Effects of a whey protein product and spray-dried animal plasma on growth performance of weanling pigs[1,2]

G. S. Grinstead, R. D. Goodband[3], S. S. Dritz[4], M. D. Tokach, J. L. Nelssen, J. C. Woodworth, and M. Molitor[5]

Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66560-0201

ABSTRACT: Five experiments were conducted to evaluate the effects of a high-protein, whey protein product (WPP; 73% CP, 6.8% lysine, 12.8% fat, and 5% lactose) and spray-dried animal plasma (SDAP) on growth performance of weanling pigs. In all experiments, pigs were fed experimental diets from d 0 to 14 after weaning in a pelleted form and then a common diet in meal form for the remainder of the experiment. Dietary treatments were established by substituting WPP or SDAP for dried skim milk (Exp. 1) or soybean meal (Exp. 2, 3, 4, and 5) in the control diet. In Exp. 1, we maintained a constant level of lactose in all diets by adjusting the amount of added crystalline lactose. The amount of lactose in diets used in Exp. 2 through 5 varied slightly by the addition of WPP. In Exp. 1 and 2, 180 weanling pigs (initially 5.8 kg and 19 ± 1 d of age or 5.5 kg and 17 ± 1 d of age, respectively) were used. Treatment diets contained SDAP (2.5 and 5%) or WPP (2.7 and 5.4% in Exp.1, and 2.5 or 5.0% in Exp. 2). In Exp. 1, from d 0 to 7 after weaning, ADG and ADFI increased with increasing SDAP (linear, $P < .01$). No other treatment effects were observed during the d 0 to 14 period. In Exp. 2, from d 0 to 14 after weaning, ADG and G:F increased (linear, $P < .04$) with increasing SDAP or WWP. In Exp. 3, 305 weanling pigs (initially 4.1 kg and 12 ± 1 d of age) were used. The control diet contained 2.5% SDAP. The experimental diets were similar to the control diet but contained an additional 2.5 or 5.0% SDAP or 2.5 or 5.0% WPP. From d 0 to 14 after weaning, ADG, ADFI, and G:F increased (quadratic, $P < .05$) with increasing SDAP up to 5.0%. Increasing WPP increased ADG (quadratic, $P < .07$) and ADFI (linear, $P < .09$). In Exp. 4 and 5, 329 and 756 weanling pigs (initially 4.1 kg and 12 ± 1 d of age and 5.2 kg and 18 ± 1 d of age, respectively) were fed diets in which WPP was substituted for 0, 25, 50, 75, and 100% (Exp. 4) or 0, 50, and 100% (Exp. 5) of the SDAP in the control diet. In Exp. 4 and 5, from d 0 to 14 after weaning, pigs fed a 1:1 blend of each protein source had better ADG (quadratic, $P < .04$) than those only fed SDAP. In conclusion, WPP can be used in combination with or as a total replacement for SDAP in diets for weanling pigs without reducing performance.

Key Words: Pigs, Blood Plasma, Whey Protein

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Introduction

Diets containing milk products can improve growth performance of weanling pigs (Himmelberg et al., 1985; Tokach et al., 1989; Lepine et al., 1991), and because of recent changes in fluid milk processing and the demand for different milk products, specialized products are now available for use in swine diets. When liquid whey is forced through a series of porous membranes, the components are separated based on size and shape and this can concentrate whey proteins to produce products with 34 to 80% CP. In this process, ash and lactose concentrations decrease as protein increases (Zadow, 1992). However, because of their large size, whey phospholipids and fat globules are restricted by the membrane and are concentrated with the protein (M. Molitor, personal communication).

The whey protein product used in our experiments (73% CP) was similar to the super-concentrated whey protein (> 70% CP) that is used for human consumption. However, unlike other high-protein whey concentrates, this whey product contains approximately two to three times more phospholipids and total fat (Morr and Foegeding, 1990). Indeed, the 12.8% total fat content of this whey product exceeds the 10% fat maximum for whey protein concentrate (Code of Federal Regulations,

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[3]Correspondence.

[4]Food Animal and Health Management Center, College of Veterinary Medicine.

[5]Foremost Farms USA, Sauk City, Wisconsin.

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1998). The process of selectively concentrating part of the larger protein fractions could also increase the immunoglobulin content relative to other high-protein whey concentrates. This may have important nutritional implications, because immunoglobulins may be important components for spray-dried animal plasma (Owen et al., 1995; Pierce et al., 1995; Weaver et al., 1995).

Therefore, our objective was to determine whether this concentrated whey protein product could replace spray-dried animal plasma in the diets for weanling pigs without adversely affecting growth performance.

Materials and Methods

Animal Care and Use. The experimental protocols used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and Housing. Weanling pigs (n = 180) were used in two 35-d experiments. Pigs in Exp. 1 were initially 5.8 ± .86 kg and 19 ± 1 d of age, and pigs in Exp. 2 were initially 5.1 ± .51 kg and 17 ± 1 d of age. All pigs (PIC, L326 × C22) were blocked by weight, equalized for sex and ancestry, and allotted randomly to one of five experimental treatments. Each treatment had six pigs per pen and six pens (replications) per treatment. Pigs were housed at the Kansas State University Swine Teaching and Research Center in an environmentally controlled nursery. Each pen (1.2 × 1.5 m) had a single nipple waterer, a five-hole feeder, and woven wire flooring.

Experiment 3 used 315 pigs (initially 4.1 ± .73 kg and 12 ± 1 d of age), and Exp. 4 used 310 pigs (initially 4.2 ± .93 kg and 12 ± 1 d of age); both experiments lasted 28 d. At weaning, pigs (PIC, L326 × C22) were blocked by initial weight and allotted randomly to one of five dietary treatments. Each treatment had seven or eight pigs per pen with eight replications per treatment (Exp. 3) and eight or nine pigs per pen with seven replications per treatment (Exp. 4). In both experiments there was an equal number of pigs within each block. All pigs in Exp. 3 and 4 were housed on a commercial swine operation in Northeast Kansas in an environmentally controlled nursery. Each pen (1.2 × 1.5 m) had two nipple waterers, a six-hole feeder, and woven wire flooring.

In Exp. 5, weanling pigs (n = 756; initially 5.2 ± .17 kg and 18 ± 1 d of age) were used in a 28-d experiment. Pigs (PIC L420 × C14) were blocked by initial weight and allotted randomly to one of three dietary treatments. There were six observations per treatment. Each observation consisted of two pens with 21 pigs in each pen; both pens were served by the same fence line feeder. Pigs were housed on a commercial operation in Southeast Minnesota in an environmentally controlled nursery. Each pen (3.1 × 1.7 m) contained a cup waterer, a six-hole feeder, and plastic flooring.

In all experiments, nurseries were maintained at 34°C for the first week after weaning. Then temperature was reduced 1.5°C each week, and air flow was regulated to maintain pig comfort. Pigs were provided ad libitum access to feed and water throughout the experiments. Average daily gain, ADFI, and gain:feed ratio (**G:F**) were determined by weighing pigs and measuring feed disappearances at weekly intervals for the duration of each experiment.

Chemical Analysis. Samples of the spray-dried animal plasma and whey protein product were collected and analyzed for amino acid concentrations. The same lot of whey protein product was used in Exp. 1 through 4 (Table 1), but a different lot was used in Exp. 5 (not analyzed). A different lot of spray-dried animal plasma was used for each experiment. Samples from each lot of spray-dried animal plasma were collected and analyzed. Amino acid analysis was performed by ion exchange chromatography following acid hydrolysis (Knabe et al., 1989). Methionine and cystine were determined following oxidation with performic acid (Moore, 1963). Tryptophan was determined following alkaline hydrolysis (LaRue, 1985). Analyzed values of the whey protein product were slightly different from those provided by the supplier. Diet formulations in Exp. 2 through 5 used analyzed values. Values provided by the supplier for spray-dried animal plasma were used in each experiment. All experimental diets were sampled and analyzed for CP (AOAC, 1990).

Dietary Treatments. In Exp. 1 through 4, the trials were divided into two phases, with the pelleted experimental diets fed from d 0 to 14 after weaning. All experimental diets were formulated to contain .9% Ca and

Table 1. Composition of high-protein whey product and spray-dried animal plasma

Item, %	Whey protein product[a]	Spray-dried animal plasma[b]
Protein	73.18	79.25 (70.00)
Fat	12.80	2.00
Lactose	5.00 (10.00)	—
Ash	2.60	9.00
Amino acids[b]		
Arginine	2.32 (1.4)	4.51 (5.30)
Cystine	1.68 (1.9)	2.59 (2.50)
Histidine	1.49 (1.2)	2.52 (2.80)
Isoleucine	4.15 (4.15)	2.72 (1.96)
Leucine	7.43 (7.7)	7.66 (5.56)
Lysine	6.81 (6.3)	6.99 (6.80)
Methionine	1.52 (1.57)	.81 (.53)
Phenylalanine	2.67 (2.5)	4.39 (4.10)
Threonine	4.64 (4.8)	4.67 (4.13)
Tryptophan	1.63 (1.7)	1.40 (1.33)
Tyrosine	2.34 (2.3)	4.05 (3.90)
Valine	4.42 (3.6)	5.29 (4.12)

[a]Analyzed values expressed on an as-fed basis; calculated values used in Exp. 1 are provided in parentheses. Values for the whey protein product are from the same lot of material used in Exp. 1 through 4.

[b]Values represent the means of five samples. Values used for diet calculations are provided in parentheses.

Table 2. Composition of diets (Exp. 1, as-fed basis)

Ingredient, %	Control[a]	Spray-dried animal plasma, %[a] 2.5	Spray-dried animal plasma, %[a] 5.0	Whey protein product, %[a] 2.7	Whey protein product, %[a] 5.4	Day 14 to 35[b]
Corn	37.15	37.68	38.22	37.73	38.32	51.87
Soybean meal (47.5% CP)	24.17	24.17	24.17	24.17	24.17	26.85
Dried whey	15.00	15.00	15.00	15.00	15.00	10.00
Dried skim milk	13.40	6.70	—	6.70	—	—
Whey protein product	—	—	—	2.70	5.40	—
Spray-dried animal plasma	—	2.50	5.00	—	—	—
Spray-dried blood meal	1.00	1.00	1.00	1.00	1.00	2.50
Soybean oil	5.00	5.00	5.00	5.00	5.00	4.00
Lactose	—	3.35	6.70	3.08	6.16	
Monocalcium phosphate	1.36	1.50	1.65	1.65	1.94	1.65
Antibiotic[c]	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	.72	.87	1.01	.77	.82	.98
Zinc oxide	.37	.37	.37	.37	.37	.25
Premix[d]	.40	.40	.40	.40	.40	.40
Salt	.20	.20	.20	.20	.20	.25
L-Lysine HCl	.15	.15	.15	.15	.15	.15
DL-Methionine	.08	.11	.13	.08	.07	.10
Chemical analysis, %						
CP	20.68	21.06	21.04	20.94	20.45	19.24

[a]Diets were formulated to contain 1.5% lysine, .42% methionine, .9% Ca, and .8% P and fed from d 0 to 14 after weaning.
[b]Diet was formulated to contain 1.35% lysine, .38% methionine, .9% Ca, and .8% P and fed to all pigs after d 14 in Exp. 1, 2, 3, and 4.
[c]Provided 55 mg/kg of carbadox.
[d]Premix provided per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 16 mg; I, .3 mg; Se, .3 mg; vitamin A, 11,025 IU; vitamin D_3, 1,103 IU; vitamin E, 44 IU; menadione (menadione sodium bisulfate complex), 4.4 mg; riboflavin, 9.9 mg; d-pantothenic acid, 33 mg; niacin, 55 mg; choline, 166 mg; and vitamin B_{12}, .04 mg.

.8% P. From d 14 to 28 or 35 after weaning, a common corn-soybean meal diet containing 10% dried whey and 2.5% spray-dried blood meal was fed in a meal form. The common diet was formulated to contain 1.35% lysine, .9% Ca, and .8% P (Table 2).

In Exp. 1, dietary treatments were based on a corn-soybean meal control diet containing 15% dried whey, 1% spray-dried blood meal, and 13.4% dried skim milk (Table 2). Spray-dried animal plasma (2.5 or 5.0%) or whey protein product (2.7 or 5.4%) and lactose replaced dried skim milk on an equal lysine and lactose basis in the control diet. All diets were formulated to 1.50% total lysine. Formulations were based on amino acid concentrations provided by the suppliers of whey protein product and spray-dried animal plasma and on amino acid concentrations reported by NRC (1988) for the other ingredients.

In Exp. 2, dietary treatments (Table 3) were based on a corn-soybean meal control diet that contained fewer specialty protein sources than the basal diet of Exp. 1. All diets fed in Exp. 2 were formulated to contain 1.40% total lysine and contained 15% dried whey and no dried skim milk or spray-dried blood meal. Based on results of Exp. 1, we decreased the amount and number of added specialty protein sources in the control diet to ensure we would observe improvements in growth performance with the test ingredients. Analyzed values of whey protein product were used in diet formulation and calculated values for spray-dried animal plasma. Spray-dried animal plasma (2.5 or 5.0%) or whey protein product (2.5 or 5.0%) replaced soybean meal, on an equal lysine basis, in the control diet to provide the additional experimental diets.

Because health status of the pigs and environmental conditions will influence the magnitude of response to spray-dried animal plasma (Coffey and Cromwell, 1995; Bergstrom et al., 1997), we conducted Exp. 3, 4, and 5 in commercial nurseries to confirm the results of Exp. 2. The control diets in Exp. 3, 4, and 5 were similar to the diets currently used in these production systems and contained more specialty protein and carbohydrate sources than used in Exp. 1 and 2. These adjustments were made to account for differences in weaning age (12 d of age in Exp. 3 and 4) and feeding regimen (Exp. 5). In Exp. 3, dietary treatments were based on a corn-soybean meal control diet containing 25% dried whey, 6% fish meal, 5% lactose, 2.5% spray-dried animal plasma, and 1.75% spray-dried blood meal (Table 4). Additional spray-dried animal plasma (2.5 or 5.0%) or whey protein product (2.5 or 5.0%) replaced soybean meal, on an equal lysine basis, in the control diet to provide the additional experimental treatments. All diets were formulated to contain 1.70% total lysine.

In Exp. 4, dietary treatments were based on a corn-soybean meal control diet containing 25% dried whey, 6% fish meal, 5% lactose, 6.7% spray-dried animal

Table 3. Composition of diets (Exp. 2, as-fed basis)

		Spray-dried animal plasma, %[a]		Whey protein product, %[a]	
Ingredients, %	Control[a]	2.5	5.0	2.5	5.0
Corn	40.84	44.22	47.62	44.22	47.59
Soybean meal (47.5% CP)	34.36	28.43	22.50	28.42	22.49
Dried whey	15.00	15.00	15.00	15.00	15.00
Soybean oil	5.00	5.00	5.00	5.00	5.00
Whey protein product	—	—	—	2.50	5.00
Spray-dried animal plasma	—	2.50	5.00	—	—
Monocalcium phosphate	1.66	1.64	1.60	1.77	1.88
Antibiotic[b]	1.00	1.00	1.00	1.00	1.00
Limestone	.95	1.00	1.05	.90	.85
Zinc oxide	.38	.38	.38	.38	.38
Premix[c]	.40	.40	.40	.40	.40
Salt	.20	.20	.20	.20	.20
L-Lysine HCl	.15	.15	.15	.15	.15
DL-Methionine	.06	.08	.10	.06	.06
Chemical analysis, %					
CP	21.00	20.46	20.27	20.20	18.84

[a]Diets were formulated to contain 1.4% lysine, .42% methionine, .9% Ca, and .8% P and fed from d 0 to 14 after weaning.
[b]Provided 55 mg/kg of carbadox.
[c]See Table 2 for premix composition.

plasma, and 1.75% spray-dried blood meal (Table 5). Whey protein product replaced 25, 50, 75, and 100% of the spray-dried animal plasma on an equal lysine basis. All diets were formulated to contain 1.70% lysine.

In Exp. 5, the trial was divided into two phases, with the pelleted experimental diets fed from d 0 to 14 after weaning. However, unlike the previous experiments, each pen was initially provided with .45 kg/pig of their respective experimental diet. After this diet was consumed, pigs were then fed a less-complex transitional diet until d 14 after weaning. The basal diet that was fed first (.45 kg/pig) was a corn-soybean meal control diet containing 25% dried whey, 6.0% fish meal, 6.7% spray-dried animal plasma, and 1.75% spray-dried

Table 4. Composition of diets (Exp. 3, as-fed basis)

		Added spray-dried animal plasma, %[a]		Whey protein product, %[a]	
Ingredients, %	Control[a]	2.5	5.0	2.5	5.0
Corn	27.81	31.22	34.65	31.20	34.58
Dried whey	25.00	25.00	25.00	25.00	25.00
Soybean meal (47.5% CP)	22.44	16.51	10.57	16.50	10.56
Spray-dried animal plasma	2.50	5.00	7.50	2.50	2.50
Whey protein product	—	—	—	2.50	5.00
Spray-dried blood meal	1.75	1.75	1.75	1.75	1.75
Soybean oil	6.00	6.00	6.00	6.00	6.00
Fish meal	6.00	6.00	6.00	6.00	6.00
Lactose	5.00	5.00	5.00	5.00	5.00
Antibiotic[b]	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate	.82	.78	.75	.93	1.05
Limestone	.40	.45	.49	.35	.30
Zinc oxide	.38	.38	.38	.38	.38
Premix[c]	.40	.40	.40	.40	.40
Salt	.20	.20	.20	.20	.20
L-Lysine HCl	.15	.15	.15	.15	.15
DL-Methionine	.15	.16	.16	.14	.13
Chemical analysis, %					
CP	23.26	23.03	22.55	22.31	21.36

[a]Diets were formulated to contain 1.7% lysine, .48% methionine, .9% Ca, and .8% P and were from d 0 to 14 after weaning.
[b]Provided 55 mg/kg of carbadox.
[c]See Table 2 for premix composition.

Table 5. Composition of diets (Exp. 4, as fed basis)

	Animal plasma:whey protein product, %[a]				
Ingredients, %	6.7:0	5.0:1.7	3.35:3.35	1.7:5.0	0:6.7
Corn	33.57	33.55	33.52	33.50	33.47
Soybean meal (47.5% CP)	12.47	12.47	12.47	12.47	12.47
Dried whey	25.00	25.00	25.00	25.00	25.00
Whey protein product	—	1.70	3.35	5.00	6.70
Spray-dried animal plasma	6.70	5.00	3.35	1.70	—
Spray-dried blood meal	1.75	1.75	1.75	1.75	1.75
Soybean oil	6.00	6.00	6.00	6.00	6.00
Fish meal	6.00	6.00	6.00	6.00	6.00
Lactose	5.00	5.00	5.00	5.00	5.00
Antibiotic[b]	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate	.76	.86	.96	1.06	1.16
Limestone	.47	.41	.35	.28	.22
Zinc oxide	.38	.38	.38	.38	.38
Premix[c]	.40	.40	.40	.40	.40
Salt	.20	.20	.20	.20	.20
L-Lysine HCl	.15	.15	.15	.15	.15
DL-Methionine	.15	.13	.12	.11	.10
Chemical analysis, %					
CP	21.68	21.96	21.83	21.69	21.54

[a]Diets were formulated to contain 1.7% lysine, .48% methionine, .9% Ca, and .8% P and fed from d 0 to 14 after weaning.
[b]Provided 55 mg/kg of carbadox.
[c]See Table 2 for premix composition.

blood meal and was formulated to contain 1.70% lysine. The transitional basal diet was a corn-soybean meal diet containing 20% dried whey, 5.0% fish meal, 2.25% spray-dried animal plasma, and 1.25% spray-dried blood meal and was formulated to contain 1.55% lysine. In both diets, whey protein product was substituted for spray-dried animal plasma on an equal lysine basis. It replaced 50 and 100% of the spray-dried animal plasma in the control diets to provide the additional experimental treatments (Table 6). From d 14 to 28 after weaning, a common corn-soybean meal diet containing 8.75% dried whey, 3% fish meal, and 1.25% spray-dried blood meal was fed in a meal form. It was formulated to contain 1.4% lysine, .9% Ca, and .8% P (Table 6). In all experimental diets, all amino acids met or exceeded requirement estimates of NRC (1988).

Statistical Analysis. All experiments were analyzed as randomized complete block designs. Pigs were blocked by initial body weight, and the pen was the experimental unit. Analysis of variance was performed using the GLM procedures of SAS (1998). Linear and quadratic polynomials (Peterson, 1985) were evaluated for increasing spray-dried animal plasma and(or) whey protein product.

Results

Experiment 1. From d 0 to 7 after weaning, ADG and ADFI increased with increasing spray-dried animal plasma (linear, $P < .01$; Table 7). Increasing spray-dried animal plasma had no effect on G:F. Increasing whey protein product had no effects on ADG, ADFI, or G:F. From d 7 to 14 and d 0 to 14 after weaning, no differences were observed for pigs fed either of the experimental protein sources.

When all pigs were fed a common diet (d 14 to 35 after weaning), protein sources fed from d 0 to 14 after weaning had no effect on ADG or G:F. However, ADFI increased (quadratic, $P < .05$) for pigs previously fed 2.5% spray-dried animal plasma from d 0 to 14 after weaning.

From d 0 to 35 after weaning, no differences in ADG or G:F were observed in pigs fed spray-dried animal plasma from d 0 to 14. However, as found for the d 14 to 35 period, ADFI tended to increase for pigs previously fed 2.5% spray-dried animal plasma then decrease (quadratic, $P < .08$) for pigs fed 5.0% spray-dried animal plasma from d 0 to 14 after weaning. Increasing whey protein product from d 0 to 14 after weaning had no effect on overall ADG or ADFI; however, G:F tended to decrease for pigs fed 2.7% and then increase (quadratic, $P < .07$) for those fed 5.4%.

Experiment 2. From d 0 to 7 after weaning, ADG increased with increasing spray-dried animal plasma and whey protein product (linear, $P < .002$ and .02, respectively, Table 8). Average daily feed intake also increased (linear, $P < .04$) with increasing spray-dried animal plasma, but it was unchanged for pigs fed whey protein product. Feed efficiency was increased for pigs fed increasing spray-dried animal plasma (linear, $P < .01$) and whey protein product (linear, $P < .002$, quadratic $P < .06$).

From d 7 to 14 after weaning, ADG improved with increasing spray-dried animal plasma and whey protein product (linear, $P < .02$ and .05 respectively, Table 8). Experimental protein sources had no effect on ADFI,

Table 6. Composition of diets (Exp. 5, as fed basis)

	Experimental diet 1[a] Animal plasma:whey protein product, %			Experimental diet 2[b] Animal plasma:whey protein product, %			
Ingredients, %	6.7:0	3.35:3.35	0:6.7	2.25:0	1.13:1.13	0:2.25	Day 14 to 28[c]
Corn	40.57	40.49	40.49	41.58	41.53	41.57	48.23
Soybean meal (47.5% CP)	11.90	11.90	11.90	21.39	21.39	21.39	30.32
Dried whey	25.00	25.00	25.00	20.00	20.00	20.00	8.75
Whey protein product	—	3.35	6.70	—	1.13	2.25	—
Spray-dried animal plasma	6.70	3.35	—	2.25	1.13	—	—
Spray-dried blood meal	1.75	1.75	1.75	1.25	1.25	1.25	1.25
Fish meal	6.00	6.00	6.00	5.00	5.00	5.00	3.00
Choice white grease	5.00	5.00	5.00	5.00	5.00	5.00	4.00
Antibiotic[d]	.50	.50	.50	.50	.50	.50	1.00
Dicalcium phosphate	.80	1.05	1.25	1.20	1.30	1.35	2.00
Limestone	.40	.25	.08	.40	.35	.28	.43
Acidifier[e]	.20	.20	.20	.20	.20	.20	—
Zinc oxide	.38	.38	.38	.38	.38	.38	.25
Premix[f]	.25	.25	.25	.25	.25	.25	.25
Salt	.20	.20	.20	.30	.30	.30	.30
L-Lysine HCl	.15	.15	.15	.15	.15	.15	.15
DL-Methionine	.15	.13	.10	.10	.09	.08	.07
Choline chloride	.05	.05	.05	.05	.05	.05	—

[a]Diets were formulated to contain 1.7% lysine, .48% methionine, .9% Ca, .8% P and fed at .45 kg/per pig.
[b]Diet was formulated to contain 1.55% lysine, .46% methionine, .9% Ca, .8% P and fed after experimental diet 1 until d 14 after weaning.
[c]Diet was formulated to contain 1.4% lysine, .41% methionine, .9% Ca, .8% P and fed from d 14 to 28 after weaning.
[d]Provided 110 mg/kg of terramycin and 110 mg/kg of oxytetracycline in experimental diets 1 and 2. Provided 55 mg/kg of carbodox for diet fed from d 14 to 28 after weaning.
[e]Kemgest, Kemin Industries, Des Moines, IA.
[f]Premix provided per kilogram of complete diet: Mn, 249 mg; Fe, 155 mg; Zn, 125 mg; Cu, 18.75 mg; I, .3 mg; Se, .3 mg; vitamin A, 11,000 IU; vitamin D_3, 1,650 IU; vitamin E, 55 IU; menadione (menadione sodium bisulfate complex), 2.26 mg; riboflavin, 9.9 mg; d-pantothenic acid, 30 mg; niacin, 41 mg; and vitamin B_{12}, 3.35 mg; limestone, 649 mg.

Table 7. Effect of increasing whey protein product and spray-dried animal plasma on weanling pig performance (Exp. 1)[a]

		Spray-dried animal plasma, %		Whey protein product, %			Probability ($P <$) Animal plasma		Whey protein	
Item	Control	2.5	5.0	2.7	5.4	SEM	Linear	Quadratic	Linear	Quadratic
Day 0 to 7										
ADG, g	190	219	239	196	195	11.5	.01	.75	.79	.79
ADFI, g	173	203	222	190	185	9.5	.01	.64	.38	.39
Gain:feed	1.10	1.08	1.08	1.04	1.05	.042	.75	.91	.42	.48
Day 7 to 14										
ADG, g	363	359	316	366	384	25.1	.20	.54	.57	.82
ADFI, g	383	357	359	368	376	22.3	.45	.60	.83	.66
Gain:feed	.94	1.01	.88	.99	1.02	.053	.41	.14	.35	.85
Day 0 to 14										
ADG, g	277	289	278	281	289	15.5	.97	.53	.58	.93
ADFI, g	278	280	290	279	281	13.6	.54	.49	.89	.95
Gain:feed	.99	1.04	.96	1.01	1.03	.036	.52	.19	.49	.99
Day 14 to 35										
ADG, g	572	585	576	552	599	16.6	.86	.60	.26	.12
ADFI, g	860	916	873	868	877	15.0	.56	.02	.42	.95
Gain:feed	.66	.64	.66	.63	.68	.018	.85	.32	.47	.88
Day 0 to 35										
ADG, g	454	466	457	444	475	11.6	.87	.44	.21	.16
ADFI, g	627	661	640	632	639	12.3	.48	.08	.52	.94
Gain:feed	.72	.71	.71	.70	.74	.014	.65	.47	.28	.07

[a]A total of 180 weanling pigs (initially 5.8 kg and 19 ± 1 d of age) with six pigs per pen and six replications per treatment.

Table 8. Effect of increasing whey protein product and spray-dried animal plasma on weanling pig performance (Exp. 2)[a]

		Spray-dried animal plasma, %		Whey protein product, %			Probability (P <)			
							Animal plasma		Whey protein	
Item	Control	2.5	5.0	2.7	5.0	SEM	Linear	Quadratic	Linear	Quadratic
Day 0 to 7										
ADG, g	173	214	243	223	225	14.2	.002	.72	.02	.19
ADFI, g	223	238	267	235	237	14.0	.04	.68	.50	.76
Gain:feed	.77	.90	.91	.95	.96	.036	.01	.24	.002	.06
Day 7 to 14										
ADG, g	283	310	337	310	329	15.5	.02	.98	.05	.82
ADFI, g	379	393	414	397	373	16.1	.14	.89	.82	.29
Gain:feed	.75	.79	.82	.79	.88	.039	.24	.94	.03	.62
Day 0 to 14										
ADG, g	228	262	290	267	277	12.1	.002	.85	.01	.35
ADFI, g	301	316	341	316	305	12.5	.04	.75	.82	.40
Gain:feed	.76	.83	.85	.85	.90	.030	.04	.56	.01	.66
Day 14 to 35										
ADG, g	594	556	583	541	597	16.4	.64	.16	.90	.05
ADFI, g	822	831	845	798	832	17.1	.35	.88	.68	.18
Gain:feed	.72	.67	.69	.68	.72	.018	.21	.17	.89	.11
Day 0 to 35										
ADG, g	439	433	459	425	461	12.5	.27	.32	.22	.12
ADFI, g	601	612	631	593	609	13.5	.13	.82	.70	.50
Gain:feed	.73	.71	.73	.72	.76	.017	.91	.35	.27	.29

[a]A total of 180 weanling pigs (initially 5.1 kg and 17 ± 1 d of age) with six pigs per pen and six replications per treatment.

but G:F was increased for pigs fed increasing whey protein product (linear, $P < .03$).

From d 0 to 14 after weaning, ADG, ADFI, and G:F increased (linear, $P < .002$, .04, and .04, respectively) with increasing spray-dried animal plasma (Table 8). Increasing whey protein product increased (linear, $P < .01$) ADG and G:F, but it did not affect ADFI. From d 14 to 35 after weaning, ADG decreased then returned to control values (quadratic, $P < .05$) for pigs previously fed 2.5 and 5.0% whey protein product from d 0 to 14, respectively. No differences in ADG, ADFI, or G:F were observed from d 14 to 35 after weaning in pigs fed spray-dried animal plasma from d 0 to 14. For the entire experimental period, d 0 to 35 after weaning, no differences were observed in pigs previously fed any of the experimental treatments.

Experiment 3. From d 0 to 7 after weaning ADG and ADFI increased in pigs fed 2.5% whey protein product then decreased (quadratic, $P < .05$) in those fed 5.0% (Table 9). Although not significant, a similar numerical increase and decrease ($P > .10$) was observed in ADG with increasing spray-dried animal plasma. Average daily feed intake increased linearly with increasing spray-dried animal plasma ($P < .04$); however, G:F was not affected.

From d 7 to 14 and d 0 to 14 after weaning, ADG, ADFI, and G:F increased with increasing spray-dried animal plasma (quadratic, $P < .003$, .08, and .02, respectively), with pigs fed 2.5% added spray-dried animal plasma (5.0% total) having the best ADG. Average daily gain tended to increase in pigs fed 2.5% whey protein product and then decrease (quadratic, $P < .07$) in those fed 5.0%, whereas ADFI tended to increase linearly ($P < .09$). Feed efficiency was not affected by whey protein product.

From d 14 to 28 after weaning, ADG (linear, $P < .12$) and ADFI (linear, $P < .05$) tended to decrease numerically in pigs fed increasing spray-dried animal plasma from d 0 to 14 after weaning. Feed efficiency was not affected. No differences in ADG, ADFI, or G:F were observed from d 14 to 28 after weaning in pigs fed whey protein product from d 0 to 14.

For the cumulative period, d 0 to 28 after weaning, no differences in ADG or ADFI were observed in pigs fed either increasing spray-dried animal plasma or whey protein product from d 0 to 14 after weaning. Pigs previously fed increasing whey protein product from d 0 to 14 after weaning had improved G:F (quadratic, $P < .03$).

Experiment 4. From d 0 to 7 and d 7 to 14 after weaning, as whey protein product replaced increasing amounts of spray-dried animal plasma, ADG increased and then returned to control values (quadratic, $P < .10$, Table 10). Average daily feed intake and G:F were not affected by increasing whey protein product.

From d 0 to 14 after weaning, ADG and ADFI increased and then returned to control values with increasing whey protein product (quadratic, $P < .04$, and .09, respectively). Feed efficiency was not affected by whey protein concentrate. During this period, pigs fed any of the whey protein product and spray-dried animal

Table 9. Effect of increasing whey protein product and spray-dried animal plasma on weanling pig performance (Exp. 3)[a]

		Added spray-dried animal plasma, %		Whey protein product, %			Probability ($P <$)			
							Animal plasma		Whey protein	
Item	Control[b]	2.5	5.0	2.5	5.0	SEM	Linear	Quadratic	Linear	Quadratic
Day 0 to 7										
ADG, g	99	120	112	126	108	8.1	.25	.16	.44	.04
ADFI, g	124	143	141	143	134	5.8	.04	.14	.23	.05
Gain:feed	.78	.83	.81	.87	.80	.041	.67	.47	.73	.13
Day 7 to 14										
ADG, g	259	292	248	275	272	9.2	.42	.002	.33	.44
ADFI, g	277	297	274	296	299	9.8	.83	.08	.14	.51
Gain:feed	.94	.99	.90	.93	.91	.023	.24	.02	.52	.98
Day 0 to 14										
ADG, g	178	206	180	199	189	6.7	.87	.003	.27	.07
ADFI, g	200	220	207	219	215	6.2	.41	.04	.09	.14
Gain:feed	.89	.93	.87	.91	.88	.019	.34	.02	.63	.32
Day 14 to 28										
ADG, g	352	342	320	356	340	13.8	.12	.71	.56	.57
ADFI, g	494	492	445	489	477	16.7	.05	.27	.51	.88
Gain:feed	.71	.70	.72	.72	.71	.016	.59	.35	.93	.40
Day 0 to 28										
ADG, g	266	274	252	281	269	8.5	.26	.17	.79	.20
ADFI, g	348	355	325	355	352	10.3	.13	.13	.17	.64
Gain:feed	.76	.77	.78	.79	.76	.009	.27	.94	.85	.03

[a]A total of 315 weanling pigs (initially 4.1 kg and 12 ± 1 d of age) with seven or eight pigs per pen and eight replications per treatment.
[b]All experimental treatment groups were fed diets that contained a minimum of 2.5% spray-dried animal plasma from d 0 to 14 after weaning.

Table 10. Effect of replacing spray-dried animal plasma with whey protein product on weanling pig performance (Exp. 4)[a]

	Animal plasma:whey protein product, %						Probability ($P <$)	
Item	6.7:0	5.0:1.7	3.35:3.35	1.7:5.0	0:6.7	SEM	Linear	Quadratic
Day 0 to 7								
ADG, g	116	127	130	122	112	8.4	.62	.10
ADFI, g	131	144	137	137	123	8.2	.57	.22
Gain:feed	.89	.88	.95	.94	.86	.059	.98	.32
Day 7 to 14								
ADG, g	209	228	234	245	226	10.2	.14	.08
ADFI, g	254	276	255	294	267	9.6	.17	.30
Gain:feed	.85	.82	.93	.83	.86	.047	.81	.60
Day 0 to 14								
ADG, g	163	178	182	183	169	7.6	.47	.04
ADFI, g	193	210	195	215	197	5.8	.46	.09
Gain:feed	.85	.84	.93	.85	.86	.035	.77	.35
Day 14 to 28								
ADG, g	440	454	431	444	447	12.1	.91	.77
ADFI, g	444	470	440	458	467	13.8	.47	.78
Gain:feed	.97	.96	.96	.95	.95	.030	.59	.84
Day 0 to 28								
ADG, g	301	315	307	314	308	6.4	.56	.34
ADFI, g	318	339	318	337	332	8.1	.35	.74
Gain:feed	.94	.92	.95	.92	.93	.020	.80	.74

[a]A total of 310 weanling pigs (initially 4.2 kg and 12 to 13 d of age) with eight or nine pigs per pen and seven replications per treatment.

Table 11. Effect of replacing spray-dried animal plasma with whey protein product on weanling pig performance (Exp. 5)[a]

Item	Spray-dried animal plasma, %	Animal plasma/ whey product, %	Whey protein product, %	SEM	Probability (*P* <)	
	100	50/50	100		Linear	Quadratic
Day 0 to 7						
ADG, g	99	107	104	4.6	.70	.29
ADFI, g	125	130	127	2.4	.42	.25
Gain:feed	.80	.82	.82	.036	.94	.60
Day 7 to 14						
ADG, g	247	265	262	8.4	.79	.12
ADFI, g	319	336	340	5.8	.67	.02
Gain:feed	.77	.79	.77	.014	.39	.68
Day 0 to 14						
ADG, g	173	186	183	4.3	.64	.04
ADFI, g	222	233	233	3.1	.93	.001
Gain:feed	.78	.80	.78	.012	.47	.49
Day 14 to 28						
ADG, g	390	395	401	9.7	.67	.51
ADFI, g	588	592	592	8.4	.99	.73
Gain:feed	.66	.67	.68	.014	.60	.60
Day 0 to 28						
ADG, g	281	290	292	5.6	.86	.17
ADFI, g	405	412	412	4.6	.99	.20
Gain:feed	.69	.70	.71	.014	.79	.41

[a]A total of 756 weanling pigs (initially 5.2 kg and 17 to 19 d of age) with 42 pigs per pen and six replications per treatment.

plasma combinations had greater ADG than pigs fed either of the protein sources alone.

From d 14 to 28 after weaning or the cumulative experimental period, no differences in ADG, ADFI, or G:F were observed as a result of protein sources fed from d 0 to 14 after weaning.

Experiment 5. From d 0 to 7 after weaning, no differences in ADG, ADFI, or G:F were observed. However, from d 7 to 14 and d 0 to 14 after weaning, increasing whey protein product increased ADFI (quadratic, $P < .05$, Table 11). From d 0 to 14, pigs fed diets containing the combination of whey protein product and spray-dried animal plasma had greater ADG (quadratic, $P < .05$) than pigs fed diets containing only spray-dried animal plasma. Pigs fed only whey protein product had intermediate ADG. No differences in G:F were observed. Experimental diets fed from d 0 to 14 after weaning had no effect on growth performance from d 14 to 28 and from d 0 to 28.

Discussion

Spray-dried animal plasma has been shown to be an excellent protein source for weanling pigs (Gatnau and Zimmerman, 1991; Sohn et al., 1991; Hansen et al., 1993; Kats et al., 1994a,b). However, pig weight, age, and health status can influence the magnitude of response to spray-dried animal plasma (Coffey and Cromwell, 1995; Bergstrom et al., 1997). In Exp. 1, pigs fed increasing spray-dried animal plasma had higher ADG and ADFI only during the initial 7-d period after weaning. These results are consistent with previous studies showing spray-dried animal plasma to be a superior protein source compared with dried skim milk (Hansen et al., 1993; Kats et al., 1994a). However, the magnitude or duration of the response to spray-dried animal plasma was not as great as previously observed. Kats et al. (1994a) and Hansen et al. (1993) found increases in ADG (30 to 35%) and ADFI (33 to 40%) when comparing pigs fed spray-dried animal plasma with those fed dried skim milk, and these responses were maintained throughout the first 14 d of the studies. In Exp. 1, the control diet contained spray-dried blood meal, dried skim milk, and(or) lactose. This may have provided sufficient specialty protein and carbohydrate sources for pigs of this age and weight to enhance growth performance. Therefore, this suggests that age and initial weight in our study combined with a control diet already sufficient as specialty protein sources may have been responsible for the small response to spray-dried animal plasma.

Because of observations in Exp. 1, a second experiment was conducted to further evaluate whey protein product as a replacement for spray-dried animal plasma in younger pigs with less-complex diets. In Exp. 2, increasing spray-dried animal plasma and whey protein product improved growth performance during the entire time that experimental diets were fed (d 0 to 14 after weaning). All performance observations (ADG, ADFI, and G:F) were improved with increasing spray-dried animal plasma. Kats et al. (1994a) found increases in ADG and ADFI from d 0 to 14 for pigs fed up to 10% spray-dried animal plasma. Improvement in G:F is generally not observed from increasing substitution of spray-dried animal plasma for dried skim milk (Hansen et al., 1993; Kats et al., 1994a). However, in the current study, G:F was improved when soybean meal was replaced. Bergstrom et al. (1997) also observed an increase in G:F as soybean meal was replaced by spray-dried animal plasma and suggested that the response was due to a relatively greater digestibility of spray-dried animal plasma. In our study, pigs fed increasing whey protein product had greater ADG than pigs fed the control diet. The linear increases in ADG were similar for pigs fed whey protein product and spray-dried animal plasma. This suggests that whey protein product can replace spray-dried animal plasma. Spray-dried animal plasma seems to increase ADG predominantly from an increase in feed intake (Gatnau and Zimmerman, 1990; Hansen et al., 1993; Kats et al., 1994a); however, we did not observe an increase in ADFI with whey protein product. The improvement in ADG seemed to be a result of better feed efficiency. This suggests that the mechanisms for increased ADG from spray-dried animal plasma and whey protein product are independent.

Based on greater responses observed in Exp. 2 using lighter and younger pigs, a third study was conducted to validate the results in a commercial production system. In Exp. 3, increasing spray-dried animal plasma improved pig performance from d 0 to 14. However, little if any increase in ADG occurred as spray-dried animal plasma increased from 5 to 7.5%. Nessmith (1996) observed similar growth performance of pigs fed 2.5 or 5.0% spray-dried animal plasma. In contrast, Kats et al. (1994a) observed growth performance to improve with up to 10% spray-dried animal plasma. However, experimental diets fed in Exp. 3 contained fish meal and spray-dried blood meal as protein sources because of the age and weight of the pigs. These other protein sources may have contributed to the observation of maximized performance at 5% spray-dried animal plasma. Also, the excellent health status of pigs in Exp. 3 may have resulted in a lower inclusion rate of spray-dried animal plasma necessary to maximize pig performance (Coffey and Cromwell, 1995; Bergstrom et al., 1997).

In Exp. 3, pigs fed the combination of whey protein product and spray-dried animal plasma had greater growth performance than pigs fed the control diet during the first week after weaning. However, pigs fed the highest inclusion of each protein source did not show further increases in ADG or ADFI.

On d 14 after weaning, when pigs fed 5.0 or 7.5% spray-dried animal plasma (d 0 to 14) were switched to a common diet (no spray-dried animal plasma), a decrease in ADFI and a tendency for a decease in ADG (d 14 to 28) were observed. Studies by Kats et al. (1994a) and Nessmith (1996) also observed the same depression in growth performance and suggested that a sequential decrease in plasma protein may be necessary to maintain the benefits from feeding spray-dried animal plasma during the initial period after weaning. This depression was not observed (d 14 to 28) in pigs fed whey protein product (d 0 to 14). However, under our experimental conditions, no differences in cumulative performance (d 0 to 28) were observed for either protein source fed from d 0 to 14. Nonetheless, in a commercial feeding regimen when diet changes are based on pig weight and not on time, as in our study, the initial differences in growth performance might be maintained.

Results from Exp. 3 suggested that responses to a combination of spray-dried animal plasma and whey protein were similar to those observed for spray-dried animal plasma alone. Therefore, Exp. 4 and 5 were conducted to evaluate pig performance when increasing levels of spray-dried animal plasma were replaced with whey protein product.

In Exp. 4 and 5, pigs fed combinations of spray-dried animal plasma and whey protein product (from d 0 to 14) had better growth performance than pigs fed either of the protein sources fed alone. Our findings are similar to those of Kats et al. (1994a), who demonstrated that pigs fed combinations of spray-dried animal plasma and spray-dried blood meal had greater ADG and G:F compared with those fed either protein source alone. This response suggests different mechanisms of action for spray-dried animal plasma and whey protein product. As observed in Exp. 2, increased ADG from spray-dried animal plasma is primarily from increased feed intake, but whey protein product seems to increase ADG as a result of better feed efficiency. One factor that may account for some of the improved feed efficiency observed in pigs fed whey protein product may be the added fat it provided or the type of fat (whey phospholipids) and its effect on fat digestibility. We did not adjust diet formulation for the increase in fat content provided by the whey protein product in our experiments. Additional studies will be needed to determine whether the added fat and(or) phospholipid is responsible for the improved pig growth performance.

In spray-dried animal plasma, IgG is the protein fraction thought to be responsible for the increase in ADFI, which results in higher ADG (Owen et al., 1995; Pierce et al., 1995; Weaver et al., 1995). The processing procedures for whey protein product that concentrate the proteins also would concentrate the IgG protein fraction. Therefore, IgG levels would be higher in whey protein product than in dried whey or dried skim milk. Although spray-dried animal plasma and whey protein product apparently increase ADG through intake and efficiency, respectively, the IgG contribution from whey protein product cannot be over looked.

Implications

These studies demonstrate that whey protein product can be used as a partial or complete replacement for spray-dried animal plasma in diets for weanling pigs. However, the optimum inclusion of either protein source should be based on weight, age, and health status of the pigs as well as other dietary protein sources.

Literature Cited

AOAC. 1990. Official Method of Analysis (15th Ed.). Association of Official Analytical Chemists, Arlington, VA.

Bergström, J. R., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, K. Q. Owen, and W. B. Nessmith, Jr. 1997. Evaluation of spray-dried animal plasma and select menhanden fish meal in transition diets fed to pigs weaned at 12 to 14 days of age and reared in different production systems. J. Anim. Sci. 75:3004–3009.

Code of Federal Regulations. 1998. Food and Drugs. Office of the Federal Register National Archives and Records Administration. 184.1979c.

Coffey, R. D., and G. L. Cromwell. 1995. The impact of environment and antimicrobial agents on the growth response of early weaned pigs to spray-dried porcine plasma. J. Anim. Sci. 73:2532–2539.

Gatnau, R., and D. R. Zimmerman. 1990. Spray-dried porcine plasma (SDPP) as a source of protein for weanling pigs. J. Anim. Sci. 68(Suppl. 1):374 (Abstr.).

Gatnau, R., and D. R. Zimmerman. 1991. Spray dried porcine plasma (SDPP) as a source of protein for weanling pigs in two environments. J. Anim. Sci. 69(Suppl. 1):103 (Abstr.).

Hansen, J. A., J. L. Nelssen, R. D. Goodband, and T. L. Weeden. 1993. Evaluation of animal protein supplements in diets of early-weaned pigs. J. Anim. Sci. 71:1853–1862.

Himmelberg, L. V., E. R. Peo, Jr., A. J. Lewis, and J. D. Crenshaw. 1985. Weaning weight response of pigs to simple and complex diets. J. Anim. Sci. 61:18–26.

Kats, L. J., J. L. Nelssen, M. D. Tokach, R. D. Goodband, J. A. Hansen, and J. L. Laurin. 1994a. The effects of spray-dried porcine plasma on growth performance in the early-weaned pig. J. Anim. Sci. 72:2075–2081.

Kats, L. J., J. L. Nelssen, M. D. Tokach, R. D. Goodband, T. L. Weeden, S. S. Dritz, J. A. Hansen, and K. G. Friesen. 1994b. The effects of spray-dried blood meal on growth performance of the early-weaned pig. J. Anim. Sci. 72:2860–2869.

Knabe, D. A., D. C. LaRue, E. J. Gregg, G. M. Martinez, and T. D. Tanksley, Jr. 1989. Apparent digestiblity of nitrogen and amino acids in protein feedstuffs by growing pigs. J. Anim. Sci. 67:441–458.

LaRue, D. C. 1985. Comparative alkaline hydrolysis for the determination of the tryptophan requirements for 5 to 20 and 20 to 50 kilogram pigs. Ph.D. dissertation. Texas A&M Univ., College Station.

Lepine, A. J., D. C. Mahan, and Y. K. Chung. 1991. Growth performance of weanling pigs fed corn-soybean meal diets with or without dried whey at various L-lysine-HCl levels. J. Anim. Sci. 69:2026–2032.

Moore, S. 1963. On the determination of cystine as cysteic acid. J. Biol. Sci. 238:235–237.

Morr, C. V., and E. A. Foegeding. 1990. Composition and functionality of commercial whey and milk protein concentrates and isolates: A status report. Food Technol. (April):100–112.

Nessmith, W. B. 1996. The effects and possible interactions between various carbohydrate and protein sources on weanling pig performance. M.S. thesis. Kansas State Univ., Manhattan.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, DC.

Owen, K. Q., J. L. Nelssen, R. D. Goodband, M. D. Tokach, K. G. Friesen, B. T. Richert, J. W. Smith, and L. E. Russell. 1995. Effects of various fractions of spray-dried porcine plasma on performance of early weaned pigs. J. Anim. Sci. 73(Suppl. 1):81 (Abstr.).

Peterson, R. G. 1985. Design and Analysis of Experiments. Marcel Dekker, New York.

Pierce, J. L., G. L. Cromwell, M. D. Lindemann, and R. D. Coffey. 1995. Assessment of three fractions of spray-dried porcine plasma on performance of early-weaned pigs. J. Anim. Sci. 73(Suppl. 1):81 (Abstr.).

SAS. 1998. SAS/STAT® User's Guide (Release 6.12). SAS Inst. Inc., Cary, NC.

Sohn, K. S., C. V. Maxwell, and D. S. Buchanan. 1991. Plasma protein as an alternative protein source for early weaned pigs. J. Anim. Sci. 69(Suppl. 1):362 (Abstr.).

Tokach, M. D., J. L. Nelssen, and G. L. Allee. 1989. Effect of protein and(or) carbohydrate fractions of dried whey on performance and nutrient digestibility of early weaned pigs. J. Anim. Sci. 67:1307–1312.

Weaver, E. M., L. E. Russell, and M. D. Drew. 1995. The effect of spray-dried animal plasma fractions on performance of newly weaned pigs. J. Anim. Sci. 73(Suppl. 1):81 (Abstr.).

Zadow, J. G. 1992. Whey and Lactose Processing. Elsevier Science Publishing Co., Inc., New York.