Evaluation of methods to reduce bacteria concentrations in spray-dried animal plasma and its effects on nursery pig performance[1]

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ABSTRACT: Four experiments with 1,040 weanling pigs (17 ± 2 d of age at weaning) were conducted to evaluate the effects of spray-dried animal plasma source, drying technique, and methods of bacterial reduction on nursery pig performance. In Exp. 1, 180 barrows and gilts (initial BW 5.9 ± 1.8 kg) were used to compare effects of animal plasma, animal plasma source, drying technique (spray-dried or freeze-dried), and plasma irradiation in nursery pig diets. From d 0 to 10, pigs fed diets containing irradiated spray-dried animal plasma had increased ADG and ADFI ($P < 0.05$) compared with pigs fed diets containing nonirradiated spray-dried animal plasma. Pigs fed irradiated animal plasma Sources 1 and 2 were similar in ADG and ADFI, but pigs fed animal plasma Source 1 had greater ADG ($P < 0.05$) than pigs fed animal plasma Source 2 and pigs not fed plasma. Pigs fed freeze-dried animal plasma had growth performance similar ($P > 0.36$) to pigs fed spray-dried animal plasma. Overall (d 0 to 24), pigs fed irradiated spray-dried animal plasma were heavier ($P < 0.05$) than pigs fed no animal plasma, whereas pigs fed nonirradiated spray-dried plasma were intermediate. In Exp. 2, 325 barrows and gilts (initial BW 5.8 ± 1.7 kg) were used to compare the effects of irradiation or formaldehyde treatment of animal plasma and formaldehyde treatment of the whole diet. Pigs fed diets containing irradiated animal plasma had greater ADG ($P < 0.05$) than pigs fed nonirradiated plasma. Pigs fed formaldehyde-treated plasma had greater ADG and ADFI ($P < 0.05$) than pigs fed diets with either nonirradiated plasma or whole diet treated with formaldehyde. In Exp. 3 (360 barrows and gilts; initial BW 6.3 ± 2.7 kg) and Exp. 4 (175 barrows and gilts; initial BW 6.1 ± 1.7 kg), the irradiation of feed (high bacteria) and food-grade (low bacteria) animal plasma in nursery pig diets was examined. Pigs fed irradiated feed-grade plasma Product 2 had increased ADG ($P < 0.05$) compared with pigs fed nonirradiated plasma Product 2 and pigs fed the control diet without plasma. In Exp. 3 and 4, pigs fed irradiated food-grade plasma had growth performance similar to pigs fed nonirradiated food-grade plasma ($P > 0.12$). These studies indicate that bacterial reduction of feed-grade, but not food-grade animal plasma, improves nursery pig performance.

Key Words: Animal Plasma, Bacteria, Formaldehyde, Growth, Irradiation, Nursery Pigs

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Introduction

Previously, spray-dried animal plasma has been shown to improve performance in diets for early-weaned pigs (Hansen et al., 1993; Kats et al., 1994). Recent research trials have focused on improving the quality of animal plasma. Previous studies (Steidinger, 2000) evaluated variation in animal plasma between and within different manufacturers by comparing immunoglobulin, Na, and Cl in plasma, but no definitive conclusions were reached. Drying procedures used in manufacturing dried blood products may be a source of variation, as they can affect its feeding value (Hamm and Searcy, 1976). Currently, all feed-grade animal plasma that is commercially available is spray-dried. Although spray drying is generally preferred over vat or ring drying, protein damage from heat exposure may also occur during this process. Freeze drying, which uses ambient temperature air, provides a model to which the spray-drying process may be compared in order to test protein quality.

Bacterial content is another possible source of variation in animal plasma. Nursery pigs fed irradiated spray-dried blood meal (DeRouchey et al., 2003) and feed-grade spray-dried animal plasma (DeRouchey et al., 2002) had improved growth performance compared with pigs fed spray-dried blood meal or spray-dried ani-

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Table 1. Chemical analyses of animal plasma used in Experiments 1 and 2[a]

	Experiment 1						
	Source 1	Source 2		Experiment 2			
Item, %	Spray-dried	Spray-dried	Freeze-dried	Regular	Irradiated	Chemical[b]	NRC[c]
CP (N × 6.25)	80.49	76.35	77.52	81.52	82.56	81.93	78.0
Amino acid							
Arginine	4.64	4.29	4.46	4.73	4.83	4.65	4.55
Cystine	2.51	2.13	2.46	2.72	2.78	2.71	2.63
Histidine	2.73	2.41	2.67	2.71	2.77	2.64	2.55
Isoleucine	2.88	2.45	2.65	3.03	3.13	2.78	2.71
Leucine	7.93	7.09	7.59	7.85	7.88	7.78	7.61
Lysine	6.95	6.15	6.60	7.30	7.54	7.48	6.84
Methionine	0.71	0.64	0.66	0.74	0.76	0.89	0.75
Phenylalanine	4.56	4.07	4.32	4.63	4.62	4.41	4.42
Tyrosine	3.98	3.47	3.81	4.21	4.25	4.10	3.53
Threonine	4.36	3.77	4.24	4.44	4.53	4.79	4.72
Tryptophan	1.70	1.64	1.64	1.48	1.46	1.41	1.36
Valine	5.33	4.83	5.18	5.33	5.37	5.49	0.94

[a]Values are expressed on an as-fed basis.
[b]Formaldehyde treatment.
[c]Values provided from the NRC (1998) that were used in diet formulation (Exp. 1 and 2).

mal plasma that was not irradiated. Although the mode of action for this improvement is not known, it was theorized that a reduction in bacteria from irradiation might be responsible for the increased growth performance. Chemical products, such as formaldehyde-based antibacterial feed additives, help decrease and prevent recontamination of bacteria in feeds (Kaiser, 1992; Anderson et al., 2001); however, little information is available on their effects in nursery pig diets. Food-grade animal plasma with very low initial bacterial concentration may provide a comparison with feed-grade animal plasma treated via irradiation or chemicals.

The objectives of these experiments were to determine the effects of 1) drying technique and irradiation of animal plasma on nursery pig performance, 2) formaldehyde treatment to animal plasma and whole diets for nursery pigs, and 3) irradiation on feed and food-grade plasma in nursery pig diets.

Materials and Methods

General

The Kansas State University Institutional Animal Care and Use Committee approved all experimental protocols used in this study. All pigs used in the experiments were 17 ± 2 d of age at weaning and randomly allotted and blocked by weaning weight to dietary treatments.

The nutrient composition of ingredients provided by the NRC (1998) was used in diet formulation, except for feed-grade Product 2 and food-grade animal plasma products in Exp. 3 and 4, which were provided by the supplier (American Protein Corp., Ames, IA). All diets were formulated to meet or exceed the NRC (1998) nutrient requirements. Experimental diets in Exp. 1 and 2 and the common diet in Exp. 3 and 4 were fed in meal form, whereas experimental diets in Exp. 3 and 4 were pelleted. All pens in the experiments had a single self-feeder and one stainless steel nipple water to allow ad libitum access to feed and water.

Spray-dried animal plasma samples were collected prior to diet manufacturing, and complete feed samples were collected for analyses at the start of each trial. Animal plasma samples in each experiment were analyzed for DM, CP, and individual amino acids at the University of Missouri (AOAC, 1995; Tables 1 and 2). Bacteria concentrations of plasma (Exp. 1, 2, 3, and 4) and whole diet (Exp. 1 and 2); total coliforms of plasma (Exp. 1, 3, and 4) and whole diet (Exp. 1); and immunoglobulin (IgG), endotoxin, and *E. coli* concentrations (Exp. 3 and 4) were determined (Carter and Cole, 1990).

Experiment 1

One hundred eighty barrows and gilts (Line 327 sire × C22 dams; PIC, Franklin, KY) were used in a 24-d growth assay (initial BW 5.9 × 1.8 kg). Pigs were housed in an environmentally controlled nursery in 1.2- × 1.5-m pens with woven metal flooring. There were six dietary treatments with six replications (pens) and five pigs per pen.

Treatment diets were fed from d 0 to 10 after weaning. Treatments included a control diet containing no animal plasma and five diets containing 5% spray-dried animal plasma from two different sources and drying techniques (Table 3). From Source 1 (AP 920; American Proteins Corp.), spray-dried animal plasma was purchased and half the total lot was irradiated. From Source 2 (California Spray Dry, Stockton, CA), a single lot of liquid plasma was divided and subsequently

Table 2. Chemical analyses of animal plasma used in Experiments 3 and 4[a]

	Experiment 3				Experiment 4			
	Feed-grade product		Food-grade product		Feed-grade product	Food-grade product		
Item, %	1	2	1	2	2	3	NRC[b]	Other[c]
CP (N × 6.25)	80.2	69.91	71.19	71.46	69.28	71.15	78.0	70.0
Amino acid	4							
Arginine	4.61	3.92	4.12	4.05	3.81	4.10	4.35	4.20
Cystine	2.63	2.39	2.53	2.51	2.26	2.49	2.63	2.50
Histidine	2.45	2.15	2.17	2.17	2.04	2.20	2.55	2.50
Isoleucine	2.61	2.09	2.19	2.23	1.97	2.14	2.71	2.60
Leucine	7.71	6.81	7.00	6.96	6.65	7.01	7.61	7.00
Lysine	6.88	6.37	6.21	6.26	5.69	6.26	6.84	6.10
Methionine	0.90	0.77	0.80	0.78	0.73	0.79	0.75	0.60
Phenylalanine	4.24	3.73	3.75	3.80	3.62	3.83	4.42	4.10
Tyrosine	4.02	3.47	3.55	3.55	3.37	3.58	3.53	3.30
Threonine	4.95	4.37	4.45	4.28	4.39	4.42	4.72	4.30
Tryptophan	1.68	1.54	1.35	1.43	1.52	1.44	1.36	1.20
Valine	5.54	2.39	4.79	4.84	4.64	4.80	4.94	4.80

[a]Values are expressed on an as-fed basis.
[b]Values provided from the NRC (1998) were used in diet formulation for feed-grade Product 1 (Exp. 3).
[c]Values provided from ingredient supplier that were used in diet formulation for feed-grade Product 2 and all food-grade products.

spray- or freeze-dried. A portion of the animal plasma that was spray-dried was irradiated, along with all of the freeze-dried animal plasma. As a result, there were three animal plasma treatments from Source 1, which were spray-dried, spray-dried and irradiated, or freeze-dried and irradiated. Animal plasma irradiation was accomplished via gamma ray (cobalt-60 source; Steri-Genics, Tustin, CA) at an average dose of 9.8 kGy. Diets were also balanced for Ca, P, Na, and Cl concentrations. A common diet was fed from d 10 to 24 (Table 3). Pigs were weighed and feed disappearance measured on d 5, 10, and 24 to determine ADG, ADFI (as-fed basis), and gain:feed (**G:F**).

Experiment 2

A total of 325 barrows and gilts (Line 42; PIC) were used in a 14-d growth assay (initial BW 5.8 ± 1.7 kg). Pigs were housed in an environmentally controlled nursery in 1.2-m^2 pens with slatted metal flooring. There were a total of five dietary treatments with 13 replications (pens) and five pigs per pen.

Treatment diets were fed from d 0 to 14 after weaning. The treatments were as follows (Table 3): 1) control diet with regular spray-dried animal plasma (AP 920; American Proteins Corp.), 2) control diet with irradiated animal plasma, 3) control diet with formaldehyde (Termin-8, Anitox Corp., Buford, GA)-treated animal plasma; 4) control diet with formaldehyde treatment to the whole diet, and 5) Treatment 2 with formaldehyde treatment to the whole diet. Formaldehyde application was provided at the FDA-approved level of 3 mg/kg of total product (plasma or complete diet). The spray-dried animal plasma used in this experiment was the same as that of Source 1 in Exp. 1. Irradiation of animal plasma was completed via electron beam (Iowa State University) at a dosage of 9.8 kGy. All individual ingredients used in the diets originated from similar lots. Pigs were weighed and feed disappearance measured on d 7 and 14 to determine ADG, ADFI, and G:F.

Experiment 3

Three hundred sixty barrows and gilts (Line 42; PIC) were used in a 24-d growth assay (initial BW 6.3 ± 2.7 kg). Pigs were housed in an environmentally controlled nursery in 1.2-m^2 pens with slatted metal flooring. There were a total of nine dietary treatments with eight replications (pens) and five pigs per pen.

Treatment diets were fed from d 0 to 14 after weaning (Table 4). Treatments consisted of a control diet or the control diet with 5% spray-dried animal plasma from either feed-grade (American Proteins Corp.; Products 1 and 2) or food-grade animal plasma (American Proteins Corp.; Products 1 and 2). Within each animal plasma product, they were either fed irradiated or as-is. Irradiated animal plasma was processed with an average dose of 8.5 kGy via electron beam (Iowa State University). All pigs were fed a common diet for d 14 to d 24 after weaning. Pigs were weighed and feed disappearance measured on d 7, 14, and 24 to determine ADG, ADFI, and G:F.

Experiment 4

One hundred seventy-five barrows and gilts (Line 42; PIC) were used in a 24-d growth assay (initial BW 6.1 ± 1.7 kg). There were a total of five dietary treatments with seven replications (pens) and five pigs per pen. The housing, care of pigs, and response criteria were similar to those of Exp. 3.

Table 3. Composition of experimental diets used in Experiments 1 and 2 (as-fed basis)[a]

Ingredient, %	Exp. 1 No plasma control	Exp. 1 Added plasma	Exp. 1 Common	Exp. 2
Corn	41.88	49.39	48.83	49.06
Soybean meal, 46.5% CP	37.68	25.71	29.00	25.74
Spray-dried whey	15.00	15.00	10.00	15.00
Animal plasma	—	5.00	—	5.00
Formaldehyde or cornstarch[b]	—	—	—	0.30
Choice white grease	—	—	5.00	—
Spray-dried blood cells	—	—	2.50	—
Monocalcium phosphate, 21% P	1.49	1.38	1.85	1.38
Limestone	1.02	1.15	0.95	1.15
Antibiotic[c]	1.00	1.00	1.00	1.00
Salt	0.42	0.30	0.25	0.30
Zinc oxide	0.39	0.39	—	0.39
Vitamin premix[d]	0.25	0.25	0.25	0.25
Trace mineral premix[d]	0.15	0.15	0.15	0.15
Sodium bicarbonate	0.38	—	—	—
L-Lysine HCl	0.15	0.15	0.15	0.15
DL-Methionine	0.16	0.13	0.07	0.13
L-Threonine	0.03	—	—	—
Calculated analysis				
Lysine, %	1.50	1.50	1.40	1.50
Met:lysine ratio, %	34	30	28	30
Met and Cys:lysine ratio, %	60	60	55	60
Threonine:lysine ratio, %	64	64	65	64
Isoleucine:lysine ratio, %	68	61	62	19
Tryptophan:lysine ratio, %	20	19	20	3,236
ME, kcal/kg	3,191	3,237	3,462	0.90
Ca, %	0.90	0.90	0.89	0.80
P, %	0.80	0.80	0.80	0.46
Na, %	0.43	0.43	0.23	0.43
Cl, %	0.53	0.53	0.39	0.53

[a]For Exp. 1, experimental diets fed from d 0 until 10, with the common diet fed from d 10 to 24 after weaning. For Exp. 2, experimental diets were fed from d 0 to 14.
[b]Formaldehyde inclusion rate of 3 mg/kg of complete feed.
[c]Provided 55 mg of carbadox/kg of complete diet.
[d]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfite); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenic acid); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.3 mg of Se; 165.4 mg of Zn; and 0.3 mg of I.

Treatment diets used in this experiment included a control diet, and the control diet containing feed-grade plasma Product 2 (similar to Product 2 in Exp. 3) or food-grade plasma product 3 (Table 4). Within each animal plasma product, they were either fed irradiated or as-is. Irradiated animal plasma was processed with an average dose of 8.0 kGy via electron beam (Iowa State University).

Statistical Analyses

Data for all experiments was analyzed using the MIXED procedures of SAS (SAS Institute Inc., Cary, NC) as randomized complete block designs with pen as the experimental unit. In Exp. 1, the least square difference test was used to determine differences among treatments ($P < 0.05$) and contrasts were used to determine the effects of plasma and irradiation. In Exp. 2, the least square difference test was used to determine differences among treatments ($P < 0.05$). In Exp. 3 and 4, contrasts were used to determine whether differences existed between control, nonirradiated, and irradiated animal plasma treatments: 1) control vs. all added plasma treatments; 2) control vs. nonirradiated; and 3) irradiated vs. nonirradiated plasma.

Results

Amino Acid Analyses

For Exp. 1, Source 1 spray-dried animal plasma had a higher level of CP and concentration of the majority of amino acids, compared to the NRC (1998) estimates and animal plasma from Source 2 (Exp. 1; Table 1). In addition, drying method did not influence amino acid composition. For Exp. 2, irradiation or formaldehyde treatment carried out on spray-dried animal plasma did not affect CP and amino acid levels. For the feed-grade products in Exp. 3 and 4, the CP and amino acid compositions for Product 1 (Exp. 3) were slightly higher

Table 4. Composition of diets used in Experiments 3 and 4 (as-fed basis)

	Treatment diets[a]			
Ingredient, %	No plasma[b]	Feed-grade product 1[c]	Other animal plasma products[d]	Common[e]
Corn	36.47	43.91	43.91	46.97
Soybean meal, 46.5% CP	38.14	26.18	26.18	31.11
Spray-dried whey	15.00	15.00	15.00	10.00
Spray-dried animal plasma	—	5.00	5.00	—
Spray-dried blood cells	—	—	—	2.50
Soy oil	5.00	5.00	5.00	5.00
Medication[f]	1.00	1.00	1.00	1.00
Monocalcium phosphate, 21% P	1.55	1.44	1.44	1.29
Limestone	0.99	1.13	1.13	1.00
Salt	0.42	0.30	0.30	0.35
Sodium bicarbonate	0.38	—	—	—
Zinc oxide	0.39	0.39	0.39	0.25
Vitamin premix[g]	0.25	0.25	0.25	0.25
Trace mineral premix[g]	0.15	0.15	0.15	0.15
L-Lysine HCl	0.15	0.15	0.15	0.05
DL-Methionine	0.09	0.11	0.11	0.09
L-Threonine	0.01	—	—	—
Calculated analysis				
Lysine, %	1.50	1.50	1.46	1.40
Met:lysine ratio, %	29	28	28	29
Met and Cys:lysine ratio, %	55	58	58	55
Threonine:lysine ratio, %	62	64	64	62
Tryptophan:lysine ratio, %	20	19	19	20
ME, kcal/kg	3,440	3,484	3,471	3,468
Ca, %	0.90	0.90	0.90	0.80
P, %	0.80	0.80	0.72	0.70
Na, %	0.43	0.43	0.43	0.26
Cl, %	0.53	0.53	0.60	0.43

[a]Diet fed from d 0 to 14 after weaning.
[b]Experiments 3 and 4.
[c]Experiment 3.
[d]Feed-grade Product 2 and food-grade Products 1, 2, and 3, Exp. 3 and 4.
[e]Diet fed from d 14 to 28 after weaning.
[f]Provided 55 mg of carbadox per kg of complete feed.
[g]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfite); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenic acid); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.3 mg of Se; 165.4 mg of Zn; and 0.3 mg of I.

than those of values used for diet formulation (NRC, 1998), whereas values for Product 2 (Exp. 3 and 4) were similar to those provided by the ingredient supplier and used in diet formulation (Table 2). For food-grade products (Exp. 3 and 4), CP and amino acid compositions were slightly higher than those of values used for diet formulation as provided by the ingredient supplier (Table 2). However, in the authors' opinion, differences in total amino acid concentrations between formulated and chemically analyzed values were not large enough to cause growth differences observed because of the relatively low inclusion of various spray-dried animal plasma products made to the diet.

Experiment 1

From d 0 to 5, pigs fed irradiated spray-dried animal plasma had increased ADG ($P < 0.05$) and tended to have greater ADFI ($P < 0.10$) compared to pigs fed nonirradiated spray-dried animal plasma, regardless of source (Table 5). In addition, pigs fed Source 1 nonirradiated plasma had improved ADG and G:F ($P < 0.05$) compared to those fed the control diet. From d 5 to 10 after weaning, pigs fed spray-dried animal plasma Source 1 had increased ADG and ADFI ($P < 0.05$) compared to pigs fed the control diet without spray-dried animal plasma. From d 0 to 10, ADG ($P < 0.05$) increased and ADFI ($P < 0.10$) tended to improve for pigs fed irradiated spray-dried animal plasma vs. animal plasma that was not irradiated. Pigs fed Source 2 freeze-dried and irradiated plasma had similar growth performance ($P > 0.36$) compared to pigs fed Source 2 of irradiated spray-dried animal plasma.

From d 10 to 24, ADFI was increased ($P < 0.05$) for pigs previously fed diets containing spray-dried animal plasma that were irradiated compared to pigs fed diets containing nonirradiated spray-dried animal plasma. Overall (d 0 to 24), pigs fed irradiated spray-dried ani-

Table 5. Effects of animal plasma source, processing technique, and irradiation of plasma on weanling pig growth performance (Exp. 1)[a]

Item	Control	Plasma source 1		Plasma source 2			SEM
		Spray-dried	Spray-dried and irradiated	Spray-dried	Spray-dried and irradiated	Freeze-dried and irradiated	
Initial wt, kg	5.94	5.90	5.94	5.94	5.93	5.94	0.08
Day 0 to 5							
ADG, g[bd]	223[f]	268[g]	321[h]	223[f]	280[g]	273[g]	14.6
ADFI, g[e]	209[f]	215[f]	284[g]	212[f]	238[f]	220[f]	18.5
Gain:feed[c]	1.07[f]	1.26[g]	1.15[fg]	1.04[f]	1.19[fg]	1.25[g]	0.06
Day 5 to 10							
ADG, g[b]	239[f]	294[g]	330[g]	253[fg]	297[fg]	288[fg]	14.5
ADFI, g[b]	280[f]	328[g]	364[g]	293[fg]	325[fg]	308[fg]	18.7
Gain:feed	0.72	0.74	0.76	0.76	0.77	0.77	0.04
Day 0 to 10							
ADG, g[bd]	239[f]	295[hi]	330[i]	253[fg]	297[hi]	288[gh]	14.5
ADFI, g[be]	281[f]	328[fg]	364[g]	293[f]	325[fg]	307[f]	18.7
Gain:feed	0.85	0.90	0.91	0.86	0.92	0.94	0.03
Day 10 wt, kg[bd]	8.34[f]	8.85[hi]	9.24[hi]	8.44[fg]	8.90[hi]	8.82[gh]	0.14
Day 10 to 24							
ADG, g	399[f]	359[g]	374[fg]	400[f]	405[f]	345[g]	14.1
ADFI, g[d]	491[fg]	449[f]	480[fg]	456[f]	508[g]	450[f]	15.2
Gain:feed	0.81[f]	0.79[f]	0.77[f]	0.87[g]	0.79[f]	0.76[f]	0.02
Final wt, kg[be]	12.75[f]	13.57[fg]	14.20[g]	13.48[fg]	14.18[g]	13.37[fg]	0.35
Animal plasma, cfu/g							
Aerobic plate count	N/A	2.6×10^4	3.5×10^2	9.0×10^4	4.5×10^1	0	—
Coliform count	N/A	0	0	0	0	0	—
Whole diet, cfu/g							
Aerobic plate count	3.7×10^4	1.0×10^4	7.6×10^3	1.0×10^4	3.1×10^2	6.8×10^3	—
Coliform count	2.8×10^4	6.0×10^3	1.0×10^3	6.7×10^3	3.0×10^2	2.1×10^2	—

[a]A total of 180 pigs (five pigs per pen and six pens per treatment) initially 17 ± 2 d of age.
[b]Control vs. mean of plasma treatments ($P < 0.05$).
[c]Control vs. mean of plasma treatments ($P < 0.10$).
[d]Spray-dried plasma vs. spray-dried and irradiated plasma ($P < 0.05$).
[e]Spray-dried plasma vs. spray-dried and irradiated plasma ($P < 0.10$).
[f,g,h,i]Within a row, means without a common superscript differ ($P < 0.05$).

mal plasma were heavier ($P < 0.05$) compared to pigs fed the control diet, whereas pigs fed nonirradiated spray-dried plasma were not ($P > 0.11$).

Irradiation decreased the bacteria concentration in the spray-dried animal plasma, regardless of source (Table 5). However, the reduction of bacteria in the animal plasma had little effect on total bacterial level in the whole diet.

Experiment 2

From d 0 to 7 (Table 6), pigs fed diets containing irradiated animal plasma had greater ADG ($P < 0.05$) than pigs fed the control diet and pigs fed whole diets treated with formaldehyde containing either regular or irradiated animal plasma. Pigs fed irradiated animal plasma had improved ADFI ($P < 0.05$) compared with pigs fed the whole diets treated with formaldehyde. Additionally, pigs fed formaldehyde-treated animal plasma had increased ADFI ($P < 0.05$) compared with the pigs fed the control and increased ADG and ADFI ($P < 0.05$) compared with pigs fed whole diets treated with formaldehyde (containing either nonirradiated or irradiated animal plasma). In addition, pigs fed the control diet tended to have increased ADFI ($P < 0.09$) compared with the whole diets treated with formaldehyde.

From d 7 to 14, pigs fed diets containing formaldehyde-treated animal plasma had greater ADG and ADFI ($P < 0.05$) than pigs fed either of the two whole diets treated with formaldehyde. In addition, pigs fed diets containing formaldehyde-treated animal plasma tended to have greater ADG ($P < 0.10$) than pigs fed the control diet. Pigs fed the control diet had reduced G:F ($P < 0.05$) compared with pigs fed the whole diet treated with formaldehyde that contained nonirradiated animal plasma.

Overall (d 0 to 14), pigs fed diets containing irradiated animal plasma had greater ADG ($P < 0.05$), and pigs fed diets containing formaldehyde-treated animal plasma had improved ADG and ADFI ($P < 0.05$), compared with pigs fed the control diet and pigs fed whole diets treated with formaldehyde. In addition, pigs fed the control diet tended ($P < 0.06$) to have greater ADFI than those fed the whole diet treated with formaldehyde that con-

Table 6. Effects of irradiation or formaldehyde of plasma and/or whole diet on growth performance of nursery pigs (Exp. 2)[a]

Item	Control	Irradiated plasma	Formaldehyde plasma[b]	Formaldehyde whole diet[b]	Formaldehyde whole diet with irradiated plasma[b]	SEM
Initial wt, kg	5.78	5.78	5.77	5.75	5.76	0.02
Day 0 to 7						
ADG, g	155[ce]	196[d]	185[cd]	131[e]	139[e]	13.8
ADFI, g	176[ce]	196[cd]	213[d]	149[e]	149[e]	11.9
Gain:feed	0.89	1.00	0.87	0.87	0.93	0.04
Day 7 to 14						
ADG, g	316[cd]	341[cd]	348[c]	305[d]	312[d]	16.3
ADFI, g	387[cde]	403[cd]	422[c]	348[e]	364[de]	17.6
Gain:feed	0.82[c]	0.85[cd]	0.83[cd]	0.88[d]	0.86[cd]	0.03
Day 0 to 14						
ADG, g	235[c]	269[d]	266[d]	218[c]	225[c]	12.3
ADFI, g	281[de]	299[cd]	318[c]	248[e]	256[e]	13.0
Gain:feed	0.84	0.90	0.84	0.88	0.88	0.03
Final wt, kg	9.26[cd]	9.42[c]	9.54[c]	8.90[d]	8.93[d]	0.25
Aerobic plate count, cfu/g						
Plasma	4.8×10^5	0	9.1×10^4	1.8×10^5	0	—
Whole diet	4.8×10^4	5.0×10^4	6.3×10^4	6.5×10^3	1.1×10^4	—

[a]A total of 325 pigs (five pigs per pen and 13 pens per treatment) initially 17 ± 2 d of age.
[b]Formaldehyde inclusion rate of 3 mg per kg of plasma or whole diet.
[c,d,e]Within a row, means without a common superscript differ ($P < 0.05$).

tained nonirradiated animal plasma. No differences in G:F ($P > 0.11$) were observed among dietary treatments.

Irradiation of spray-dried animal plasma eliminated all detectable bacteria (Table 6), whereas formaldehyde application decreased the bacterial concentration by approximately 1 $\log_{10}$ compared with nonirradiated spray-dried animal plasma. In addition, the use of formaldehyde reduced the bacterial concentrations of the total diet compared to those not treated with formaldehyde.

Experiment 3

Analysis of the animal plasma products demonstrated that irradiation decreased bacterial concentrations for all sources used in this study (Table 7). As expected, both feed-grade products had substantially higher bacterial levels than both food-grade sources, which were anticipated. Bacterial concentrations of both food-grade products were very low and with total coliforms and *E. coli* concentrations below detectable levels except for the food-grade Product 1. Furthermore, irradiation did not influence the CP or IgG concentration of plasma, when comparing the nonirradiated and irradiated individual plasma products. Endotoxin concentration did not follow any specific pattern; however, in some instances, the level was increased with irradiation, which cannot currently be explained.

For d 0 to 7, pigs fed diets containing animal plasma, regardless of product, had improved ADG, ADFI, and G:F ($P < 0.05$) compared with pigs fed the control diet. Pigs fed both nonirradiated and irradiated feed-grade Product 2 animal plasma tended ($P < 0.10$) to have improved G:F compared with those fed the control diet (Table 8).

For d 7 to 14, pigs fed food-grade plasma Product 2 tended to have reduced G:F ($P < 0.10$) compared with pigs fed the control diet. During the overall treatment period (d 0 to 14), pigs fed animal plasma had greater

Table 7. Chemical analyses of spray-dried animal plasma (Exp. 3)

Item	Feed-Grade Product 1		Feed-Grade Product 2		Food-Grade Product 1		Food-Grade Product 2	
	Nonirradiated	Irradiated	Nonirradiated	Irradiated	Nonirradiated	Irradiated	Nonirradiated	Irradiated
CP, %	79.9	80.4	69.19	73.2	71.1	71.3	70.9	71.0
IgG, %[a]	22.9	22.6	14.4	18.6	16.3	16.5	16.3	15.3
Endotoxin, ng/g	7,116	21,388	17,000	249,740	3,962	16.4	4.8	62.2
Aerobic plate count, cfu/g	$>3.0 \times 10^5$	1.0×10^2	1.7×10^4	$<1.0 \times 10^2$	6.5×10^3	$<1.0 \times 10^2$	7.0×10^2	1.0×10^2
Total coliforms, cfu/g	<3.0	<3.0	<3.0	<3.0	2.3×10^1	<3.0	<3.0	<3.0
E. coli, cfu/g	<3.0	<3.0	<3.0	<3.0	2.3×10^1	<3.0	<3.0	<3.0

[a]Immunoglobulin.

Table 8. Effect of irradiation of spray-dried animal plasma on growth performance of the nursery pigs (Exp.3)[a]

		Feed-Grade Product 1		Feed-Grade Product 2		Food-Grade Product 1		Food-Grade Product 2		
Item	Control	Nonirradiated	Irradiated	Nonirradiated	Irradiated	Nonirradiated	Irradiated	Nonirradiated	Irradiated	SEM[g]
Initial wt, kg	6.29	6.28	6.28	6.30	6.28	6.28	6.27	6.30	6.30	0.34
Day 0 to 7										
ADG, g[b]	191	233[c]	253[e]	242[c]	239[e]	255[c]	262[e]	273[c]	263[e]	16.8
ADFI, g[b]	169	205[c]	215[e]	203[c]	202[e]	219[c]	226[e]	233[c]	216[e]	11.7
Gain:feed[b]	1.10	1.13	1.18	1.19[d]	1.19[f]	1.17	1.16	1.17	1.21[e]	0.04
Day 7 to 14										
ADG, g	325	328	332	337	322	342	315	333	315	17.2
ADFI, g	342	353	355	365	352	366	347	371	346	16.1
Gain:feed	0.95	0.94	0.93	0.92	0.92	0.93	0.91	0.90[d]	0.90	0.02
Day 0 to 14										
ADG, g[b]	258	281	292[e]	290[d]	280	299[c]	288[f]	303[c]	288[f]	13.9
ADFI, g[b]	255	279	285[e]	284[c]	277	293[c]	287[e]	302[c]	281[f]	12.0
Gain:feed	1.01	1.01	1.03	1.02	1.01	1.02	1.01	1.00	1.02	0.02
Day 14 to 24										
ADG, g	401	410	392	401	404	383	410	391	384	19.4
ADFI, g	571	558	523[f]	551	540	529	564	545	540	24.6
Gain:feed	0.71	0.74	0.77	0.73	0.75	0.72	0.73	0.72	0.71	0.04
Day 0 to 24										
ADG, g	318	334	334	336	332	334	339	340	328	13.4
ADFI, g	387	395	384	395	386	391	402	403	389	15.3
Gain:feed	0.82	0.85	0.88[f]	0.85	0.86	0.85	0.84	0.84	0.84	0.02
Final wt, kg	14.32	14.40	14.22	14.16	14.27	14.34	14.41	14.30	14.08	0.58

[a]A total of 360 pigs (five pigs per pen and eight pens per treatment) initially 17 ± 2 d of age. All pigs were fed experimental diets from d 0 to 14, and than switched to a common diet from d 14 to 24.
[b]Control vs. mean of plasma treatments ($P < 0.05$).
[c]Control vs. nonirradiated ($P < 0.05$).
[d]Control vs. nonirradiated ($P < 0.10$).
[e]Control vs. irradiated ($P < 0.05$).
[f]Control vs. irradiated ($P < 0.10$).
[g]No irradiation effect ($P > 0.10$).

Table 9. Chemical analyses of spray-dried animal plasma (Exp. 4)

	Feed-Grade Product 2		Food-Grade Product 3	
Item	Nonirradiated	Irradiated	Nonirradiated	Irradiated
CP, %	69.28	69.16	71.15	71.75
IgG, %[a]	17.3	17.6	15.7	15.4
Endotoxin, ng/g	38,708	38,592	56	187
Aerobic plate count, cfu/g	$>3.0 \times 10^5$	2.0×10^2	5.6×10^3	1.0×10^2
Total coliforms, cfu/g	<3.0	<3.0	<3.0	<3.0
E. coli, cfu/g	<3.0	<3.0	<3.0	<3.0

[a]Immunoglobulin.

ADG and ADFI ($P < 0.05$) than pigs fed the control diet. Pigs fed irradiated feed-grade plasma Product 1, as well as nonirradiated food-grade plasma Products 1 and 2, had greater ADG ($P < 0.05$) than those fed the control diet. Furthermore, pigs fed irradiated feed-grade plasma Product 1, nonirradiated feed-grade plasma Product 2, nonirradiated and irradiated food-grade plasma Product 1 and nonirradiated food-grade plasma Product 2 had improved ADFI ($P < 0.05$) compared with pigs fed the control diet. No differences ($P > 0.17$) were detected between pigs fed diets that contained irradiated plasma compared to pigs fed plasma in the nonirradiated form.

From d 14 to 24 (common period), pigs fed irradiated feed-grade plasma Product 1 had a tendency for decreased ADFI ($P < 0.10$) compared with pigs fed the control diet. For the overall experiment (d 0 to 24), pigs fed irradiated feed-grade plasma Product 1 had a tendency for improved G:F ($P < 0.10$) compared with pigs fed the control diet.

Experiment 4

Similar to previous experiments, irradiation reduced bacteria concentrations without influencing the CP or IgG concentration of animal plasma (Table 9). However, unlike Exp. 3 when endotoxin levels were increased in some of the treatment plasma sources when irradiated, no noticeable changes were seen in this experiment.

For d 0 to 7, pigs fed diets containing animal plasma had improved ADG, ADFI, and G:F ($P < 0.05$) compared with pigs fed the control diet (Table 10). Also, pigs fed irradiated feed-grade plasma Product 2 had a tendency for increased ADG and ADFI ($P < 0.10$) compared with pigs fed nonirradiated feed-grade plasma Product 2.

From d 7 to 14, pigs fed diets containing irradiated feed-grade plasma Product 2 had greater ADG ($P < 0.05$) and tended to have greater ADFI ($P < 0.10$) than pigs fed nonirradiated feed-grade plasma Product 2. For the overall treatment period (d 0 to 14), pigs fed animal plasma had improved ADG and G:F ($P < 0.05$) compared with pigs fed the control diet. Also, pigs fed the irradiated feed-grade plasma Product 2 and nonirradiated and irradiated food-grade plasma Product 3 had increased ADG ($P < 0.05$) compared with pigs fed the control diet. Furthermore, pigs fed irradiated feed-grade plasma Product 2 had greater ADG ($P < 0.05$) than those fed nonirradiated feed-grade plasma Product 2.

For d 14 to 24 (common period), ADFI was greater ($P < 0.05$) for pigs previously fed irradiated feed-grade plasma Product 2 and tended ($P < 0.10$) to be higher for pigs fed the control diet compared with pigs fed diets containing nonirradiated feed-grade plasma Product 2. For the overall experiment (d 0 to 24), no benefit in growth performance ($P > 0.10$) was detected for pigs fed diets containing animal plasma compared to pigs fed the control diet. However, pigs fed diets containing irradiated feed-grade plasma Product 2 had increased ADG, final body weight, and ADFI ($P < 0.05$) compared with pigs fed nonirradiated feed-grade plasma Product 2. In addition, pigs fed irradiated feed-grade plasma Product 2 tended ($P < 0.10$) to have greater ADG and final body weight than pigs fed the control diet.

Discussion

Because dried blood products are added to nursery diets as a source of highly digestible amino acids, their quality is imperative. We evaluated animal plasma that had been freeze-dried because this drying technique is free of the additional heat that ring- and spray-drying involve. The freeze-drying process utilizes ambient temperature air (no heat application) under vacuum to dry the plasma. In our study, we only used freeze-dried plasma that had been irradiated because pathogenic viruses or bacteria may be present when animal plasma has not received any heat processing. The spray-drying process has been shown to eliminate certain viruses and decrease the total bacterial concentration in blood meal relative to the liquid form (Downes et al., 1987). Currently, all animal plasma used in diets for nursery pigs is spray-dried. In our study, pigs performed equally when fed plasma from the same original lot that had been either freeze-dried or spray-dried and irradiated, thus indicating that the spray-drying process used to dry the plasma in our studies does not damage protein quality.

Steidinger et al. (2000) reported differences in growth performance with pigs fed animal plasma from different sources. Our data support those findings because significant differences in growth performance were noted

Table 10. Effect of irradiation of animal plasma on growth performance of the nursery pigs (Exp. 4)[a]

		Feed-Grade Product 2		Food-Grade Product 3		
Item	Control	Nonirradiated	Irradiated	Nonirradiated	Irradiated	SEM
Initial wt, kg	6.09	6.07	6.10	6.10	6.09	0.38
Day 0 to 7						
ADG, g[b]	102	144[c]	169[eh]	183[c]	195[e]	11.0
ADFI, g[b]	105	116	138[eh]	158[c]	161	9.5
Gain:feed[b]	0.98	1.25[c]	1.22[e]	1.18[c]	1.21[e]	0.04
Day 7 to 14						
ADG, g	349	329	369[g]	338	344	22.6
ADFI, g	366	344	379[h]	355	369	22.3
Gain:feed	0.95	0.96	0.98	0.95	0.93	0.02
Day 0 to 14						
ADG, g[b]	226	236	269[eg]	261[c]	270[e]	11.7
ADFI, g	235	230	259[f]	256	265[f]	12.2
Gain:feed[b]	0.96	1.03[c]	1.04[e]	1.02[c]	1.02[e]	0.02
Day 14 to 24						
ADG, g	419	398	435	427	412	22.7
ADFI, g	556	491[d]	572[g]	559	535	30.8
Gain:feed	0.75	0.83[d]	0.76[h]	0.76	0.77	0.03
Day 0 to 24						
ADG, g	311	305	338[fg]	330	332	13.9
ADFI, g	369	339[d]	389[g]	383	378	17.7
Gain:feed	0.85	0.91[c]	0.87	0.86	0.88	0.02
Final wt, kg	13.55	13.36	14.20[fg]	14.01	14.06	0.65

[a]A total of 175 pigs (five pigs per pen and seven pens per treatment) initially 6.1 ± 1.7 kg BW. All pigs were fed experimental diets from d 0 to 14 and then switched to a common diet from d 14 to 24.
[b]Control vs. mean of plasma treatments ($P < 0.05$).
[c]Control vs. nonirradiated ($P < 0.05$).
[d]Control vs. nonirradiated ($P < 0.10$).
[e]Control vs. irradiated ($P < 0.05$).
[f]Control vs. irradiated ($P < 0.10$).
[g]Irradiated vs. nonirradiated ($P < 0.05$).
[h]Irradiated vs. nonirradiated ($P < 0.10$).

between the two sources used in Exp. 1. In Exp. 1, pigs fed nonirradiated plasma Source 2 did not have improved growth performance compared to pigs fed the control diet, whereas pigs fed nonirradiated plasma Source 1 did have improved performance. This reinforces the importance of evaluating the consistency and quality of animal plasma from individual manufacturers and that detectable differences exist.

DeRouchey et al. (2003) reported improvements in growth performance when nursery pigs were fed irradiated blood meal compared to pigs fed nonirradiated blood meal. In Exp. 1, similar improvements in growth were seen for pigs fed irradiated compared with nonirradiated animal plasma. Importantly, pigs fed irradiated plasma, regardless of source, were significantly heavier than the control pigs at the end of the experiment, whereas pigs fed nonirradiated plasma were not.

Formaldehyde treatment of animal plasma was used as a comparative model to help determine whether the improved growth from Exp. 1 was a result of a decrease in the bacteria concentration in animal plasma. The use of formaldehyde is well recognized as a preservative in laboratories, mortuaries, vaccines, and grains. Formaldehyde-based antimicrobial feed additives have been used to reduce bacteria and help prevent recontamination in complete feeds for poultry (Kaiser, 1992; Anderson et al., 2001), finishing pigs (Anitox, 1996a), and sows (Anitox, 1996b). Inclusion of formaldehyde into animal plasma was less effective than irradiation in decreasing bacterial concentrations; however, pigs from either treatment had similar growth performance, and ADG for both was greater than control pigs. When the whole diet was treated with formaldehyde, growth performance was not changed from that of the control diet, even though the total bacterial concentration of the whole diet was decreased. This agrees with the results of DeRouchey et al. (2002), who reported no improvements in growth performance when the whole diet had a reduced bacterial concentration by means of irradiation. The reasons for the lack of growth response when the whole diet has been bacterially reduced compared to the improvements in growth performance seen when only when animal plasma has a reduced bacteria level are unknown and need to be further investigated.

Collection, storage, and handling of blood from harvesting facilities can influence the bacterial concentrations of dried blood products (DeRouchey et al., 2003). Animal blood used in the production of food-grade animal plasma is collected directly from an animal's brachial region via a catheter. This more sterilized and controlled method of blood collection prior to spray-drying is responsible for the lower initial bacterial concentrations of food-grade animal plasma compared to feed-grade animal plasma, which is collected under conventional procedures from animal slaughter facilities. According to the knowledge of the present authors, food-grade plasma has not been widely studied in diets for nursery pigs, likely due to its high cost from specialized handling and collection.

In both experiments, evaluating nonirradiated and irradiated feed and food-grade animal plasma (Exp. 3 and 4), no difference in growth performance was detected for pigs fed irradiated and nonirradiated food-grade plasma. This lack of response supports the hypothesis that the initial bacterial concentrations may influence the overall quality of dried blood products. When comparing pigs fed irradiated and nonirradiated blood meal or animal plasma, DeRouchey et al. (2002; 2003) suggest improvements in growth performance. In the experiments described in the current study, pigs either had statistically increased growth performance in Exp. 1, 2, and 4, whereas no response was found in Exp. 3 when comparing pigs fed irradiated feed-grade plasma compared to its nonirradiated form. Although improvements in growth from bacteria reduction were not realized in every trial, the reduction in bacteria seems to have an effect because it was the only factor that was altered in the treatment diets. If initial bacterial levels of animal plasma did not influence growth performance, we would expect that pigs would perform similarly when fed nonirradiated and irradiated forms in all experiments. Inherent variability may exist in spray-dried animal plasma, which would prevent from finding a growth performance response to bacteria reduction because variability in growth responses associated with diets containing spray-dried animal plasma has been well documented regarding Na, Cl, and IgG concentrations (Steidinger et al., 2000). Variation exists both among and within ingredient suppliers of animal plasma (Steidinger et al., 2000). Because of this, it is no surprise that a consistent pattern in growth performance was not shown from irradiating dried blood products (feed-grade Source 2 in Exp. 3 and 4).

The IgG concentration, which is an important component of dried animal plasma for increasing pig performance (Owen et al., 1995; Pierce et al., 1995), was not changed when animal plasma was irradiated. In addition, the CP, amino acid profile, and the endotoxin level was not altered by irradiation of animal plasma. Feed-grade animal plasma sources had noticeably higher levels of endotoxin present, which would be logical because endotoxins are a waste product of bacteria (i.e., higher endotoxin levels would be the result of higher bacterial levels). Although the endotoxin level was increased in some instances when different sources of animal plasma were irradiated, it was not a constant increase in all sources and cannot be explained by the authors. Additionally, other studies have reported no physical changes in solubility and emulsifying capacity (Hayashi et al., 1991), pH (Dimitrova and Brankova, 1975), and Fe concentration (Turubatovic et al., 1993) with the irradiation of dried blood products. Thus, irradiation at the levels used in the current experiments provides a means of reducing the bacterial concentration in animal plasma without harmful physical or chemical changes.

These experiments attempted to evaluate bacterially reduced animal plasma and diets. Results indicate that pig growth performance was increased when bacteria was reduced in feed-grade plasma (initially high bacteria) and not when food-grade plasma (initially low bacteria) or when the entire diet had reduced bacteria levels.

Implications

These studies indicate that irradiation or chemical treatment as methods of decreasing the final bacterial concentration in feed-grade animal plasma can result in increased growth performance by weanling pigs. Sterilized collection and handling procedures carried out to decrease the initial bacteria concentrations or to make bacterial reductions in dried animal plasma may improve the quality of dried blood products. Although the threshold levels of bacteria concentration in spray-dried animal plasma that may affect nursery pig performance were not measured in these studies, further research to determine these maximum levels seems warranted.

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