Effects of Providing a Water-Soluble Globulin in Drinking Water and Diet Complexity on Growth Performance of Weanling Pigs[1,2]

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ABSTRACT: Two experiments were conducted to evaluate the effects of providing a water-soluble globulin in the drinking water on growth performance of weanling pigs. In Exp. 1, 360 weanling pigs (5.0 ± 1.2 kg; 17 ± 3 d of age; PIC) were blocked by initial weight and allotted to one of six treatments in a 2 × 3 factorial arrangement. Treatments included three diet complexity regimens with or without water-soluble globulin (3 and 1.5% solutions; d 0 to 7 and d 0 to 14, respectively) provided in the drinking water. The 35-d study was divided into three phases (d 0 to 7, 7 to 14, and 14 to 35) with corresponding lysine levels of 1.6, 1.5, and 1.35%. Soybean meal replaced specialty protein and lactose sources to provide three different complexity regimens. From d 0 to 7, a water-soluble globulin × diet complexity interaction ($P < 0.05$) was observed for average daily gain (ADG) and gain:feed (G/F). Increasing diet complexity increased ADG and G/F for pigs provided water, whereas the medium diet complexity regimen optimized performance for pigs offered water-soluble globulin. From d 0 to 14, pigs fed the two more complex regimens had greater ADG and G/F ($P < 0.01$) than the pigs fed the least complex regimen. Pigs offered water-soluble globulin had decreased ($P < 0.01$) ADFI, but increased ($P < 0.001$) G/F from d 0 to 14. For overall performance (d 0 to 35), increasing diet complexity increased ($P < 0.03$) ADG and ADFI, whereas water-soluble globulin offered from d 0 to 14 had no effect. In Exp. 2, 360 weanling pigs (5.2 ± 1.6 kg; 19 ± 4 d of age) were used in a 21-d growth assay. The trial was arranged as a 2 × 3 factorial with pigs fed the low- or medium-complexity diets (Exp. 1) with water or a 3% solution of water-soluble globulin offered for 4 or 8 d after weaning. From d 0 to 4, pigs offered water-soluble globulin had increased ($P < 0.001$) ADG and G/F compared with pigs provided water, whereas from d 4 to 8, pigs provided water had increased ($P < 0.05$) ADG and G/F compared with pigs offered water-soluble globulin. Pigs fed the medium-complexity diet had increased ADG and G/F (d 4 to 8 and d 8 to 12) compared with pigs fed the low-complexity diet. From d 0 to 8 and d 0 to 21, pigs provided water-soluble globulin for 4 or 8 d after weaning had improved G/F compared with pigs provided water. Results demonstrate that providing water-soluble globulin through the water source of weanling pigs improves ADG and G/F immediately after weaning.

Key Words: Diet, Globulins, Piglets

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Introduction

Pigs typically do not eat a large amount of feed for the first 24 to 72 h after weaning, which results in little, if any, weight gain. Pigs weaned at 28 d of age and fed a dried milk product-based diet do not show normal levels of feed consumption (defined by time spent at the feeder) or eating behavior until the second day after weaning (Metz and Gonyou, 1990). Gonyou et al. (1998) observed that pigs weaned at 12 d of age do not begin eating until approximately 36 h after weaning. Many ingredients have been tested and used in weanling pig diets to stimulate feed intake during the first few days after weaning. This has resulted in the use of specialty protein and lactose sources as ingredients in starter diets (Dritz et al., 1996).

One specialty protein product, spray-dried animal plasma, has been shown to increase feed intake and improve growth performance in weanling pigs (Hansen

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et al., 1993). However, Gonyou et al. (1998) demonstrated that even with spray-dried animal plasma-based diets and weaning at 21 d of age, pigs needed 24 h after weaning before normal eating behavior began. An alternative method of providing nutrients through the water may allow pigs to begin consuming readily available nutrient sources as soon as they are weaned (Morrow et al., 1995).

A new product—water-soluble globulin—composed of spray-dried animal serum, globulin, spray-dried animal plasma, and other ingredients, is processed to make it soluble in water and has been introduced as a supplement for early-weaned pigs. Borg et al. (1999b) observed that offering water-soluble globulin in the water for 14 d improved weanling pig feed intake and growth performance. Therefore, our experimental objective was to study the effects of water-soluble globulin feeding duration in combination with different diet complexity regimens on weanling pig performance.

Materials and Methods

Animal Use and Care. The experimental protocol used in this study was approved by the Kansas State University Institutional Animal Care and Use Committee.

Water-Soluble Globulin. The water-soluble globulin used in both studies was provided by APC, Inc. (Ames, IA). Proximate and mineral analyses of the water-soluble globulin were done by AOAC (1995) procedures. Amino acid analysis was done with an HPLC (model 6300, Beckman Instruments, Palo Alto, CA) following AOAC (1995) procedures (Table 1).

Table 1. Chemical analysis of water-soluble globulin (Exp. 1 and 2)[a]

Item	Amount
Gross energy, kcal/kg	5,183
Ash, %	3.84
Dry matter, %	94.00
Crude protein, %	67.24
Crude fat, %	0.95
Minerals	
Ca, %	0.14
P, %	0.11
Mg, %	<0.01
K, %	0.93
S, %	1.07
Na, %	0.89
Zn, ppm	14
Fe, ppm	30
Mn, ppm	1
Cu, ppm	8
Amino acids, %	
Arginine	3.72
Cystine	2.58
Histidine	2.38
Isoleucine	1.84
Leucine	6.75
Lysine	6.25
Methionine	1.79
Phenylalanine	3.66
Threonine	4.24
Tryptophan	1.17
Tyrosine	3.30
Valine	4.57

[a]Values are expressed on an as-fed basis and represent the mean of two samples.

To provide water (or water-soluble globulin) to the weanling pigs, 36 plastic containers (28 × 36 × 46 cm) were placed above 72 pens in the nursery. Each plastic container provided water for two adjacent pens of pigs because of the design of the waterers used in the facility. A rubber hose, 9.5 mm in diameter, connected the plastic containers to a T-waterer with two gravity-flow nipples (Trojan Spiglet 97, Trojan Specialized Livestock Equipment; Conrad, IA) to provide ad libitum consumption of water or water-soluble globulin. Because the container supplying water (or water-soluble globulin) was shared by two pens, each pair of pens was used as the experimental unit. Treatments were allotted randomly to experimental units to determine if the tubs would contain water-soluble globulin or water. Each morning, liquid left over from the previous day was collected, weighed, and recorded for each experimental unit.

Fresh water or water-soluble globulin was prepared and provided daily. A container (38 × 46 × 76 cm) was filled with water and approximately 11.4 kg of water was removed, weighed, and added to each container for the control pens. For the water-soluble globulin treatments, 2.46 or 1.23 kg of the dry water-soluble globulin product was combined with 82 kg of water to provide the respective 3 or 1.5% solutions used in the studies. This mixture was stirred for approximately 5 min using an electric drill equipped with a paint mixer to ensure that the water-soluble globulin was completely dissolved. A portion of the mixture (approximately 11.4 kg) was weighed and deposited into the individual containers to provide water-soluble globulin to the respective pens. On d 14 and 8 (for Exp. 1 and 2, respectively), hoses were disconnected from the tubs and reconnected to the standard water lines, and all pigs were offered water for the remainder of the studies.

Animals and Diets. Weanling pigs (PIC, Line 326 × C15, Franklin, KY) were transported approximately 45 min from a commercial sow farm to the Kansas State University Segregated Early Weaning Facility. Pigs were monitored closely to ensure that they were eating and drinking shortly after weaning. Unlike our standard operating procedures, the waterers were not allowed to trickle (to teach the pigs where to find water) immediately after weaning because daily water disappearance was a response criterion. The pigs were housed in an environmentally regulated nursery with the temperature maintained at 32°C for the first week and lowered approximately 3°C each week thereafter. Each pen (1.22 m^2) contained five pigs and was equipped with one nipple waterer and a four-hole feeder to allow ad libitum access to liquid and feed.

Experiment 1. Weanling pigs (n = 360) with an initial BW of 5.0 ± 1.2 kg (17 ± 3 d of age) were allotted to one of six treatments. Treatments included three diet

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

	Day 0 to 7[a]			Day 7 to 14[b]			Day 14 to 35[c]		
Ingredient, %	High	Medium[d]	Low[d]	High	Medium	Low	High[e]	Medium	Low
Corn	37.00	39.08	40.95	45.97	47.80	46.68	53.78	52.68	56.38
Soybean meal (46.5% crude protein)	9.01	23.06	35.53	19.16	31.63	40.25	26.15	34.78	35.95
Spray-dried animal plasma	6.70	2.50	—	2.50	—	—	—	—	—
Fish meal, select menhaden	6.00	2.50	—	2.50	—	—	—	—	—
Dried whey	25.00	20.00	10.00	20.00	10.00	5.00	10.00	5.00	—
Choice white grease	6.00	6.00	6.00	3.00	3.00	3.00	3.00	3.00	3.00
Lactose	5.00	—	—	—	—	—	—	—	—
Spray-dried blood cells	1.65	2.50	2.50	2.50	2.50	—	2.50	—	—
Monocalcium P (21% P)	0.70	1.25	1.70	1.25	1.75	1.70	1.35	1.30	1.40
Limestone	0.58	0.78	1.00	0.80	1.00	1.05	0.98	1.03	1.05
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.35	0.35	0.35
Vitamin premix[f]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[g]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.16	0.15	0.15	0.15	0.15	0.13	0.10	0.08	0.08
Zinc oxide	0.38	0.38	0.38	0.38	0.38	0.38	0.25	0.25	0.25
Medication[h]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[a]Diets were fed in pelleted form and formulated to contain 1.60% lysine, 0.9% Ca, and 0.8% P.
[b]Diets were fed in meal form and formulated to contain 1.50% lysine, 0.9% Ca, and 0.8% P.
[c]Diets were fed in meal form and formulated to contain 1.35% lysine, 0.8% Ca, and 0.7% P.
[d]Also fed in Exp. 2 from d 0 to 8.
[e]Also fed in Exp. 2 as a common diet from d 8 to 21.
[f]Premix provided the following per kilogram of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,103 IU; vitamin E, 44 IU; menadione (menadione sodium bisulfate complex), 4.4 mg; riboflavin, 8.3 mg; D-pantothenic acid, 29 mg; niacin, 50 mg; choline, 166 mg; and vitamin B_{12}, 33 μg.
[g]Premix provided the following per kilogram of complete diet: Mn, 12 mg; Fe, 165 mg; Zn, 165 mg; Cu, 16 mg; I, 0.3 mg; Se, 0.3 mg.
[h]Provided 55 μg/kg carbadox.

complexity regimens with or without supplemental water-soluble globulin provided in the drinking water from d 0 to 14 after weaning (3.0% solution from d 0 to 7 and 1.5% from d 7 to 14). Soybean meal replaced different amounts of specialty protein and lactose sources to obtain the three different diet complexities (Table 2). The 35-d growth assay was divided into three phases (d 0 to 7, 7 to 14, and 14 to 35) with corresponding dietary lysine levels of 1.6, 1.5, and 1.35%. All diets were formulated to meet or exceed all other nutrient requirement estimates of NRC (1998). Diets fed during d 0 to 7 were pelleted (3.97 mm diameter), and diets fed during d 7 to 14 and d 14 to 35 were in meal form. Diet samples were collected and analyzed for DM (AOAC, 1995).

Pig weights and feed disappearance were determined weekly for the entire 35-d study. These data were used to calculate ADG, ADFI, and gain:feed ratio (**G/F**). To account for water-soluble globulin intake, DMI and feed efficiency also were calculated. Dry matter intake was calculated by adding DMI from both feed and liquid. Dry matter feed efficiency was calculated by dividing ADG by DMI. Liquid disappearance (water or water-soluble globulin) was recorded daily from d 0 to 14.

Experiment 2. Weanling pigs (n = 360) with an initial BW of 5.2 ± 1.6 kg (19 ± 4 d of age) were used in a 21-d growth assay. The study was divided into two phases (d 0 to 8 and d 8 to 21 after weaning), and treatments included two diet complexities fed from d 0 to 8 and water or a 3% solution of water-soluble globulin offered for 4 or 8 d after weaning. The decision to provide water-soluble globulin for only 4 or 8 d after weaning, as well as to use only two different diets, was based on the responses observed in Exp. 1. The two diets were identical to the low- and medium-complexity diets used during d 0 to 7 in Exp. 1 and were pelleted (3.97 mm diameter). From d 8 to 21, all pigs were fed a common diet (1.35% lysine) in meal form and provided with water (Table 2).

Pig weights and feed disappearance were determined at weaning (d 0) and on d 4, 8, 12, and 21 after weaning. From these data, ADG, ADFI, and G/F were calculated for the four time periods. Similar to Exp. 1, DM G/F also was calculated. Liquid disappearance (water or water-soluble globulin) was recorded daily from d 0 to 8.

Statistical Analysis. Both experiments were randomized complete block designs and arranged as 3×2 factorials. Pigs were blocked by initial weight and allotted randomly to one of the six treatments, with six replications per treatment. The experimental unit was comprised of two adjoining pens (five pigs/pen) that shared the same liquid source. Data in both experiments were analyzed using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). The statistical model included main and interactive effects of water-soluble globulin and diet complexity.

Results

Water-Soluble Globulin Analysis. The water-soluble globulin used in these studies contained 3.84% ash and 67.2% CP (Table 1). These values, as well as other nutri-

Table 3. Effects of water-soluble globulin (WSG) on liquid disappearance (kg/pig) of weanling pigs fed high-, medium-, and low-complexity diets (Exp. 1)[a]

	Water			Water-soluble globulin[b]				Probability (P <)		
Day	High	Medium	Low	High	Medium	Low	SEM	WSG	Diet complexity	WSG × diet
1	0.83	0.83	0.78	0.81	0.82	0.89	0.085	0.54	0.97	0.40
2	1.01	0.92	0.89	1.18	1.14	1.17	0.080	0.001	0.53	0.67
3	1.40	1.27	1.09	1.55	1.49	1.47	0.137	0.006	0.19	0.49
4	1.26	1.12	1.08	1.48	1.47	1.44	0.121	0.001	0.28	0.53
5	1.17	1.08	0.80	1.35	1.27	1.25	0.096	0.001	0.02	0.13
6	1.06	0.99	0.71	1.29	1.24	1.10	0.084	0.001	0.001	0.44
7	1.17	1.10	0.88	1.41	1.23	1.08	0.0906	0.007	0.003	0.77
8	0.84	0.87	0.75	1.04	0.98	0.94	0.072	0.005	0.33	0.79
9	0.96	0.97	0.89	1.00	1.04	1.10	0.097	0.05	0.93	0.33
10	1.00	1.04	1.06	1.07	1.11	1.12	0.101	0.19	0.67	0.99
11	1.32	1.33	1.39	1.25	1.40	1.31	0.093	0.67	0.53	0.58
12	1.39	1.36	1.35	1.25	1.42	1.48	0.098	0.73	0.32	0.10
13	1.43	1.40	1.49	1.42	1.45	1.42	0.070	0.90	0.85	0.66
14	1.49	1.42	1.44	1.43	1.36	1.46	0.098	0.64	0.66	0.88

[a]A total of 360 weanling pigs initially 5.0 ± 1.2 kg and 17 ± 3 d of age. Values represent the mean of six replications per treatment with two adjoining pens (five pigs/pen) used as the experimental unit.
[b]Water-soluble globulin was added to the water at 3.0% from d 0 to 7 and at 1.5% from d 7 to 14.

ent values, are generally lower than NRC (1998) estimates for spray-dried animal plasma. This is because water-soluble globulin is a blended product containing serum, globulin, lactose, fructo-oligosaccharide, DL-methionine, and KCl. Whereas most amino acids were lower in concentration in water-soluble globulin than in spray-dried animal plasma (NRC, 1998), they were approximately the same as a percentage of CP with the exception of isoleucine (lower) and methionine (higher from added DL-methionine).

Experiment 1. No water-soluble globulin × diet complexity interactions were observed for liquid disappearance (Table 3). Pigs provided water-soluble globulin had increased ($P < 0.05$) liquid intake beginning on d 2 and continuing through d 9 after weaning compared with pigs provided water. Pigs fed the high- and medium-complexity regimens had similar ($P > 0.10$) liquid intakes on d 5, 6, and 7 after weaning, which were greater ($P < 0.02$) than the intakes of pigs fed the low-complexity regimen.

From d 0 to 7, water-soluble globulin × diet complexity interactions ($P < 0.05$) were observed for ADG, G/F, and DM G/F (Table 4). For pigs offered water, ADG decreased ($P < 0.05$) as diet complexity decreased (124, 92, and 39 g/d). However, when water-soluble globulin was provided, pigs fed the high-complexity regimen had similar ($P > 0.10$) ADG to pigs fed the medium-complexity regimen, and both had greater ($P < 0.01$) ADG than pigs fed the low-complexity regimen (121, 128, and 86 g/d, respectively). Similarly, the interactions for G/F and DM G/F were the results of G/F improving as diet complexity increased for pigs provided water, but remaining similar across diet complexity regimens for pigs provided water-soluble globulin. No other water-soluble globulin × diet complexity interactions were observed ($P > 0.10$). No differences ($P > 0.10$) in ADFI occurred between pigs fed the high- and medium-complexity regimen, but both groups had greater ($P < 0.001$) ADFI than pigs fed the low-complexity regimen. Water-soluble globulin had no effect ($P > 0.10$) on ADFI from d 0 to 7 after weaning. However, when DMI of the feed was combined with calculated DMI from the water-soluble globulin, DM ADFI was greater ($P < 0.001$) for those pigs offered water-soluble globulin compared with those offered water.

From d 0 to 14 after weaning, pigs fed the high- and medium-complexity regimens had similar ($P > 0.10$) ADG, ADFI, and DM G/F, which were greater ($P < 0.002$) than those of pigs fed the low-complexity regimen. Water-soluble globulin had no effect ($P > 0.10$) on ADG, but decreased ($P < 0.001$) ADFI, which resulted in increased ($P < 0.001$) G/F compared with pigs offered water. Whereas pigs offered water-soluble globulin had decreased ADFI, DM ADFI tended ($P < 0.08$) to be greater than those offered water, and thus had no effect ($P > 0.10$) on DM G/F from d 0 to 14.

From d 14 to 35, pigs fed the high-complexity regimen had numerically greater ($P < 0.06$) ADG, but similar ($P > 0.10$) ADFI, G/F, and DM G/F compared with pigs fed the medium-complexity regimen. Pigs fed the low-complexity regimen had decreased ($P < 0.001$) ADG and ADFI, but improved ($P < 0.01$) G/F and DM G/F compared with pigs fed the high- or medium-complexity regimens. Water-soluble globulin offered during d 0 to 14 after weaning had no effect ($P > 0.10$) on ADG, ADFI, or G/F from d 14 to 35.

For the overall study (d 0 to 35), pigs fed the high- and medium-complexity regimens had similar ($P > 0.10$) ADG and ADFI, and both were greater ($P < 0.001$) than those of pigs fed the low-complexity regimen. Pigs fed the low-complexity regimen had improved ($P < 0.03$) G/F compared with pigs fed the medium-complexity regimen and with those fed the high-complexity regimen intermediate. Pigs fed the high- and medium-complexity regimens had similar ($P > 0.10$) DM G/F, which was poorer (P

Table 4. Effects of water-soluble globulin (WSG) on the growth performance of weanling pigs fed high-, medium-, and low complexity diets (Exp. 1)[a]

	Water			Water-soluble globulin[b]				Probability (P <)		
Item	High	Medium	Low	High	Medium	Low	SEM	WSG	Diet complexity	WSG × diet
Day 0 to 7										
ADG, g	124	92	39	121	128	86	12.5	0.003	0.001	0.05
ADFI, g	122	116	95	107	117	91	9.75	0.37	0.01	0.58
DM ADFI, g	111	105	86	134	142	117	12.9	0.001	0.053	0.77
Gain:feed	1.02	0.79	0.40	1.11	1.09	0.95	0.070	0.001	0.001	0.003
DM gain:feed[c]	1.12	0.87	0.44	0.87	0.90	0.74	0.069	0.59	0.001	0.001
Day 0 to 14										
ADG, g	184	173	126	174	181	141	13.5	0.54	0.001	0.35
ADFI, g	220	217	189	181	203	164	12.8	0.001	0.002	0.37
Gain:feed	0.84	0.80	0.66	0.95	0.89	0.86	0.031	0.001	0.003	0.15
DM gain:feed[c]	0.92	0.88	0.73	0.85	0.82	0.77	0.033	0.19	0.001	0.15
Day 14 to 35										
ADG, g	524	506	478	520	502	462	21.2	0.31	0.001	0.76
ADFI, g	735	712	617	739	715	624	37.5	0.71	0.001	0.99
DM ADFI, g	669	646	558	673	648	565	21.4	0.74	0.001	0.98
Gain:feed	0.72	0.71	0.78	0.70	0.70	0.75	0.018	0.09	0.001	0.66
DM gain:feed[c]	0.79	0.79	0.86	0.77	0.77	0.82	0.020	0.09	0.001	0.66
Day 0 to 35										
ADG, g	388	373	336	380	372	335	17.6	0.64	0.001	0.89
ADFI, g	529	514	444	514	508	442	26.8	0.34	0.001	0.81
DM ADFI, g	482	467	403	484	476	413	14.0	0.33	0.001	0.91
Gain:feed	0.74	0.73	0.76	0.74	0.73	0.76	0.015	0.84	0.07	0.99
DM gain:feed[c]	0.81	0.80	0.84	0.81	0.81	0.84	0.017	0.84	0.04	0.99

[a]A total of 360 weanling pigs initially 5.0 ± 1.2 kg and 17 ± 3 d of age. Values represent the mean of six replications per treatment with two adjoining pens (five pigs/pen) used as the experimental unit.
[b]Water-soluble globulin was added to the water at 3.0% from d 0 to 7 and at 1.5% from d 7 to 14.
[c]Calculated by dividing ADG by DM intake from both feed and liquid.

< 0.04) than that of pigs fed the low-complexity regimen. Supplementing early-weaned pigs with water-soluble globulin from d 0 to 14 had no effect ($P > 0.10$) on overall growth performance.

Experiment 2. A water-soluble globulin × diet complexity interaction ($P < 0.01$) was observed for liquid disappearance on d 1 after weaning (Table 5). Among pigs fed the medium-complexity diet, those offered water had increased ($P < 0.001$) liquid disappearance compared with those offered water-soluble globulin for 4 d after weaning, whereas water-soluble globulin did not affect liquid disappearance for pigs fed the low-complexity diet. On d 2, pigs offered water-soluble globulin had numerically greater ($P > 0.06$) liquid disappearance, followed by increased ($P < 0.005$) liquid disappearance on d 3 and 4 after weaning compared with pigs provided water. On d 5 after weaning, pigs offered water-soluble globulin for 8 d after weaning had greater ($P < 0.01$) liquid disappearance than that of pigs provided water, whereas those provided water-soluble globulin for 4 d were intermediate ($P < 0.07$). On d 6 after weaning, pigs offered water-soluble globulin for 4 or 8 d after weaning had similar

Table 5. Effects of water-soluble globulin (WSG) duration on liquid disappearance (kg/pig) of weanling pigs fed medium- and low-complexity diets (Exp. 2)[a]

	Water		4-d WSG[b]		8-d WSG[c]			Probability (P <)		
Day	Medium[d]	Low[e]	Medium[d]	Low[e]	Medium[d]	Low[e]	SEM	WSG	Diet complexity	WSG × diet
1	0.82	0.83	0.47	0.72	0.69	0.61	0.068	0.001	0.16	0.01
2	0.78	0.81	0.96	0.81	1.07	0.97	0.094	0.07	0.33	0.59
3	0.79	0.96	1.19	1.16	1.35	1.19	0.133	0.02	0.94	0.47
4	1.14	1.07	1.49	1.42	1.44	1.34	0.107	0.001	0.24	0.98
5	0.86	0.84	1.12	1.15	1.35	1.31	0.103	0.001	0.87	0.94
6	0.82	0.79	1.19	1.04	1.10	1.17	0.118	0.01	0.94	0.36
7	0.84	0.88	0.96	0.78	1.27	1.04	0.080	0.001	0.07	0.21
8	1.11	1.22	1.24	1.17	1.42	1.33	0.116	0.04	0.32	0.82

[a]A total of 360 weanling pigs initially 5.2 ± 1.6 kg and 19 ± 4 d of age. Values represent the mean of six replications per treatment with two adjoining pens (five pig/pen) used as the experimental unit.
[bc]Water-soluble globulin (3%) was offered for 4 or 8 d, respectively.
[de]Meduim- and low-complexity diets in Exp. 1 (d 0 to 7) fed from d 0 to 8, respectively.

Table 6. Effects of water-soluble globulin (WSG) duration on growth performance of weanling pigs fed medium- and low-complexity diets (Exp. 2)[a]

	Water		4-d WSG[b]		8-d WSG[c]			Probability (P <)		
Item	Medium[d]	Low[e]	Medium[d]	Low[e]	Medium[d]	Low[e]	SEM	WSG	Diet complexity	WSG × diet
Day 0 to 4										
ADG, g	20	0	72	84	88	64	12.9	0.001	0.33	0.34
ADFI, g	75	64	71	68	67	67	9.0	0.94	0.50	0.80
DM ADFI, g	68	57	94	91	93	89	8.7	0.003	0.40	0.88
Gain:feed	0.02	–0.18	0.89	1.21	1.30	0.95	0.208	0.001	0.65	0.26
DM gain:feed[f]	0.02	–0.20	0.71	0.90	0.92	0.69	0.189	0.001	0.58	0.46
Day 4 to 8										
ADG, g	200	165	163	83	145	136	18.3	0.01	0.01	0.17
ADFI, g	214	195	206	179	186	180	12.8	0.26	0.11	0.72
DM ADFI, g	195	176	187	162	198	206	12.2	0.100	0.09	0.77
Gain:feed	0.95	0.85	0.78	0.46	0.77	0.76	0.066	0.001	0.01	0.08
DM gain:feed[f]	1.05	0.94	0.86	0.51	0.69	0.69	0.069	0.001	0.01	0.06
Day 0 to 8										
ADG, g	110	83	118	84	116	100	10.8	0.54	0.01	0.71
ADFI, g	145	129	138	124	127	123	9.4	0.45	0.16	0.77
DM ADFI, g	132	117	141	127	150	144	8.9	0.06	0.12	0.85
Gain:feed	0.77	0.63	0.85	0.68	0.90	0.81	0.049	0.01	0.003	0.71
DM gain:feed[f]	0.84	0.70	0.76	0.59	0.62	0.57	0.044	0.003	0.003	0.41
Day 8 to 12										
ADG, g	255	274	236	257	197	207	12.8	0.001	0.13	0.90
ADFI, g	348	319	295	280	239	259	14.4	0.001	0.52	0.23
DM ADFI, g	318	288	268	254	217	234	13.1	0.001	0.41	0.21
Gain:feed	0.76	0.86	0.80	0.92	0.84	0.81	0.045	0.48	0.08	0.25
DM gain:feed[f]	0.83	0.95	0.88	1.02	0.92	0.90	0.050	0.48	0.06	0.25
Day 12 to 21										
ADG, g	399	408	411	413	393	401	11.9	0.56	0.61	0.97
ADFI, g	550	552	531	518	493	515	14.2	0.01	0.74	0.47
DM ADFI, g	500	499	483	468	449	467	12.8	0.01	0.98	0.46
Gain:feed	0.73	0.74	0.78	0.80	0.80	0.78	0.018	0.007	0.91	0.53
DM gain:feed[f]	0.80	0.81	0.86	0.88	0.88	0.86	0.020	0.007	0.65	0.53
Day 0 to 21										
ADG, g	260	259	265	256	249	248	8.88	0.31	0.64	0.88
ADFI, g	355	348	335	321	302	315	9.93	0.001	0.74	0.38
DM ADFI, g	326	314	312	298	291	300	11.4	0.68	0.37	0.54
Gain:feed	0.74	0.74	0.80	0.80	0.82	0.79	0.017	0.001	0.56	0.39
DM gain:feed[f]	0.81	0.82	0.87	0.88	0.87	0.90	0.018	0.001	0.84	0.39

[a]A total of 360 weanling pigs initially 5.2 ± 1.6 kg and 19 ± 4 d of age. Values represent the mean of six replications/treatment with two adjoining pens (five pig/pen) used as the experimental unit.
[bc]Water-soluble globulin (3%) was offered for 4 or 8 d, respectively.
[de]Medium- and low-complexity diets in Exp. 1 (d 0 to 7) fed from d 0 to 8, respectively.
[f]Calculated by dividing ADG by the DM intake of both feed and liquid.

(P > 0.10) liquid disappearance, which was greater (P < 0.01) than that of pigs provided water. On d 7 and 8 after weaning, pigs offered water-soluble globulin for 8 d after weaning had increased (P < 0.02) liquid disappearance compared with those offered water-soluble globulin for 4 d after weaning and compared with pigs provided water for 8 d after weaning.

From d 0 to 4 after weaning, no water-soluble globulin × diet complexity interactions (P > 0.10) were observed (Table 6). However, pigs provided water-soluble globulin (4 or 8 d) had similar (P > 0.10) ADG, DM ADFI, G/F, and DM G/F, which were greater (P < 0.001) than those of pigs offered water. Diet complexity did not affect (P > 0.10) performance from d 0 to 4 after weaning.

From d 4 to 8, trends (P < 0.08) for water-soluble globulin × diet complexity interactions were observed for G/F and DM G/F. For pigs provided water or water-soluble globulin for 8 d, diet complexity did not affect (P > 0.10) G/F or DM G/F. However, among pigs offered water-soluble globulin for 4 d after weaning, those fed the medium-complexity diet had improved (P < 0.002) G/F and DM G/F compared with those fed the low-complexity diet. No other water-soluble globulin × diet complexity interactions (P > 0.10) were observed. Pigs offered water-soluble globulin for 4 or 8 d after weaning had similar (P > 0.10) ADG, which was lower (P < 0.03) than that of pigs offered water from d 0 to 8. Pigs fed the medium-complexity diet had increased (P < 0.01) ADG compared with pigs fed the low-complexity diet. Average daily feed intake was not affected (P > 0.10) by water-soluble globulin or diet complexity.

From d 0 to 8 after weaning, pigs offered water-soluble globulin for 8 d after weaning had improved (P < 0.003) G/F compared with pigs offered water, whereas pigs offered water-soluble globulin for 4 d after weaning had intermediate G/F. However, pigs offered water had improved ($P < 0.04$) DM G/F compared with pigs offered water-soluble globulin for 4 or 8 d after weaning. Pigs fed the medium-complexity diet had increased ($P < 0.007$) ADG, G/F, and DM G/F compared with pigs fed the low-complexity diet. Average daily feed intake was not affected ($P > 0.10$) by water-soluble globulin or diet complexity, but those pigs offered water-soluble globulin tended to have greater ($P < 0.06$) DM ADFI than those offered water.

From d 8 to 12 after weaning, pigs offered water from d 0 to 8 had greater ($P < 0.001$) ADG than pigs offered water-soluble globulin for 8 d after weaning, whereas pigs offered water-soluble globulin for 4 d after weaning had intermediate ADG. Pigs offered water also had greater ($P < 0.004$) ADFI compared with pigs provided water-soluble globulin for 4 d after weaning, which in turn had greater ($P < 0.01$) ADFI than pigs offered water-soluble globulin for 8 d after weaning.

From d 12 to 21 and d 0 to 21 after weaning, ADG was not affected ($P > 0.10$) by water-soluble globulin or diet complexity. However, pigs offered water had greater ($P < 0.003$) ADFI than pigs offered water-soluble globulin for 8 d, and had numerically greater ($P > 0.07$) ADFI than pigs offered water-soluble globulin for 4 d. This resulted in pigs offered water-soluble globulin for 4 or 8 d after weaning having improved ($P < 0.006$) G/F and DM G/F compared with pigs offered water.

Discussion

Spray-dried animal plasma has been shown to consistently improve growth performance of early-weaned pigs (Gatnau and Zimmerman, 1990; Hansen et al., 1993; Kats et al., 1994). Some studies that evaluated the mode of action have concluded that the factors responsible for this improved performance are in the globulin fraction of spray-dried animal plasma (Owen et al., 1995; Pierce et al., 1995; Weaver et al., 1995). Based on this concept, the further refined plasma product water-soluble globulin has been introduced. This refinement, as well as the addition of some other ingredients, helps prevent clotting when mixed with water.

The 27 and 35% improvements in ADG and G/F (d 0 to 7 after weaning) observed in Exp. 1 agree with the results of Borg et al. (1999b). They found improvements of 65, 33, and 27% for ADG, ADFI, and G/F, respectively, when pigs were offered water-soluble globulin compared with those provided water (d 0 to 7 after weaning). However, unlike the results of Borg et al. (1999b), we did not observe improvements in d 0 to 7 ADFI, and d 0 to 14 ADFI decreased when water-soluble globulin was offered to weanling pigs in our study. Miller and Toplis (2001) observed that pigs provided animal plasma in the feed, water, or both had greater ADG and G/F the first week after weaning. However, there was no added benefit to providing animal plasma in both the water and feed. Recently, Ward and Cook (2000) observed improved ADG, G/F, and fewer pigs removed from the test when water-soluble globulin was offered for 8 d after weaning. In that study, the weight advantage from providing water-soluble globulin from d 0 to 8 after weaning was maintained throughout the 45-d study.

Although the 16% improvement in G/F we observed from d 0 to 14 agrees with the improvement in G/F (7.3%, d 0 to 18 after weaning) reported in a second trial by Borg (1999a), we did not observe a continued improvement in ADG (d 0 to 14) when pigs were offered water-soluble globulin for 2 wk after weaning. Borg (1999a) reported an 8.8% increase in ADG from d 0 to 18 after weaning for pigs that received water-soluble globulin. The decreased ADFI (d 0 to 14) we observed for pigs offered water-soluble globulin may be responsible for the lack of an ADG response, despite increased efficiency. Although Borg et al. (1999a) used an equivalent amount of globulin, it was in a more concentrated form and, therefore, was proportioned at only 0.9% through the drinking water compared with the 3 and 1.5% in our study.

Water-soluble globulin supplementation in Exp. 1 seemed to affect performance only during the initial 2 wk after weaning. Although water-soluble globulin did not affect overall performance (d 0 to 35 after weaning) in Exp. 1, it decreased overall (d 0 to 21) ADFI and improved G/F in Exp. 2. These results may be explained by examining previous research conducted with spray-dried animal plasma.

Feeding high levels of spray-dried animal plasma for prolonged periods after weaning (i.e., 14 d) has been shown to decrease subsequent performance when it is removed from the diet. Kats et al. (1994) reported that increasing the amount of spray-dried animal plasma (0 to 10%) in the diet fed from d 0 to 14 resulted in a linear reduction in ADG from d 14 to 28 after weaning. Hansen et al. (1993) observed that pigs fed diets containing 10.35% spray-dried animal plasma from d 0 to 14 had the greatest ADG during wk 1 and 2, but the poorest ADG during wk 3 and 4 when spray-dried animal plasma was removed from the diet on d 14. The decrease in ADFI for pigs offered water-soluble globulin observed in Exp. 1, in conjunction with the decreases in ADG from d 4 to 8 and d 8 to 12 observed for pigs offered water-soluble globulin for 4 and 8 d, respectively, in Exp. 2, agree with the results found in those previous studies. Miller and Toplis (2001) observed that pigs previously fed animal plasma in the feed and water had decreased ADG in the third week of the trial when all pigs were fed the same diet compared with those previously fed animal plasma only in the feed.

In Exp. 1, increasing diet complexity from low to medium or high resulted in improved growth performance throughout the study. Although water-soluble globulin improved ADG and G/F for pigs fed the medium- or low-complexity regimens (d 0 to 7), it did not affect the performance of pigs fed the high-complexity regimens during the first week after weaning. This implies that pigs fed the high-complexity regimen had adequate spray-dried animal plasma intake without water-soluble globulin, whereas pigs fed the medium- and low-complexity diets did not and benefited from receiving water-soluble globulin. Therefore, water-soluble globulin provided through the water may be a substitute for spray-dried animal plasma in the diet. The water-soluble globulin increased d 0 to 7 ADG of pigs fed the medium- and low-complexity regimens to values similar to those of pigs fed the high- and medium-complexity regimens and offered water. Therefore, our results may be comparable to the responses of pigs fed increasing levels of spray-dried animal plasma in other studies (Gatnau and Zimmerman, 1992; Kats et al., 1994). Results from Exp. 1 indicate that providing water-soluble globulin in the drinking water may allow for the use of a less complex diet; however, this was not confirmed by results of Exp. 2.

Using highly complex diets, researchers have observed improvements in ADG and ADFI after weaning (Himmelberg et al., 1985; Dritz et al., 1996). However, such diets contain expensive protein sources, which increase the cost per unit of gain. Dritz et al. (1996) used high-, medium-, and low-complexity diets fed in different sequences and for different amounts of time after weaning to study the optimal dietary sequence for early-weaned pigs. They reported that increasing diet complexity improved performance immediately after weaning; however, when pigs reached 7.0 kg, feeding a low-complexity regimen resulted in similar performance as feeding a high-complexity regimen and decreased the cost per unit of gain.

Therefore, diet complexity is important to facilitate eating after weaning, but the need for a highly complex diet decreases rapidly as the pig becomes heavier. The level of complexity and feeding duration are dependent upon weaning age and management skill, but should be as simple as possible for increased economic return without sacrificing growth performance (Dritz et al., 1996). This implies that the amount of time for which a high-complexity diet is fed, or water-soluble globulin is offered, must be monitored closely to maximize ADG and decrease cost per unit of gain.

Water-soluble globulin, when offered to weanling pigs via the water source, affected performance in a manner similar to spray-dried animal plasma. As observed with spray-dried animal plasma, water-soluble globulin concentrations and duration had dramatic effects on the growth performance of the weanling pig immediately after weaning. However, water-soluble globulin may provide nutrients to weanling pigs during the period immediately after weaning before they begin eating solid food, which offers an advantage over conventional protein sources.

Implications

These results support previous research demonstrating that increasing diet complexity improves growth performance in the early-weaned pig. Additionally, supplementing weanling pigs with water-soluble globulin through the water source also improves daily gain and feed efficiency immediately after weaning.

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