Comparison of wheat gluten and spray-dried animal plasma in diets for nursery pigs[1,2]

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ABSTRACT: Five experiments were conducted to determine the effects of different wheat gluten (WG) sources (Source 1 = enzymatically hydrolyzed, Source 2 = nonmodified ring-dried, Source 3 = spray-dried, and Source 4 = flash-dried) on growth performance of nursery pigs compared with soybean meal (SBM), spray-dried animal plasma (SDAP), or other specialty protein sources. In Exp. 1, pigs (n = 220, initially 6.1 ± 2.5 kg) were fed a control diet containing (as-fed basis) 6% SDAP or WG Source 1 or 2. The WG and L-lysine·HCl replaced 50 or 100% of the SDAP. From d 0 to 21, increasing WG (either source) decreased ADG and ADFI (linear, $P < 0.01$), but improved (linear, $P < 0.02$) G:F. In Exp. 2, pigs (n = 252, initially 6.2 ± 3.0 kg) were fed a negative control diet containing no SDAP or WG, diets containing (as-fed basis) 9% WG Source 1 or 5% SDAP, or combinations of WG and SDAP where WG and L-lysine·HCl replaced 25, 50, or 75% of SDAP. From d 0 to 14, pigs fed increasing WG had decreased ADG (linear, $P < 0.05$). In Exp. 3, pigs (n = 240, initially 7.0 ± 2.5 kg) were fed a negative control diet, a diet containing (as-fed basis) either 3, 6, 9, or 12% WG Source 3, or a positive control diet containing 5% SDAP. The diets containing 9% WG and 5% SDAP had the same amount of SBM. From d 0 to 7, pigs fed 5% SDAP had greater ($P < 0.04$) ADG than pigs fed the diet containing 9% WG. From d 0 to 14, increasing WG had no effect on ADG, ADFI, or G:F. In Exp. 4, pigs (n = 200, initially 6.0 ± 2.4 kg) were fed a negative control diet, the control diet with (as-fed basis) 4.5 or 9.0% WG Source 1, or the control diet with 2.5 or 5.0% SDAP. Diets containing WG and SDAP had similar SBM levels. From d 0 to 7 and 0 to 14, increasing SDAP tended to improve (linear, $P < 0.06$) ADG, but increasing WG had no effect. In Exp. 5, 170 barrows and gilts (initially 7.5 ± 2.8 kg) were used to determine the effects of WG Source 1 and 4 compared with select Menhaden fish meal or spray-dried blood cells and a negative control diet (SBM) on the growth performance of nursery pigs from d 5 to 26 postweaning (d 0 to 21 of experiment). No differences were found in ADG or G:F, but pigs fed the diet containing (as-fed basis) 2.5% spray-dried blood cells had greater ADFI than pigs fed the negative control from d 0 to 21. Wheat gluten source had no effect on ADG, ADFI, or G:F. The results of these studies suggest that increasing WG in diets fed immediately after weaning did not improve growth performance relative to SBM or SDAP.

Key Words: Pigs, Plasma Protein, Soybean Oilmeal, Wheat Gluten

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Introduction

Spray-dried animal plasma (**SDAP**) stimulates feed intake and improves performance of nursery pigs when substituted immediately after weaning for a number of commonly used ingredients. These include dried skim milk (**DSM**; Hansen et al., 1993; Kats et al., 1994; de Rodas et al., 1995), soybean meal (**SBM**; Fakler et al., 1993, Coffey and Cromwell, 1995; de Rodas et al., 1995), dried whey (Hansen et al., 1993), or spray-dried blood meal (Hansen et al., 1993; de Rodas et al., 1995). Wheat gluten (**WG**) is a protein (80%), lipid (8%), carbohydrate (12%) complex (Hoseney, 1986) prepared by removing starch from wheat flour and drying the remaining high-protein gluten. Wheat gluten is relatively high in CP, of which a major constituent is glycine (approximately 12.5% of CP), but it is also relatively low in lysine, threonine, and tryptophan. Richert et al. (1994) ob-

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Table 1. Chemical analyses of specialty protein sources (as-fed basis)

	Exp. 1		Exp. 2			Exp. 3	Exp. 4	Exp. 5	
Item, %	WG Source 1[ab]	WG Source 2[b]	WG Source 1[b]	Dried whey[c]	SDAP[c]	WG Source 3[b]	WG Source 1[b]	WG Source 1[b]	WG Source 4[b]
CP	70.68 (80.09)	68.11 (80.09)	73.58 (80.09)	10.81 (12.10)	76.44 (78.00)	73.06 (76.00)	66.78 (80.09)	70.68 (80.09)	72.20 (75.16)
Amino acid									
Arganine	2.55 (2.75)	2.41 (2.75)	2.52 (2.75)	0.27 (0.26)	4.21 (4.55)	2.69 (2.99)	2.44 (2.75)	2.55 (2.75)	2.62 (2.63)
Cystine	*	*	*	* (0.25)	* (2.63)	* (1.17)	*	*	* (1.50)
Histidine	1.54 (1.48)	1.48 (1.48)	1.62 (1.48)	0.22 (0.23)	2.34 (2.55)	1.59 (1.66)	1.45 (1.48)	1.54 (1.48)	1.55 (1.71)
Isoleucine	2.59 (2.84)	2.51 (2.84)	2.81 (2.84)	0.65 (0.62)	2.27 (2.71)	2.75 (2.88)	2.42 (2.84)	2.59 (2.84)	2.59 (2.33)
Leucine	5.03 (5.48)	4.73 (5.48)	5.20 (5.48)	1.12 (1.08)	7.05 (7.61)	5.16 (5.14)	4.76 (5.48)	5.03 (5.48)	5.02 (5.33)
Lysine	1.14 (1.32)	1.06 (1.32)	1.14 (1.32)	0.89 (0.90)	6.87 (6.84)	1.34 (1.46)	1.11 (1.32)	1.14 (1.32)	1.27 (1.30)
Methionine	1.15 (162)	1.06 (1.62)	1.13 (1.62)	0.17 (0.17)	0.87 (0.75)	1.20 (1.11)	1.08 (1.62)	1.15 (1.62)	1.14 (1.19)
Phenylalanine	3.86 (4.80)	3.67 (4.80)	4.05 (4.80)	0.35 (0.36)	3.91 (4.42)	3.85 (3.81)	3.62 (4.80)	3.86 (4.80)	3.82 (4.31)
Threonine	2.89 (2.14)	2.62 (2.14)	1.79 (2.14)	0.71 (0.72)	4.66 (4.72)	3.02 (2.44)	1.77 (2.14)	2.89 (2.14)	3.07 (2.31)
Tryptophan	0.83 (0.64)	0.87 (0.64)	0.88 (0.64)	0.24 (0.18)	1.61 (1.36)	0.95 (0.56)	0.89 (0.64)	0.83 (0.64)	0.86 (0.57)
Tyrosine	2.39 (2.81)	2.28 (2.81)	2.52 (2.81)	0.26 (0.25)	3.73 (3.53)	2.55 (3.87)	2.24 (2.81)	2.39 (2.81)	2.52 (2.41)
Valine	2.90 (3.13)	2.73 (3.13)	3.04 (3.13)	0.61 (0.60)	5.09 (4.94)	3.05 (3.08)	2.74 (3.13)	2.90 (3.13)	2.88 (2.76)

[a]Wheat gluten (WG) sources were: 1 = enzymatically hydrolyzed; 2 = nonmodified ring-dried; 3 = spray-dried; and 4 = flash-dried.
[b]Values in parentheses were provided by the wheat gluten suppliers and used in diet formulation.
[c]Spray-dried animal plasma (SDAP) and dried whey values in parentheses were provided by NRC (1998) and used in diet formulation.
*Not analyzed.

Table 2. Diet composition (Exp. 1)[a]

	Wheat gluten:spray-dried animal plasma ratio		
Ingredient, %	0:100	50:50	100:0
Corn	47.02	46.67	46.36
Soybean meal, 46.5% CP	19.21	19.21	19.21
Spray-dried whey	15.00	15.00	15.00
Spray-dried animal plasma	6.00	3.00	—
Wheat gluten Source 1 and 2	—	3.00	6.00
Soybean oil	5.00	5.00	5.00
Select Menhaden fish meal	3.00	3.00	3.00
Limestone	1.30	1.18	1.08
Monocalcium phosphate, 21% P	1.08	1.30	1.50
Medication[b]	1.00	1.00	1.00
Zinc oxide[c]	0.35	0.35	0.35
Salt	0.30	0.30	0.30
Vitamin premix[d]	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.34	0.51
Trace mineral premix[e]	0.15	0.15	0.15
DL-Methionine	0.15	0.13	0.10
Threonine	0.04	0.10	0.15
Tryptophan	—	0.02	0.04
Calculated analyses			
Apparent digestible lysine, %	1.28	1.28	1.28
Total lysine, %	1.51	1.49	1.46
Ile:Lys ratio, %	57	58	59
Met Cys:Lys ratio, %	61	60	60
Thr:Lys ratio, %	66	66	65
Trp:Lys ratio, %	19	19	19
Val:Lys ratio, %	73	70	67
ME, kcal/kg	3,476	3,422	408
CP, %	21.30	21.30	21.40
Ca, %	1.05	1.04	1.04
P, %	0.79	0.79	0.78
Available P, %	0.56	0.56	0.56
Lysine:calorie ratio, g/Mcal	4.35	4.36	4.35

[a]Diets fed from d 0 to 21. Values calculated on an as-fed basis. Wheat gluten was fed from two different sources, comprising four of the five experimental treatments, consisting of enzymatically hydrolyzed (Source 1) and nonmodified ring-dried (Source 2) wheat gluten.
[b]Provided 55 mg of carbadox/kg of complete diet.
[c]Provided 2,523 mg Zn/kg of complete diet.
[d]Provided (per kilogram of complete diet): 11, 025 IU of vitamin A; 1,654 IU of vitamin D3; 44 IU of vitamin E; 4.4 mg of vitamin K (menadione sodium bisulfite); 55.1 mg of niacin; 33.1 kg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; and 0.044 mg of B_{12}.
[e]Provided (per kilogram of complete diet): 39.7 mg of Mn (oxide); 165.4 mg of Fe (sulfate); 165 mg of Zn (oxide); 16.5 mg of Cu (sulfate); 0.30 mg of I (as Ca iodate); and 0.30 mg of Se (as Na selenite).

served that spray-dried WG substituted for DSM and soybean products in nursery diets maintained or improved ADG and ADFI better than other WG products (flash-dried WG and solubilized-modified WG). The WG–SBM-based diet supported the best overall ADG and ADFI compared with diets that were DSM–SBM based or DSM-WG based. Burnham et al. (1995) determined the nutritional value of WG and spray-dried porcine plasma (**SDPP**) blends for diets in weanling pigs, and found when replacing SDPP with WG, no differences in growth from d 0 to 14 postweaning.

Diet formulation, weaning age, and other management aspects have changed since many of the first WG evaluation studies were conducted. Therefore, the objective of our experiments was to compare growth performance of nursery pigs fed different sources of WG replacing traditional protein sources such as SDAP, select menhaden fish meal, and spray-dried blood cells.

Materials and Methods

General

The Kansas State University Institutional Animal Care and Use Committee approved all experimental protocols used in this study.

Pigs (Line 327 sire × Line 42, Exp. 1, 2, 3, and 5; Line 42, Exp. 4, PIC, Franklin, KY) were housed in environmentally controlled nurseries. Each pen (Exp. 1, 2, 3, and 5 = 1.8 m^2; Exp. 4 = 1.44 m^2) had slatted metal flooring and contained a stainless steel self-feeder and one nipple waterer to allow ad libitum consumption of feed and water. Room temperature was initially 32°C then lowered approximately 1.5°C weekly.

Experimental diets were fed for 21 d postweaning in Exp. 1, and for 14 d postweaning in Exp. 2, 3, and 4. Diets were pelleted in Exp. 1, 2, 3, and 4, and fed in meal form in Exp. 5. In Exp. 5, pigs were fed a complex diet from d 0 to 5 postweaning and experimental diets from d 5 to 26 postweaning. All diets were formulated to meet or exceed the nutrient requirement estimates of pigs suggested by the NRC (1998). Ingredient nutrient compositions provided by the NRC (1998) were used in diet formulation, unless provided by the ingredient supplier. In all experiments, pigs were weighed and allotted to treatments at weaning (Exp. 1, 2, 3, and 4) or d 5 postweaning (Exp. 5). Average daily gain, ADFI, and G:F were determined by weighing pigs and measuring feed disappearance every 7 d for each experiment. Samples of the WG were collected and analyzed for individual AA (University of Missouri-Columbia Agric. Exp. Stn. Chemical Laboratories, Columbia, MO; Table 1). In Exp. 2, samples of spray-dried whey (Land O' Lakes, Inc., Arden Hills, MN) and SDAP (APC, Inc.; Ames, IA) were collected and analyzed for individual AA (Table 1).

Experiment 1

One hundred ten barrows and 110 gilts (initially 6.1 ± 2.5 kg and 21 ± 3 d of age at weaning) were used in a 35-d growth assay to determine the effects of substituting enzymatically hydrolyzed and nonmodified ring-dried WG for SDAP. Pigs were blocked by initial weight and allotted randomly to one of five dietary treatments. Each treatment had eight replications (pens). Four of those eight replications contained six pigs/pen, and the other four replications contained five pigs per pen for a total of 220 pigs.

Pigs were fed experimental diets from d 0 to 21 postweaning. Treatments included a control diet containing 6% of either SDAP, enzymatically hydrolyzed WG (Source 1) or nonmodified ring-dried WG (Source 2) and the WG and L-lysine·HCl replaced 50 or 100% of the SDAP (Table 2). Wheat gluten and L-lysine·HCl replaced SDAP on an apparent ileal digestible lysine basis. Apparent ileal digestibility coefficients in wheat gluten were as follows: lysine and threonine, 96%; tryptophan, 97%; methionine, cystine, and valine, 98%; isoleucine and leucine, 99%. The AA digestibility coefficients were provided by the ingredient manufacturer, whereas NRC (1998) values were used for other ingredients. Pigs were fed the same common diet from d 21 to 35 postweaning (Table 3).

Table 3. Composition of common diets (as-fed basis)[a]

	Exp.		
	5	1, 2, 3, and 4	5
Ingredient, %	Phase I	Phase II	Phase III
Corn	32.37	50.04	60.80
Soybean meal, 46.5% CP	12.80	27.20	32.25
Spray-dried whey	25.00	10.00	—
Spray-dried animal plasma	6.70	—	—
Select Menhaden fish meal	6.00	5.00	—
Choice white grease	6.00	—	—
Lactose	6.00	—	—
Soybean oil	—	4.00	3.00
Spray-dried blood meal	1.65	—	—
Medication[b]	1.00	1.00	0.50
Monocalcium phosphate, 21% P	0.75	0.98	1.45
Limestone	0.45	0.65	1.05
Zinc oxide[c]	0.38	0.25	—
Vitamin premix[d]	0.25	0.25	0.25
Salt	0.20	0.25	0.35
Trace mineral premix[d]	0.15	0.15	0.15
L-Lysine·HCl	0.15	0.15	0.15
DL-Methionine	0.15	0.08	0.05
Calculated analyses			
Lysine, %	1.70	1.40	1.25
Met:lys ratio, %	30	32	30
Met Cys:Lys ratio, %	57	57	58
Thr:Lys ratio, %	65	61	62
Trp:Lys ratio, %	18	18	20
ME, kcal/kg	3,524	3,447	3,418
CP, %	22.4	21.3	20.2
Ca, %	0.90	0.87	0.80
P, %	0.80	0.76	0.70
Available P, %	0.66	0.48	0.38

[a]In Exp. 1, treatment diets were fed from d 0 to 21, then the Phase II diet from d 21 to 35. In Exp. 2 and 3, treatment diets were fed from d 0 to 14, then Phase II from d 14 to 28. In Exp. 4, treatment diets were fed from d 0 to 14, then Phase II from 14 to 35. In Exp. 5, 0.20 kg of Phase I was fed per pig from d 0 to 5 after weaning, experimental diets were fed from d 5 to 26 after weaning, and a common Phase III diet 26 to 40 postweaning.

[b]Phase I and II diets provided 55 mg of carbadox/kg of complete diet, and the Phase III diet provided 27.5 mg of carbadox/kg of complete diet.

[c]Provided 2,742 and 1,804 mg of Zn/kg of complete diet.

[d]See Table 2.

Experiment 2

One hundred twenty-six barrows and 126 gilts (initially 6.2 ± 3.0 kg and 21 ± 3 d of age at weaning) were

Table 4. Diet composition (Exp. 2)[a]

	Wheat gluten:spray-dried animal plasma ratio					
Ingredient, %	0:0	100:0	75:25	50:50	25:75	0:100
Corn	34.98	38.47	39.57	40.70	41.80	42.93
Soybean meal, 46.5% CP	36.71	24.79	24.79	24.79	24.79	24.79
Spray-dried whey	20.00	20.00	20.00	20.00	20.00	20.00
Wheat gluten Source 1	—	9.00	6.75	4.50	2.25	—
Spray-dried animal plasma	—	—	1.25	2.50	3.75	5.00
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.04	1.11	1.02	0.93	0.84	0.75
Medication[b]	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	0.98	1.03	1.07	1.11	1.15	1.19
Zinc oxide[b]	0.35	0.35	0.35	0.35	0.35	0.35
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[b]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine·HCl	0.15	0.45	0.38	0.30	0.23	0.15
Threonine	0.04	0.06	0.05	0.03	0.02	—
DL-Methionine	1.05	0.04	0.07	0.09	0.12	0.14
Calculated analyses						
Total lysine, %	1.50	1.50	1.50	1.50	1.50	1.50
Ile:Lys ratio, %	67	67	65	63	61	60
Met Cys:Lys ratio, %	56	61	61	61	60	60
Thr:Lys ratio, %	64	64	64	64	64	64
Trp:Lys ratio, %	20	19	19	19	19	19
Val:Lys ratio, %	73	74	74	74	73	73
ME, kcal/kg	3,355	3,355	3,364	3,369	3,379	3,384
CP, %	22.50	24.40	23.70	23.00	22.20	21.50
Ca, %	0.85	0.85	0.85	0.85	0.85	0.85
P, %	0.72	0.67	0.67	0.67	0.68	0.68
Available P, %	0.43	0.43	0.43	0.43	0.43	0.43
Lysine:calorie ratio, g/Mcal	4.48	4.48	4.47	4.46	4.45	4.44

[a]Diets were fed from d 0 to 14 postweaning. Values calculated on an as-fed basis. Wheat gluten was enzymatically hydrolyzed.
[b]See Table 2.

used to determine the optimal blend of WG and SDAP on growth performance of weanling pigs. Pigs were blocked by initial weight and allotted randomly to one of six dietary treatments. Each treatment had seven replications (pens), with six pigs per pen.

Pigs were fed experimental diets (Table 4) from d 0 to 14 postweaning. Diets included a negative control containing no SDAP or WG, diets containing 9% WG Source 1 or 5% SDAP, or combinations of WG and SDAP where WG and L-lysine·HCl replaced 25, 50, or 75% of SDAP. A common diet was fed from d 14 to 28 after weaning (Table 3).

Experiment 3

One hundred twenty barrows and 120 gilts (initially 7.0 ± 2.5 kg and 21 ± 3 d of age at weaning) were used in a 28-d growth assay to determine the optimal inclusion rate of WG in the diet. Pigs were blocked by initial weight and allotted randomly to one of six dietary treatments. Each treatment had seven replications (pens), with five replications consisting of six pigs per pen and two replications consisting of five pigs per pen.

Pigs were fed experimental diets from d 0 to 14 postweaning (Table 5), which included a negative control diet with no spray-dried WG or SDAP, or the control diet with 3, 6, 9, and 12% spray-dried WG (Source 3) substituted with SBM, and a positive control, containing 5% SDAP. Wheat gluten Source 3 was from a different manufacturer than WG Sources 1 and 2 in Exp. 1 and 2. Pigs were fed the same Phase II common diet from d 14 to 28 postweaning (Table 3).

Experiment 4

One hundred barrows and 100 gilts (initially 6.0 ± 2.4 kg and 21 ± 3 d of age at weaning) were used to compare the optimal inclusion rate of WG using enzymatically hydrolyzed WG on the same protein basis with SDAP. Pigs were blocked by weight and allotted randomly to one of five dietary treatments. Each treatment had eight replications (pens) per treatment, with five pigs per pen.

Pigs were fed experimental diets from d 0 to 14 postweaning (Table 6). These included a negative control diet containing no WG or SDAP, or diets containing 4.5 and 9% enzymatically hydrolyzed WG (Source 1), or 2.5 and 5% SDAP. The diets containing 4.5 and 9% WG were replaced with 2.5 and 5% SDAP, respectively, and L-lysine·HCl on an equal lysine basis. Pigs were fed the same common diet from d 14 to 35 postweaning (Table 3).

Table 5. Diet composition (Exp. 3)[a]

Ingredient, %	Wheat gluten, % 0	3	6	9	12	5% SDAP
Corn	36.06	36.74	37.42	38.12	38.82	42.51
Soybean meal, 46.5% CP	36.70	32.92	29.13	25.34	21.55	25.34
Spray-dried whey	20.00	20.00	20.00	20.00	20.00	20.00
Wheat gluten Source 3	—	3.00	6.00	9.00	12.00	—
Spray-dried animal plasma	—	—	—	—	—	5.00
L-Lysine·HCl	0.15	0.24	0.33	0.41	0.50	0.13
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.05	1.06	1.08	1.09	1.10	0.75
Medication[b]	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	0.85	0.86	0.88	0.89	0.90	1.08
Zinc oxide[b]	0.35	0.35	0.35	0.35	0.35	0.35
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[b]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15	0.15
Threonine	0.04	0.04	0.04	0.04	0.04	0.04
DL-Methionine	0.10	0.09	0.07	0.06	0.04	0.10
Calculated analyses						
Total lysine, %	1.50	1.50	1.50	1.50	1.50	1.50
Ile:Lys ratio, %	67	67	67	68	68	60
Met Cys:Lys ratio, %	55	56	56	56	56	58
Thr:Lys ratio, %	64	65	65	65	66	67
Trp:Lys ratio, %	20	19	19	18	18	20
Val:Lys ratio, %	73	73	74	75	75	74
ME, kcal/kg	3,360	3,360	3,360	3,360	3,365	3,389
CP, %	22.6	23.3	24.1	24.8	25.6	21.7
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.72	0.71	0.69	0.68	0.67	0.68
Available P, %	0.43	0.43	0.43	0.43	0.43	0.43
Lysine:calorie ratio, g/Mcal	4.48	4.48	4.47	4.47	4.47	4.44

[a]Diets fed from d 0 to 14 postweaning. Values were calculated on an as-fed basis. The wheat gluten source was spray-dried; SDAP = spray-dried animal plasma.

[b]See Table 2.

Experiment 5

Eighty-five barrows and 85 gilts (21 ± 3 d of age at weaning) were used in a 35-d growth assay to determine the effects of two WG sources processed by different methods and compared with spray-dried whey, spray-dried blood cells, and select menhaden fish meal. Pigs were blocked by weight and allotted randomly to one of five dietary treatments on d 5 postweaning. Each treatment had six replications (pens). Four replications consisted of six pigs per pen, and two replications consisted of five pigs per pen, for a total of 170 pigs.

Pigs (7.5 kg to 15.6 kg) were fed experimental diets from d 5 to 26 (d 0 to 21 of the experiment) postweaning (Table 7). Diets included a control containing 10% dried whey with either 4.48% select menhaden fish meal, 2.5% spray-dried blood cells, 3.72% enzymatically hydrolyzed WG (Source 1) or 3.54% flash-dried WG (Source 4). Protein sources replaced SBM in the control diet such that all diets containing the test protein contained the same quantity of soybean meal. Pigs were fed the same common diet (Table 3) from d 26 to 40 postweaning (d 21 to 35 of the experiment).

Statistical Analyses

Data from each experiment were analyzed as a randomized complete block design, with pen as the experimental unit. Pigs were blocked based on weight in all experiments and analysis of variance was performed using the Mixed procedure of SAS (SAS Inst., Inc., Cary, NC). Contrasts were used to determine the effect of WG in diets compared with the diets with no WG. Linear and quadratic polynomial contrasts were used to determine the effects of increasing WG (Exp. 1, 2, 3, and 4). In addition, single degree of freedom contrasts were used to determine the effect of WG source (Exp. 1 and 5) and other specialty protein sources (Exp. 5).

Results

Experiment 1

There were no differences between WG Sources 1 and 2 for any response criteria. For the overall treatment period, d 0 to 21, both ADG and ADFI decreased (Source 1 and 2 linear, $P < 0.01$), but G:F improved (Source 1 linear, $P < 0.02$; Source 2 linear, $P < 0.01$) with increasing WG (Table 8). From d 21 to 35, there were no differences in ADG, ADFI, or G:F. Overall (d 0 to 35), pigs fed 6% SDAP had the greatest ADG and ADFI. There was a decrease (linear, $P < 0.01$) in ADG and ADFI with increasing either WG source; however, pigs fed either WG source had improved (linear, $P < 0.01$) G:F.

Table 6. Diet composition (Exp. 4)[a]

	Wheat gluten, %			Spray-dried animal plasma, %	
Ingredient %	0	4.5	9.0	2.5	5.0
Corn	35.58	36.88	38.46	39.43	42.93
Soybean meal, 46.5% CP	36.71	30.74	24.79	30.74	24.79
Spray-dried whey	20.00	20.00	20.00	20.00	20.00
Wheat gluten Source 1	—	4.50	9.00	—	—
Spray-dried animal plasma	—	—	—	2.50	5.00
Soybean oil	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.04	1.07	1.11	0.89	0.75
Medication[b]	1.00	1.00	1.00	1.00	1.00
Limestone	0.98	1.00	1.03	1.09	1.19
Salt	0.30	0.30	0.30	0.30	0.30
Threonine	0.38	0.38	0.06	0.02	—
Zinc oxide[b]	0.35	0.35	0.35	0.35	0.35
Vitamin premix[b]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15
L-Lysine·HCl	0.15	0.30	0.45	0.15	0.15
DL-Methionine	0.11	0.08	0.05	0.13	0.14
Calculated analyses					
Total lysine, %	1.50	1.50	1.50	1.50	1.50
Ile:Lys ratio, %	67	67	67	63	60
Met Cys:Lys ratio, %	56	59	62	58	59
Thr:Lys ratio, %	64	64	64	64	64
Trp:Lys ratio, %	20	19	19	20	19
Val:Lys ratio, %	73	74	74	73	73
CP, %	22.50	23.50	24.40	22.00	21.50
Ca, %	0.85	0.85	0.85	0.85	0.85
P, %	0.72	0.69	0.67	0.70	0.68
Available P, %	0.43	0.43	0.43	0.43	0.43
Lysine:calorie ratio, % g/Mcal	4.48	4.48	4.48	4.46	4.44

[a]Diets fed from d 0 to 14. Values calculated on an as-fed basis. Wheat gluten used in this experiment was enzymatically hydrolyzed.
[b]See Table 2.

Experiment 2

From d 0 to 14, pigs fed the diet containing 5% SDAP had the greatest ADG with a decrease (linear, $P < 0.05$) in ADG as WG concentration increased (Table 9). For the common period, d 14 to 28, there were no differences in growth performance due to the dietary treatment fed from d 0 to 14 after weaning. The overall results (d 0 to 28) showed no differences in ADG or ADFI, but pigs fed increasing WG from d 0 to 14 had greater G:F (linear, $P < 0.03$).

Experiment 3

From d 0 to 7, pigs fed the diet containing 5% SDAP had greater ADG ($P < 0.04$) than pigs fed the diet containing 9% WG (230 vs. 170 g/d, respectively). Neither ADFI nor G:F were different ($P > 0.14$ and $P < 0.98$) for this 7-d period (data not shown). From d 0 to 14, replacing SBM with increasing levels of WG Source 3 had no affect on ADG, ADFI, or G:F (Table 10). For the common period, d 14 to 28, there were no differences in ADG, ADFI, or G:F among pigs fed either protein source from d 0 to 14. Overall (d 0 to 28), no differences were observed for ADG, ADFI, or G:F.

Experiment 4

Average daily gain increased (linear, $P < 0.04$) from d 0 to 7 with increasing SDAP (122, 163, and 176 g/d for control 2.5 and 5.0% SDAP, respectively). There were no differences observed during this period ($P > 0.16$ and $P < 0.97$) in ADFI or G:F (data not shown). From d 0 to 14, increasing SDAP numerically ($P < 0.06$) increased ADG, but increasing WG did not (Table 11). Pigs fed the diet containing 5% SDAP had greater ($P < 0.04$) ADG and ADFI than those fed 9% WG (diets containing the same amount of soybean meal). From d 14 to 35 and from d 0 to 35, there were no differences in pig performance.

Experiment 5

For the overall treatment period from d 0 to 21, pigs fed the diets containing either 2.5% spray-dried blood cells or 5% select menhaden fish meal had numerically ($P = 0.34$) greater ADG than pigs fed the control diet, with pigs fed either WG source having intermediate ADG (Table 12). Pigs fed the diet containing 2.5% spray-dried blood cells had greater ADFI ($P < 0.05$) than pigs fed the control diet. No differences were found in G:F. From d 21 to 35, when pigs were fed a common diet,

Table 7. Diet composition (Exp. 5)[a]

Ingredient, %	Control	Select Menhaden fish meal	Spray-dried blood cells	Wheat gluten Source 1	Wheat gluten Source 4
Corn	47.18	51.00	51.96	50.58	50.73
Soybean meal, 46.5% CP	35.06	27.60	27.60	27.60	27.60
Spray-dried whey	10.00	10.00	10.00	10.00	10.00
Fish meal	—	4.48	—	—	—
Spray-dried blood meal	—	—	2.50	—	—
Wheat gluten Source 1	—	—	—	3.72	—
Wheat gluten Source 4	—	—	—	—	3.54
Soybean oil	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.48	1.00	1.60	1.62	1.63
Medication[b]	1.00	1.00	1.00	1.00	1.00
Limestone	0.98	0.65	0.98	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35
Zinc oxide[b]	0.35	0.35	0.35	0.35	0.35
Vitamin premix[b]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15
L-Lysine·HCl	0.10	0.10	0.10	0.31	0.32
DL-Methionine	0.08	0.04	0.10	0.07	0.06
Threonine	0.02	0.03	0.06	0.05	0.07
Calculated analyses					
Total lysine, %	1.35	1.35	1.35	1.35	1.35
Ile:Lys ratio, %	69	66	59	65	65
Met Cys:Lys ratio, %	58	56	56	57	59
Thr:Lys ratio, %	65	65	65	65	65
Trp:Lys ratio, %	20	19	19	18	19
Val:Lys ratio, %	77	76	82	74	74
CP, %	21.5	21.2	20.8	21.2	21.2
Ca, %	0.85	0.85	0.85	0.85	0.85
P, %	0.76	0.75	0.75	0.75	0.76
Available P, %	0.45	0.47	0.48	0.48	0.48

[a]Diets fed from d 0 to 21. Values calculated on an as-fed basis. Wheat gluten Source 1 was enzymatically hydrolyzed, and wheat gluten Source 4 was flash-dried.
[b]See Table 2.

Table 8. Evaluation of two wheat gluten (WG) sources and spray-dried animal plasma (SDAP) in diets for early-wean pigs (Exp. 1)[a]

	Treatment (WG:SDAP ratio)						
	6% SDAP	WG Source 1		WG Source 2			Source
Item	0:100	50:50	100:0	50:50	100:0	SE	1 vs. 2
d 0 to 21[bc]							
ADG, g	413	377	352	394	363	15.3	0.19
ADFI, g	468	419	383	439	392	20.6	0.32
G:F	0.93	0.94	0.96	0.94	0.97	0.02	0.68
d 21 to 35							
ADG, g	549	535	546	550	529	18.6	0.95
ADFI, g	839	794	816	830	794	20.8	0.71
G:F	0.65	0.66	0.67	0.66	0.66	0.02	0.71
d 0 to 35[e]							
ADG, g	467	440	430	457	430	12.0	0.33
ADFI, g	616	569	557	595	553	16.5	0.33
G:F	0.82	0.83	0.85	0.83	0.85	0.01	0.94

[a]A total of 220 weanling pigs (eight pens per treatment with four of those eight consisting of six pigs per pen and the other four consisting of five pigs per pen), with an average initial BW of 6.1 kg, was used. Experimental diets were fed from d 0 to 21 postweaning, and a common Phase II diet was fed from d 21 to 35 after weaning. Wheat gluten was fed from two different sources consisting of enzymatically hydrolyzed (Source 1) and unmodified ring-dried (Source 2) wheat gluten.
[b]Linear effect of Source 1 (ADG and ADFI, $P < 0.01$; G:F, $P < 0.02$).
[c]Linear effect of Source 2, $P < 0.01$.
[d]All ADFI values are as-fed.
[e]Linear effect of Source 1 and 2, $P < 0.01$.

Table 9. Effect of wheat gluten (WG) and spray-dried animal plasma (SDAP) blends on growth performance of nursery pigs (Exp. 2)[a]

	Treatment (WG:SDAP Ratio)						
Item	0:0	0:100	25:75	50:50	75:25	100:0	SE
d 0 to 14							
ADG, g[b]	312	330	318	305	319	294	15.9
ADFI, g	319	341	322	313	327	301	20.3
G:F	0.88	1.01	1.03	1.02	1.05	1.05	0.02
d 14 to 28							
ADG, g	476	469	471	489	471	480	16.0
ADFI, g	667	655	660	682	662	652	20.6
G:F	0.71	0.71	0.71	0.72	0.71	0.74	0.02
d 0 to 28							
ADG, g	394	400	395	397	395	387	11.6
ADFI, g	493	498	491	498	494	476	16.5
G:F[c]	0.88	0.86	0.87	0.87	0.88	0.89	0.01

[a]252 pigs (seven replications, with six pigs per pen), with an average initial BW of 6.2 kg. Dietary treatments were fed from d 0 to 14, and a common Phase II diet was fed from d 14 to 28. No significant effect of 0:0 vs. 0:100 or 100:0. Wheat gluten was enzymatically hydrolyzed (Source 1). All ADFI values are as-fed.
[b]Linear effect, $P < 0.05$.
[c]Linear effect, $P < 0.03$.

there were no differences in growth performance. In addition, no differences among treatments were observed in the overall period (d 0 to 35).

Discussion

Many methods have been investigated for incorporating various protein sources into starter diets, with the goals of improving pig performance and decreasing diet cost. Feeding milk products, such as dried whey and whey protein concentrate (Mahan et al., 1992; Grinstead et al., 2000), and animal products, such as select menhaden fish meal (Stoner et al., 1990; Bergstrom et al., 1997), have resulted improved growth performance by weanling pigs. Several studies have suggested that SDAP is an effective protein source that increases ADG and ADFI when used in diets for pigs from d 0 to 14 after weaning (Hansen et al., 1993; Kats et al., 1994; de Rodas et al., 1995). It is likely that SDAP diets are more palatable to pigs than DSM diets (Ermer et al., 1994). The addition of SDAP in diets has increased feed intake and growth rate when added at the expense of soy protein (Kats et al., 1992), dried skim milk (Hansen et al., 1991; Sohn et al., 1991), or whey protein (Gatnau and Zimmerman, 1991; Richert et al., 1992).

Table 10. Effect of increasing wheat gluten (WG) on growth performance of nursery pigs (Exp. 3)[a,b]

	WG, %					SDAP, %[c]	
Item	0	3	6	9	12	5	SE
d 0 to 14							
ADG, g	319	320	303	302	310	331	21.3
ADFI, g	325	315	306	291	305	333	25.0
G:F	1.07	1.13	1.08	1.12	1.09	1.09	0.03
d 14 to 28							
ADG, g	512	517	478	474	496	494	21.3
ADFI, g	678	705	672	661	675	667	25.0
G:F	0.75	0.71	0.70	0.70	0.73	0.72	0.03
d 0 to 28							
ADG, g	416	419	390	388	403	412	15.0
ADFI, g	502	510	489	476	491	500	19.1
G:F	0.91	0.92	0.89	0.91	0.91	0.91	0.02

[a]240 pigs (five replications with six pigs per pen and two replications with five pigs per pen), with an average initial BW of 7.0 kg. Dietary treatments were fed from d 0 to 14 after weaning, and a common Phase II diet from d 14 to 28 postweaning. Wheat gluten was spray-dried (Source 3). All ADFI values are as-fed.
[b]No significant linear or quadratic effects, $P > 0.11$ to $P < 0.96$.
[c]SDAP = spray-dried animal plasma.

Table 11. Effect of wheat gluten (WG) and spray-dried animal plasma (SDAP) on growth performance of nursery pigs (Exp. 4)[a,b]

	Treatments					
	Control	WG, %		SDAP, %		
Item	0.0	4.5	9.0	2.5	5.0	SE
d 0 to 14[c]						
ADG, g[d]	259	263	248	288	298	20.2
ADFI, g	271	266	254	290	309	25.4
G:F	1.00	1.03	1.03	1.06	1.03	0.03
d 14 to 35						
ADG, g	570	555	561	549	553	17.0
ADFI, g	760	751	771	756	763	22.4
G:F	0.76	0.74	0.74	0.73	0.73	0.02
d 0 to 35						
ADG, g	445	438	436	444	451	13.5
ADFI, g	564	557	565	569	581	18.6
G:F	0.85	0.86	0.85	0.86	0.85	0.02

[a]A total of 200 pigs (eight replications with five pigs per pen), with an initial average BW of 6.0 kg, was used. Dietary treatments were fed from d 0 to 14 after weaning, and a common Phase II diet was fed from d 14 to 35 after weaning. Wheat gluten was enzymatically hydrolyzed (Source 1). All ADFI values are as-fed.

[b]No linear or quadratic effects ($P < 0.05$) of WG (0, 4.5, and 9.0%), or SDAP (0, 2.5, and 5.0%).

[c]Contrast 9% WG vs. 5% SDAP (ADG, $P < 0.02$; ADFI, $P < 0.04$).

[d]Linear trend ($P < 0.06$) of SDAP (0, 2.5, and 5.0%).

However, some studies have suggested that the magnitude of response to specialty protein sources such as SDAP and fish meal may depend on the health status of the pigs and whether the study was conducted in a university research facility or commercial facility (Coffey and Cromwell, 1995; Bergstrom et al., 1997). All of the studies reported herein were conducted in university research facilities. Although no attempt was made to analytically quantify health status, the pigs were relatively healthy and the research herd is porcine reproductive and respiratory syndrome virus-free.

Wheat gluten is highly soluble, has a high protein content, is very digestible, and could serve as an alternative to SDAP (Richert et al., 1994; Burnham et al., 2000). Wheat gluten products have a high glutamine content (30% of AA), which is a key contributor to intestinal energy generation and thought to improve gut health (Reeds et al., 2000).

Table 12. Effect of different protein sources on growth performance of weanling pigs (Exp. 5)[a]

		Protein source				
Item	Control	5% Select menhaden fish meal	2.5% Spray-dried blood cells	WG Source 1	WG Source 4	SE
d 0 to 21						
ADG, g	373	406	403	389	387	16.7
ADFI, g	519[c]	544[bc]	554[b]	527[bc]	527[bc]	16.9
G:F	0.73	0.76	0.75	0.75	0.74	0.02
d 21 to 35						
ADG, g	621	633	643	632	613	21.3
ADFI, g	986	1,010	1,040	1,006	993	23.4
G:F	0.63	0.63	0.62	0.63	0.62	0.02
d 0 to 35						
ADG, g	472	497	499	486	477	16.6
ADFI, g	706	730	749	719	714	22.6
G:F	0.69	0.71	0.69	0.70	0.69	0.01

[a]170 pigs (two replications with five pigs per pen and four replications with six pigs per pen), with an initial average BW of 7.5 kg. All pigs were fed a common diet from weaning until the start of the experiment at 5 d after weaning (d 0 of experiment). Dietary treatments were fed from d 0 to 21 of the experiment, and a common Phase III diet was fed from d 21 to 35 of the experiment. Wheat gluten (WG) was fed from two different sources consisting of enzymatically hydrolyzed (Source 1) and flash-dried (Source 4) wheat gluten. All ADFI values are as-fed.

[b,c]Means in the same row with different superscripts differ, $P < 0.05$.

Burnham et al. (2000) determined the nutritional value of WG and SDPP. In one experiment, the researchers found that pigs fed a diet containing 9.25% SDPP had greater ADG and ADFI than pigs fed a diet containing 8.88% WG. The results from our experiments are consistent with this previous research in that pigs fed 5.0% SDAP had greater ADG and ADFI than pigs fed a diet containing 9.0% WG. However, Burnham et al. (2000) found that from d 14 to 21 (common period), pigs previously fed a diet containing 8.88% WG had greater ADG and ADFI than pigs previously fed a diet containing 9.25% SDPP. In contrast, our studies did not show the improved growth performance after d 14.

Based on the results of another experiment conducted by Burnham et al. (2000), it was suggested that spray-dried WG could replace up to 50% of the SDPP in a complex nursery diet without negatively affecting growth performance. Results from our experiments contradict these data. In the current data, increasing levels of WG in the diet decreased ADG and ADFI in Exp. 1 and ADG in Exp. 2. Possible explanations for the different results might be the method of substituting L-lysine·HCl for various protein sources. Because WG is very low in lysine (approximately 1.5%), high concentrations of crystalline lysine are necessary to effectively substitute WG for other protein sources. The amount of added lysine used in our experiments and those of Burnham et al. (2000) were similar, suggesting that the use of crystalline lysine should not have been a factor. Another possible difference was that Burnham et al. (2000) used spray-dried WG, whereas the WG used in the present experiments were from different sources and different processing methods. In addition, Burnham et al. (2000) found the greatest growth performance with a blend of 4% spray-dried porcine plasma and 3.64% WG. We found the greatest performance with pigs fed 5% SDAP. If only 4 to 5% SDAP is needed to maximize growth performance of weanling pigs, this explains why Burnham et al. (2000) did not observe a decrease in ADG, whereas in our studies with lower levels of SDAP, substituting WG decreased ADG.

Richert et al. (1994) conducted three experiments to determine the nutritional value of flash-dried, spray-dried, and two enzyme-modified WG for weanling pigs. In the first experiment, pigs fed WG had greater apparent N digestibility than the diet with SBM. In a second experiment, pigs fed WG from d 0 to 14 had greater G:F than pigs fed soy isolate. These results are in agreement with ours, where pigs fed WG had greater G:F than pigs fed SBM. However, unlike Richert et al. (1994), who observed increased ADG when WG replaced SBM, we did not observe any benefits in ADG of pigs fed WG compared with those fed SDAP or SBM.

In previous studies, increased ADG has been observed in the period immediately after pigs have been fed diets containing WG (Richert et al., 1994; Burnham et al., 2000). This result might be attributed to the high glutamine content of WG and its potential to affect gut health (Reed et al., 2000). However, we did not observe any improvement in growth in the period immediately after feeding WG in any of the experiments reported herein.

Implications

As in many past trials, these studies confirm the improved growth performance of nursery pigs fed spray-dried animal plasma from d 0 to 14 postweaning. Replacing spray-dried animal plasma with different wheat gluten sources resulted in decreased average daily gain and no improvement in growth performance relative to spray-dried animal plasma. Our current studies suggest that wheat gluten is not an effective replacement for spray-dried animal plasma in diets for weanling pigs. Different drying methods of wheat gluten evaluated in this study do not seem to influence growth performance by nursery pigs.

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