Kansas Agricultural Experiment Station Research Reports

Volume 5
Issue 8 *Swine Day*

Article 12

2019

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Recommended Citation

Richert, J.; Thayer, M.; Chastain, C.; Duttlinger, A.; Feldpausch, J.; Garcia, R.; Richert, B.; and Nelssen, J. L. (2019) "The Effects of Cordyceps Mushroom Powder and Purified Mushroom Beta-Glucan on Nursery Pig Performance," *Kansas Agricultural Experiment Station Research Reports*: Vol. 5: Iss. 8. https://doi.org/10.4148/2378-5977.7842

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The Effects of *Cordyceps* Mushroom Powder and Purified Mushroom Beta-Glucan on Nursery Pig Performance

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Summary

One hundred thirty-two gilts and barrows (18.2 d of age) weighing an average of 13.4 lb (Duroc × (York × Landrace)) were put on test for a 35-day growth trial to assess the effects of *Cordyceps* mushroom powder (MP) or purified mushroom beta-glucan (BG) as an antibiotic alternative in nursery diets. There were 6 diets, negative and positive controls (NC and PC), 150 and 300 ppm mushroom powder, and 150 and 300 ppm beta-glucan equivalents to the MP diets. Pigs were divided by weight, sex, litter, and assigned to 6 body weight (BW) blocks. Within BW blocks, sex ratios were constant in each pen. Pigs and feeders were weighed weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G). During phase 1 (d 0 to 7), pigs fed the PC had increased ADG, ADFI, and d 7 BW ($P < 0.05$) compared to pigs fed the NC. Beta-glucan and MP also increased ADFI in phase 1 ($P < 0.05$) compared to the NC. During phase 2 (d 7 to 14), a health challenge (hemolytic *Escherichia coli*) went through half of the pigs with the other half challenged in phase 3 (d 14 to 21). This led to some erratic performance because of the pigs eating, but losing weight. In phase 4 there was a BG and MP interaction between source and dose. Pigs fed 300 level of MP had improved F/G, while those fed the 300 level of BG had poorer efficiency in phase 4 ($P < 0.07$). Overall, there was an improvement ($P > 0.05$) in F:G ratio in the PC when compared to the NC. There was also an interaction between source and dose for ADFI ($P < 0.05$) between the BG and MP treatments. There was a significant improvement in F/G in MP and BG pigs compared to NC pigs ($P < 0.05$). On day 35, there were no differences in final BW among treatments. A premarket weight was collected on all pigs at d 154 after weaning, and pigs fed the 300 BG from day 0 to 35 were 24.4 lb heavier than the NC ($P < 0.05$) and 15.4 lb heavier than the PC ($P < 0.05$).

Introduction

Swine producers are reducing the use of antibiotics, following the trend of consumer desires. Antibiotics are an important aspect of swine production as disease treatment and prevention, resulting in a growth promotion effect. Growth-promoting antimicrobials used in feed post-weaning such as neomycin and chlortetracycline are under heavy

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scrutiny in today's environment due to the growing concerns of antibiotic resistance. Pigs fed antimicrobials can greatly improve growth performance and feed efficiency compared to pigs fed diets containing no antimicrobial agents. This has led to research in effective alternatives to antimicrobials due to industry concern over potential monetary losses when attempting to produce pork under an antibiotic-free program. One possible alternative is a Chinese herbal mushroom blend of *Cordyceps militaris* and *Cordyceps sinensis*.[2] These mushrooms have been used by the Chinese as a health-promoting additive for centuries. The mushroom itself has antimicrobial and antiviral characteristics.[3] Another alternative is a purified mushroom beta-glucan. Beta-glucans have been shown to have antimicrobial effects as well as the ability to enhance the hosts' immune function.[4] Based on previous positive results with this mushroom product, an investigation was initiated to determine if the high levels of beta-glucans present in the *Cordyceps* mushroom powder are responsible for a portion of the increased pig performance previously observed.

Procedures

One hundred thirty-two gilts and barrows (18.2 d of age) weighing an average of 13.4 lb, with US purebred genetics (Duroc × (York × Landrace)) were put on test for a 35-day growth trial. Growth performance was analyzed using BW, ADG, ADFI, and feed conversion as feed-to-gain (F:G) ratio. There were 6 diets, negative and positive controls, 150 or 300 ppm mushroom powder, and 150 or 300 ppm equivalent of beta-glucan. Pigs were divided by weight, sex, and litter, then assigned to BW blocks with 3 or 4 pigs per pen. Within BW blocks, sex ratios were constant in each pen. Each pen within a BW block was then randomly assigned a diet. The studies were performed at Purdue University's Animal Sciences Research and Education Center (ASREC). Purdue University's Animal Care and Use Committee approved the protocol used in this experiment. Feed was made at the ASREC feed mill.

Pigs were provided *ad libitum* access to feed and water with a 4- or 5-hole nursery feeder and one nipple waterer. Feeders and waterers were checked daily, with a target of having partial pan coverage (40–50% coverage) while also minimizing feed wastage. Feeders were cleaned when feed became spoiled, and waterers adjusted to shoulder height of the pigs throughout the study. Due to cold weather and transport of the newly weaned pigs to the Kansas State University Segregated Early Weaning facility (Manhattan, KS) all pigs were given a preventative shot of Excede (0.5 mL). Daily checks consisted of checking feeders, waterers, observations of the pigs, filling feeders if needed, treating pigs with antibiotics when signs of disease were detected, and completing treatment records. Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35. The individual BW and pen feed intake were recorded, data were analyzed using the GLM procedure of SAS (v 9.4, SAS Institute, Inc., Cary, NC). The parameters measured were BW, ADG, ADFI, F/G every week and summarized by dietary phase and overall. All pigs were fed a common antibiotic feed regimen during the grow-finish period consisting of linco-

[2] Shen, H.S., S. Shao, J.C. Chen, T. Zhou. 2017. Antimicrobials from Mushrooms for Assuring Food Safety. Comprehensive Reviews in Food Science and Food Safety. Vol. 16:316-329.

[3] Zhou, X.L., L. Luo, W. Dressel, G. Shadier, D. Krumbiegel, P. Schmidtke, F. Zepp. 2008. Cordycepin is an immunoregulatory active ingredient of *Cordyceps sinesis*. Am J Chin Med 36:967-980.

[4] Hetland, G., N. Ohno, I. S. Aaberge, M. Lovik. 2000. Protective effect of β-glucan against Streptococus pneumonia infection in mice. FEMS Immunol. Med. Microbiol. 2000; 27:111-116.

mycin and tylosin, followed by antibiotic-free diets in the last 3 weeks before harvesting. All pigs were weighed at the end of this period (d 154) to evaluate any potential nursery treatment carry-over effects into the grow-finish period.

Diets

There were six dietary treatments tested in this study. All diets contained supplemental pharmacological copper from copper sulfate, but no supplemental pharmacological zinc to simulate future European Union regulations. The negative control (NC) contained 0.5% fine ground corn premix, which was then partially replaced with *Cordyceps* mushroom powder (MP; Aloha Medicinals, Carson City, NV) at 150 ppm or 300 ppm; purified mushroom beta-glucan (BG) diets containing 50 ppm or 100 ppm to match the beta glucan concentration of the mushroom diets; and the positive control contained neomycin/oxytetracycline (10 mg/lb/BW) during phases 1 and 2. Phase 3 contained 440 ppm chlortetracycline and phase 4 had 110 ppm lincomycin.

The pigs were fed four dietary phases over a 35 day period. Phase 1 was d 0 to 7, phase 2 was d 7 to 14, phase 3 was d 14 to 21, and phase 4 was d 21 to 35. Phases 1 and 2 were made with a basal diet which was split and then remixed with the treatment premixes added. Phases 3 and 4 were made as individual diet treatment batches.

Feed samples for each phase were collected and stored for future analysis at the Purdue University Swine Nutrition Laboratory (West Lafayette, IN) for crude protein, energy, dry matter, ash, and phosphorus concentrations. Prior to analyzing the diets they were ground through a 1 mm screen.

Results and Discussion

During phase 1 (d 0 to 7) pigs fed the PC diet had increased ADG, ADFI, and d 7 BW ($P < 0.05$) compared to the pigs fed NC. Pigs fed BG and MP also differed from the NC with increased ADFI in phase 1 ($P < 0.01$). During phase 2 (d 7 to 14,) half of the pigs experienced a health challenge, with the other half challenged in phase 3 (d 14 to 21). This led to erratic values in performance because of the pigs eating, but losing weight. Feed intake in phase 2 was improved in BG, MP, and PC compared to the NC ($P < 0.05$). In phase 2 there was a statistical difference between the BG and MP diets, with pigs fed BG having greater ADG, ADFI, and d 14 BW ($P < 0.04$). There was an interaction effect of dose × source of beta-glucans ($P < 0.01$) in ADFI with 300 BG increasing ADFI, but 300 MP decreasing ADFI from d 7 to 14. Pigs fed the positive control diet had improved ADG, F/G, and d 21 BW in phase 3 when compared to the NC fed pigs ($P < 0.05$). Pigs fed the BG and MP diet had improved feed efficiency compared to the negative control ($P < 0.01$) during phase 3. During phase 4, pigs fed the PC had reduced ADFI ($P < 0.01$) compared to the NC. All pigs fed either BG or MP had improved F/G compared to the NC-fed pigs during phase 4 ($P < 0.04$). Pigs fed the 300-ppm level of mushroom powder had improved feed efficiency, while the 300 ppm level of beta-glucans reduced efficiency in phase 4 (source × dose interaction; $P < 0.07$). Overall (d 0–35), pigs fed the PC diets had improved efficiency ($P < 0.05$) compared to the NC-fed pigs. Overall, MP and BG pigs had improved F/G compared to NC pigs ($P < 0.05$) and tended ($P < 0.10$) to have greater ADG. For the entire nursery period there also tended ($P < 0.06$) to be an interaction between dose and source of mushroom products with 300 BG increasing ADFI and 300 MP tending to decrease ADFI. On day 35, there were no treatment differences for BW.

Pigs were weighed twice during a common grow-finish period, on d 63 and d 154 post-weaning. For d 63 BW, BG pigs were 5.0 lb heavier at the 150 level, and 7.3 lb heavier at the 300 ppm level than the NC and heavier than the MP pigs ($P < 0.02$). There were also differences in ADG between BG and MP pigs ($P < 0.01$), as well as a trend for a difference between NC and BG and MP pigs ($P = 0.05$). For d 154 BW, BW increased for pigs fed BG and MP ($P < 0.01$), as well as BG and MP pigs when compared to the NC ($P = 0.03$). At this first marketing (d 154) pigs fed the BG 300 treatment were 24.4 lb heavier than the NC, and 15.4 lb heavier than the PC. Because of this large difference in BW, a difference in ADG occurred when comparing BG to MP as well as when comparing BG and MP to NC from days 63 to 154 post-weaning, and day 35 to 154 postweaning ($P < 0.05$).

With the illness affecting the pigs in the middle of this study, it is difficult to draw conclusions from phases 2 and 3. Phase 4 can also be questioned because it is unknown how much of these data are due to compensatory gain and the many therapeutic injections (Table 4). However, during phase 4 the 300 level of BG and MP were the numerically greatest in gain at 0.89 and 0.96 lb/d, respectively. The positive control pigs ended the study very poorly, this appears to coincide with the antibiotic switch from CTC to lincomycin but may also relate to the lower therapeutic injections the PC pigs received. These data indicate that the mushroom powder has a late nursery effect. More research needs to be conducted to determine if the mushroom powder is economical to feed in the first two weeks of the nursery phase, or if it can simply be a late nursery additive to improve performance while removing antibiotics. In Table 4 are the recorded treatments given during this study. Week one only had two pigs treated, so the data were not included. During week two, there was a large outbreak in enteric disease (hemolytic *Escherichia coli*), as a result 37.2% of pigs receiving the positive treatment and 81.7% of pigs on the mushroom powder 150 ppm diet required treatment. Pigs on the BG diets required fewer treatments than those receiving the MP diet ($P < 0.01$). There was also a source by dose interaction with the 300 concentration of BG diet requiring less treatments compared to the 150 BG level, while 300 MP-treated pigs required more than the 150MP group. During weeks 3 and 4, disease treatments were not as prevalent as week 2; however, there was still a significant portion of pigs requiring treatment (10–42%). In week 5, the number of treatments were reduced with treatments at less than 10% for all diets. When looking at the overall data, there were no differences in percentage of pigs treated. There were trends for differences in total therapies given when comparing the NC and PC, as well as the BG and MP ($P = 0.06$, $P = 0.08$). There also was a trend for difference when considering therapies per pig between the NC and PC ($P = 0.08$). The 300 ppm MP had 2.58 therapies given per pig, and the lowest total of the treatments had 1.07 per pig for the PC treatment.

This study investigated whether the active compound of the *Cordyceps* mushroom powder is beta-glucans, or if something other than beta-glucans is active in improving growth performance in nursery pigs. Unfortunately, during this study an enteric disease broke out in these pigs, making this evaluation difficult; however, pigs fed BG300 were the heaviest pigs in this study, greater than the MP-fed pigs, suggesting that it may be primarily a beta-glucan effect.

Due to the illness during the nursery phase, we decided to follow these pigs to market to observe whether there was a carry-over effect once out of the nursery. Pigs fed the BG 300 treatment had BW at d 154 that was 15.4 lb greater than the PC pigs, and 24.4 lb greater than the NC pigs. The PC pigs were 9.0 lb heavier than the NC pigs. With this hemolytic *E. coli* outbreak, it is worth considering this beta-glucan product promoted gut healing, and led to a more rapid full recovery that may have had long-term effects into the grow-finish period.

In conclusion, pigs fed the BG 300 diets from day 0 to 35 after weaning had increased final d 154 BW. However, due to the illness, we recommend repeating the study to determine if this is the response in healthy pigs. We also recommend a controlled illness challenge to see if these results can be repeated. Purified beta-glucans from mushroom sources may have the potential to replace antibiotics in the nursery phase and provide long-term improvements in pig growth performance to market.

Table 1. Basal diet composition

Ingredient,%	Phase 1	Phase 2	Phase 3	Phase 4
Corn	36.205	42.925	51.500	59.840
Soybean, crude protein 48%	14.000	17.700	25.670	32.900
Choice white grease	---	---	---	3.000
Soybean oil	5.000	4.000	3.000	0.000
Limestone	0.650	0.770	0.860	1.290
Monocalcium P	0.480	0.640	0.490	0.800
Vitamin premix[1]	0.250	0.250	0.250	0.250
Trace mineral premix[2]	0.125	0.125	0.125	0.125
Se premix[3]	0.050	0.050	0.050	0.050
Phytase[4]	0.100	0.100	0.100	0.100
Salt	0.250	0.250	0.300	0.350
Plasma protein	5.000	2.500	---	---
Spray-dried blood meal	1.500	1.000	---	---
Soy protein concentrate	5.000	4.000	2.500	---
Fish meal	4.650	4.000	4.000	---
Dried whey	25.750	20.000	10.000	---
Lysine-HCL	0.130	0.240	0.280	0.350
DL-Methionine	0.230	0.220	0.180	0.170
L-Threonine	0.060	0.110	0.120	0.135
L-Tryptophan	0.010	0.020	0.015	---
Banminth-48	---	---	---	0.100
Copper sulfate	0.060	0.600	0.060	0.040
Corn premix	**0.500**	**0.500**	**0.500**	**0.500**
Total	100.00	100.00	100.00	100.00

continued

Table 1. Basal diet composition

Ingredient,%	Phase 1	Phase 2	Phase 3	Phase 4
Calculated nutrients				
Metabolizable energy, Kcal/lb	1605.4	1577.6	1556.1	1542.2
Net energy, Kcal/lb	1244.9	1214.2	1173.6	1144.5
Crude protein, %	24.49	22.86	22.34	21.21
Total Lys, %	1.73	1.61	1.50	1.40
SID Lys, %	1.55	1.45	1.35	1.25
SID Met, %	0.55	0.53	0.50	0.45
SID M+C, %	0.91	0.85	0.79	0.73
SID Thr, %	0.97	0.91	0.84	0.78
SID Tryp, %	0.28	0.27	0.25	0.23
SID Iso, %	0.86	0.82	0.83	0.77
SID Val, %	1.08	0.97	0.89	0.83
Ca,%	0.85	0.85	0.80	0.75
P, %	0.76	0.72	0.64	0.56
Available P, %	0.55	0.50	0.45	0.35

[1]Provided per lb of diet available minerals: iron, 55.0 mg; zinc, 55.0 mg; manganese, 6.8 mg; copper, 5.1 mg; and iodine, 0.21 mg.
[2]Provided per lb of diet: vitamin A, 3000 IU; vitamin D3, 300 IU; vitamin E, 20 IU; vitamin K, 1.0 mg; riboflavin, 4.1 mg; pantothenic acid, 11.0 mg; niacin, 15.0 mg, and B12 17.5 mg.
[3]Provided 0.136 mg Se per lb of the diet.
[4]Provided 272 FTU per lb of the diet.
SID = standard ileal digestible.

Table 2. Nursery pig growth performance when fed *Cordyceps* mushroom powder (MP) or mushroom beta-glucans (BG)

								Probability, $P <$				
Diet	NC	PC	BG150	BG300	MP150	MP300	SE	NC vs. PC	BG vs. MP	150 vs. 300	Interaction source × dose	NC vs. BG and MP
Pens/diet	6	6	6	6	6	5						
Initial BW, lb	13.41	13.43	13.33	13.36	13.35	13.35	1.389	0.92	0.94	0.89	0.91	0.68
d 0 to 7												
ADG, lb	0.24	0.37	0.23	0.30	0.23	0.22	0.035	0.01	0.22	0.34	0.24	0.72
ADFI, lb	0.34	0.44	0.41	0.45	0.42	0.41	0.031	0.02	0.59	0.50	0.40	0.01
F/G	1.46	1.23	1.96	1.55	1.89	2.21	0.266	0.49	0.24	0.85	0.15	0.11
d 7 BW, lb	15.05	16.00	14.95	15.47	14.97	14.91	1.312	0.02	0.32	0.41	0.29	0.94
d 7 to 14												
ADG, lb	0.22	0.23	0.24	0.26	0.19	0.12	0.060	0.82	0.02	0.50	0.31	0.63
ADFI, lb	0.49	0.62	0.60	0.70	0.61	0.50	0.076	0.02	0.02	0.92	0.01	0.01
F/G	-1.14	4.24	2.79	3.23	5.38	-2.08	2.456	0.10	0.56	0.14	0.10	0.18
d 14 BW, lb	16.60	17.64	16.64	17.25	16.28	15.73	1.064	0.09	0.04	0.94	0.19	0.79
d 14 to 21												
ADG, lb	0.29	0.51	0.45	0.41	0.39	0.35	0.072	0.02	0.43	0.58	0.97	0.13
ADFI, lb	0.76	0.90	0.87	0.85	0.82	0.73	0.064	0.10	0.16	0.34	0.60	0.42
F/G	3.04	1.85	2.13	2.10	2.20	1.51	0.2951	0.01	0.35	0.21	0.25	<0.01
d 21 BW, lb	18.60	21.23	19.77	20.13	19.04	18.19	1.215	0.02	0.11	0.77	0.46	0.44
d 21 to 35 (phase 4)												
ADG, lb	0.80	0.72	0.86	0.89	0.86	0.96	0.077	0.35	0.64	0.30	0.62	0.20
ADFI, lb	1.76	1.43	1.47	1.75	1.68	1.68	0.097	0.01	0.45	0.14	0.12	0.25
F/G	2.54	2.22	1.83	2.30	2.18	1.89	0.244	0.26	0.90	0.66	0.07	0.04
d 35 BW, lb	29.80	31.25	31.79	32.65	31.02	31.54	1.911	0.40	0.46	0.59	0.89	0.16
d 0 to 35												
ADG, lb	0.47	0.51	0.53	0.55	0.51	0.53	0.034	0.36	0.49	0.46	0.96	0.10
ADFI, lb	1.02	0.97	0.94	1.10	1.04	1.00	0.058	0.44	0.97	0.27	0.06	0.98
F/G	2.21	1.91	1.83	2.01	2.07	1.92	0.114	0.05	0.49	0.88	0.13	0.04

[1]Diets: Negative control (NC) = no feed antimicrobial with pharmacological copper sulfate; positive control (PC) = NC + antimicrobials (neomycin+ oxytetracycline 10 mg/lb/d phases 1 and 2, chlortetracycline 400 g/ton phase 3 and lincomycin 100 g/ton); BG150 = NC + mushroom beta-glucan powder at 150 ppm equivalent (50 ppm actual beta-glucan); BG300 = NC + mushroom beta-glucan powder at 300 ppm equivalent (100 ppm of actual beta-glucan); MP150 = NC + *Cordyceps* mushroom powder at 150 ppm; and MP300 = NC + *Cordyceps* mushroom powder at 300 ppm.

[2]Contrasts: NC vs. PC = negative control vs. antibiotic positive control; BG vs. MP = 150BG + 300BG vs. 150MP + 300M; 150 vs. 300 = 150BG + 150MP vs. 300BG + 300MP; interaction source × level = the interaction between source of mushroom products (BG or MP) and level (150 and 300 ppm) treatments; and NC vs. BG and MP = contrasts the NC diet to the average of all the BG and MP treatments.

BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.

Table 3. Grow-finish growth performance

	NC	PC	BG150	BG300	MP150	MP300	SE	Probability, *P* < NC vs. PC	BG vs. MP	150 vs. 300	Interaction source × dose	NC vs. BG and MP
BW d 35, lb	30.5	31.0	30.3	32.2	30.6	29.6	1.52	0.81	0.45	0.80	0.33	0.93
BW d 63, lb	67.3	68.6	72.7	75.0	67.6	67.7	2.58	0.71	0.02	0.65	0.66	0.24
BW d 154, lb	247.9	256.9	267.1	272.3	250.6	253.6	5.28	0.23	<0.01	0.43	0.83	0.03
ADG d 35 to 65, lb	1.31	1.35	1.51	1.53	1.32	1.36	0.054	0.69	<0.01	0.61	0.83	0.05
ADG d 63 to 154, lb	1.98	2.07	2.14	2.17	2.01	2.05	0.043	0.14	<0.01	0.40	0.95	0.02
ADG d 35 to 154, lb	1.83	1.90	1.99	2.02	1.85	1.89	0.041	0.20	<0.01	0.37	0.90	0.02

[1]Diets: Negative control (NC) = no feed antimicrobial with pharmacological copper sulfate; positive control (PC) = NC + antimicrobials (neomycin + oxytetracycline 10 mg/lb/d phase 1 and 2, chlortetracycline 400 g/ton phase 3 and lincomycin 100 g/ton); BG150 = NC + mushroom beta-glucan (BG) powder at 150 ppm equivalent (50 ppm actual beta-glucan); BG300 = NC + mushroom beta-glucan powder at 300 ppm equivalent (100 ppm of actual beta-glucan); MP150 = NC + *Cordyceps* mushroom powder at 150 ppm; and MP300 = NC + *Cordyceps* mushroom powder at 300 ppm.

[2]Contrasts: NC vs. PC = negative control vs. antibiotic positive control; BG vs. MP = 150BG + 300BG vs. 150MP + 300M; 150 vs. 300 = 150BG + 150MP vs. 300BG + 300MP; interaction source × level = the interaction between source of mushroom products (BG or MP) and level (150 and 300 ppm) treatments; and NC vs. BG and MP = contrasts the NC diet to the average of all the BG and MP treatments.

MP = mushroom powder. BW = body weight. ADG = average daily gain.

Table 4. Nursery treatment percentages

	NC	PC	BG150	BG300	MP150	MP300	SE	Probability, *P* < NC vs. PC	BG vs. MP	150 vs. 300	Interaction source × dose	NC vs. BG and MP
Week 2 treatments, %	56.7	37.2	71.9	52.5	81.6	65.0	14.76	0.25	0.35	0.13	0.91	0.40
Week 3 treatments, %	30.6	13.9	26.4	8.3	37.5	58.3	9.36	0.22	<0.01	0.88	0.05	0.84
Week 4 treatments, %	38.9	9.7	38.9	40.3	37.5	41.7	13.26	0.13	1.00	0.84	0.92	0.96
Week 5 treatments, %	8.3	4.2	5.6	0.0	0.0	4.2	3.94	0.46	0.86	0.86	0.23	0.19
Phase 4 treatments, %	47.2	13.9	38.9	40.3	37.5	41.7	12.89	0.08	1.00	0.83	0.91	0.60
Overall treatments, %	62.5	36.1	70.8	48.6	73.6	77.8	13.17	0.17	0.24	0.50	0.32	0.73
Total therapies	6.1	2.5	6.0	3.8	6.8	7.8	1.50	0.06	0.08	0.66	0.24	0.98
Therapies/pig	2.1	1.1	2.2	1.4	2.3	2.6	0.48	0.08	0.10	0.51	0.19	0.85

[1]Diets: Negative control (NC) = no feed antimicrobial with pharmacological copper sulfate; positive control (PC) = NC + antimicrobials (neomycin + oxytetracycline 10 mg/lb/d phase 1 and 2, chlortetracycline 400 g/ton phase 3 and lincomycin 100 g/ton); BG150 = NC + mushroom beta-glucan (BG) powder at 150 ppm equivalent (50 ppm actual beta-glucan); BG300 = NC + mushroom beta-glucan powder at 300 ppm equivalent (100 ppm of actual beta-glucan); MP150 = NC + *Cordyceps* mushroom powder (MP) at 150 ppm; MP300 = NC + *Cordyceps* mushroom powder at 300 ppm.

[2]Contrasts: NC vs. PC = Negative control vs. antibiotic positive control; BG vs. MP = 150BG+300BG vs. 150MP + 300M; 150 vs. 300 = 150BG + 150MP vs. 300BG + 300MP; interaction source × level = the interaction between source of mushroom products (BG or MP) and level (150 and 300 ppm) treatments; and NC vs. BG and MP = contrasts the NC diet to the average of all the BG and MP treatments.