leq 0.006$ for cytokines (GM-CSF, IFN-γ, IL-1α, IL-1β, IL-1ra, IL-2, IL-4, IL-6, IL-8, IL-10, and IL-18).

[4] Treatment: $P = 0.121$; day: $P < 0.001$; treatment × day: $P = 0.018$.

[5] Treatment: $P = 0.003$; day: $P < 0.001$; treatment × day: $P = 0.001$.

[6] Treatment: $P = 0.378$; day: $P < 0.001$; treatment × day: $P = 0.005$.