Effects of spray-dried animal plasma and immunoglobulins on performance of early weaned pigs[1,2]

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ABSTRACT: Five experiments were conducted to evaluate the effects of dietary spray-dried porcine plasma (SDPP) and spray-dried bovine plasma (SDBP) and their various molecular weight fractions on performance of pigs weaned at approximately 14 or 21 d of age. In addition, the efficacy of various levels of the immunoglobulin G (IgG)-rich fraction of SDPP and SDBP were evaluated. Experiment 1 evaluated the dietary addition of SDPP and three of its fractions (IgG-rich, albumin-rich, and low molecular weight fractions). Pigs fed SDPP grew faster and consumed more feed than the controls during the first week ($P < 0.05$). The IgG-rich fraction resulted in improvements in ADG and ADFI that were similar to those of pigs fed SDPP. The albumin-rich fraction had no effect on growth rate, but the low molecular weight fraction decreased feed intake as well as growth rate. Experiments 2 and 3 evaluated SDPP and graded levels of its IgG-rich fraction in pigs weaned at 21 or 14 d, respectively. In Exp. 2, pigs fed SDPP grew faster and consumed more feed than the controls during the first week ($P < 0.05$). Pig performance was enhanced with the addition of the IgG-rich fraction that provided 80% of the amount of IgG in the SDPP diet. In Exp. 3, there was no response to SDPP during the first week, but a positive growth response to SDPP ($P < 0.01$) occurred by the end of wk 2 (0 to 14 d). Feeding the IgG-rich fraction increased growth rate compared with controls ($P < 0.05$). Over the entire experiment, the greatest ADG occurred with the IgG-rich fraction that provided 128% of the amount of IgG provided by SDPP (quadratic; $P < 0.05$). Two additional experiments assessed feeding SDBP and bovine IgG-rich fractions to early weaned pigs. In Exp. 4, SDPP was superior to SDBP in stimulating growth and feed intake, but this difference did not occur in Exp. 5. In both experiments, the IgG fraction of bovine plasma seemed to be as effective at improving growth as SDPP and more effective than SDBP. The results indicate that both porcine and bovine plasma are beneficial to young pig performance during the first week after weaning and that the IgG fraction of plasma is the component that is responsible for the enhancement in growth rate and feed intake.

Key Words: Immunoglobulin, Pig, Spray-Dried Animal Plasma

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Introduction

Spray-dried porcine plasma (**SDPP**) is now a common protein source in starter diets for early weaned pigs in North America. Spray-dried plasma is commonly included in phase I diets because it stimulates feed intake during the first several days after weaning and attenuates the growth lag that commonly occurs in young pigs following weaning (Kats et al., 1994; Coffey and Cromwell, 2001; Van Dijk et al., 2001).

The mode of action by which SDPP increases feed intake and growth rate is not completely understood. Ermer et al. (1994) suggested that it might be due to an appetite stimulant in SDPP. Others have suggested that the positive responses might result from specific immunoglobulin proteins in the plasma that enhance growth performance (Gatnau et al., 1995; Owen et al., 1995; Weaver et al., 1995). This finding is supported

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by research showing that growth and feed intake responses to supplemental SDPP are greater in challenged vs. clean environments for pigs (Coffey and Cromwell, 1995) as well as broilers (Campbell et al., 2003) and turkeys (Campbell et al., 2004a).

Plasma from bovine species has been shown in some instances to be as effective as plasma from porcine species (Gatnau and Zimmerman, 1994; Russell, 1994; Russell and Weaver, 1996). Furthermore, dried bovine serum or bovine immunoglobulins have been shown to benefit poultry challenged with *Pasteurella multocida* (Campbell et al., 2004b).

The objectives of this research were to assess the effects of various molecular weight fractions of spray-dried plasma from different species (porcine and bovine) on the growth performance of weanling pigs and to determine the optimal level of immunoglobulin protein from porcine and bovine plasma on performance of weanling pigs.

Materials and Methods

General

We conducted five experiments to assess the effects of SDPP, spray-dried bovine plasma (**SDBP**), and various fractions of those products on growth performance of early weaned pigs. The experiments were conducted in accordance with the Institutional Animal Care and Use Committee of the University of Kentucky.

Crossbred (Hampshire × Yorkshire) pigs were used in the experiments. Pigs from a given weaning group were ranked by BW and allotted randomly to treatments within blocks. Ancestry and sex were balanced across treatments as much as possible. In Exp. 1 to 4, pigs were housed in groups of four or five pigs per pen in an off-site experimental nursery. Room temperature was maintained at approximately 33°C for the first week and then lowered 3°C/wk for the next 3 wk. Pigs in Exp. 5 were housed in groups of five to seven pigs per pen in an on-site nursery. In that nursery, room temperature ranged from approximately 24 to 38°C.

The pens in the off-site unit were elevated decks (1.5 × 1.5 m) with galvanized wire flooring over plastic flush pans. The pens in the on-site nursery were elevated decks (1.0 × 2.1 m) with plastic-coated wire flooring over a manure pit. In both nurseries, the pens were equipped with a stainless steel feeder and nipple waterer. Pigs were allowed to consume feed (meal form) and water ad libitum. Pigs were weighed individually, and feed intake was determined weekly.

The experimental diets (Table 1) consisted mainly of corn and dehulled soybean meal (**SBM**) with 20% dried whey and were formulated to meet or exceed all the requirements for weanling pigs from 5 to 10 kg of BW (NRC, 1998). The SBM and dried whey were included at the same level in all diets within each experiment. Soy protein concentrate (**SPC**) was included in the basal diets. When SDPP or SDBP were added at 8%, all the SPC and salt were deleted, and adjustments were made in the amounts of corn, corn oil, L-lysine·HCl, and DL-methionine to maintain constant levels of lysine, methionine, Na, and ME across the diets. Similarly, the plasma fractions were added at the expense of SPC, and amounts of corn, corn oil, L-lysine·HCl, and DL-methionine were adjusted to maintain constant levels of nutrients and ME across diets. Adjustments were made in the amounts of dicalcium phosphate and ground calcitic limestone to maintain a constant level of Ca and P across all diets. The diets also contained antimicrobial agents (Aureomix-500, Roche Vitamins, Parsippany, NJ) and copper sulfate (250 mg Cu/kg of diet).

The SDPP and SDBP and the crude extracts of different molecular weight fractions of these plasma sources were provided by APC Company, Ankeny, IA (formerly American Protein Corp., Ames, IA). The plasma fractions included immunoglobulin G (**IgG**)-rich, albumin-rich, and low molecular weight fractions from porcine plasma and an IgG-rich fraction from bovine plasma. These fractions were prepared by American Protein Corp. using chemical precipitation, centrifugation, and membrane filtration procedures.

The SDPP and SDBP and the IgG fraction of each were analyzed for IgG content by American Protein Corp. using turbidimetric assay procedures (Etzel et al., 1997). Immunoglobulin concentrations ranged from 17.9 to 22.5% in the SDPP and were 16.0 and 16.6% in SDBP (Table 2). The IgG in the IgG-rich fractions was 2.0 to 3.7 times as concentrated as that in the dried plasma (Table 2).

Amino acid concentrations in the dried plasma sources and IgG-rich fractions were analyzed by HPLC after acid hydrolysis. Methionine and cysteine were oxidized to methionine sulfone and cysteic acid by treatment with performic acid before hydrolysis. Tryptophan was analyzed after alkaline hydrolysis. The AA analysis was performed by Ajinomoto Heartland LLC (Chicago, IL). The diets were analyzed for CP at the University of Kentucky by a combustion and recovery method (AOAC, 1995) using an N analyzer (Foss Heraeus, UIC Inc., Joliet, IL).

Experiment 1

Eighty pigs initially averaging 5.6 kg and 21.0 d of age were used in a 28-d experiment to evaluate SDPP and three molecular weight fractions of SDPP, which consisted of an IgG-rich fraction, an albumin-rich fraction, and a low molecular weight fraction. The pigs were in groups of four pigs per pen, and there were four pen-replicates per treatment. Diet 1 consisted of corn, SBM, spray-dried whey, and SPC and was formulated to contain 1.41% lysine (Table 1). In diet 2, 8.0% SDPP was added. The IgG-rich fraction was included in diet 3 at 3.57% such that the amount of IgG in diet 3 was equal to the amount of IgG contributed by the SDPP in diet 2. This amount was based on the IgG-

Table 1. Composition of control and common diets in the experiments, as-fed basis[a]

	Control diet					Common diet
Ingredient	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 4 and 5
Ground corn	45.81	47.52	46.27	47.55	47.59	58.64
Dehulled soybean meal	17.58	17.30	17.50	17.30	17.00	20.00
Soy proetin concentrate	10.40	10.00	11.00	10.00	10.00	3.50
Spray-dried whey	20.00	20.00	20.00	20.00	20.00	15.00
Spray-dried porcine plasma	—[b]	—[b]	—[b]	—[b]	—[b]	—
Spray-dried bovine plasma	—	—	—	—[c]	—[c]	—
Porcine IgG-rich fraction	—[d]	—[e]	—[f]	—	—	—
Bovine IgG-rich fraction	—	—	—	—[g]	—[h]	—
Porcine albumin-rich fraction	—[i]	—	—	—	—	—
Porcine LMW fraction	—[j]	—	—	—	—	—
Corn oil	2.50	1.45	1.45	1.45	1.66	—
Dicalcium phosphate	1.74	1.75	1.72	1.72	1.76	1.17
Ground limestone	0.70	0.70	0.71	0.70	0.70	0.78
Iodized salt	0.58	0.58	0.58	0.58	0.58	0.35
L-Lysine HCl	0.15	0.17	0.24	0.17	0.18	0.18
DL-Methionine	0.12	0.11	0.11	0.11	0.11	—
Vitamin-trace mineral mix[k]	0.175	0.175	0.175	0.175	0.175	0.175
Antioxidant[l]	0.02	0.02	0.02	0.02	0.02	—
Antimicrobial[m]	0.125	0.125	0.125	0.125	0.125	0.125
Copper sulfate[n]	0.10	0.10	0.10	0.10	0.10	0.08
Calculated analysis, %[a]						
Lysine	1.41	1.41	1.50	1.40	1.40	1.20
Ca	0.90	0.90	0.90	0.90	0.90	0.75
P	0.80	0.80	0.80	0.80	0.80	0.65

[a]The dried plasma products and fractions were substituted for corn, soy protein concentrate, and lysine HCl on a lysine basis. Adjustments were made in the amounts of dicalcium phosphate, ground limestone, and corn oil to maintain a constant level of Ca, P, and ME across all diets. IgG = immunoglobulin G and LMW = low molecular weight.

[b]In diet 2, 8.00% spray-dried porcine plasma.

[c]In diet 4, 8.00% spray-dried bovine plasma.

[d]In diet 3, 3.57% porcine IgG-rich fraction.

[e]In diets 3, 4, and 5, respectively, 1.25, 2.50, and 3.75% porcine IgG-rich fraction.

[f]In diets 3, 4, and 5, respectively, 1.38, 2.76, and 4.14% porcine IgG-rich fraction.

[g]In diets 2 and 3, respectively, 1.07 and 2.14% bovine IgG-rich fraction.

[h]In diets 2 and 3, respectively, 2.03 and 4.06% bovine IgG-rich fraction.

[i]In diet 4, 4.32% porcine albumin-rich fraction.

[j]In diet 5, 0.074% porcine LMW fraction.

[k]Supplied the following per kilogram of diet: 6,600 IU of vitamin A, 880 IU of vitamin D_3, 22 IU of vitamin E, 6.4 mg of vitamin K (as meadione sodium bisulfite complex), 8.8 mg of riboflavin, 22 mg of pantothenic acid, 44 mg of niacin, 0.022 mg of vitamin B_{12}, 0.22 mg of D-biotin, 1.1 mg of folic acid, 135 mg of Zn (ZnO), 135 mg of Fe ($FeSO_4 \cdot H_2O$), 45 mg of Mn (MnO), 13 mg of Cu ($CuSO_4 \cdot 5H_2O$), 1.5 mg I (CaI_2O_6), and 0.3 mg of Se ($NaSeO_3$).

[l]Santoquin (Monsanto, St. Louis, MO) provided 132 mg of ethoxyquin/kg of diet.

[m]Aureomix-500 (Roche Vitamins, Inc., Parsippany, NJ) supplied 110 mg of chlortetracycline, 110 mg of sulfamethazine, and 55 mg of penicillin/kg of diet.

[n]Supplied 250 and 200 mg of Cu/kg in experimental and common diets, respectively.

rich fraction containing 50.5% IgG and the SDPP containing 22.5% IgG (Table 2). The same procedure was used to determine the amount of albumin-rich fraction that was added to diet 4. The albumin-rich fraction contained 89% albumin, and the SDPP contained 48% albumin. Therefore, 4.32% of the albumin fraction was included in diet 4. Diet 5 was formulated to contain 200% of the level of low molecular weight fraction found in the SDPP, which contained only 0.46% of this fraction. The low molecular weight fraction was considered to be 100% pure, so the level of the fraction added to the diet was 0.074%. The diets were fed throughout the 28-d test period.

Table 2. Immunoglobulin G (IgG) concentration of products and fractions used in the five experiments

	Experiment				
Item	1	2	3	4	5
	IgG concentration, % air-dry basis				
Spray-dried porcine plasma	22.5	22.5	17.9		
Porcine IgG-rich fraction	50.5	57.1	65.3		
Spray-dried bovine plasma				16.0	16.6
Bovine IgG-rich fraction				59.8	32.8

Experiment 2

A 21-d experiment was conducted using 80 pigs initially averaging 6.3 kg of BW and 21.3 d of age to determine the dietary level of porcine IgG that would optimize growth performance in weanling pigs. Diets 1 and 2 were approximately the same as in Exp. 1 (Table 1). The IgG-rich fraction was included in diets 3, 4, and 5 at 1.25, 2.50, and 3.75%, respectively. The levels of IgG provided by the IgG-rich fraction represented 40, 80, and 120% of the IgG provided by the SDPP in diet 2. The diets were fed throughout the 21-d test period. There were four pen replicates of four pigs per pen for each treatment.

Experiment 3

Ninety-five pigs initially averaging 5.3 kg of BW and 14.8 d of age were allotted randomly to five dietary treatments in a 28-d experiment to determine the dietary level of porcine IgG for optimizing growth performance in very early weaned pigs. Diets 1 and 2 were similar to those used in Exp. 1 and 2, except that the diets were formulated to contain 1.5% lysine (Table 1). The IgG-rich fraction was included in diets 3, 4, and 5 at 1.38, 2.76, and 4.14%, respectively. The levels of IgG provided by the IgG-rich fraction represented approximately 64, 128, and 192% of the IgG provided by the SDPP in diet 2. The diets were fed throughout the 28-d test period. Pigs were housed four or five pigs per pen with four pen replicates per treatment.

Experiment 4

A 28-d experiment was conducted with 95 pigs initially averaging 5.6 kg of BW and 19.7 d of age to compare the growth response of pigs fed SDPP or SDBP and to assess the effect of two dietary levels of bovine IgG for early weaned pigs. Diet 1, the control, consisted primarily of corn, SBM, spray-dried whey, and SPC (Table 1). In diets 2 and 3, respectively, SDPP or SDBP was added at 8.0% of the diet. The bovine IgG-rich fraction was included in diets 4 and 5 at levels of 1.07 and 2.14%, respectively. These levels of IgG-rich fraction provided 50 and 100% of the IgG that was supplied by the SDBP in diet 3. These diets were fed for 14 d, after which the pigs were fed a common diet that did not contain SDPP, SDBP, or the IgG fraction for the final 14 d of the experiment. The common diet consisted primarily of corn, SBM, dried whey, and SPC and was formulated to contain 1.20% lysine (Table 1). There were four or five pigs per pen with four pen replicates per treatment.

Experiment 5

One hundred fifty-two pigs, averaging 6.4 kg of BW and 22.5 d of age, were used in a 28-d experiment to evaluate SDBP, SDPP, and two levels of bovine IgG-rich fraction for early weaned pigs housed in a conventional on-site nursery. The same two dietary levels of bovine IgG used in Exp. 4 were evaluated (Table 1). The diets were similar to those used in Exp. 4 with the exception of the levels of bovine IgG. The percentages of bovine IgG-rich fraction were increased to 2.03 and 4.06% because of a lower concentration of IgG in the IgG-rich fraction (Table 2). These two levels of the IgG-rich fraction provided 50 and 100% of the IgG supplied by the SDBP in diet 3 (Table 2). The diets were fed for 14 d, after which the pigs were fed the same common diet used in Exp. 4 for the final 14 d of the experiment. There were five pen replicates of six pigs per pen for each treatment.

Statistical Analyses

The data from each experiment were analyzed as a randomized complete block design (Snedecor and Cochran, 1989) using the GLM procedures of SAS (SAS Inst., Cary, NC). Treatments were deemed sufficiently unrelated in Exp. 1, 4, and 5 that means were separated by LSD. Treatment means in Exp. 2 and 3 were assessed using preplanned contrasts of control vs. SDPP, control vs. mean of IgG-rich fractions, SDPP vs. mean of IgG-rich fractions, and linear and quadratic trends within the three IgG-rich fractions. In all experiments, pen was considered the experimental unit. Unless stated otherwise, an α level of <0.05 was considered statistically significant.

Results

Experiment 1

During the first week of the test, pigs fed SDPP gained faster ($P < 0.05$) and consumed more feed ($P < 0.05$) than the controls (Table 3). Similarly, inclusion of the IgG-rich fraction during wk 1 resulted in improvements ($P < 0.05$) in ADG and ADFI compared with controls; means were not significantly different from those of pigs fed SDPP. Feed:gain responses also tended to improve in pigs fed SDPP or the IgG-rich fraction compared with the controls, but the differences were not significant. Performance by pigs fed the albumin or low molecular weight fraction during the first week of the test did not differ significantly from controls.

At the end of the second week and at the end of the 4-wk study, there were no differences in ADG or ADFI among pigs fed SDPP or the plasma fractions vs. the controls. Feed intake over the entire 4-wk experimental period was greater by pigs fed SDPP than by pigs fed either the IgG-rich or albumin-rich fractions of plasma ($P < 0.05$).

Experiment 2

Pigs fed the diet containing SDPP grew faster ($P < 0.05$) and consumed more feed ($P < 0.05$) than those fed the control diet during the first week of the experiment (Table 4). Similarly, feeding the IgG-rich fraction resulted in greater weight gains and feed intakes compared with those of control pigs ($P < 0.05$). During this

Table 3. Gain, feed intake (as-fed basis), and feed:gain of pigs in Exp. 1[a]

	Diet					
Item	Control	SDPP	Porcine IgG-rich fraction	Porcine albumin-rich fraction	Porcine LMW fraction	CV
End of wk 1 (0 to 7 d)						
ADG, g	141[x]	229[y]	241[y]	150[x]	119[x]	21.1
ADFI, g	311[x]	462[y]	410[y]	297[x]	300[x]	17.8
Feed:gain	2.35	2.10	1.99	2.16	2.77	22.6
End of wk 2 (0 to 14 d)						
ADG, g	252	281	262	228	223	16.2
ADFI, g	438[xyz]	500[y]	443[xy]	359[z]	416[xz]	12.2
Feed:gain	1.74	1.81	1.74	1.74	1.88	18.0
End of wk 4 (0 to 28 d)						
ADG, g	390	384	360	358	375	13.8
ADFI, g	704[xy]	731[y]	630[x]	608[x]	673[xy]	9.8
Feed:gain	1.82	1.94	1.77	1.72	1.80	9.2

[a]Each mean represents four pens of four pigs each, initially averaging 5.6 kg of BW and 21.0 d of age. SDPP = spray-dried porcine plasma, IgG = immunoglobulin G, and LMW = low molecular weight.
[x,y,z]Means within a row that do not have a common superscript letter differ, $P < 0.05$.

period, ADG seemed to maximize at the intermediate inclusion rate of the IgG-rich fraction even though only the linear component was significant ($P < 0.05$). Feed:gain was not affected by dietary treatment during wk 1.

Similar response patterns in ADG and ADFI continued through the second week of the study. Pigs fed SDPP or the IgG-rich fraction consumed more feed than control pigs ($P < 0.05$), and growth rates and feed intakes of pigs fed the IgG-rich fraction were similar to those of pigs fed SDPP. By the end of the 3-wk study, there were no differences in performance among the treatment groups, except that feed:gain was poorer for the SDPP-fed pigs than for those fed the control diet or the IgG-rich diets. In this experiment, growth rate seemed to be maximized with IgG concentrations that were equivalent to 80 or 120% of the level of IgG provided by the SDPP diet.

Experiment 3

In this experiment, the addition of SDPP to the diet during wk 1 did not increase feed intake or growth rate significantly (Table 5); however, by the end of the second week, improvements in ADG and ADFI were evident from SDPP inclusion. Inclusion of the IgG-rich fraction of porcine plasma resulted in increased ($P <$ 0.05) growth rate at the end of wk 1, wk 2, and at

Table 4. Gain, feed intake (as-fed basis), and feed:gain of pigs in Exp. 2[a]

	Diet					
Item	Control	SDPP	Porcine IgG-rich 40%	Porcine IgG-rich 80%	Porcine IgG-rich 120%	CV
End of wk 1 (0 to 7 d)						
ADG, g[bcd]	162	272	228	272	273	10.9
ADFI, g[bc]	216	376	291	347	317	17.6
Feed:gain	1.37	1.42	1.27	1.30	1.18	20.9
End of wk 2 (0 to 14 d)						
ADG, g[c]	274	334	334	333	349	10.1
ADFI, g[bc]	386	461	461	471	470	8.0
Feed:gain[b]	1.43	1.40	1.40	1.42	1.38	6.1
End of wk 3 (0 to 21 d)						
ADG, g	363	371	372	416	413	11.6
ADFI, g	525	589	548	563	572	7.6
Feed:gain[be]	1.45	1.59	1.49	1.50	1.40	5.6

[a]Each mean represents four pens of four pigs each, initially averaging 6.3 kg of BW and 21.3 d of age. SDPP = spray-dried porcine plasma, and IgG = immunoglobulin G.
[b]Control vs. SDPP, $P < 0.05$.
[c]Control vs. mean of IgG-rich fractions, $P < 0.05$.
[d]Linear effect within IgG-rich fractions, $P < 0.05$.
[e]SDPP vs. mean of IgG-rich fractions, $P < 0.05$.

Table 5. Gain, feed intake (as-fed basis), and feed:gain of pigs in Exp. 3[a]

	Diet					
Item	Control	SDPP	Porcine IgG-rich 64%	Porcine IgG-rich 128%	Porcine IgG-rich 192%	CV
End of wk 1 (0 to 7 d)						
ADG, g[bc]	117	102	146	180	167	19.2
ADFI, g[b]	178	187	196	225	204	10.0
Feed:gain[c]	1.57	1.99	1.45	1.29	1.24	23.6
End of wk 2 (0 to 14 d)						
ADG, g[bd]	170	228	228	264	258	11.6
ADFI, g[bd]	243	356	325	373	356	10.3
Feed:gain[c]	1.44	1.57	1.45	1.41	1.39	7.6
End of wk 4 (0 to 28 d)						
ADG, g[bc]	327	335	363	395	341	8.4
ADFI, g	474	515	527	554	525	9.9
Feed:gain	1.45	1.53	1.45	1.40	1.55	5.0

[a]Each mean represents four pens of four or five pigs each, initally averaging 5.3 kg of BW and 14.8 d of age. SDPP = spray-dried porcine plasma, and IgG = immunoglobulin G.
[b]Control vs. mean of IgG-rich fractions, $P < 0.05$.
[c]SDPP vs. mean of IgG-rich fractions, $P < 0.05$.
[d]Control vs. SDPP, $P < 0.05$.
[e]Quadratic effect within IgG-rich fractions, $P < 0.05$.

termination of the 4-wk study. Feed:gain of pigs fed the IgG fraction was less ($P < 0.05$) than for those fed SDPP at the end of wk 1 and 2 of the study, but these differences were not evident at the end of the study.

As in the previous experiment, the growth and feed intake response seemed to maximize at the intermediate level of IgG inclusion, but a quadratic ($P < 0.05$) response was evident only for growth rate at the end of the study.

Experiment 4

Pigs fed SDPP grew faster, consumed more feed, and were more efficient ($P < 0.05$) than pigs fed the control diet during the first week of the test (Table 6). The same effects for growth rate and feed intake continued ($P < 0.05$) through the second week. The ADG and feed intake responses to SDBP through wk 1 and 2 were less pronounced than for SDPP ($P < 0.05$), and the responses to SDBP did not differ ($P = 0.10$) from controls. However, improvements ($P < 0.05$) in ADG and feed:gain occurred when the bovine IgG-rich fraction was added to the diet during wk 1, and these trends continued over the initial 2-wk period. The higher bovine IgG treatment level resulted in slightly faster growth rates and feed intakes than the lower bovine IgG level, but the differences were not significant.

At the end of the 4-wk test period following a 2-wk period in which pigs were fed the same diet, the initial growth and feed intake responses to SDPP and to the higher level of the bovine IgG-rich fraction were maintained. In both cases, ADG and ADFI of pigs previously fed SDPP or IgG were greater than controls ($P < 0.05$).

Experiment 5

During the first week, pigs fed SDBP, SDPP, or the two levels of the bovine IgG-rich fraction grew faster, consumed more feed, and had lower feed:gain than pigs fed the control diet ($P < 0.05$; Table 7). The two sources of plasma did not differ significantly, nor did the two levels of the IgG-rich fraction differ significantly for any of the performance traits during wk 1; however, pigs fed the IgG-rich fraction consumed less feed than those fed SDPP or SDBP during this period ($P < 0.05$). Similar trends in ADG, ADFI, and feed:gain continued through the second week of the experiment, but some of the differences were not significant.

At the end of the experiment following the feeding of a common diet, the performance advantages that occurred during wk 1 for SDPP and the highest level of the IgG-rich fraction were essentially lost. The only trend that was maintained was a numerical improvement in ADG for the SDBP and the 50% IgG-rich fraction over controls (neither were significant) and an ADFI advantage of the SDBP and 50% IgG-rich groups vs. the SDPP treatment ($P < 0.05$).

Discussion

Evaluation of SDPP

The beneficial effects resulting from the inclusion of SDPP in diets for early weaned pigs that were first reported by Zimmerman (1987) and Gatnau et al. (1989) have stimulated much research over the past decade. Reviews of numerous research studies have clearly shown that SDPP enhances growth and feed intake by young pigs (Coffey and Cromwell, 2001; Van

Table 6. Gain, feed intake (as-fed basis), and feed:gain of pigs in Exp. 4[a,b]

Item	Diet					
	Control	SDPP	SDBP	Bovine IgG-rich 50%	Bovine IgG-rich 100%	CV
End of wk 1 (0 to 7 d)						
ADG, g	99^{x}	206^{y}	141^{xz}	182^{yz}	202^{y}	21.5
ADFI, g	209^{x}	352^{y}	264^{xz}	270^{xz}	296^{yz}	15.6
Feed:gain	2.14^{x}	1.73^{yz}	1.93^{xy}	1.52^{z}	1.49^{z}	14.5
End of wk 2 (0 to 14 d)						
ADG, g	174^{x}	267^{y}	194^{xz}	223^{yz}	254^{y}	12.9
ADFI, g	285^{x}	451^{y}	336^{xz}	352^{z}	391^{yz}	10.8
Feed:gain	1.65	1.69	1.76	1.60	1.54	9.9
End of wk 4 (0 to 28 d)						
ADG, g	272^{x}	312^{yz}	287^{xz}	327^{yz}	328^{y}	8.5
ADFI, g	480^{x}	564^{y}	520^{xz}	547^{yz}	548^{yz}	5.1
Feed:gain	1.76	1.81	1.82	1.69	1.67	6.4

[a]Each mean represents four pens of four or five pigs each, initially averaging 5.6 kg of BW and 19.7 d of age. SDPP = spray-dried porcine plasma, SDBP = spray-dried bovine plasma, and IgG = immunoglobulin G.
[b]A common diet was fed during wk 3 and 4 of the experiment.
[x,y,z]Means within a row that do not have a common superscript letter differ, $P < 0.05$.

Dijk et al., 2001). In our study, SDPP produced superior growth and feed intakes during the first week in four of the five experiments compared with pigs fed the control diet. The improvement in ADG over controls during wk 1 ranged from 63 and 68% in Exp. 1 and 2 to 108 and 110% in Exp. 4 and 5, respectively. There was also an overall improvement in ADG of 67%, averaged across all five experiments. During this same period, ADFI also increased by an average of 52%. Through wk 2 (0 to 14 d) of the studies, ADG and ADFI increased by an average of 27 and 33%, respectively, in pigs fed SDPP. Feed:gain was not consistently affected by SDPP, but feed efficiency was improved in pigs fed SDPP during wk 1 in the last two experiments. The additional BW gain from feeding SDPP compared with controls during wk 1 was maintained to the end of the study only in Exp. 4. The improvements in ADG and ADFI from feeding SDPP immediately after weaning are consistent with those of other research (Kats et al., 1994; Coffey and Cromwell, 2001; Van Dijk et al., 2001).

Identification of Plasma Component Responsible for Increased Performance

Experiment 1 was designed to identify the molecular weight fraction of SDPP that is responsible for the postweaning growth enhancement in early weaned

Table 7. Gain, feed intake (as-fed basis), and feed:gain of pigs in Exp. 5[a,b]

Item	Diet					
	Control	SDPP	SDBP	Bovine IgG-rich 50%	Bovine IgG-rich 100%	CV
End of wk 1 (0 to 7 d)						
ADG, g	87^{x}	183^{y}	157^{y}	162^{y}	150^{y}	23.4
ADFI, g	175^{x}	287^{y}	256^{y}	235^{z}	229^{z}	13.8
Feed:gain	2.25^{x}	1.60^{y}	1.75^{y}	1.46^{y}	1.66^{y}	13.3
End of wk 2 (0 to 14 d)						
ADG, g	228^{x}	265^{xy}	268^{xy}	287^{y}	271^{xy}	12.3
ADFI, g	333^{x}	425^{y}	404^{y}	389^{y}	380^{xy}	9.9
Feed:gain	1.47^{xy}	1.62^{y}	1.53^{xy}	1.35^{x}	1.43^{x}	9.3
End of wk 4 (0 to 28 d)						
ADG, g	367^{xy}	339^{x}	390^{xy}	404^{y}	365^{xy}	10.4
ADFI, g	588^{xy}	566^{x}	636^{y}	635^{y}	588^{xy}	7.9
Feed:gain	1.61^{xy}	1.68^{y}	1.63^{xy}	1.57^{x}	1.62^{xy}	4.5

[a]Each mean represents five pens of five to seven pigs initially averaging 5.6 kg of BW and 19.7 d of age. SDPP = spray-dried porcine plasma, SDBP = spray-dried bovine plasma, and IgG = immunoglobulin G.
[b]A common diet was fed during wk 3 and 4 of the experiment.
[x,y,z]Means within a row that do not have a common superscript letter differ, $P < 0.05$.

pigs. Of the three molecular weight fractions tested, only the IgG-rich fraction resulted in increased ADG and ADFI ($P < 0.05$) that were similar to those of pigs fed SDPP during the first week of the experiment. Neither of the other two fractions tested improved growth performance. The results clearly indicated that the initial growth response to SDPP was associated with the contribution of the IgG-rich fraction and not the albumin-rich or the low molecular weight fractions of plasma.

Significant improvements in ADG and ADFI from feeding the porcine IgG-rich fraction also were evident at the end of wk 1 and 2 in Exp. 2 and 3; growth responses (averaged across levels) were superior to those of pigs fed SDPP. In Exp. 2, the additional BW gain of pigs fed the IgG-rich fraction over controls during wk 1 (670 g) was maintained through wk 2 (905 g) and to the end of the study (784 g). Similar responses were evident in Exp. 3 with earlier weaned pigs (331, 1,120, and 1,101 g of BW gain advantage through wk 1, 2, and 3, respectively). These improvements are attributable to the continuous source of immunoglobulins until the pig is capable of synthesizing its own immunoglobulins (Wilson, 1974). Milk-derived immunoglobulins added to milk replacers have been shown to increase growth performance following gut closure in early weaned pigs (Leibbrant et al., 1987).

Evaluation of Porcine IgG Levels

Numerous studies have shown that growth performance is maximized with approximately 8% SDPP in the diet (Gatnau and Zimmerman, 1992; Owen et al., 1995; Coffey and Cromwell, 2001), which is the level of SDPP that we used in our study. For that reason, we selected levels of IgG that were below and above the amount of IgG that was provided by 8% SDPP (i.e., 40, 80, and 120% of the IgG in SDPP in Exp. 1; and 64, 128, and 192% of the IgG in SDPP in Exp. 2). The results of Exp. 2 indicate that pigs responded favorably to the addition of 80% of the porcine IgG found in the 8% SDPP diet with essentially no further improvement resulting from feeding a higher level of IgG (i.e., 120% of the IgG in the 8% SDPP diet). In Exp. 3, with younger pigs weaned at 14 d of age, the improvements in ADG and ADFI to IgG inclusion were more pronounced than in Exp. 2 with pigs weaned at 21 d, and the responses seemed to maximize at the 128% level of IgG. In both experiments, the early response to the IgG fraction was not lost as the experiment progressed in time, as was observed with the intact plasma product. Averaged across the three levels of IgG and the two experiments, the advantage in BW gain of pigs fed the porcine IgG fraction compared with controls was 501 g during wk 1, 1,013 g by the end of wk 2, and 943 g for the entire test.

These results confirm the earlier suggestion by Gatnau et al. (1995) and others that the positive responses to SDPP may result from specific immunoglobulin proteins, and they help to explain why greater responses to SDPP occur in a challenged vs. clean environment for pigs (Coffey and Cromwell, 1995) and poultry (Campbell et al., 2003, 2004a).

Evaluation of SDBP

Another objective of our study was to further determine whether there was a species-specific response to spray-dried plasma. Three recent reports suggested that there were no differences between responses of pigs fed diets containing SDBP or SDPP for 2 wk after weaning (Gatnau and Zimmerman, 1994; Russell, 1994; Russell and Weaver, 1996), whereas other studies (Hansen et al., 1993; Rantanen et al., 1994; Smith et al., 1995) indicated that SDBP was not as effective as SDPP.

Experiments 4 and 5 were conducted to compare the relative efficacy of SDBP and SDPP. Experiment 4 was conducted in the same experimental, off-site nursery that housed the pigs in Exp. 1, 2, and 3, whereas Exp. 5 was conducted in an on-farm facility with relatively continuous pig flow. In Exp. 4, pigs fed SDPP grew faster and consumed more feed than those fed SDBP during the first 2 wk of the experiment ($P < 0.05$). Similar trends occurred in Exp. 5, but the differences in ADG and ADFI between pigs fed the two plasma sources were not significant. Following the feeding of a common diet for 2 wk, however, the ADG and ADFI responses for the entire 4-wk period were in favor of SDBP vs. SDPP ($P < 0.05$ for ADFI). The additional BW gains by pigs fed plasma initially were maintained through wk 2 and to the end of the test period in Exp. 4 (SDPP = 749 g for wk 1, 1,302 g for wk 1 and 2, and 1,120 g for entire test; SDBP = 294, 280, and 420 g, respectively) but only for the SDBP treatment in Exp. 5 (SDPP = 672, 518, and −784 g; SPBP = 490, 560, and 644 g, respectively).

The results of these two experiments suggest that the type of environment may affect the relative response to SDPP or SDBP. In the off-site nursery (cleaner environment), there tended to be an advantage in the SDPP compared with the SDBP, whereas there was essentially no difference in the two sources of plasma in the on-site nursery except for an ADFI advantage following the feeding of a common diet for pigs previously fed the SDBP for the initial 2 wk. However, because the two environments were not replicated over time, no statistical evaluation of a possible interaction could be made.

Evaluation of Bovine IgG Levels

The use of IgG from SDBP in early weaned pig diets had not been previously researched at the time of this study. Based on the results of Exp. 1 that the IgG fraction of SDPP is responsible for the increase in growth rate and ADFI in early weaned pigs, we expected that the IgG fraction of SDBP might be as effective as the intact SDBP product during the early postweaning period. The results of the two final experiments indicated that the bovine IgG-rich fraction was effective in improving growth rate and feed intake during the early postweaning period. In both experiments, the inclusion of the bovine IgG-rich fraction at 50% of the IgG level provided by 8% SDBP was as effective as 100% of the IgG level with respect to improvements in ADG and ADFI during wk 1 and through wk 2. The performance resulting from bovine IgG inclusion was superior ($P < 0.05$) to that of SDBP in Exp. 4 but not in Exp. 5. Averaged across both experiments and both levels of IgG, the BW gain advantage of treated pigs over controls during wk 1 (567 g) was maintained through wk 2 (809 g) and to the end of the study (1,022 g).

In a review, Coffey and Cromwell (2001) concluded that it now seems that SDPP and SDBP enhance pig performance by improving the immunocompetence of the young pig, most likely mediated by the IgG component in the plasma. The IgG prevents viruses and bacteria from damaging the gut wall, thereby resulting in a more functional intestinal wall. Several studies have shown that pigs fed dried plasma have improved intestinal morphology and enzyme activity as evidenced by increased villus surface area (Gatnau et al., 1995), longer villi and a greater villus:crypt (Touchette et al., 1997; Spencer et al., 1997), and increased mucosal maltase and lactase activities (Cain et al., 1992; Gatnau et al., 1995).

In summary, from the results of these experiments, it can be concluded that porcine and bovine IgG are as effective as SDPP or SDBP with respect to stimulating growth rate and feed intake and thereby potentially decreasing the postweaning growth lag in early weaned pigs.

Implications

Spray-dried plasma of either bovine or porcine origin enhances feed intake and growth rate of early weaned pigs, especially during the first week after weaning. The immunoglobulin G fraction of porcine or bovine plasma is responsible for the enhanced pig performance that occurs when spray-dried plasma is fed. The immunoglobulin G fraction of porcine or bovine plasma seems to stimulate equal or better growth performance than the whole plasma products, and the early responses seem to be more consistently maintained into later postweaning periods. Spray-dried animal plasma or the immunoglobulin G-rich fraction of animal plasma should decrease the postweaning growth lag that can occur in early weaned pigs.

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