Journal of Animal Science, 2023, **101**, 1–8
https://doi.org/10.1093/jas/skad065
Advance access publication 27 February 2023
Non ruminant nutrition

No carryover effect of feeding spray dried plasma to weanling pigs in phase 1 on energy and nutrient digestibility in phase 2 were observed

Hannah M. Bailey,[†,1] Joy M. Campbell,[‡] Natalia S. Fanelli,[†] and Hans H. Stein[†,2]

†Division of Nutritional Sciences, University of Illinois, Urbana, IL 61801, USA
‡APC LLC, Ankeny, IA 50021, USA
[1]Current address: Nestle Purina Petcare Company, St. Louis, MO 63102, USA
[2]Corresponding author: hstein@illinois.edu

Abstract

Spray dried plasma (SDP) is commonly used in phase 1 diets for weanling pigs, but it is unknown if SDP affects energy or nutrient digestibility of the subsequent diet. Therefore, two experiments were conducted to test the null-hypothesis that inclusion of SDP in a phase 1 diet fed to weanling pigs will not affect energy or nutrient digestibility of a phase 2 diet without SDP. In experiment 1, 16 newly weaned barrows with an initial body weight (BW) of 4.47 ± 0.35 kg were randomly allotted to a phase 1 diet without SDP or a diet including 6% SDP for 14 d. Both diets were fed on an ad libitum basis. All pigs (BW: 6.92 ± 0.42 kg) had a T-cannula surgically inserted in the distal ileum, moved to individual pens, and fed the common phase 2 diet for 10 d with ileal digesta collection on days 9 and 10. In experiments 2, 24 newly weaned barrows (initial BW: 6.60 ± 0.22 kg) were randomly allotted to phase 1 diets without SDP or a diet containing 6% SDP for 20 d. Both diets were provided on an ad libitum basis. All pigs (BW: 9.37 ± 1.40 kg) were then moved to individual metabolism crates and fed the common phase 2 diet for 14 d with the initial 5 d being the adaptation period to the diet followed by 7 d of fecal and urine collection according to the marker-to-marker procedure. The apparent ileal digestibility (AID) of starch, crude protein (CP), amino acids (AA), and acid hydrolyzed ether extract (AEE), was determined in experiment 1, and the apparent total tract digestibility (ATTD) of gross energy (GE), insoluble-, soluble-, and total-dietary fiber, Ca, and P, and the retention and biological value of N were determined in experiment 2. The statistical model included diet as fixed effect and block and pig within block as random effects. Results of experiment 1 indicated that the AID of starch, CP, AEE, and AA in phase 2 were not affected by phase 1 treatment. Results of experiment 2 indicated that the ATTD of GE, insoluble-, soluble-, and total-dietary fiber, Ca, and P and N retention and biological value in phase 2 were also not affected by phase 1 treatment. In conclusion, feeding weanling pigs a diet with 6% SDP in phase 1 did not affect the AID or ATTD of energy and nutrients in a phase 2 diet without SDP.

Lay Summary

Highly digestible and palatable ingredients are usually included in diets for newly weaned pigs to improve feed consumption and nutrient digestibility. Weaning typically causes a decrease in digestion and nutrient absorption, but inclusion of sprayed dried plasma (SDP) in phase 1 diets to weanling pigs may increase nutrient digestibility. However, data to demonstrate possible effects of including SDP to a phase 1 diet for newly weaned pigs on nutrient digestibility of a phase 2 diet without SDP are limited. Therefore, two experiments were conducted to test the hypothesis that inclusion of SDP in a phase 1 diet fed to weanling pigs does not affect the energy or nutrient digestibility of a phase 2 diet without SDP. Results of the two experiments demonstrated that weaned pigs fed a phase 1 diet with 6% SDP did not increase nutrient or energy digestibility of phase 2 compared with pigs fed diets without SDP, indicating that SDP had no carryover effects on nutrient digestibility. Therefore, it appears that feeding SDP in phase 1 diets to weanling pigs does not cause long-term intestinal changes that will affect digestibility of nutrients and energy in phase 2.

Key words: apparent ileal digestibility, apparent total tract digestibility, carryover effect, pigs, spray dried plasma

Abbreviations: AA, amino acids; AEE, acid hydrolyzed ether extract; AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; BW, body weight; CP, crude protein; DE, digestible energy; DM, dry matter; GE, gross energy; IDF, insoluble dietary fiber; ME, metabolizable energy; SDF, soluble dietary fiber; SDP, spray dried plasma; TDF, total dietary fiber

Introduction

Weaning is a stressful period for pigs because they are removed from the sow, mixed with pigs from other litters, moved to a new environment, and transitioned from sows' milk to solid feed (Torrallardona, 2010). Weaning often results in a decrease in the total weight of the mucosal layer and tissue in the small intestine (Lallès et al., 2004). Villus height and crypt depth in the duodenum also decrease after weaning leading to reduced digestion and absorption of nutrients (Lallès et al., 2004; Zhang et al., 2015). Highly palatable and digestible ingredients are often included in formulation of diets for newly weaned pigs to promote feed intake and to supply a concentrated source of nutrients (Kil and Stein, 2010; Torrallardona, 2010).

Spray dried plasma (**SDP**) is an animal protein with highly digestible amino acids (**AA**) and P (Mateo and Stein, 2007; Almeida et al., 2013). The AA provided by SDP are 92% to

Received December 30, 2022 Accepted February 23, 2023.

100% digestible by pigs (Almeida et al., 2013), and when included in diets for weanling pigs, protein synthesis and growth performance are improved (van Dijk et al., 2001). Phosphorus is required for the development and maintenance of skeletal tissue (Veum, 2010), and the P in SDP is nearly 100% digestible by pigs (Almeida and Stein, 2011). The beneficial effects of including SDP in diets for weanling pigs on growth performance is more pronounced in the first week postweaning compared with the second week, and continued improvements in growth performance have not always been observed after pigs are fed a diet without SDP (van Dijk et al., 2001). Additionally, SDP contains immunoglobulins, which are biologically active proteins that act in the intestinal tract to prevent pathogen colonization of the mucosal membrane leading to an improvement of intestinal barrier function and a reduction of intestinal inflammation (Peace et al., 2011). These improvements in intestinal health may result in increased nutrient digestibility and it is possible that these improvements will carry over to the following phase. If that is the case, it is expected that pigs fed SDP in phase 1 will have greater digestibility of energy and nutrients in phase 2 than pigs fed no SDP in phase 1. However, data to demonstrate improved digestibility of energy and nutrients in phase 2 if pigs are fed SDP in phase 1 are limited. Therefore, the objective of this experiment was to determine digestibility of energy and nutrients in weanling pigs. The null hypothesis that there was no carryover effect of feeding a diet with SDP to pigs in phase 1 on the ileal and total tract digestibility of energy and nutrients of a diet without SDP fed in phase 2 was tested.

Materials and Methods

Before initiation of animal work, the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved protocols for both experiments (numbers 18190 and 19130). In both experiments, barrows that were the offspring of Line 359 boars mated to Camborough females were used (Pig Improvement Company, Hendersonville, TN, USA).

Diets, animals, and feeding

In both experiments, SDP (i.e., Appetein B; APC LLC, Ankeny, IA, USA) was fed. Two phase 1 diets were formulated without or with 6% SDP and a common phase 2 diet without SDP was also fed (Tables 1, 2, and 3). In experiment 1, the phase 2 diet contained 0.40% chromic oxide to enable calculation of apparent ileal digestibility (**AID**). Vitamins and minerals were included in all diets to meet or exceed current nutritional requirements for 5 to 7 kg or 7 to 11 kg pigs in phase 1 and phase 2, respectively (NRC, 2012). All diets were provided in meal form and a sample of the main ingredients and all diets were collected at the time of diet mixing and were used for the chemical analysis.

In experiment 1, 16 barrows that had an initial body weight (**BW**) of 4.47 ± 0.35 kg at weaning (20 ± 2 d of age) were randomly allotted to be fed a phase 1 diet without or with 6% SDP. Pigs were fed their assigned diet on an ad libitum basis for 2 wk. Pigs were group housed in pens (1.8 × 1.2 m; 4 pigs per pen) that had a fully slatted floor, a feeder (Thorp Equipment, model ND-30SC; Thorp, WI, USA), and a nipple drinker in an environmentally controlled room (26 to 28 °C). After 2 wk, all pigs (BW: 6.92 ± 0.42 kg) had a T-cannula surgically installed in the distal ileum (Stein et al., 1998). Following surgery, pigs were moved to individual pens (1.2 × 1.5 m) in an environmentally controlled room (20 °C to 22 °C). Pens had fully slatted tribar floors and smooth walls composed of white polyvinyl chloride. A feeder (Thorp Equipment, model WDUP-32; Thorp, WI, USA) and a nipple drinker were

Table 1. Ingredient composition of experimental diets, experiments 1 and 2

Item, %	Phase 1[1]		Phase 2	
	Experiments 1 and 2		Experiment 1	Experiment 2
Spray dried plasma	–	6.00	–	–
Corn, ground	40.88	43.16	44.87	48.65
Soybean meal	25.00	25.00	30.00	25.00
Whey powder	20.00	20.00	15.00	15.00
Soy protein concentrate	8.00	–	–	5.00
Fish meal	–	–	5.00	–
Soybean oil	3.14	3.10	3.00	3.50
Limestone, ground	0.95	1.20	0.86	0.99
Dicalcium phosphate	1.10	0.80	0.30	1.00
Sodium chloride	0.10	0.10	0.10	0.10
L-Lys HCl	0.38	0.29	0.20	0.36
DL-Met	0.20	0.15	0.10	0.16
L-Thr	0.10	0.05	0.02	0.09
Chromic oxide	–	–	0.40	–
Vitamin mineral premix[2]	0.15	0.15	0.15	0.15

[1]Phase 1 treatments (0% SDP or 6% SDP).
[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamin mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 2. Analyzed nutrient composition of ingredients and diets (as-fed basis), experiment 1

Item	Ingredients						Phase 1 diet		Phase 2 diet
	SDP[1]	Corn	Soybean meal	Whey powder	Soy protein concentrate	Fish meal	0% SDP	6% SDP	0% SDP
Gross energy, kcal/kg	4,914	3,840	4,113	3,677	4,331	4,244	3,954	4,050	4,035
Dry matter, %	93.91	86.82	88.49	89.38	89.92	91.14	88.82	89.29	89.06
Starch, %	–	69.71	–	–	–	–	27.77	31.21	33.15
Crude protein, %	79.26	7.21	45.97	12.19	58.31	62.54	20.01	21.43	23.80
Ash, %	8.46	1.09	6.98	7.49	6.04	20.10	6.19	6.35	6.24
AEE[2], %	0.47	3.15	1.25	1.31	0.77	6.48	4.48	5.02	4.85
Indispensable AA[2], %									
Arg	4.66	0.32	3.26	0.38	4.23	3.65	1.28	1.22	1.29
His	2.48	0.19	1.21	0.25	1.49	1.20	0.51	0.55	0.53
Ile	2.48	0.24	2.29	0.60	2.92	2.56	0.98	0.89	0.97
Leu	7.56	0.76	3.56	1.15	4.6	4.22	1.71	1.84	1.75
Lys	7.24	0.24	2.95	0.92	3.63	4.59	1.58	1.56	1.43
Met	0.90	0.13	0.61	0.17	0.75	1.59	0.51	0.38	0.45
Phe	4.26	0.33	2.42	0.42	3.17	2.40	1.01	1.03	1.03
Thr	5.33	0.24	1.79	0.69	2.24	2.44	0.88	1.03	0.86
Trp	1.44	0.04	0.59	0.18	0.79	0.55	0.26	0.30	0.26
Val	5.49	0.31	2.26	0.63	2.89	2.89	1.03	1.12	1.02
Total	41.84	2.80	20.94	5.39	26.71	26.09	9.75	9.92	9.59
Dispensable AA, %									
Ala	3.93	0.48	2.02	0.54	2.55	3.95	0.97	1.03	1.07
Asp	7.96	0.44	5.15	1.11	6.56	5.36	2.17	2.08	2.11
Cys	2.67	0.15	0.66	0.26	0.85	0.48	0.34	0.47	0.31
Glu	11.26	1.18	8.33	1.80	10.58	8.19	3.63	3.41	3.61
Gly	2.78	0.27	1.96	0.28	2.46	4.73	0.82	0.79	0.96
Pro	4.32	0.57	2.33	0.62	3.05	2.99	1.16	1.18	1.17
Ser	5.32	0.31	1.96	0.54	2.53	2.18	0.88	0.97	0.89
Tyr	4.16	0.22	1.61	0.29	2.09	1.80	0.69	0.75	0.68
Total	42.40	3.62	24.02	5.44	30.67	29.68	10.66	10.68	10.80
Total AA, %	84.24	6.42	44.96	10.83	57.38	55.77	20.41	20.60	20.39

[1]SDP, spray dried plasma.
[2]AEE, acid hydrolyzed ether extract; AA, amino acids.

installed in each pen. Pens also were equipped with a heat lamp and a floor mat. All pigs were fed the common phase 2 diet without SDP immediately after surgery for 10 d. Feed was restricted while the pigs recovered from surgery, beginning with a full hand of feed in the first day after surgery and progressing to 1.5 cups of feed on days 2 and 3. Beginning on day 4, postsurgery feed was provided on an ad libitum basis. All pigs had free access to water during the entire experiment.

In experiment 2, 24 barrows weaned at 20 ± 2 d (initial BW: 6.60 ± 0.22 kg) were randomly allotted to be fed a phase 1 diet without or with 6% SDP for. Pigs were group housed in pens (1.8 × 1.2 m; 4 pigs per pen) in an environmentally controlled room and fed their assigned diet for 20 d. All pigs (BW: 9.37 ± 1.40 kg) were then moved to individual metabolism crates that were equipped with a feeder, a nipple drinker, a fully slatted stainless steel screen floor, and a urine tray, which allowed for the total, but separate, collection of feces and urine. All pigs were fed the common phase 2 diet without SDP for 14 d. Feed was provided in a daily amount of 3.3 times the maintenance energy requirement (i.e., 197 kcal/kg $BW^{0.60}$; NRC, 2012) and provided in two equal meals at 0700 and 1600 hours. Water was available at all times throughout the experiment.

Sample collection

In experiment 1, pig weights were recorded at the beginning of the experiment, before cannulation, and at the conclusion of the experiment. Ileal digesta collection occurred on days 9 and 10 for 9 h (from 0700 to 1600 hours). In short, a plastic bag was attached to the cannula barrel and digesta flowing into the bag were collected. Bags were removed when filled with ileal digesta, or at least once every 30 min, and immediately frozen at −20 °C to prevent bacterial degradation of the AA in the digesta (Stein et al., 1998). At the conclusion of the experiment, ileal digesta samples were thawed, homogenized, and a subsample was lyophilized and ground through a 0.5-mm screen prior to chemical analysis.

In experiment 2, the initial 5 d were considered the adaptation period to the diet followed by 7 d of fecal and urine collection according to the marker-to-marker procedure (Adeola, 2001). The start marker (i.e., indigo carmine - 0.5%) was mixed into the morning meal on day 6 and fecal collections

Table 3. Analyzed nutrient composition of ingredients and diets (as-fed basis), experiment2

Item	Ingredients					Phase 1 diet		Phase 2 diet
	SDP[1]	Corn	Soybean meal	Whey powder	Soy protein concentrate	0% SDP	6% SDP	0% SDP
Gross energy, kcal/kg	4,929	3,822	4,223	3,614	4,378	4,032	4,016	4,060
Dry matter, %	93.84	85.97	88.15	90.04	90.52	88.81	88.83	88.39
Starch, %	–	60.20	–	–	–	25.56	23.62	28.86
Crude protein, %	79.75	6.48	46.90	10.76	63.13	21.49	22.12	18.96
Total dietary fiber, %	6.20	8.60	16.30	ND	25.80	10.70	8.90	10.50
Insoluble dietary fiber, %	2.90	8.60	15.90	ND[2]	18.70	10.40	8.70	10.20
Soluble dietary fiber, %	3.40	ND	0.40	ND	7.00	0.30	0.10	0.10
Ash, %	9.35	1.14	6.14	8.15	6.77	5.76	6.08	5.23
Calcium, %	0.12	0.01	0.31	0.48	0.39	0.85	0.97	1.24
Phosphorus, %	1.64	0.25	0.55	0.53	0.58	0.55	0.58	0.48
Indispensable AA[2], %								
Arg	4.54	0.35	3.21	0.22	4.49	1.28	1.12	1.21
His	2.42	0.21	1.15	0.18	1.65	0.52	0.51	0.50
Ile	2.5	0.26	2.22	0.63	3.12	0.98	0.83	0.91
Leu	7.48	0.76	3.59	1.01	4.94	1.74	1.73	1.64
Lys	7.25	0.29	2.86	0.83	4.00	1.61	1.50	1.41
Met	0.96	0.15	0.61	0.13	0.87	0.48	0.42	0.38
Phe	4.16	0.33	2.32	0.32	3.23	1.00	0.94	0.94
Thr	5.10	0.25	1.72	0.64	2.41	0.95	0.94	0.82
Trp	1.54	0.06	0.63	0.2	0.86	0.29	0.32	0.26
Val	5.58	0.35	2.31	0.58	3.22	1.01	1.07	0.98
Total	41.53	3.01	20.62	4.74	28.79	9.86	9.38	9.05
Dispensable AA, %								
Ala	3.94	0.51	1.96	0.49	2.74	0.98	0.98	0.95
Asp	7.95	0.51	5.08	1.04	7.10	2.20	1.94	2.01
Cys	2.75	0.17	0.61	0.24	0.89	0.33	0.40	0.30
Glu	11.31	1.23	8.16	1.73	11.43	3.69	3.22	3.43
Gly	2.77	0.31	1.93	0.20	2.66	0.82	0.75	0.80
Pro	4.05	0.61	2.26	0.58	3.18	1.14	1.10	1.11
Ser	5.01	0.31	1.86	0.41	2.66	0.89	0.89	0.84
Tyr	3.83	0.16	1.64	0.20	2.19	0.67	0.71	0.63
Total	41.61	3.81	23.50	4.89	32.85	10.72	9.99	10.07
Total AA, %	83.14	6.82	44.12	9.63	61.64	20.58	19.37	19.12

[1]SDP, spray dried plasma.
[2]ND, not detected; AA, amino acids.

were initiated when the marker appeared in the feces. Fecal collections ceased when the stop marker (i.e., ferric oxide - 1%), which was mixed into the morning meal on day 13, appeared in the feces. All pigs were weighed at the beginning of the experiment, prior to moving into metabolism crates, and at the end of the collection period. Orts were collected daily and weighed to determine feed intake. During the collection period, feces were collected twice daily and stored at −20 °C immediately after collection. Urine was collected over a preservative of 50 mL of 6 N HCl in buckets placed under the metabolism crates. The urine buckets were emptied daily, the weight of the collected urine was recorded, and 20% was stored at −20 °C. At the conclusion of the experiment, fecal samples were dried at 65 °C in a forced air oven (Metalab Equipment Corp., Hicksville, NY, USA) and finely ground through a 0.5-mm screen using a 500G stainless steel mill grinder (RRH, Zhejiang, China) prior to chemical analysis. Urine samples were thawed, mixed, and two subsamples were collected. One urine subsample was lyophilized and the other subsample was stored at −20°C until analysis for N.

Chemical analysis

In both experiments, all diet and ingredient samples were analyzed for dry matter (**DM**; method 927.05; AOAC Int., 2007) and ash (method 942.05; AOAC Int., 2007). Gross energy (**GE**) was analyzed using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA). The concentration of N was analyzed by combustion (method 990.03; AOAC Int., 2007) using a LECO FP628 analyzer (LECO Corp., Saint Joseph, MI, USA) with subsequent calculation of crude protein (**CP**) as N × 6.25. All diets and ingredients were also analyzed for AA [method 982.30 E (a, b, c); AOAC Int., 2007], and for total starch using the glucoamylase procedure (method 979.10; AOAC Int., 2007).

In experiment 1, diet, ingredient, and ileal digesta samples were analyzed for acid hydrolyzed ether extract (**AEE**) by acid hydrolysis using 3 *N* HCl (AnkomHCl, Ankom Technology, Macedon, NY) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019) on a Ankom^{XT15} (Ankom Technology, Macedon, NY). Ileal digesta samples were also analyzed for DM, N, AA, and starch as described for diets and ingredients. The phase 2 diet and all ileal digesta samples were analyzed for chromium (method 990.08; AOAC Int., 2007).

In experiment. 2, all diet, ingredient, and fecal samples were analyzed for Ca and P by inductively coupled plasma spectroscopy (method 985.01 A, B, and C; AOAC Int., 2007) after wet ash sample preparation (method 975.03 B(b); AOAC International, 2007). The lyophilized urine samples and dried fecal samples were analyzed for GE as described for experiment 1, and fecal samples and urine samples that were not lyophilized were analyzed for N using the Kjeldahl method (method 984.13; AOAC Int., 2007) on a Kjeltec 8400 (FOSS Inc., Eden Prairie, MN, USA) with subsequent calculation of CP using a conversion factor of 6.25. Fecal samples were also analyzed for DM and ash, and insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) were analyzed in ingredients, diets, and fecal samples according to method 991.43 (AOAC Int., 2007) using the Ankom Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber (**TDF**) was calculated as the sum of IDF and SDF.

Samples were analyzed for AA and chromium at Chemical Laboratories, University of Missouri, Columbia, MO, USA and starch was analyzed at Illinois Crop Improvement, Champaign, IL, USA. All other analyses were conducted in the Monogastric Nutrition Laboratory, University of Illinois, Urbana, IL, USA.

Calculations and statistical analysis

In experiment 1, AID of CP, AA, starch, and AEE for the phase 2 diet was calculated (Stein et al., 2007), and in experiment 2, the apparent total tract digestibility (**ATTD**) of GE, SDF, IDF, TDF, N, Ca, and P was calculated (NRC, 2012). The digestible energy (**DE**) and metabolizable energy (**ME**) in the diet was calculated by subtracting the GE in feces and the GE in feces and urine, respectively, from GE in the diet (NRC, 2012). The retention of N for each pig was also calculated (Pedersen et al., 2007). The biological value of N in the diet was calculated by expressing N retention as a percentage of the difference between N intake and N output in feces (Rojas and Stein, 2013).

Normality of residuals was verified and outliers were identified using the UNIVARIATE and BOXPLOT procedures, respectively (SAS Inst. Inc., Cary, NC, USA) for both experiments. Outliers were removed if the value deviated from the

Table 4. Apparent ileal digestibility of acid hydrolyzed ether extract (AEE), starch, crude protein, and amino acids (AA) in the phase 2 diet, experiment 1[1]

Item, %	Phase 1 diet, % SDP[2]		Pooled SEM	*P*-value
	0	6		
Starch	91.6	90.6	0.60	0.27
AEE	75.7	74.1	1.69	0.52
Crude protein	72.7	72.2	1.44	0.84
Indispensable AA				
Arg	84.8	85.5	0.85	0.57
His	77.9	77.9	1.29	1.00
Ile	77.7	77.4	1.06	0.86
Leu	77.9	76.8	1.24	0.56
Lys	75.6	76.3	1.28	0.70
Met	85.1	84.2	0.78	0.41
Phe	77.4	76.6	1.21	0.62
Thr	67.6	66.9	1.32	0.74
Trp	78.7	78.6	1.04	0.96
Val	74.9	73.8	1.34	0.56
Mean	77.5	77.2	1.10	0.83
Dispensable AA				
Ala	71.6	70.2	1.41	0.49
Asp	70.8	71.0	1.09	0.90
Cys	58.6	58.3	2.43	0.92
Glu	77.3	78.9	7.83	0.89
Gly	60.1	60.4	2.33	0.93
Ser	73.8	74.4	1.10	0.71
Tyr	72.7	72.6	1.25	0.93
Mean	78.6	77.5	1.03	0.44
Total AA	72.7	72.4	1.61	0.90

[1]Data are least squares means of eight observations for pigs fed the phase 1 diet without SDP and seven observations for pigs fed the phase 1 diet with SDP.
[2]SDP, spray dried plasma.

1st or 3rd quartiles by more than three times the interquartile range (Tukey, 1977). Data were analyzed using PROC MIXED of SAS (SAS Institute Inc. Cary, NC, USA) with the pig as the experimental unit for all analyses. For both experiments, data were analyzed in a randomized complete block design with BW used as the blocking factor. The statistical model to determine phase 2 differences in AID of CP, AA, starch, and AEE (experiment 1) or ATTD of GE, DE, ME,

Table 5. Apparent total tract digestibility of gross energy (ATTD), Ca, P, digestible energy, and metabolizable energy in the phase 2 diet (as-fed basis), experiment 2[1]

Item	Phase 1 diet, % SDP[2]		Pooled SEM	*P*-value
	0	6		
Intake				
Feed intake, g/d	670	679	18	0.728
Gross energy, Mcal/d	2.72	2.76	0.07	0.731
Calcium, g/d	8.31	8.41	0.22	0.739
Phosphorus, g/d	3.23	3.27	0.09	0.728
Insoluble dietary fiber, g/d	68.32	69.21	1.81	0.731
Soluble dietary fiber, g/d	0.67	0.68	0.02	0.668
Total dietary fiber, g/d	70.32	71.24	1.86	0.730
Fecal excretion				
Dry feces output, g/d	60.3	63.3	2.3	0.359
Gross energy, kcal/d	284	298	11	0.377
Ca, g/d	1.31	1.41	0.06	0.290
P, g/d	1.44	1.47	0.05	0.663
Insoluble dietary fiber, g/d	18.27	18.64	0.64	0.692
Soluble dietary fiber, g/d	1.83	1.74	0.22	0.782
Total dietary fiber, g/d	20.12	20.38	0.75	0.810
ATTD, %				
Gross energy	89.6	89.1	0.4	0.394
Calcium	84.1	83.0	0.9	0.416
Phosphorus	55.4	54.7	1.3	0.696
Insoluble dietary fiber	73.2	73.1	0.7	0.869
Soluble dietary fiber	-179.9	–151.8	32.9	0.553
Total dietary fiber	71.3	71.4	0.8	0.906
Digestible energy in diet, kcal/kg	3,636	3,619	14	0.394
Urine output, kg/d	2.30	2.72	0.30	0.334
Urinary gross energy output, kcal/d	100	116	10	0.246
Metabolizable energy in diet, kcal/kg	3,488	3,449	13	0.041

[1]Data are least squares means of 12 observations for pigs fed the phase 1 diet without SDP and 11 observations for pigs fed the phase 1 diet with SDP.
[2]SDP, spray dried plasma.

Table 6. Nitrogen balance of pigs fed a phase 2 diet without spray dried plasma, experiment 2[1]

Item	Phase 1 diet, % SDP[2]		Pooled SEM	*P* - value
	0	6		
Feed intake, g/7 d	4,688	4,750	124	0.731
N intake, g/7 d	142	144	4	0.731
N output in feces, g/7 d	17.8	19.6	0.9	0.165
N output in urine, g/7 d	21.9	21.2	1.2	0.686
ATTD[3] of N, %	87.5	86.3	0.6	0.181
N retention, g/7 d	102	103	3	0.838
N retention, %	72.1	71.7	0.6	0.641
Biological value[4], %	82.4	83.1	0.6	0.412

[1]Data are least squares means of 12 observations for the phase 1 diet without SDP and 11 observations for phase 1 diet with SDP.
[2]SDP, spray dried plasma.
[3]ATTD, apparent total tract digestibility.
[4]Biological value was calculated as (*N* retained/ [*N* intake – *N* output in feces]) × 100 (Rojas and Stein, 2013).

IDF, SDF, TDF, Ca, and P (experiment 2) between pigs fed a phase 1 diet without or with 6% SDP included phase 1 diet as the fixed effect and block and pig within block as the random effects. Treatment means were calculated using the LSMEANS statement in SAS, and if significant, means were separated using the PDIFF option in the MIXED procedure. For all analyses, an alpha value of 0.05 was used to assess significance among means.

Results and Discussion

One pig was removed from experiment 1 on day 4 after cannulation, but all other pigs in both experiments remained healthy and readily consumed their daily feed allowances. Following data analysis, one pig in experiment 2 was identified as an outlier and removed.

Experiment 1: ileal digestibility

No impact of phase 1 diet on phase 2 feed intake was observed. The AID of starch, CP, AA, and AEE in phase 2 were not different between pigs fed the phase 1 diet without SDP and pigs fed the phase 1 diet with 6% SDP (Table 4). We believe this is the first time this effect has been reported in pigs. In an experiment with broiler chickens where SDP was fed at three inclusion levels (0, 10, or 20 g/kg) from hatch to 10 d of age followed by a commercial diet without SDP until 24 d of age (Beski et al., 2016), the ileal digestibility of DM, GE, CP, and AA did not differ among treatments. Beski et al. (2016). It therefore appears that inclusion of SDP in phase 1 diets for pigs or broiler chickens does not affect ileal digestibility of starch, CP, AA, or AEE in the subsequent diet.

Experiment 2: total tract digestibility

The average daily intake and average daily gain in phase 2 were not impacted by the diet provided in phase 1 (data not shown). This observation is in agreement with van Dijk et al. (2002) who reported that weaned pigs fed a diet containing 3% SDP during the initial 21 d postweaning did not have greater growth performance during the subsequent phase compared with control pigs fed no SDP in phase 1.

The ATTD of GE, IDF, SDF, TDF, Ca, and P was not affected by phase 1 diet (Table 5). These data are in agreement with Pendergraft et al. (1993) who observed no differences in ATTD of DM after pigs previously fed a diet without or with SDP were fed a nonSDP diet for 6 d. In the current experiment, the ME in the phase 2 diet fed to pigs previously fed the phase 1 diet with SDP was less ($P < 0.05$) than the ME in the phase 2 diet fed to pigs previously fed the phase 1 diet without SDP, which was the result of a numerical increase in the urine output and urinary GE output of pigs previously fed the phase 1 diet with SDP compared with pigs fed the phase 1 diet without SDP. Thomson et al. (1995) observed greater metabolic energy losses of mice fed a diet with SDP for 21 d compared with control mice fed a diet without SDP. Liver weights increased for mice fed a diet with SDP compared with control mice, indicating that dietary SDP may result in hyperplasia or hypertrophy of the liver (Thomson et al., 1994). The increased liver weights may have resulted in an increase in the basal metabolic rate resulting in increased metabolic losses (Thomson et al., 1995). Therefore, pigs previously fed a phase 1 diet with SDP may have had increased liver weight resulting in greater maintenance energy requirements, which may have resulted in increased urine loss of energy. However, because liver weights were not determined in the present experiment, we are not able to confirm this hypothesis.

During the 7-d collection period in experiment2, there were no differences in feed intake, N intake, or N output in feces or urine between pigs previously fed the phase 1 diet without SDP and pigs fed the diet with SDP (Table 6). There were also no differences in the ATTD of N, N retention, or the biological value of N between pigs previously fed a phase 1 diet without SDP or with 6% SDP. These data are in agreement with Pendergraft et al. (1993) who observed no effect of feeding a phase 1 diet with SDP on ATTD of N in phase 2. It therefore appears that provision of SDP in phase 1 does not result in changes in the intestinal tract that will influence digestibility in phase 2. The reason for this may be that the intestinal epithelium exhibits rapid turnover, undergoing complete renewal every 2 to 3 d (Verdile et al., 2019), and therefore, responds quickly to diet changes. As a consequence, even if a phase 1 diet results in increased intestinal health, this change may not be maintained in phase 2 due to the rapid intestinal turnover.

Conclusion

Spray dried plasma provides highly digestible AA and P in diets for weanling pigs. Data from the current experiments indicate that pigs fed a diet with 6% SDP during the initial 14 to 20 d postweaning and then switched to a diet without SDP do not have increased AID of starch, CP, AA, or AEE nor did the ATTD of energy, fiber, Ca, and P, or N retention increase. Therefore, it is concluded that there was no carryover effect of feeding SDP in phase 1 on energy and nutrient digestibility in a phase 2 diet without SDP.

Acknowledgments

Funding for this research by American Protein Corporation, Ankeny, IA is greatly appreciated.

Conflict of Interest Statement

JMC is an employer of American Protein Corporation, which is a supplier of spray dried plasma protein. HMB, NSF, and HHS have no conflicts of interest.

Literature Cited

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, *Swine Nutrition*. 2nd ed. Washington, DC: CRC Press. p. 903–916.

Almeida, F. N., and H. H. Stein. 2011. Standardized total tract digestibility of phosphorus in blood products fed to weanling pigs. *Rev. Colom. Cienc. Pecua*. 24:617–622.

Almeida, F. N., J. K. Htoo, J. Thomson, and H. H. Stein. 2013. Comparative amino acid digestibility in US blood products fed to weanling pigs. *Anim. Feed Sci. Technol.* 181:80–86. doi:10.1016/j.anifeedsci.2013.03.002

AOAC Int. 2007. *Official methods of analysis*. 18th ed. Rev. 2. Gaithersburg, MD, USA: AOAC Int.

AOAC Int. 2019. *Official methods of analysis of AOAC Int*. 21th ed. *AOAC Int*., Rockville, MD, USA.

Beski, S. S. M., R. A. Swick, and P. A. Iji. 2016. The effect of the concentration and feeding duration of spray-dried plasma protein on growth performance, digestive enzyme activities, nutrient digestibility and intestinal mucosal development of broiler chickens. *Anim. Prod. Sci*. 56:1820–1827. doi:10.1071/an141021 van Dijk, A. J., H. Everts, M. J. A. Nabuurs, R. J. C. F. Margry, and A. C. Beynen. 2001. Growth performance of weanling pigs fed spray-dried animal plasma: a review. *Livest. Prod. Sci*. 68:263–274. doi:10.1016/S0301-6226(00)00229-3

van Dijk, A. J., R. J. C. F. Margery, A. G. van der Lee, G. Hemke, and A. C. Beynen. 2002. Growth performance and health status in weanling piglets fed spray-dried porcine plasma under typical Northern European conditions. J. Anim. Physiol. *Anim. Nutr*. 86:17–25. doi:10.1046/j.1439-0396.2002.00352.x

Kil, D. Y., and H. H. Stein. 2010. Board invited review: management and feeding strategies to ameliorate the impact of removing antibiotic growth promoters from diets fed to weanling pigs. *Can. J. Anim. Sci*. 90:447–460. doi:10.4141/cjas10028

Lallès, J. P., G. Boudry, C. Favier, N. Le Floc'h, I. Luron, L. Montagne, I. P. Oswald, S. Pié, C. Piel, and B. Sève. 2004. Gut function and dysfunction in young pigs: Physiol. *Anim. Res*. 53:301–316. doi:10.1051/animres:2004018

Mateo, C. D., and H. H. Stein. 2007. Apparent and standardized ileal digestibility of amino acids in yeast extract and spray dried plasma protein by weanling pigs. *Can. J. Anim. Sci*. 87:381–383. doi:10.4141/cjas06011

NRC. 2012. *Nutrient requirements of swine*. 11th ed. Washington DC: Natl. Acad. Press.

Peace, R. M., J. Campbell, J. Polo, J. Crenshaw, L. Russell, and A. Moeser. 2011. Spray-dried porcine plasma influences intestinal barrier function, inflammation, and diarrhea in weaned pigs. *J. Nutr*. 141:1312–1317. doi:10.3945/jn.110.136796

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Energy and nutrient digestibility in Nutridense corn and other cereal grains fed to growing pigs. *J. Anim. Sci*. 85:2473–2483. doi:10.2527/jas.2006-620

Pendergraft, J. S., C. G. Mills, L. L. Burnham, R. H. Hines, and J. D. Hancock. 1993. Effects of wheat gluten and plasma protein on growth performance and digestibility of nutrients in nursery pigs. *Kans. Agric. Exp. Stn*. 10:62–66. doi:10.4148/2378-5977.6376

Rojas, O. J., and H. H. Stein. 2013. Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs. *J. Anim. Sci*. 91:4397–4405. doi:10.2527/jas.2013-6409

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: a technique for inserting a T-cannula into the distal ileum of pregnant sows. *J. Anim. Sci*. 76:1433–1436. doi:10.2527/1998.7651433x

Stein, H. H., B. Seve, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange; Committee on terminology to Report AA bioavailability and digestibility. 2007. Invited review: amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. *J. Anim. Sci*. 85:172–180. doi:10.2527/jas.2005-742

Thomson, J. E., E. E. Jones, and E. J. Eisen. 1994. Effect of spray-dried porcine plasma protein on feed intake, growth rate, and efficiency of gain in mice. *J. Anim. Sci*. 72:2690–2695. doi:10.2527/1994.72102690x

Thomson, J. E., E. E. Jones, and E. J. Eisen. 1995. Effects of spray-dried porcine plasma protein on growth traits and nitrogen and energy balance in mice. *J. Anim. Sci*. 73:2340–2346. doi:10.2527/1995.7382340x

Torrallardona, D. 2010. Spray dried animal plasma as an alternative to antibiotics in weanling pigs - a review. Asian-Aust. *J. Anim. Sci*. 23:131–148. doi:10.5713/ajas.2010.70630

Tukey, J. W. 1977. *Exploratory data analysis*. Reading, Mass: Addison-Wesley Pub. Co.

Verdile, N., R. Mirmahmoudi, T. A. L. Brevini, and F. Gandolfi. 2019. Evolution of pig intestinal stem cells from birth to weaning. *Animal*. 13:2830–2839. doi:10.1017/S1751731119001319

Veum, T. L. 2010. Phosphorus and calcium nutrition and metabolism. In: D. M. S. S. Vitti, and E. Kebreab, editors, *Phosphorus and calcium utilization and requirements in farm animals*. Wallingford, UK: CABI. p. 94–111. doi:10.1079/9781845936266.0094

Zhang, Y., D. W. Chen, B. Yu, J. He, J. Yu, X. B. Mao, J. X. Wang, J. Q. Luo, Z. Q. Huang, G. X. Cheng, et al. 2015. Spray-dried chicken plasma improves intestinal digestive function and regulates intestinal selected microflora in weaning piglets. *J. Anim. Sci*. 93:2967–2976. doi:10.2527/jas.2014-8820