Effect of Mannan Oligosaccharide (Bio-Mos) Addition With and Without Zinc Oxide on Performance and Immunocompetence of Weanling Pigs

E. Davis, C. Maxwell, B. de Rodas, and D. Brown[1]

Story in Brief

An experiment involving 216 weanling barrows (1/2 Large White x 1/4 Duroc x 1/4 Landrace; 21 ± 2 d of age; 13.7 ± 0.07 lb initial BW) was conducted to determine the efficacy of Bio-Mos as an alternative to growth-promoting concentrations of zinc oxide. Pigs were blocked by initial BW and penned in groups of six with nine pens/treatment in an off-site nursery. Treatments were arranged as a 2 x 2 factorial with two concentrations of Bio-Mos (0% and 0.2%) and two concentrations of dietary Zn (165 ppm and 2465 ppm). Experimental diets were fed throughout the study and contained 1.5% lysine during Phase 1 (day 0 to 10), 1.35% lysine during Phase 2 (day 10 to 24), and 1.2% lysine during Phase 3 (day 24 to 38). Two pigs/pen were bled via venipuncture, and a lymphocyte blastogenesis assay was performed. Addition of zinc oxide increased ($P < 0.05$) ADG during Phase 1, ADFI during Phase 1 and 2, and F/G in the overall study (day 0 to 38). In Phase 2 and overall, ADG increased when Bio-Mos was added to diets containing 165 ppm Zn but decreased when Bio-Mos was added to diets with 2465 ppm Zn (interaction, $P < 0.08$). Response to Bio-Mos supplementation in early-weaned pigs appears to be dependent on the level of ZnO in the diet.

Introduction

Bio-Mos is a mannan oligosaccharide derived from the cell wall of yeast and has resulted in improved weight gain and feed efficiency when fed to broiler chicks and weanling pigs. Polysaccharides derived from yeast cell wall material have also been implicated in enhancing immune function. Researchers in aquaculture have found that yeast glucan enhances the nonspecific defense mechanism and survival in fish (Engstad et al., 1992). Similarly, performance has been improved in early-weaned pigs fed a glucan isolated from yeast (Schoenherr et al., 1994). Because of these observed improvements in performance, Bio-Mos could serve as a potential replacement for additions of high levels of trace minerals such as ZnO and copper sulfate that are added in excess of the pigs' dietary requirement. The objective of this study was to further assess the efficacy of Bio-Mos in improving performance in weaned pigs, and determine its potential as a replacement for ZnO in nursery pig diets. The effect of diet on immunocompetence of weanling pigs was also evaluated.

Experimental Procedures

A total of 216 weanling barrows (1/2 Large White x 1/4 Duroc x 1/4 Landrace; 21 ± 2 d of age; 13.7 ± 0.07 lb BW) were obtained from a single source and transported to the University of Arkansas off-site nursery facility. Pigs were sorted by weight and divided into weight groups (blocks). Pigs within each weight group were allotted into equal subgroups (six pigs per pen), and treatments were randomly assigned to pens (subgroups) within each of the weight groups.

Four dietary treatments were fed consisting of two concentrations of inorganic Zn (165 and 2465 ppm) with and without the addition of Bio-Mos (0 or 0.3% Bio-Mos, Alltech, Nicholasville, KY.) in a 2 x 2 factorial arrangement of treatments. Because results in field studies suggest that pigs may respond better to a Bio-Mos regimen in which Bio-Mos supplementation is greater during the initial nursery period than in the latter nursery phases, Bio-Mos was supplemented at 0.3% of the diet during Phase 1 and 0.2% during Phase 2 and 3. The specific diets during the first 10 d postweaning (Phase 1) consisted of the following: 1) a

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negative control diet containing Zn at 165 ppm from $ZnSO_4$ (Table 1); 2) the negative control diet plus 2300 ppm Zn as ZnO; 3) the negative control diet supplemented with 0.3% Bio-Mos; and 4) the negative control diet plus 2300 ppm Zn as ZnO, and supplemented with 0.3% Bio-Mos. Substitutions in all diets were made at the expense of corn. Phase 1 diets were formulated to contain 1.50% lysine, 0.87% methionine plus cystine, 0.90% calcium, 0.80% phosphorus, and 14.53% lactose and were fed for a period of 10 d. Upon completion of the Phase 1 diet, pigs were fed a Phase 2 diet (1.35% lysine) from day 10 to 24 and a Phase 3 diet (1.20% lysine) from day 24 to 38 postweaning (Table 1). Pig BW and feed intake were determined at the initiation of the study and weekly thereafter to evaluate ADG, ADFI, and F/G.

Pigs were housed in an off-site nursery facility in pens with two nipple waterers, a five-hole feeder, and Maxima nursery flooring. Pigs had ad libitum access to feed and water. For the first week of the trial, the nursery was maintained at 85ºF and decreased 1ºF/wk.

In vitro cellular immune response was measured using a lymphocyte blastogenesis assay (Blecha et al., 1983). A total of 72 pigs (18 pigs per treatment) were sampled, and approximately 15 ml of blood was collected in heparinized tubes by venipuncture for isolation of mononuclear cells. Cells were plated at a concentration of 2×10^6 cells/ml, and phytohemagglutinin (PHA) and pokeweed mitogen (PWM) were used as mitogens for cellular proliferation at a concentration of 10 mg/ml. Incubation, labeling with [3]H-thymidine, and cell harvesting followed procedures outlined by van Heugten and Spears (1997). Uptake of [3]H-thymidine served as the measure of cell proliferation.

Performance data were analyzed as a randomized complete-block design with pen as the experimental unit and blocks based on initial BW. Analysis of variance was performed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). The effects of block, ZnO, Bio-Mos, and Bio-Mos x ZnO interaction effects were evaluated.

Results and Discussion

Treatment means are presented where a Bio-Mos x ZnO interaction was observed (Table 2), while data in which no such interaction was observed and the results of the lymphocyte proliferation assay are presented as main-effect means (Table 3). Average daily gain ($P < 0.01$), ADFI ($P < 0.01$), and F/G ($P < 0.01$) improved in pigs fed diets containing 2465 ppm Zn during Phase 1 compared to those fed diets with 165 ppm Zn.

Average daily gain increased ($P < 0.01$) during the first week (day 10 to 17) of Phase 2 in pigs fed diets supplemented with 2465 ppm Zn. Additionally, Zn supplementation increased ADFI from day 10 to 17, day 17 to 24, and overall in Phase 2 ($P < 0.01$, $P = 0.06$, and $P < 0.01$, respectively). Average daily gain and F/G increased during the second week (day 17 to 24) of Phase 2 and the entire phase (day 10 to 24) with the addition of Bio-Mos at 165 ppm Zn but were similar when Bio-Mos was added to diets with 2465 ppm Zn. This resulted in a tendency for a Bio-Mos x ZnO interaction during days 17 to 24 of the trial and a significant interaction overall in Phase 2 (day 10 to 24) for ADG ($P = 0.14$ and $P < 0.05$, respectively). Also a tendency for an interaction for F/G ($P = 0.14$) for these two intervals was observed.

During the fourth week of the study (day 24 to 31), ADG increased with the addition of Bio-Mos at 165 ppm Zn but decreased with the addition of Bio-Mos to diets supplemented with 2465 ppm Zn. This resulted in a Bio-Mos x ZnO interaction for ADG ($P < 0.05$). There were no significant interactions or main effects observed during the overall Phase 3 (day 24 to 38) period.

For the overall study (day 0 to 38), ADG and ADFI increased with the addition of Bio-Mos at 165 ppm Zn, but decreased with the addition of Bio-Mos in diets with 2465 ppm Zn. This resulted in a Bio-Mos x ZnO interaction for ADG ($P < 0.05$) and a tendency for an interaction for ADFI ($P = 0.14$). Feed/gain was improved ($P < 0.05$) in pigs fed diets with 2465 ppm Zn compared to those fed diets containing 165 ppm Zn. Dietary treatments did not affect lymphocyte proliferation after mitogen stimulation in samples taken on days 10, 11, 14, and 15, postweaning.

As observed in the current study, addition of ZnO at pharmacological levels in previous experiments resulted in increased gain and feed intake in young pigs (Hahn and Baker, 1993; Smith et al., 1997). However, response to the addition of Bio-Mos was not as pronounced as observed in a prior study comparing it with copper sulfate addition (Davis et al., 1999). This may be due to the higher level of Bio-Mos fed during Phase 1 of this study (0.3% of the diet) compared to the level fed in the previous experiment (0.2% of the diet). Several tendencies for a Bio-Mos x ZnO interaction were observed, in which ADG increased with Bio-Mos addition to the low Zn diets but decreased with the addition of Bio-Mos when the diet was supplemented with 2300 ppm ZnO. Titration of a yeast glucan product (Macrogard) indicated that performance does not increase linearly with increasing dosage (Schoenherr et al., 1994). Additionally, immunostimulants often have a maximum level that can be administered, after which there is a lack of a response or a toxic effect on performance (Raa, 1998).

The effect of dietary Bio-Mos and ZnO addition on the immunocompetence of weanling pigs was evaluated by mitogen-stimulated lymphocyte proliferation. As observed in a previous experiment (Davis et al., 1999), neither Bio-Mos nor ZnO had a significant effect on the proliferation of lymphocytes in vitro; however, stimulated cell cultures from pigs supplemented with Bio-Mos and 2465 ppm Zn had numerically greater proliferation of lymphocytes.

Implications

The results of this study suggest a tendency for Bio-Mos added at 0.2% of the diet to improve weanling pig performance in pigs fed 165 ppm Zn during Phase 2 (day 10

to 24), Phase 3 (day 24 to 38), and the overall trial (day 0 to 38). However, addition of Bio-Mos at 0.3% of the diet during Phase 1 (day 0 to 10) tended to increase F/G and may indicate a negative effect associated with the higher dietary Bio-Mos level.

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Table 1. Composition of basal diets.[a]

Item, %	Phase 1	Phase 2	Phase 3
Yellow corn	39.17	48.07	62.325
Steam rolled oats	5.00	-	-
Deproteinized whey	17.50	10.00	-
Processed soy protein (Optipro)	6.75	-	-
Soybean meal, 48% CP	10.00	28.30	30.00
AP-301	2.00	2.00	-
AP-920	3.75	-	-
Select menhaden fish meal	8.50	4.00	-
Soybean oil	4.00	4.00	-
Fat	-	-	4.00
Ethoxyquin	0.03	0.03	0.03
Lysine HCl	-	-	0.16
Threonine	0.05	-	-
Methionine	0.15	0.12	0.07
Tylan-40	-	-	0.125
Neo-terromycin 10/5	1.00	1.00	-
Mineral premix (NB-8557B)[b]	0.15	0.15	0.15
Vitamin premix (NB-6157B)[b]	0.25	0.25	0.25
Dicalcium phosphate	1.30	1.40	1.88
Calcium carbonate	0.10	0.38	0.61
Salt	0.30	0.30	0.40
Calculated Composition			
Lysine	1.50	1.35	1.20
Threonine	0.98	0.87	0.77
Tryptophan	0.27	0.26	0.24
Methionine + cystine	0.90	0.82	0.72
Calcium	0.90	0.80	0.80
Phosphorus	0.80	0.70	0.70
Metabolizable energy, kcal/lb	1533	1542	1557
Lactose	14.53	8.3	-

[a] Basal diets were supplemented with 0.32% ZnO or with Bio-Mos added at 0.3% (Phase 1) or 0.2% (Phase 2 and 3) to provide four diets in each phase with and without Bio-Mos and with and without 2465 ppm Zn. Zinc oxide and Bio-Mos were added at the expense of corn.

[b] Vitamins and minerals met or exceeded NRC (1998) requirements.

Table 2. Treatment means showing interaction effects of Bio-Mos and zinc oxide on gain, feed intake, and efficiency of segregated early weaned pigs.

Bio-Mos, %	0	0	0.2	0.2	
Zinc oxide, ppm	165	2465	165	2465	SE
Phase 2 (days 17 to 24)					
ADG, lb[a]	1.08	1.16	1.15	1.10	0.04
F/G[a]	1.33	1.35	1.26	1.35	0.02
Phase 2 (days 10 to 24)					
ADG, lb[b]	0.83	0.95	0.91	0.92	0.03
F/G[a]	1.45	1.38	1.35	1.38	0.04
Phase 3 (days 24 to 31)					
ADG, lb[b]	1.13	1.28	1.26	1.23	0.05
Overall trial (days 0 to 38)					
ADG, lb[b]	0.88	0.98	0.93	0.95	0.03
ADFI, lb[a]	1.35	1.44	1.38	1.41	0.05

[a] Tendency for Bio-Mos x zinc oxide interaction; P = 0.14.

[b] Bio-Mos x zinc oxide interaction; P < 0.05.

Table 3. Main effects of Bio-Mos and zinc oxide addition to nursery pig diets.[a]

	Bio-Mos[b]			Zinc oxide		
	–	+	SE	–	+	SE
Phase 1 (days 0 to 10)						
ADG, lb[c]	0.40	0.40	0.02	0.35	0.45	0.02
ADFI, lb[c]	0.52	0.52	0.02	0.48	0.56	0.02
F/G[d]	1.34	1.33	0.05	1.41	1.26	0.05
Days 10 to 17						
ADG, lb[c]	0.67	0.70	0.03	0.62	0.75	0.03
ADFI, lb[c]	0.98	0.98	0.03	0.92	1.04	0.03
F/G	1.49	1.42	0.04	1.50	1.41	0.04
Days 17 to 24						
ADFI, lb[e]	1.52	1.49	0.03	1.46	1.54	0.03
Phase 2 (days 10 to 24)						
ADFI, lb[c]	1.25	1.24	0.03	1.19	1.29	0.03
Days 24 to 31						
ADFI, lb	1.72	1.69	0.06	1.70	1.71	0.06
F/G	1.42	1.34	0.05	1.42	1.34	0.05
Days 31 to 38						
ADG, lb	1.27	1.24	0.04	1.25	1.26	0.04
ADFI, lb	2.26	2.29	0.05	2.27	2.28	0.05
F/G	1.76	1.84	0.04	1.81	1.80	0.04
Phase 3 (days 24 to 38)						
ADG, lb	1.24	1.24	0.03	1.23	1.26	0.03
ADFI, lb	1.99	1.99	0.05	1.98	1.99	0.05
F/G	1.59	1.59	0.03	1.61	1.57	0.03
Overall trial (days 0 to 38)						
F/G[d]	1.47	1.45	0.02	1.49	1.43	0.02
Lymphocyte proliferation, cpm[f]						
Unstimulated	488	424	169	341	571	158
PHA, 30 mg/ml	34942	36790	3412	35143	36588	3251
PWM, 10 mg/ml	29325	30597	3092	28697	31225	2946

[a] Data are means of nine pens/treatment with six pigs/pen. Pigs were 15 to 21 d of age and averaged 13.7 ± 0.07 lb of BW at the initiation of the study.

[b] Bio-Mos was supplemented at 0.3% during Phase 1 and at 0.2% during Phase 2 and 3.

[c] Zinc oxide effect; $P < .01$.

[d] Zinc oxide effect; $P < .05$.

[e] Zinc oxide effect; $P = .06$.

[f] Data are means of nine pens/treatment with two pigs/pen. One blood sample was collected from each pig on one of 4 d beginning on day 10 and ending on day 15 of the trial. Data are expressed as counts per minute (cpm).

Effect of Concentration of Mannan Oligosaccharide (Bio-Mos) Addition With and Without Zinc Oxide on Performance and Immunocompetence of Weanling Pigs

E. Davis, C. Maxwell, D. Brown, and Z. Johnson[1]

Story in Brief

A total of 216 barrows (1/2 Large White x 1/4 Duroc x 1/4 Landrace; 21 ± 2 d of age; 10.1 ± 0.01 lb BW) were used to determine the potential for Bio-Mos to serve as a replacement for pharmacological concentrations of zinc oxide. Pigs were blocked by initial BW and penned in groups of six with six pens/treatment in an off-site nursery. Treatments were arranged as a 2 x 3 factorial with three concentrations of Bio-Mos (0%, 0.2%, and 0.3%) and two concentrations of Zn (165 ppm and 2465 ppm). Experimental diets were fed throughout the study and contained 1.5% lysine during Phase 1 (day 0 to 10), 1.35% lysine during Phase 2 (day 10 to 24), and 1.2% lysine during Phase 3 (day 24 to 38). Two pigs/pen were bled via venipuncture, and a lymphocyte blastogenesis assay was performed. The addition of ZnO improved ($P < 0.05$) ADG, ADFI, and F/G during Phase 1 and in the overall trial (day 0 to 38). Supplementation with Bio-Mos at 0.3% increased ADG and improved F/G during Phase 1 and in the overall study when compared to pigs fed 0.2% Bio-Mos, but performance was not different from pigs fed diets without Bio-Mos. During Phase 2, ADG decreased in pigs fed 0.2% Bio-Mos in diets containing 165 ppm Zn but increased with the addition of 0.3% Bio-Mos. However, the addition of Bio-Mos at 0.2% and 0.3% in diets containing 2465 ppm Zn improved ADG (interaction, $P < 0.05$). Lymphocyte proliferation in response to pokeweed mitogen increased in pigs fed diets containing 2465 ppm Zn with 0.2% Bio-Mos when compared to pigs fed 0 or 0.3% Bio-Mos but was similar for all Bio-Mos concentrations in diets with 165 ppm Zn (tendency for an interaction, $P = 0.13$). Response to Bio-Mos seems to be dependent on the concentration of Bio-Mos and ZnO in the diet.

Introduction

Bio-Mos is a mannan oligosaccharide derived from the cell wall of yeast that has resulted in improved weight gain and feed efficiency when fed to weanling pigs and broiler chicks. The effect of Bio-Mos on the immune system is not as well documented. Previous research with yeast glucans reported an enhancement of nonspecific immunity in fish (Engstad et al., 1992) and an improvement in the immune response of young pigs. In addition, the conditions under which Bio-Mos is an effective supplement in weanling pig diets needs to be assessed. Previous work comparing Bio-Mos and the addition of copper sulfate (Davis et al., 1999) resulted in significant ADG and F/G responses to Bio-Mos. The pigs used for this study were from a facility with a history of several disease problems. In a subsequent experiment (Davis et al., 2000) comparing Bio-Mos and ZnO addition and obtaining pigs from a different source, main effects due to the addition of Bio-Mos were not observed, although there were some tendencies for Bio-Mos x ZnO interactions. Therefore, this study was conducted to confirm the previous response to Bio-Mos using the same source of pigs as in the initial nursery study and to further evaluate the efficacy of Bio-Mos supplementation in diets with and without growth-promoting levels of ZnO. In addition, a second concentration of Bio-Mos was evaluated based upon results of a study conducted at Louisiana State University and our previous observations of a decreased performance in pigs fed 0.3% Bio-Mos in Phase 1.

Experimental Procedures

A total of 216 weanling barrows (21 ± 2 d of age; 10.1 ± 0.01 lb BW) were obtained from a single source and transported to the University of Arkansas off-site nursery facility. Pigs were blocked by initial BW and penned with six pigs/pen (six pens/treatment). Six dietary treatments consisted of two concentrations of inorganic Zn (165 and 2465 ppm) and three concentrations of Bio-Mos (0, 0.2%, or 0.3%, Alltech, Nicholasville, KY) in a 2 x 3 factorial arrangement of treatments. The specific diets during the first 10 d postweaning (Phase 1, Table 1) consisted of the

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following: 1) a negative control diet containing Zn as $ZnSO_4$ at 165 ppm; 2) the negative control diet supplemented with 0.2% Bio-Mos; 3) the negative control diet supplemented with 0.3% Bio-Mos; 4) the negative control diet plus 2300 ppm Zn as ZnO; 5) the negative control diet plus 2300 ppm Zn as ZnO, and supplemented with 0.2% Bio-Mos; 6) the negative control diet plus 2300 ppm Zn as ZnO, and supplemented with 0.3% Bio-Mos.

Treatment diets were fed throughout Phase 2 and 3. Substitutions in all diets were made at the expense of corn. Phase 1 diets were formulated to contain 1.50% lysine, 0.90% methionine plus cystine, 0.90% calcium, 0.80% phosphorus, and 14.53% lactose and were fed for a period of 10 d. Pigs were then fed a Phase 2 diet (1.35% lysine) from day 10 to 24 and a Phase 3 diet (1.20% lysine) from day 24 to 38 postweaning (Table 1).

Pigs were housed in an off-site nursery facility in pens with two nipple waterers, a five-hole feeder, and Maxima nursery flooring. Pigs had ad libitum access to feed and water. For the first week of the trial, the nursery was maintained at 85ºF and ambient temperature was decreased 1ºF/wk throughout the study.

Pig BW and feed intake were determined at the initiation of the study and weekly to evaluate ADG, ADFI, and F/G. *I*n vitro cellular immune response was measured using a lymphocyte blastogenesis assay (Blecha et al., 1983), in which a total of 72 pigs (18 pigs/treatment) were sampled and approximately 15 ml of blood was collected in heparinized tubes by venipuncture for isolation of mononuclear cells. Phytohemagglutinin (PHA) and pokeweed mitogen were used as mitogens at a concentration of 30 and 20 mg/ml, respectively. Uptake of [3]H-thymidine served as the measure of cell proliferation.

Performance data were analyzed as a randomized complete block design with pen as the experimental unit and blocks based on initial BW. Analysis of variance was performed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). The effects of block, ZnO, Bio-Mos, and Bio-Mos x ZnO interaction were evaluated. When a significant interaction was observed, treatment means were separated using the PDIFF option of the LSMEANS statement in PROC GLM. Main effect means were evaluated when the interaction was not significant, and the same procedure was used to separate Bio-Mos main effect means.

Results and Discussion

Data in which no Bio-Mos x ZnO interactions were observed are presented as main effect means (Table 2), while treatment means are presented graphically when there was a Bio-Mos x ZnO interaction. Average daily gain increased ($P < 0.05$) and F/G improved ($P < 0.05$) during Phase 1 and in the overall study (days 0 to 38) when Bio-Mos was supplemented at 0.3% when compared to pigs fed 0.2% Bio-Mos. However, there was no difference between pigs fed 0.3% Bio-Mos and those fed diets without Bio-Mos. Addition of 2465 ppm Zn as ZnO to in the diet in Phase 1 improved ADG, ADFI and F/G ($P < 0.05$).

During week 1 of Phase 2 (days 10 to 17), performance was not significantly affected by Bio-Mos addition at either the 0.2% or 0.3% level. However, ADG, ADFI, and F/G were improved in pigs fed 2465 ppm Zn ($P < 0.05$). During week 2 of Phase 2 (days 17 to 24), ADG was improved in pigs fed Bio-Mos at the 0.2% level in combination with 2465 ppm Zn. However, ADG decreased in pigs fed 165 ppm Zn in combination with the 0.2% concentration of Bio-Mos. Gain was similar in pigs fed either concentration of Zn at the 0.3% concentration of Bio-Mos supplementation. This resulted in a Bio-Mos x ZnO interaction ($P < 0.02$, Figure 1). Average daily feed intake increased ($P < 0.05$) with ZnO addition from days 17 to 24. For the combined Phase 2 period (days 10 to 24), pigs fed Bio-Mos at either the 0.2% or 0.3% concentration in combination with 2465 ppm Zn tended to have improved ADG, whereas gain tended to be reduced at both concentrations of Bio-Mos supplementation when pigs were fed diets containing 165 ppm Zn (interaction, $P < 0.04$; Figure 2).

For the overall study (days 0 to 38), ADG, ADFI, and F/G improved ($P < 0.05$) when ZnO was supplemented in the diet, while Bio-Mos addition improved ($P < 0.05$) F/G when supplemented at 0.2%. Lymphocyte proliferation in response to PWM tended to be increased in pigs fed diets containing 2465 ppm Zn with 0.2% Bio-Mos, but was similar for all Bio-Mos concentrations in diets with 165 ppm Zn (tendency for an interaction, $P = 0.13$; Figure 3).

As in a previous study conducted at the University of Arkansas comparing Bio-Mos and ZnO (Davis et al., 2000) and in other studies evaluating the young pig's response to Zn (Hahn and Baker, 1993; Smith et al., 1997), ZnO supplementation improved performance during Phase 1 and 2 of the current trial. Response to Bio-Mos in the current study was more pronounced than in a previous trial comparing Bio-Mos and ZnO (Davis et al., 2000). This may be a response to the different disease status between the two herds. The pigs in the first study with Zn were from a farm without any evident disease problems, while the pigs used in this study were from the same facility as pigs in a trial comparing $CuSO_4$ and Bio-Mos (Davis et al., 1999) in which a response to Bio-Mos was observed.

As in the similar study presented in this report (Davis et al., 2000), a Bio-Mos x ZnO interaction for ADG was observed during Phase 2 of the experiment in which response to Bio-Mos supplementation depended on the concentration of Zn in the diet. However, in the current study, response to Bio-Mos supplementation was improved at 2465 ppm Zn but not at 165 ppm, while in the previous experiment Bio-Mos response improved when supplemented to diets with 165 ppm Zn, but not those with 2465 ppm.

Additionally, pigs fed Bio-Mos in the current study tended to have a greater lymphocyte proliferation response to PWM. This is consistent with non-significant lymphocyte proliferation responses to PWM in pigs fed supplemental Bio-Mos in two previous trials (Davis et al., 1999; Davis et al., 2000).

Implications

Bio-Mos supplementation resulted in improved performance at higher dietary Zn concentrations in this study than in the previous experiment. This discrepancy in response between the two studies suggests that the response of nursery pigs to Bio-Mos may be dependent on several factors such as environmental conditions, disease status, production facilities, or genetic diversity. Under certain management conditions, Bio-Mos may provide an effective alternative to the additions of pharmacological concentrations of Zn commonly added to nursery pig diets.

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Table 1. Composition of basal diets.[a]

Item, %	Phase 1	Phase 2	Phase 3
Yellow corn	39.17	48.07	62.325
Steam rolled oats	5.00	–	–
Deproteinized whey	17.50	10.00	–
Processed soy protein (Optipro)	6.75	–	–
Soybean meal, 48% CP	10.00	28.30	30.00
AP–301	2.00	2.00	–
AP–920	3.75	–	–
Select menhaden fish meal	8.50	4.00	–
Soybean oil	4.00	4.00	–
Fat	–	–	4.00
Ethoxyquin	0.03	0.03	0.03
Lysine HCl	–	–	0.16
Threonine	0.05	–	–
Methionine	0.15	0.12	0.07
Tylan–40	–	–	0.125
Neo-terromycin 10/5	1.00	1.00	–
Mineral premix (NB–8557B)[b]	0.15	0.15	0.15
Vitamin premix (NB–6157B)[b]	0.25	0.25	0.25
Dicalcium phosphate	1.30	1.40	1.88
Calcium carbonate	0.10	0.38	0.61
Salt	0.30	0.30	0.40
Calculated composition			
Lysine	1.50	1.35	1.20
Threonine	0.98	0.87	0.77
Tryptophan	0.27	0.26	0.24
Methionine + cystine	0.90	0.82	0.72
Calcium	0.90	0.80	0.80
Phosphorus	0.80	0.70	0.70
Metabolizable energy, kcal/lb	1533	1542	1557
Lactose	14.53	8.3	–

[a] Basal diets were supplemented with 0.32% zinc oxide or with Bio–Mos added at 0.3% or 0.2% to provide six diets in each phase with each Bio–Mos level (0, 0.2%, and 0.3%) represented with and without 2300 ppm zinc as zinc oxide. Zinc oxide and Bio–Mos were added at the expense of corn.

[b] Vitamins and minerals met or exceeded NRC (1998) requirements.

Table 2. Main effect means showing Bio-Mos and zinc oxide addition to nursery pig diets.[a]

	Bio-Mos (%)				Zinc oxide (ppm)		
	0	0.2	0.3	SEM	165	2465	SEM
Phase 1 (days 0 to 10)							
ADG, lb[b]	0.36[y,z]	0.33[z]	0.40[y]	0.02	0.32	0.40	0.02
ADFI, lb[b]	0.44	0.43	0.45	0.02	0.41	0.47	0.02
F/G [b]	1.23[z]	1.35[y]	1.14[z]	0.05	1.30	1.19	0.04
Phase 2 (days 10 to 17)							
ADG, lb[b]	0.69	0.72	0.75	0.03	0.65	0.79	0.02
ADFI, lb[b]	0.95	0.97	1.00	0.03	0.92	1.02	0.02
F/G [b]	1.37	1.37	1.34	0.03	1.41	1.31	0.02
Phase 2 (days 17 to 24)							
ADFI, lb[b]	1.36	1.42	1.35	0.04	1.31	1.44	0.04
F/G	1.22	1.29	1.24	0.04	1.21	1.28	0.03
Phase 2 (days 10 to 24)							
ADFI, lb[b]	1.15	1.19	1.17	0.03	1.11	1.23	0.03
F/G	1.30	1.33	1.29	0.02	1.31	1.29	0.02
Phase 3 (days 24 to 31)							
ADG, lb	1.11	1.12	1.14	0.02	1.14	1.11	0.02
ADFI, lb	1.77	1.82	1.83	0.03	1.81	1.80	0.03
F/G	1.59	1.63	1.60	0.02	1.60	1.62	0.02
Phase 3 (days 31 to 38)							
ADG, lb	1.35	1.34	1.31	0.03	1.30	1.36	0.02
ADFI, lb	1.81	1.82	1.76	0.05	1.80	1.80	0.04
F/G	1.34	1.36	1.34	0.03	1.38	1.32	0.03
Phase 3 (days 24 to 38)							
ADG, lb	1.23	1.23	1.22	0.02	1.22	1.24	0.02
ADFI, lb	1.79	1.82	1.79	0.03	1.81	1.80	0.03
F/G	1.47	1.50	1.47	0.02	1.49	1.47	0.02
Overall trial (days 0 to 38)							
ADG, lb[b]	0.93	0.92	0.94	0.01	0.90	0.96	0.01
ADFI, lb[b]	1.26	1.29	1.28	0.02	1.25	1.31	0.02
F/G [b]	1.35[z]	1.40[y]	1.33[z]	0.02	1.38	1.34	0.01
Lymphocyte proliferation,[c] cpm							
Unstimulated	1169	716	1071	204	829	1142	166
PHA, 30 mg/ml	43046	50570	40549	6492	43593	45850	5301

Within a row, means without a common superscript letter differ ($P < 0.05$).

[a] Data are means of six pens/treatment with six pigs/pen. Pigs were 15 to 21 d of age and averaged 10.1 ± 0.01 lb BW at the initiation of the study.

[b] Zinc oxide effect; $P < 0.05$.

[c] Data are means of six pens/treatment with one pig/pen. One blood sample was collected from each pig on one of 4 d beginning on day 24 and ending on day 29 of the trial. Data are expressed as counts per minute (cpm).

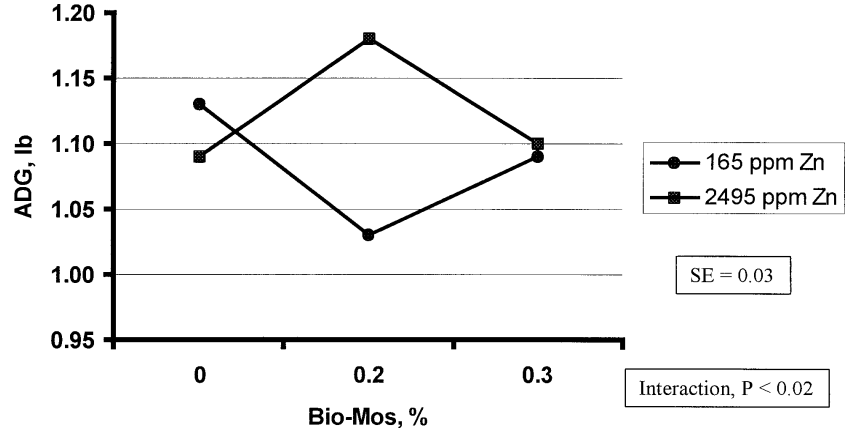

Figure. 1. Average daily gain response to Bio-Mos and zinc oxide addition in the diets of nursery pigs from days 17 to 24 (week 3).

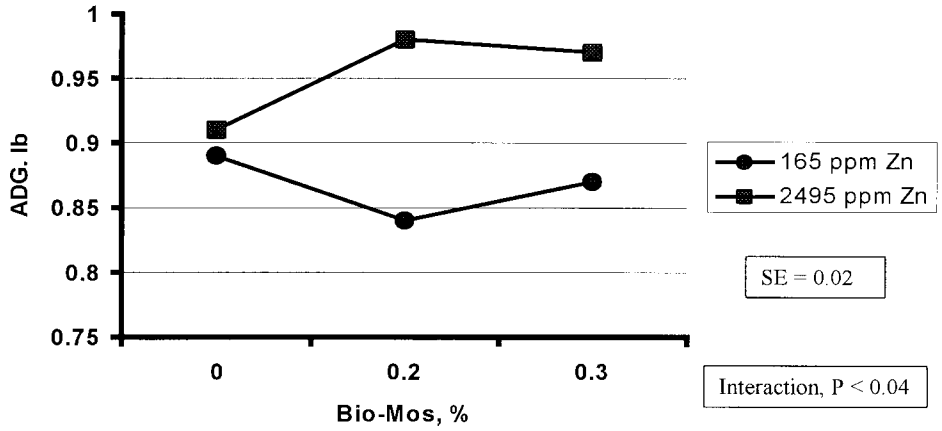

Figure. 2. Average daily gain response to Bio-Mos and zinc oxide addition in the diets of nursery pigs from days 10 to 24 (Phase 2).

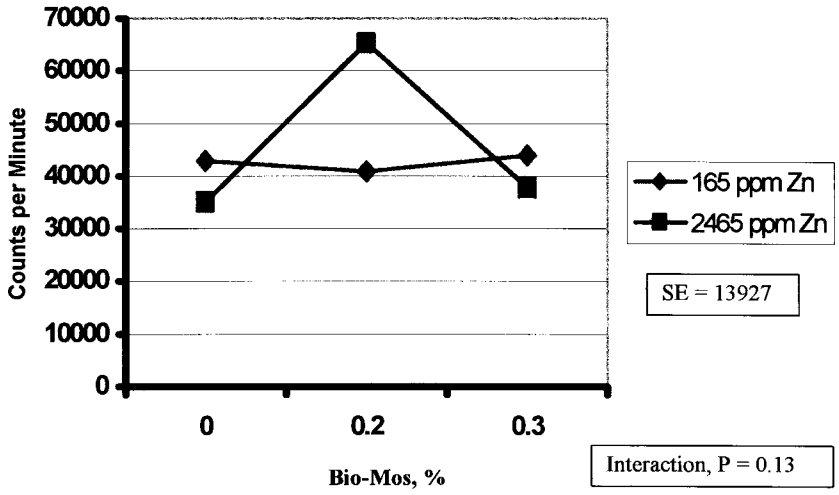

Figure. 3. Lymphocyte proliferation response to pokeweed mitogen in nursery pigs fed Bio-Mos and zinc oxide.

Potential for Profound (Multiple Protein Complex) as a Protein Source for Phase 1 Nursery Diets[a]

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Story in Brief

Protein sources for early-weaned pigs that will optimize performance are in limited supply and expensive. Egg protein has an excellent amino acid profile and should be an excellent protein source for young pigs, but the cost of processing has been prohibitive for eggs to be routinely utilized in swine Phase 1 nursery diets. American Dehydrated Foods, Inc., has recently developed an extrusion process using a combination of dry protein sources and liquid egg to produce a final multiple protein complex suitable for Phase 1 nursery diets. This new technology may provide an opportunity to produce a high-quality egg protein for use in diets for early-weaning pigs at costs lower than those associated with the currently available spray dried egg products. With use of this new process, egg protein can be incorporated with protein sources already used in young pig diets. This study was conducted to determine the potential for Profound, as a replacement for fish meal, in early-weaning pig diets. Results of this study indicate that Profound is an effective replacement for select menhaden fish meal in Phase 1 diets at either the 50 or 100% replacement level. Providing a processed soybean meal product (Optipro; Land O' Lakes, Inc) as the source of soybean meal in Profound did not improve performance.

Introduction

Pigs produced in conventional, intensively managed swine production systems are routinely weaned as early as 19 to 21 d of age and as early as 10 to 14 d of age for off-site segregated early weaning systems. At these early ages, pigs are very sensitive to the source of dietary protein. Many dietary proteins produce allergic reactions in which diarrhea, reduced growth, and increased mortality can occur (Bimbo and Crowther, 1992). Select-grade menhaden fish meal appears to be one of the most widely utilized protein sources because of a combination of consistent quality and competitive price. Inclusion levels of 8% to 9.3% have been shown to optimize gain and (or) feed intake (Stoner et al., 1990). However, its supply is limited, and therefore, this protein source is expensive.

Egg protein has an excellent amino acid profile (high in isoleucine) and should be an excellent protein source for young pigs. Several studies have suggested that heat-treated, spray-dried egg protein may replace a portion of the plasma protein without affecting performance (Owen et. al. 1993, Nessmith et. al. 1995). American Dehydrated Foods, Inc. (Springfield, MO) has developed an extrusion process using a combination of dry protein sources and liquid egg to produce a final multiple protein complex suitable for Phase 1 nursery diets. This may provide an opportunity to produce a high-quality, egg-containing protein source for use in diets for early-weaning pig at costs lower than those associated with spray-dried egg products. Using this process, egg protein can be co-produced with protein sources already used in young pig diets. Specific objectives of this study were to 1) determine the potential for Profound produced with Optipro (Land O' Lakes) as a protein source for Phase 1 nursery diets; 2) compare Optipro and soybean meal as the protein source in Profound; 3) determine the effect of level of Profound replacement of fish meal (50 and 100%) on performance; and 4) determine the effect of the experimental phase 1 diet on subsequent performance in phase 2 and 3.

Experimental Procedures

Allotment of Pigs. A total 216 weanling barrows (Line TT by line LL; 20 ± 2 d of age) were obtained from The Pork Group as a single source. Pigs were transported to University of Arkansas off-site nursery facilities, sorted by weight, and divided into six weight groups (blocks) with 36 pigs in each block. Pigs within each block were allotted into equal subgroups (six pigs/pen) with stratification based on weight.

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[a] Profound (multiple protein complex) was developed by ADF as a unique extruded product for use in swine nursery diets. This trial formula has been modified to include Optipro as a substitute for soybean meal.

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[2] Land O' Lakes, Webster City, IA.
[3] American Dehydrated Foods, Inc., Springfield, MO.

Treatments were then randomly assigned to pens (subgroups) within each of the weight groups.

Dietary Treatments. This study was conducted to determine the utility of Optipro or soybean meal in combination with poultry meal and egg protein as a replacement for fish meal in Phase 1 diets for pigs weaned at 20 ± 2 d of age and reared in an off-site nursery.

Diets during the first 10 d postweaning (Phase 1) consisted of the following, and are detailed in Table 1:

1. A negative control diet devoid of fish meal.
2. A positive control diet containing 8.00% fish meal with fish meal added at the expense of 48% soybean meal on an equal lysine basis (fish meal replaces 13.50% soybean meal).
3. The positive control diet with Profound w/Optipro replacing 50% of the fish meal on an equal lysine basis (Profound w/Optipro replaces 4.0% fish meal).
4. The positive control diet with Profound w/Optipro replacing 100% of the fish meal on an equal lysine basis (Profound w/Optipro replaces 8.0% fish meal).
5. The positive control diet with Profound w/soybean meal replacing 50% of the fish meal on an equal lysine basis (Profound w/soybean meal replaces 4.0% fish meal).
6. The positive control diet with Profound w/soybean meal replacing 100% of the fish meal on an equal lysine basis (Profound w/soybean meal replaces 8.0% fish meal).

Substitutions in all diets were made at the expense of corn. Dietary metabolizable energy was maintained constant by adding soybean oil. Diets were formulated to contain 1.60% lysine, 0.92% methionine plus cystine, 0.90% calcium, 0.80% phosphorus, and 14.70% lactose. Upon completion of the phase 1 diet, a common Phase 2 diet (Table 2, 1.35% lysine) was fed from day 10 to 24 postweaning. Upon completion of Phase 2, a common phase 3 diet (Table 2; 1.20% lysine) was fed from day 24 to 38 postweaning.

Housing. Pigs were housed in an off-site nursery facility in pens (20 ft^2) with two nipple waterers, a four-hole feeder, and Maxima nursery flooring (Double L Group, LTD.). Pigs had ad libitum access to feed and water. For the first week of the trial, the nursery was maintained at 84ºF and decreased 2ºF/wk.

Data Collection. Pig BW and feed intake was determined at initiation, at the end of phase 1, and weekly thereafter to evaluate ADG, ADFI, and F/G.

Statistical Analysis. Data were analyzed as a randomized complete-block design with pen as the experimental unit and blocks based on initial BW. Analysis of variance was performed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). The effects of source of soybean protein, level of fish meal replacement, and the source x level of replacement interaction were evaluated. In addition, contrast statements were included to compare the negative control (treatment 1, 0% fish meal) vs. the positive control (treatment 2, 8.0% fish meal) and treatment 1 vs. the average of all Profound treatments (treatments 3, 4, 5, and 6).

Results and Discussion

Means of each dietary phase are presented in Table 3. During Phase 1, pigs fed fish meal tended to grow faster (20%, $P < 0.18$) and were more efficient ($P < 0.03$) than pigs receiving the negative control diet (treatment 1 vs. treatment 2). Average daily feed intake was similar between the two treatments ($P < 0.69$). During Phase 2, when pigs were fed a common diet, pigs previously fed the negative control diet (treatment 1) or the positive control fish meal diet had similar gain and feed intake, but pigs previously fed the negative control diet tended to have improved F/G ($P < 0.11$). Although differences were not significant, pigs fed the fish meal diets were consistently heavier than those fed the negative control diet and weighed 2.1 lb more at the completion of the study.

Performance, measured by ADG, ADFI, or F/G during Phase 1, 2, or 3 or for the overall experiment, was similar among pigs fed the Profound diets formulated with either Optipro or soybean meal (treatments 3 and 4 vs. treatments 5 and 6). Similarly, pigs fed either the 50% or 100% replacement of fish meal with either Profound formulated with Optipro or Profound formulated with soybean meal had similar performance (treatments 3 and 5 vs. treatments 4 and 6). This study suggests that performance among pigs fed the Profound diets with either formula or at the 50 or 100% replacement of fish meal produced similar performance throughout the nursery study.

A direct comparison of pigs fed the Profound diets (treatments 3, 4, 5, and 6) with those fed the positive control fish meal diet (treatment 2) indicates that ADG, ADFI, and F/G were similar during Phase 1 when the specific treatments were fed. During Phase 2, when a common diet was fed to all treatment groups, pigs previously fed the positive control fish meal diet (treatment 2) had lower F/G than those fed the four Profound diets (treatments 3, 4, 5,or 6). Neither ADG nor ADFI during Phase 2 was significantly affected by the previous feeding of the fish meal or Profound diets during Phase 1. Similarly, for Phase 3 and for the overall study, performance was similar among pigs fed the positive control fish meal diet (treatment 2) or those fed the four Profound treatments (treatments 3, 4, 5, and 6).

This study confirms the superior performance of pigs fed select-grade menhaden fish meal during Phase 1 when compared to those fed soybean meal (Stoner et al., 1990). In addition, results of this study indicate that Profound is an effective replacement for select-grade menhaden fish meal in Phase 1 diets at either 50% or 100% replacement. This study suggests that the transition to a Phase 2 diet may be improved in pigs fed the Profound diets when compared to those fed fish meal during Phase 1, as evidenced by the improved feed efficiency. Providing a processed (Optipro) soybean meal product as the source of soybean meal in Profound did not improve performance.

Implications

Results of this study indicate that Profound, a product developed utilizing extrusion to process a combination of dry protein sources and liquid egg, is an effective replacement for select-grade menhaden fish meal in Phase 1 diets at either the 50 or 100% replacement. Providing a processed (Optipro) soybean meal product as the source of soybean meal in Profound did not improve performance.

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Table 1. Composition of experimental phase 1 diets.

	Phase 1 diets					
	1	2	3	4	5	6
Item, %	Negative control	Positive fish meal control	50% Fish *meal rep.* Prfound w/Optipro	100% Fish *meal rep.* Profound w/Optipro	50% Fish *meal rep.* Profound w/soybean meal	100% Fish *meal rep.* Profound w/soybean meal
Yellow corn	31.22	39.16	36.35	33.48	36.26	33.35
Steam rolled oats	5.00	5.00	5.00	5.00	5.00	5.00
Lactose	15.00	15.00	15.00	15.00	15.00	15.00
AP-301	1.75	1.75	1.75	1.75	1.75	1.75
AP –920 (plasma protein)	3.00	3.00	3.00	3.00	3.00	3.00
Soybean meal, 48% CP	33.80	20.30	20.30	20.30	20.30	20.30
Select menhaden fish meal	**0.00**	**8.00**	**4.00**	**0.00**	**4.00**	**0.00**
Profound w/Optipro	**0.00**	**0.00**	**6.00**	**12.00**	**0.00**	**0.00**
Profound w/soybean meal	**0.00**	**0.00**	**0.00**	**0.00**	**6.00**	**12.00**
Soybean oil	4.56	3.45	3.90	4.40	3.90	4.40
Ethoxyquin	0.03	0.03	0.03	0.03	0.03	0.03
Neoterromycin 10/5	1.00	1.00	1.00	1.00	1.00	1.00
Zinc oxide	0.30	0.30	0.30	0.30	0.30	0.30
$CuSO_4$	0.07	0.07	0.07	0.07	0.07	0.07
Mineral premix (NB-8557B)	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix (NB-6157B)	0.25	0.25	0.25	0.25	0.25	0.25
Dicalcium phosphate	2.19	1.25	1.55	1.90	1.62	1.95
Calcium carbonate	0.74	0.30	0.40	0.46	0.40	0.51
Lysine	0.15	0.16	0.18	0.20	0.18	0.20
Methionine	0.19	0.16	0.15	0.12	0.16	0.14
Threonine	0.10	0.12	0.10	0.09	0.11	0.10
Tryptophan	0.00	0.01	0.00	0.00	0.00	0.00
Isoleucine, 85%	0.00	0.04	0.02	0.00	0.02	0.00
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Calculated composition						
Lysine	1.60	1.60	1.60	1.60	1.60	1.60
Threonine	1.04	1.04	1.04	1.04	1.04	1.04
Tryptophan	0.31	0.29	0.29	0.31	0.30	0.32
Met + Cys	0.92	0.92	0.92	0.92	0.92	0.92
Isoleucine	0.94	0.91	0.91	0.91	0.91	0.92
Calcium	0.90	0.90	0.90	0.90	0.90	0.90
Phosphorus	0.80	0.80	0.80	0.80	0.80	0.80
Metabolizable energy	1548	1548	1548	1548	1547	1546
Lactose	14.70	14.70	14.70	14.70	14.70	14.70

Table 2. Composition of experimental Phase 2 and Phase 3 diets.

Item, %	Phase 2	Phase 3
Yellow corn	47.64	62.305
Soy meal, 48%	28.30	30.00
AP-301	2.00	0.00
Select menhaden fishmeal	4.00	0.00
Ethoxiquin	0.03	0.03
Lysine	0.00	0.16
Zinc oxide	0.30	0.00
Neoterramycin	1.00	0.00
Lactose	10.00	0.00
Methionine	0.08	0.02
$CuSO_4$	0.07	0.07
Mineral premix (NB-8557B)	0.15	0.15
Vitamin premix (NB-6157B)	0.25	0.25
Dicalcium phosphate	1.40	1.88
Fat	0.00	4.00
Soy oil	4.00	0.00
Calcium carbonate	0.38	0.61
Tylan 40	0.00	0.125
Salt	0.40	0.40
Calculated composition		
Lysine	1.35	1.20
Threonine	0.88	0.77
Tryptophan	0.26	0.24
Met + Cys	0.78	0.67
Calcium	0.80	0.80
Phosphorus	0.70	0.70
Metabolizable energy	1542.00	1557.00
Lactose	9.80	0.00

Table 3. Effect of Profound with Optipro or soybean meal at two levels of fish meal replacement on performance of nursery pigs (phase means).

	Treatment[a]						
	1	2	3	4	5	6	
Trait	Negative control	Positive fish meal control	50% Fish *meal rep.* Prfound w/Optipro	100% Fish *meal rep.* Profound w/Optipro	50% Fish *meal rep.* Profound w/soybean meal	100% Fish *meal rep.* Profound w/soybean meal	SE
ADG, lb							
Phase 1[b]	0.44	0.53	0.55	0.53	0.55	0.50	0.04
Phase 2	1.03	1.03	0.98	1.08	1.10	1.10	0.04
Phase 3	1.31	1.29	1.30	1.34	1.29	1.34	0.05
Overall (1–3)	1.01	1.07	1.00	1.04	1.03	1.03	0.03
ADFI, lb							
Phase 1	0.57	0.60	0.62	0.66	0.70	0.60	0.05
Phase 2	1.35	1.43	1.28	1.36	1.38	1.45	0.07
Phase 3	2.03	2.09	2.03	2.09	2.08	2.09	0.09
Overall (1–3)	1.39	1.45	1.58	1.44	1.46	1.46	0.06
F/G							
Phase 1[c]	0.761	0.891	0.898	0.819	0.792	0.835	0.039
Phase 2[d]	0.768	0.725	0.769	0.799	0.798	0.764	0.020
Phase 3	0.647	0.616	0.643	0.648	0.622	0.647	0.016
Overall (1–3)	0.732	0.739	0.729	0.728	0.703	0.710	0.016
Wt, lb							
Initial wt	13.76	13.76	13.76	13.79	13.76	13.76	0.013
Phase 1	18.14	19.00	19.29	19.14	19.25	18.76	0.450
Phase 2	33.11	34.61	32.96	34.22	34.68	34.19	0.996
Phase 3	52.25	54.34	51.68	53.26	52.78	53.02	1.283

[a] Six pigs per pen, six pens per treatment.

[b] Negative control vs. fish meal, $P < 0.18$.

[c] Negative control vs. fish meal, $P < 0.03$.

[d] Negative control vs. fish meal, $P < 0.15$, Positive control vs. treatments 3, 4, 5, and 6, $P < 0.02$.

Efficacy of Feather Meal for Improving Gain, Feed Efficiency and Carcass Composition in Growing Finishing Pigs

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Story in Brief

Crossbred barrows and gilts (n = 132; BW = 54.52 ± 0.18 lb) were used to assess the efficacy of hydrolyzed feather meal plus blood (FM) to improve performance and carcass composition in growing-finishing swine. Pigs were blocked by weight, segregated within blocks into subgroups based on sex and litter, and assigned randomly to 24 pens (five to six pigs/pen). Treatments were assigned randomly to pens and included 1) control corn-soybean meal (SBM) starter, grower, and finisher diets devoid of FM; 2) corn-SBM diet supplemented with 3% FM; and 3) corn-SBM diet supplemented with 6% FM. Feather meal plus blood was substituted for SBM on an equal lysine basis at the expense of corn. During the starter phase, there was a quadratic decrease in ADG ($P < 0.06$) and a quadratic increase in F/G ($P < 0.01$). However, during the grower phase, F/G decreased linearly ($P < 0.08$) as FM increased in the diet. Inclusion of FM had no effects ($P > 0.10$) on performance during the finisher phase, or the overall trial. Although carcasses from pigs fed 3% FM had greater average backfat (quadratic; $P < 0.02$) than carcasses from pigs fed control diets or diets containing 6% FM, dietary FM had no effect ($P > 0.10$) on lean carcass yield, lean ham yield, or ham fat yield. Substitution of FM for SBM in the diets of growing-finishing swine may improve feed efficiency during the grower phase with a potential to reduce diet cost, without dramatically affecting carcass composition.

Introduction

Feather meal plus blood (FM), a major byproduct of poultry processing, has been of interest to the swine and poultry industries because of its high protein content (80 to 85%). Feather meal is a relatively inexpensive protein source that has a higher concentration of valine, cystine, and threonine than soybean meal (SBM), and previous research has shown it to be a good source of extra dietary nitrogen (Chiba et al., 1995; Cabel et al., 1988). Feather meal has not been extensively used as a protein source in growing-finishing diets because of concerns about variability in quality and its low content of lysine. As a result of these concerns, FM is limited to about 5% of the diet for optimum performance (Chiba et al., 1996). Nevertheless, replacing SBM with up to 9% dietary FM enhanced leanness in finishing pigs (Chiba et al., 1995). However, Chiba and co-workers (1996) observed that feeding FM as the only source of protein in the diet, with lysine supplementation, reduced weight gain but had no effect on carcass cutability. This study was conducted to further assess the efficacy of hydrolyzed FM as a means of improving performance and carcass composition in growing-finishing pigs at reduced diet cost.

Experimental Procedures

Materials. Hydrolyzed FM containing 8% blood was obtained from Tyson's Foods, Inc. Protein Plant in Noel, MO, which was contributed by Tyson Specialty Products. Fresh poultry feathers were spread evenly on a conveyer, passed through a metal detector (to remove harmful metals), and hydrolyzed in a batch hydrolyser for 30 min at a pressure of 30 to 40 psi and a temperature of 170ºF. Feathers were hydrolyzed in a batch hydrolyzer to break keratin (long-chain proteins) into more digestible, smaller-chain proteins and to reduce microorganisms on the feathers. Blood was coagulated and added to the hydrolyzed feathers in the batch hydrolyser to increase the protein level of the product. This product was then dried in a direct contact dryer (natural gas fire dryer), milled through a mesh screen and shipped to the producer.

Allotment of Pigs. A total of 132 crossbred gilts and barrows (offspring of Yorkshire x Landrace females mated with Duroc x Hampshire sires) were moved from nursery facilities, sorted by weight, and divided into four weight groups (blocks) with 36 pigs in blocks 1 and 2 and 30 pigs in blocks 3 and 4. Pigs within each weight group were allotted into pens with six pigs per pen in blocks 1 and 2 and five

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pigs per pen in blocks 3 and 4. Stratification across pens was based on sex and litter. Treatments were then randomly assigned to pens (subgroups) within each of the four weight groups. A total of eight pens were randomly allotted to each of the three treatments during the starter, grower and finisher periods.

Experimental Treatments. Three dietary treatments consisted of three levels of FM (0, 3, or 6 %) in the starter, grower, and finisher diets (Table 1). The specific diets consisted of the following:

1. Control corn-soybean meal (SBM) starter, grower and finisher diets devoid of FM.

2. Corn-SBM diet supplemented with 3% FM (FM was substituted for SBM on an equal lysine basis at the expense of corn).

3. Corn-SBM diet supplemented with 6% FM (FM was substituted for SBM on an equal lysine basis at the expense of corn).

Pigs were fed a three-phase dietary program with transition from starter to grower and from grower to finisher occurring when the mean weight of each block reached 80 and 200 lb, respectively. The control diets met, or exceeded, NRC (1998) requirements for all nutrients. Diets were formulated to contain 1.16% lysine during the starter phase, 0.90% lysine during the grower phase, and 0.53% lysine during the finisher phase.

Performance Data. The study was terminated when the lightest block reached an average weight of 240 lb. Data collected were ADG, feed intake, and F/G during each of the three phases.

Carcass Data. Pigs were transported to Brown Packing Co. (Little Rock, AR), and harvested following industry-accepted procedures. Carcass weight and fat depth opposite the first rib, last rib, and last lumbar vertebra were recorded at 24 h postmortem. Hams from the left sides were weighed, boxed, shipped to Louisiana State University, and analyzed for lean and fat composition using a TOBEC unit. Prediction equations were utilized to estimate carcass lean yield and fat content (Knowles et al., 1998).

Statistical Analysis. Performance data for each phase and carcass data were analyzed as a randomized complete-block design with pen as the experimental unit and blocks based on initial body weight. Analysis of variance was performed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC.). Linear and quadratic polynomials were used to detect the response of replacing SBM with FM in the diet on performance and carcass characteristics.

Results and Discussion

Performance. During the starter phase, there was a quadratic decrease in ADG ($P < 0.06$), and an quadratic increase in F/G ($P < 0.01$; Table 2) because of inclusion of FM. However, during the grower phase, F/G decreased linearly ($P < 0.08$) as FM increased in the diet. Inclusion of FM had no effects ($P > 0.10$) on performance during the finisher phase or for the overall trial. As observed in the current study, previous research has shown that supplementation of FM to swine diets up to 6% had no adverse effect on ADG, ADFI, or final BW (Chiba et al., 1995; 1996). This was also observed in turkey (Eissler and Firman, 1996) and broiler (Cabel et al., 1987; 1988) diets using FM as an alternative protein source. However, the results of the current study contradict previous research by showing improved feed efficiency when a portion of SBM was substituted with dietary FM.

Carcass. Carcasses from pigs fed 3% FM had greater average backfat (quadratic; $P < 0.02$) and carcass fat measurements (quadratic; $P < 0.05$) than those fed the control diets or the diets supplemented with 6% FM (Table 3). However, dietary FM had no effect on lean ham yield, ham fat yield, ham and carcass weight or lean carcass yield. These results contradict other studies that reported that supplementation of feather meal enhanced leanness in finishing pigs (Chiba et al., 1995) and reduced abdominal fat in broilers (Cabel et al., 1988). Lean carcass traits found in previous studies could be attributed to excess supplementation of lysine and protein in the diet.

Implications

The results from this study indicate that substitution of FM for SBM in the diets of growing-finishing swine may improve feed efficiency with a potential to reduce cost, especially during the grower phase. In addition, inclusion of FM to the diets had no dramatic effects on weight gain or carcass composition.

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Table 1: Composition of research diets.

Ingredient, %	Starter Control[a]	Grower Control[a]	Finisher Control[a]
Corn	66.64	71.26	79.24
Soybean meal, 48%	28.80	18.23	3.84
Animal fat	1.90	0.35	0.00
Dicalcium phosphate	0.85	0.80	0.28
Calcium carbonate	0.76	0.86	0.86
Salt	0.50	0.50	0.35
Tylan 40	0.05	0.05	0.025
Lysine	0.15	0.15	0.15
Threonine	0.05	0.02	0.00
Midds	0.00	7.50	15.00
Mineral premix(NB-557B)	0.10	0.10	0.10
Vitamin premix(NB-6157B)	0.15	0.15	0.125
Ethoxyquin	0.03	0.03	0.03
Feather meal	0.00	0.00	0.00
Composition calculated, total			
Protein, crude	19.40	15.90	10.90
Lysine	1.16	0.90	0.53
Methionine	0.33	0.26	0.20
Methionine & cystine	0.67	0.55	0.43
Valine	0.91	0.75	0.51
Threonine	0.78	0.60	0.38
Tryptophan	0.23	0.18	0.10
Calcium	0.60	0.60	0.45
Phosphorus, available	0.23	0.23	0.15
Energy	1545	1505	1500
Composition calculated, available			
Lysine	1.030	0.790	0.450
Methionine	0.30	0.24	0.18
Methionine & cystine	0.59	0.54	0.37
Threonine	0.67	0.57	0.32
Tryptophan	0.20	0.16	0.09

[a] Control diets from starter, grower and finisher phases were supplemented with 3% or 6% FM. Feather meal plus blood was substituted for SBM on an equal lysine basis at the expense of corn.

Table 2. The effects of feather meal plus blood on performance in growing-finishing swine.

	Feather meal plus blood, %			
Item	0.0	3.0	6.0	SE
Starter (40–80 lb)				
ADG, lb[c]	1.269	1.126	1.155	0.035
ADFI, lb	3.261	3.143	3.053	0.086
F/G[a]	2.571	2.804	2.654	0.056
Grower (80–200 lb)				
ADG, lb	2.025	2.104	2.077	0.031
ADFI, lb	6.039	6.004	5.963	0.117
F/G[b]	2.984	2.851	2.872	0.043
Finisher (200–240 lb)				
ADG, lb	2.189	2.180	2.150	0.104
ADFI, lb	8.097	7.946	7.748	0.205
F/G	3.733	3.689	3.646	0.148
Overall (18–109 lb)				
ADG, lb	1.872	1.877	1.863	0.026
ADFI, lb	5.721	5.649	5.573	0.113
F/G	3.054	3.000	2.989	0.052
Wt, lb				
Initial	54.570	54.351	54.634	0.184
Starter[c]	84.775	80.883	82.267	0.973
Grower	200.683	201.244	201.077	2.288
Finisher	243.658	243.904	242.798	2.738

[a] Quadratic effect of supplementing FM ($P < 0.01$).

[b] Linear effect of supplementing FM ($P < 0.08$).

[c] Quadratic effect of supplementing FM ($P < 0.06$).

Table 3. Effect of dietary feather meal plus blood on carcass characteristics.

Trait[a]	Control	3% FMl	6% FMl	SE
BF, in[b]	1.26	1.31	1.23	0.02
HCW, lb	171.67	175.80	173.12	1.93
LCCW, lb	84.55	86.58	85.26	0.95
HAM wt., lb	20.96	21.11	20.95	0.27
C LEAN, lb	75.76	76.55	76.43	1.07
CAR FAT, lb[c]	56.64	59.64	57.34	1.01
H LEAN, lb	11.84	11.93	11.95	0.14
HAM FAT, lb	5.85	5.87	5.73	0.12

[a] BF= average backfat; HCW = hot carcass weight; LCCW = left chilled carcass weight; C LEAN = carcass lean; CAR FAT = carcass fat; H LEAN = ham lean.

[b] Quadratic effect of supplementing FM ($P < 0.02$).

[c] Quadratic effect of supplementing FM ($P < 0.05$).

The Use of Inactivated *Propionibacterium acnes* as an Immunostimulant in Off-Site Reared Piglets Challenged With *Actinobacillus pleuropneumoniae*

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Story in Brief

Ten sows were bled and antibody titers for *Actinobacillus pleuropneumoniae* were measured. Seventy-two pigs (12.8 ± 0.2 lb and 18 ± 2.5 d of age) were weaned from the 10 sows and were blocked by sow antibody titer. Treatment and pen were assigned randomly to each pig within a block. Treatment consisted of inactivated *P. acnes* injected i.m. (1 mg/animal) or the same volume (2.5 ml) of a 0.9% saline solution i.m. Twenty-four hours later, all pig were challenged with 4.12 x 10^8 colony forming units of *A. pleuropneumoniae* intranasally. Pig mortality was recorded. On day 8 postweaning, lungs were harvested from all remaining pigs and were ranked according to lesions on the lungs. The use of inactivated *P.acnes* approached significance (P = 0.14) for improved survival rate compared to controls. There was no significant difference in the lung lesion scores by treatment.

Introduction

Weaned pigs are challenged by many external factors, including the stress of being weaned and exposure to any pathogens in their environment. These challenges coupled with the pigs' immature immune system have a negative effect on growth performance. One way of helping these animals in stressful periods, while keeping an optimum performance level, has been through the use of immunostimulants (Blecha, 1988). Injectable immunostimulants may be used to activate the immune system during this time period by providing enhanced protection, while improving performance of the animal.

Actinobacillus pleuropneumoniae serotype 1 is a bacterium that can be characterized as highly virulent. In most cases, gross lung lesions are characteristic and, in chronic infections, nodular abscesses can form. *A. pleuropneumoniae* can lead to death within 6 to12 h when pigs are challenged with as many as 10^8 to 10^9 bacteria (Leman et al., 1986). Evaluation of *P. acnes* as a nonspecific immunostimulant in weaned pigs will include a challenge with *A. pleuropneumoniae* to measure morbidity and mortality.

The objective of this experiment was to assess the protective effects of inactivated *P. acnes* against an infectious pathogen (*A. pleuropneumoniae*).

Experimental Procedures

Ten sows with litters from the University of Arkansas swine farm were bled (approximately 24 h postpartum) for measuring antibody levels to *A. pleuropneumoniae* serotypes 1, 5, 9, 10, 11. Blood was collected via vena cava puncture into 6 mL serum separating Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ). Serum was separated through centrifugation and stored at -20ºC. Serum was tested by hemolysin neutralization test (HNT-titer) at the Department of Diagnostic Medicine/Pathobiology, Kansas State University, Manhattan.

A total of 72 crossbred (Tyson line TT and TT/York crossbred boars x Yorkshire, Landrace, Duroc crossbred sows) mixed sex weanling pigs (initial weight 12.8 ± 0.2 lb and average age 18 ± 2.5 d of age) were obtained from these ten sows. Animals were blocked by sow antibody titer for *A. pleuropneumoniae* (10 blocks) and randomly assigned to treatment and pen within a block. Treatment consisted of inactivated *P. acnes* (Eqstim, ImmunoVet Tampa, FL) injected i.m. (1 mg/pig) at weaning. The control group received an equal volume (2.5 ml) of a 0.9% saline solution i.m. at weaning. Pigs were transported 7.5 miles to the University of Arkansas Physiology farm and housed two pigs per pen with animal as the experimental unit. Pigs were housed in a nursery with elevated pens (30 in long x 32 in wide) with one nipple waterer, a three-hole feeder, and wire flooring. Pigs were allowed ad libitum access to feed and water. For the duration of the trial, the facility was maintained at 28ºC. Pigs were fed a diet which contained 1.5% lysine, 0.90% methionine plus cystine, 0.92% calcium, 0.80% phosphorus, and 14.5% lactose.

The *A. pleuropneumoniae* (strain 4074) was supplied by and prepared in liquid culture according to a protocol from Dr. B. Fenwick, Department of Diagnostic Medicine/Pathobiology, Kansas State University. Cultures were grown

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in RPMI 1640 medium (Sigma Chemical Co., St. Louis, MO, R-8758) with 2.5% fetal bovine serum and 0.25 g/mL NAD (Sigma Chemical Co. St. Louis, MO, N-1511) overnight at 7.5% CO_2 and 37ºC. To check for purity, cultures were streaked for isolation on chocolate agar (Remel 0-01300). The initial *A. pleuropneumoniae* culture streaked pure after 20 h of incubation. The initial seed culture was diluted in a 1:10 solution of fresh culture medium and cultured for 4 h at 7.5% CO_2 and 37ºC. At 4 h the final culture was put on ice and aliquoted into 4-ml syringes. The culture was kept agitated during the aliquoting procedure. Concentration of the final culture was checked by serial dilutions and was found to be 4.12×10^8 cfu per 4-ml dose.

Each pig was infected intranasally with 4-ml of the final bacterial culture on day 1 (24 h postweaning). Animals were monitored for signs of pneumonia twice a day. If severe distress, characterized by labored or difficulty breathing, was observed the animal was humanely euthanized through lethal injection of Euthansol (90 mg sodium pentobarbital and 12 mg phenytoin/kg BW). Animals that were killed or that died were necropsied by a veterinarian and examined for signs of pneumonia. Morbidity and mortality were recorded.

On day 8 postweaning, all remaining pigs were sacrificed through lethal injection of Euthansol and lungs were harvested. The lungs were scored according to severity of lung lesions. There was no knowledge of treatment groups during the scoring process. The scores were defined as 1 = no apparent lesions or abscesses, 2 = less than 25% of the lung was infected or no apparent abscesses, 3 = less than 50% but greater than 25% of the lung was affected or abscesses were present, and 4 = greater that 50% of the lung was affected and abscesses were present with severe necrosis of the lung tissue (Table 1).

Lung lesion scores and pig survival were analyzed using analysis of variance procedures with maternal antibody as the block. Age and treatment were included in the model in JMP (SAS Inst. Inc., Cary, NC).

Results and Discussion

Of the 72 piglets challenged with *A. pleuropneumoniae,* 28 died within the first 4 d. One-third of the *P. acnes* treated pigs died while the control group lost almost half of the pigs (17/36) (Table 2). This difference in mortality rate approached significance (P = 0.14). *Streptococcus suis* was isolated, and clinical signs were consistent with *S. suis* infection in one pig that was killed during the study period. That animal was excluded from the study. There were no significant differences in lung lesion scores (Table 3). *A. pleuropneumoniae* was re-isolated from harvested lungs to verify *A. pleuropneumoniae* infection.

Sow antibody titer affected both mortality ($P < 0.01$) and lung lesion scores ($P < 0.05$). More pigs survived that had a higher maternal antibody titer; however, those pigs had more severe lung lesion scores at 8 d postinfection than pigs with lower maternal antibody titers.

These differences in the way sow antibody titer influenced morbidity and mortality may be a result of individual pig antibody titers, which were not measured. By measuring the sow antibody titer only, an assumption was made that each pig within the block would have approximately the same degree of immunity. However, maternal antibodies found in the serum are not transferred through the placenta, but rather are selectively concentrated in colostrum towards the end of gestation (Gaskins and Kelly, 1995). The pig is limited to the quality and quantity of antibodies absorbed, which is dependent on the amount of colostrum it is able to consume and absorb. It would be necessary to measure pig antibody titers at weaning to evaluate this observation more effectively. Based on the observed mortality, inactivated *P. acnes* appeared to provide some protection (P = 0.14) for weaned pigs when challenged with *A. pleuropneumoniae.*

Implications

An immunostimulant that could be applied once at the time of weaning has potential to maximize growth while minimizing the labor associated with treating sick animals under certain environmental conditions. Inactivated *P. acnes* appeared to provide some protection for weaned piglets when challenged with *A. pleuropneumoniae.* More studies are needed to examine this product's efficacy as an immunostimulant. This product is marketed for companion animal use and would not be cost effective for swine production uses unless the price is reduced. Currently, this product is not approved by the Food and Drug Administration for use in food animals. However, with proper testing, inactivated *P. acnes* could be approved. This product is similar to other inactivated bacterial vaccines and adjuvants that are currently on the market and are used in domestic food animals.

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Table 1. Definitions of lung lesion scores in piglet lungs that were harvested 7 d after challenge with *A. peuropneumoniae.*

Score	Description
1	No apparent lesions or abscesses
2	<25% of lung affected with no abscesses
3	<50% of lung affected with abscesses present
4	>50% of lung affected with abscesses present and severe necrosis of the lung tissue

Table 2. Mortality of crossbred pigs treated with either inactivated *P. acnes* or saline at weaning then challenged 24 h later with *A. pleuropneumoniae*.[a]

Treatment	Live	Dead	Total
P. acnes	24	11	35[b]
Control	19	17	36
Total	43	28	71

[a] Treatment consisted of commercially available *P. acnes* (Eqstim®) injected i.m. (1mg/animal) or the control group received an i.m. saline injection. *A. pleuropneumoniae* was administered intranasally at a concentration of 4.12×10^8 cfu per animal 24 h after *P.acnes*/saline injection.

[b] One pig from the *P. acnes* group died. *Streptococcus suis* was isolated and clinical symptoms were consistent with *S. suis.*

Table 3. Lung lesion scores of crossbred pigs treated with either inactivated *P. acnes* or saline at weaning then challenged 24 h later with *A. pleuropneumoniae*.[a]

Treatment	1 No Lesion	2 Low	3 Med	4 High	Total
P.acnes	*7*	*7*	*7*	*3*	*24*
Control	6	3	5	5	19
Total	13	10	12	8	43

No statistical differences were found.

[a] Treatment consisted of commercially available *P. acnes* (Eqstim) injected i.m. (1mg/animal) or the control group received an i.m. saline injection. *A. pleuropneumoniae* was administered intranasally at a concentration of 4.12×10^8 cfu per animal 24 h after *P.acnes*/saline injection. The scores were defined as 1 = no apparent lesions or abscesses, 2 = less than 25 percent of the lung was infected with no apparent abscesses, 3 = less than 50 percent but greater than 25 percent of the lung was affected with abscesses present, and 4 = greater that 50 percent of the lung was affected with abscesses present and severe necrosis of the lung tissue.

Enhancement of Ovulation Rate and Litter Size in Swine

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Story in Brief

Two experiments were conducted to evaluate the effects of the immunization against ovarian steroids on ovulation rate and litter size in gilts. In Experiment 1, gilts at 165 ± 1.6 d of age were immunized against carrier (control), androstenedione (ANDRO), or 17α-hydroxyprogesterone (PROG17). Age at puberty and estrous cycle length averaged 208 ± 5.5 and 20.3 ± 2.8 d, respectively, and were not affected by treatment. The ANDRO- and PROG17-treated gilts had higher ($P < 0.05$) ovulation rates than controls (14.25 ± 0.82, 14.20 ± 0.73, and 11.40 ± 0.83, respectively). Total pigs born tended to be higher ($P = 0.15$) in the PROG17 group (11.75 ± 1.19) than in the controls (9.35 ± 1.15), suggesting the increased ovulation rate in the PROG17-immunized group resulted in an increased number of pigs born. Total pigs born for the ANDRO group was not different from controls. The number of pigs born alive tended to be higher ($P = 0.18$) in the PROG17 group compared to controls (11.3 ± 1.2 vs. 9.0 ± 1.2, respectively). Gestation length was not different between any of the treatments and the controls, averaging 115 ± 0.9 d overall. Immunization procedures used in Experiment 2 were identical to those in Experiment 1, except that only control and PROG17 treatments were included and only litter size at farrowing was measured. Total number of pigs and number of live pigs born were higher in the PROG17 treatment vs. controls (12.4 + 0.6 vs. 10.5 + 0.5; $P < 0.02$ and 11.3 + 0.6 vs. 9.2 + 0.5; $P < 0.01$, respectively). Data from this study indicate that litter size in gilts can be increased by immunization against PROG17.

Introduction

Litter size in swine is the most important factor contributing to the economic efficiency of swine production and is the primary measure of reproductive performance (Tess, 1981). Ovulation rate and thus litter size are influenced by a number of factors including breed, age at breeding, weight at breeding, and nutritional status at or near the time of breeding. Ovulation rate can be increased by the injection of superovulatory drugs, but results are variable, and such treatments frequently lead to reproductive problems such as decreased cycle length, increased duration of estrus, and cystic follicles. Genetic selection and conventional crossbreeding programs maintained for a period of several years have resulted in relatively small increases in litter size (Legault, 1985). Crossbreeding programs using prolific Chinese breeds of swine can lead to increases in litter size; however, the progeny of such exotic crosses may typically have poor carcass and growth characteristics (Legault et al., 1985). As a result of these problems, only limited success has been achieved in increasing litter size in swine.

Immunization of sheep against androstenedione, an estrogen precursor, increases ovulation rate and number of follicles > 4 mm in size (Scaramuzzi and Hoskinson, 1984). This procedure is thought to increase ovulation rate by reducing the negative feedback effects of estradiol on gonadotropin release from the pituitary, thus increasing gonadotropin stimulation of the developing follicles.

The immunization of gilts against androstenedione has been shown to increase ovulation rate but to have no effect on litter size (McKinnie, 1987; McKinnie et al., 1988). Gilts immunized against androstenedione had more follicles 5 to 10 mm in diameter, more total ovarian follicles, and more total ovarian structures than controls.

The effects of immunization against other androgen precursors on ovulation rate and litter size in gilts has not been studied. Therefore, two experiments were conducted to determine whether active immunization of gilts against androstenedione (ANDRO) or 17α-hydroxyprogesterone (PROG17) affects ovulation rate and litter size in gilts and to evaluate the effects of immunization upon other reproductive parameters.

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Experimental Procedures
Experiment 1

In Experiment 1, 15 prepubertal crossbred gilts averaging 165 ± 1.6 d of age were randomly assigned to three treatment groups of five animals each. Gilts were ranked by age and were randomly assigned to the following treatments: control (adjuvant + carrier only), ANDRO (1.0 mg of androstenedione 3-CMO:BSA), and PROG17 (1.0 mg of 17α-hydroxyprogesterone 3-CMO:BSA). Steroids coupled with bovine serum albumin were used in order to elicite an immune response in gilts. As an additional stimulus for immune response, all treatments were dissolved in 1.5 ml of 5% DEAE dextran (5% w/v in 0.45% saline), and this solution was then emulsified with an equal volume of mineral oil. Gilts received an initial 0.6-ml injection divided equally between two subcutaneous sites in the loose skin at the base of each ear, followed by a single booster injection 4 wk later. Animals in all groups received booster injections equal to one-half the original injection.

Following the booster immunization, gilts were moved to outside pens and checked for estrus twice daily. Gilts were observed through two normal periods of estrus to determine whether treatments affected age at puberty or estrous cycle length. Gilts were bred at 12 and 24 h after the second observed estrus to boars of known fertility. At 7 to 10 d after breeding, gilts were examined surgically to determine ovulation rate by counting the number of corpora lutea present on each ovary.

Following surgery, gilts were allowed to continue through pregnancy in order to determine the number of pigs born at term for each treatment. Serum samples were collected by anterior vena cava puncture immediately prior to immunization, at the booster immunization, at first estrus and at 0, 10, 12, 14, and 21 d of pregnancy (day 0 = day of first breeding). Serum was analyzed for progesterone and estradiol 17β radioimmunoassay. Serum antibody response against the antigen used in each treatment group was determined by measuring the percentage of counts bound by a 1:100 dilution of serum when 30,000 cpm of the appropriate tritium labeled antigen was added (Scaramuzzi et al., 1975).

Experiment 2

In Experiment 2, a group of 59 gilts that had previously been identified as potential replacement gilts were ranked by age and then randomly assigned to either control (n = 30) or PROG17 (n = 29) treatment groups. Immunization procedures were identical to those used in Experiment 1 except that only the control and PROG17 groups were included. In the control group, 12 gilts were removed from the study for the following reasons: four gilts did not show estrus; two were detected open after breeding; and six were culled for reasons unrelated to reproduction. In a similar manner, 12 gilts were removed from the PROG17 group as follows: two gilts did not cycle, three were detected not pregnant after breeding, two were injured, and five were culled for reasons not related to reproduction. The only measurements recorded were the total number of pigs born and the total number of pigs born live at term. Gilts that were retained in the herd for a second litter were not boosted, and reproductive parameters were assessed at the subsequent farrowing in order to determine the long-term effects of immunization on subsequent litter size.

Data Analysis

Data for reproductive performance were analyzed by analysis of variance, and means for each treatment were contrasted with the means for the control group. Hormone and antibody binding data were analyzed as a split-plot analysis using the repeated measures option of the GLM procedure of SAS (SAS Inst. Inc., Cary, NC).

Results and Discussion
Experiment 1

One gilt from the control group and one from the PROG17 group had to be reanesthetized at 14 to 17 d after breeding to correct surgical hernia problems, and both were subsequently removed from the study.

The immunization of gilts against androgenic steroid precursors did not significantly influence age at first estrus or estrous cycle length, but it did cause a significant ($P < 0.05$) increase in ovulation rate in the PROG17 and ANDRO groups compared to controls (Table 1). Mean ovulation rate was 14.25 ± 0.82, 14.20 ± 0.73, and 11.40 ± 0.83 for the ANDRO, PROG17, and control groups, respectively.

Gestation length, and average weight of pigs at birth were not significantly influenced by immunization (Table 2). Immunization did, however, tend to increase the total number of pigs born ($P = 0.15$) and the number of live pigs born per litter ($P = 0.18$). Total pigs born at term averaged 11.8 ± 1.2 in the PROG17 group and 9.4 ± 1.2 in the control group, suggesting that the increased ovulation rate in the group immunized against PROG17 translated into an increased number of pigs born at term. Average total number of pigs born in the ANDRO groups was not different from controls. The number of pigs born alive averaged 11.3 ± 1.2 in the PROG17 group compared to 9.0 ± 1.2 in control gilts.

Antibody response for each treatment compared to controls is illustrated in Figures 1A and 1B. Antibody response of the PROG17 and the ANDRO groups was different ($P < 0.05$) from the response in control gilts and was also affected ($P < 0.05$) by time after immunization.

Serum progesterone and estradiol response for each treatment is shown in Figures 2A and 2B. Serum progesterone and estradiol were not changed by immunization against any of the steroids evaluated in this study. However, both progesterone and estradiol were affected ($P < 0.01$) by day of pregnancy.

Experiment 2

Farrowing data for gilts in Experiment 2 are summarized in Table 3. Gilts immunized against PROG17 had 1.9 more total pigs born per litter than control gilts ($P < 0.02$). Similarly, gilts in the PROG17-immunized group had 2.1 more live pigs born per litter than control gilts ($P < 0.01$). When gilts were held for a second farrowing without a booster immunization, total pigs born and live pigs born were numerically higher for PROG17-immunized gilts than for controls (Table 4) but were not statistically different (10.9 ± 1.2 vs. 8.5 ± 1.1; $P = 0.17$, and 9.9 ± 1.2 vs. 8.0 ± 1.1; $P = 0.26$, respectively).

The immunization of gilts against PROG17 in this study increased ovulation rate and the number of pigs born at term. Similar to this study, McKinnie (1987) observed a significant increase in ovulation rate in gilts immunized against androstenedione but found no effect on litter size. Data in that study also indicated no significant effects on age at puberty or length of the first estrus cycle. There was no significant effect of immunization against any steroid on serum progesterone levels in the current study. In contrast, McKinnie (1987) observed significantly higher levels of progesterone at days 2, 6, 9, and 12 after mating in androstenedione-immunized gilts.

Results of these experiments indicate that immunization of gilts against androstenedione, and 17α-hydroxyprogesterone can effectively increase the ovulation rate in gilts. In addition, immunization of gilts against 17α-hydroxyprogesterone results in a significant and substantial increase in litter size.

Further studies in gilts are needed to determine whether additional booster immunizations can further improve litter size; what response is elicited when immunized gilts are boosted prior to rebreeding; what effects occur in mature sows; and what physiological changes are associated with the increase in litter size.

Implications

An increase of two pigs per litter in gilts would have a very significant impact on the economic efficiency of swine production. This product would have to be approved by the USDA and FDA prior to use in food animals, but the benefits would likely justify this expense. If this treatment would also benefit litter size in mature sows (which has not been determined), the benefits would substantially increase. In addition, an understanding of the physiological changes induced by this treatment could yield other approaches to enhancing the reproductive performance of swine.

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Table 1. Reproductive variables (mean ± SE) of immunized gilts by treatment.

Treatment[a]	Age at puberty	Estrus cycle length	Ovulation rate
Control	209 ± 3.3	22.8 ± 3.3	11.40 ± 0.83
ANDRO	210 ± 3.3	19.3 ± 3.6	14.25 ± 0.82[b]
PROG17	211 ± 3.3	20.0 ± 3.3	14.20 ± 0.73[b]

[a] Control (adjuvant + carrier only); ANDRO (1.0 mg of androstenedione 3-CMO:BSA); and PROG17 (1.0 mg of 17α-hydroxyprogesterone 3-CMO:BSA).

[b] Ovulation rate in these groups was ($P < 0.05$) higher than in the control group.

Table 2. Reproductive performance (mean ± SE) of immunized gilts by treatment.

Treatment[a]	Gestation length, d	Total pigs	Live pigs	Avg wt, lb
Control	116.0 ± 2.2	9.4 ± 1.2	9.0 ± 1.2	3.52 ± 0.44
ANDRO	115.0 ± 2.5	10.0 ± 1.2	9.8 ± 1.2	2.86 ± 0.44
PROG17	115.8 ± 2.2	11.8 ± 1.2[b]	11.3 ± 1.2[c]	2.86 ± 0.44

[a] Control (adjuvant + carrier only); ANDRO (1.0 mg of androstenedione 3-CMO:BSA); and PROG17 (1.0 mg of 17α-hydroxyprogesterone 3-CMO:BSA).

[b] Total number of pigs born tended to be higher (P = 0.15) in the PROG17 group than in the control group.

[c] Number of pigs born alive tended to be higher (P = 0.18) in the PROG17 group than in the control group.

Table 3. Summary of farrowing data (mean ± SE) for PROG17 and control gilts for Experiment 2.

Treatment[a]	Number of litters	Total pigs born	P value	Live pigs born	P value
Control	18	10.5 ± 0.5	—	9.20 ± 0.5	—
PROG17	15	12.4 ± 0.6	< 0.022	11.30 ± 0.6	< 0.01

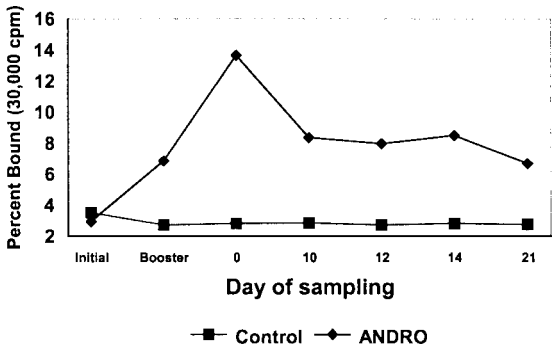
[a] Control (adjuvant + carrier only); ANDRO (1.0 mg of androstenedione 3-CMO:BSA); and PROG17 (1.0 mg of 17α-hydroxyprogesterone 3-CMO:BSA). One control litter with only three pigs born and one treatment litter in which all pigs were born dead due to an unassisted farrowing were deleted from the analysis.

Table 4. Summary of second farrowing data (mean ± SE) for PROG17 and control gilts for Experiment 2.

Treatment[a]	Number of litters	Total pigs born	P value	Live pigs born	P value
Control	13	8.5 ± 1.1	—	8.0 ± 1.1	—
PROG17	10	10.9 ± 1.2	< 0.166	9.9 ± 1.1	< 0.26

[a] Control (adjuvant + carrier only); ANDRO (1.0 mg of androstenedione 3-CMO:BSA); and PROG17 (1.0 mg of 17α-hydroxyprogesterone 3-CMO:BSA).

A



B

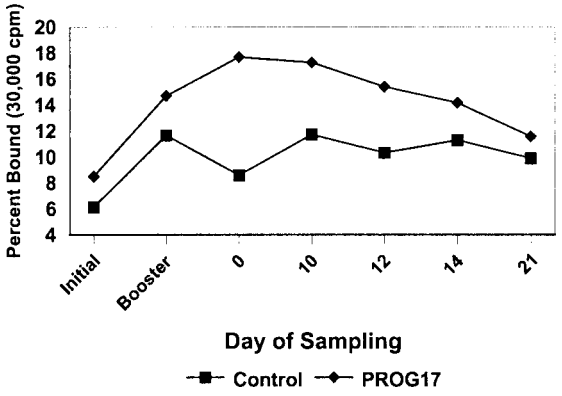
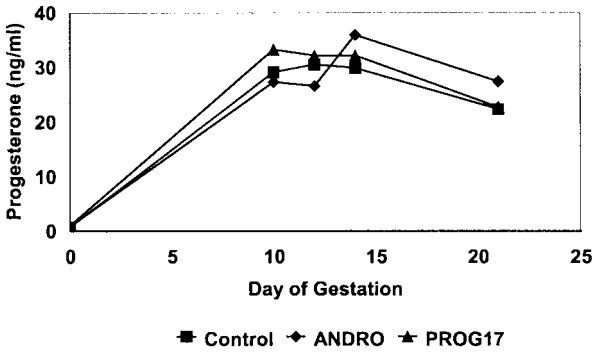


Figure 1A. Serum binding of androstenedione.
1B. Serum binding of 17-OH progesterone.

A



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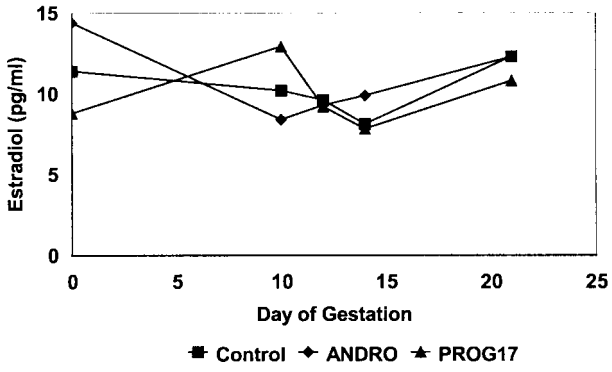

Figure 2A. Serum progesterone concentration.
2B. Serum estradiol concentration.

A Canonical Correlation Analysis of Production Traits of Large White Swine

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Story in Brief

A canonical correlation analysis was used to examine relationships between two sets of production traits for purebred Large White boars. Data consisted of performance test records of 7,529 boars collected in a commercial swine operation from 1990 to 1997. Boars were individually pen-tested for approximately 77 d (100 to 177 d of age). They were weighed at the beginning (WT100) and end of the test (WT177), and feed intake was recorded. Average daily feed intake and F/G were computed. Backfat (BF) and loin eye area (LEA) were measured at the 10th rib at the end of the test by ultrasound. Body length (LEN) was measured at that time. The traits WT100, ADFI, and F/G were adjusted to a beginning age of 100 d. Likewise WT177, BF, LEA, and LEN were adjusted to an ending age of 177 d. For the canonical correlation analysis, WT100, WT177, and LEN were one set of measurements needing less labor and expense to obtain (LLE traits), and ADFI, F/G, BF, and LEA were the second set of measurements, requiring more labor and expense to obtain (MLE traits). Three significant ($P < 0.01$) canonical correlations were obtained. Among the traits in the LLE set, WT177 had the highest correlation to canonical variate 1, and among the traits in the MLE set, ADFI had the highest correlation to canonical variate 1. The trait WT100 in the LLE set and F/G in the MLE set of traits had the highest correlations to canonical variate 2. Length in the LLE set and BF in the MLE set of traits had the highest correlations to canonical variate 3. Results of this analysis indicate strong relationships between the LLE and MLE traits that may be useful to producers in selection programs.

Introduction

It is well known that gain in swine is genetically related to feed efficiency, and selection for gain has been used quite effectively to indirectly improve feed efficiency. This approach has been taken because measuring individual feed intake is time-consuming and expensive. Emphasis is currently being placed on producing lean pigs. It is time-consuming to measure backfat and loin eye area on individual pigs. Therefore, it would be advantageous to find a trait or combination of traits related to measures of leanness that is also easier to measure. The objective of this study was to examine relationships between two sets of production traits in Large White swine through a canonical correlation analysis. One set of traits is less labor-intensive and less expensive to obtain (LLE), while the other set of traits requires more labor and expense to obtain (MLE).

Materials and Methods

Data evaluated were performance test records from 7,529 Large White boars collected in a commercial swine operation from 1990 to 1997. Boars born to approximately 60% of the litters were culled at weaning on the basis of a maternal breeding value (index) for the dam. These index values were based on the number born alive, farrowing interval, and weaning weight. Boars that were not culled were grown to 100 d of age. At this time, boars to be individually pen tested were selected primarily on the basis of phenotypic weight, with some consideration given to the maternal index.

Boars were individually penned in 2.79 m^2 pens on slatted concrete floors at approximately 100 d of age (79 to 134 d; mean = 100.4 d) for approximately 77 d. A pelleted corn-soybean meal diet that was 1.14% lysine, 19% protein, and 3,344 mcal/kg ME was offered ad libitum. Exact

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composition of the diet varied because of ingredient cost. Ending test age ranged from 152 to 211 d, with a mean of 176.2 d. Boars were weighed at the beginning and end of the test, and feed intake was recorded. Boars were typically fed three to four times a week; however, feed was only weighed back at the end of the test. Backfat (BF) and loin eye area (LEA) were measured at the 10th rib at the end of the test using B-mode ultrasound equipment. Backfat was measured 4 cm off the midline with skin excluded. Body length (LEN), measured from the top of the tail (tailset) to the point of the shoulder when the head is down, was obtained at this time. Average daily gain, ADFI, and F/G were calculated. The traits WT100, ADFI, and F/G were adjusted to a beginning age of 100 d using regression coefficients obtained from previous analyses. Likewise, WT177, BF, LEA, and LEN were adjusted to an ending age of 177 d.

A canonical correlation analysis was used to examine relationships between two sets of production traits using PROC CANCORR of SAS (SAS Inst. Inc., Cary, NC). A canonical correlation analysis is a generalization of multiple correlation analysis with more than one *y* variable. Thus there are two sets of variables — a set of *x* variables that possess some common feature and a set of *y* variables that are characterized in some other way. The objective is to find a linear combination of the first set of variables (*x*) that has maximum correlation with a linear combination of the second set of variables (*y*). This is called the first canonical correlation. A second canonical correlation can be found that is greatest for all linear combinations uncorrelated with the first linear combinations. There can be as many canonical correlations as variables in the smallest data set. Thus, all the correlation between the sets of the original variables has been channeled through the canonical correlations. It provides a way of considering overall test performance as a composite evaluation, rather than using one performance trait at a time, as in traditional regression analysis. For the canonical correlation analysis in this study, WT100, WT177, and LEN were considered to be one set of measurements (LLE traits) and DFI, F/G, BF, and LEA were considered to be the second set of measurements (MLE traits).

Results and Discussion

Simple phenotypic correlations among traits examined in this study are presented in Table 1. All correlations were different from zero ($P < 0.01$), with the exception of body length with F/G.

Results of the canonical correlation analysis are presented in Table 2. Three canonical correlations were obtained (0.96, 0.41, and 0.15). All were different from zero ($P < 0.01$). Interpretation of results is often done through examination of correlations of derived variables for each set of traits (canonical variates) with the original measured variables. This is the approach taken here (Table 2). Among the traits in the LLE set, WT177 had the highest correlation ($r = 0.90$) with canonical variate 1, and among the traits in the MLE set, ADFI had the highest correlation ($r = 0.70$) with canonical variate 1. This indicates that a major portion of the variation observed contrasted boars that ate more and were heavier at the end of the test with boars that ate less and were lighter at the end of the test. Canonical variate 2 had the highest correlation to WT100 ($r = 0.95$) in the LLE set and to F/G ($r = 0.73$) in the MLE set of traits. Thus, selecting for high values of this variate would choose boars that were heavier at 100 d and had poorer F/G values on test. Canonical variate 3 was negatively correlated with LEN ($r = –0.70$) in the LLE set and positively with BF ($r = 0.82$) in the MLE set; therefore, selecting for high values of this variate would select shorter, fatter boars, and selecting for low values of this variate would select for longer, leaner boars. Results of this analysis indicate strong relationships between the LLE and MLE traits that may be useful to producers in selection programs.

Implications

Relationships between the two sets of production traits (one set that is less labor-intensive and less expensive to measure and the other set more labor-intensive and more expensive to measure) examined in this study could be useful to producers in selection programs.

Table 1. Phenotypic correlations among traits[a] examined.

Trait	WT177	Length	F/G	ADFI	Backfat	LEA
WT100	0.58**	0.41**	0.25**	0.32**	0.21**	0.26**
WT177		0.56**	–0.13**	0.70**	0.46**	0.39**
Length			0.01	0.40**	0.17**	0.32**
F/G				0.47**	0.16**	–0.13**
ADFI					0.55**	0.18**
Backfat						0.08**

[a] WT100 = weight at 100 d of age; WT177 = weight at 177 d of age; Length = body length measured at the end of the test; F/G = feed-to-gain ratio on performance test; ADFI = average daily feed intake on performance test; Backfat = backfat at 10th rib measured at the end of the test; LEA = loin eye area measured at end of the test.

** P < 0.01.

Table 2. Correlations of canonical variates with observed variables.

Trait[a]	Variate 1	Variate 2	Variate 3
Set 1 (LLE)			
WT100	0.17	0.95	0.27
WT177	0.90	0.42	0.11
Length	0.45	0.55	–0.70
Set 2 (MLE)			
F/G	–0.30	0.73	0.26
ADFI	0.70	0.51	0.21
Backfat	0.47	0.26	0.82
LEA	0.34	0.58	–0.43
Canonical correlation	0.96**	0.41**	0.15**

[a] WT100 = weight at 100 d of age; WT177 = weight at 177 d of age; Length = body length measured at the end of the test; F/G = feed-to-gain ratio on performance test; ADFI = average daily feed intake on performance test; Backfat = backfat at 10th rib measured at the end of the test; LEA = loin eye area measured at end of the test.

** P < 0.01.