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Short communication

Growth performance of weanling pigs fed diets containing spray-dried bovine plasma or hydrolyzed spray-dried bovine plasma

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ABSTRACT

An experiment was conducted to test the hypothesis that dietary inclusion of enzymatically hydrolyzed spray-dried bovine plasma (H-SDBP) is as effective as non-hydrolyzed spray-dried bovine plasma (SDBP) for increasing growth performance of weanling pigs housed in uncleaned pens. A control diet based on corn, soybean meal, and 90 g/kg soy protein concentrate (SPC) was formulated. Four diets containing either SDBP (i.e., 25 or 50 g/kg) or H-SDBP (i.e., 28 or 56 g/kg) that partially or fully replaced SPC were also formulated. A randomized complete block design with 240 weanling pigs (6.52 ± 0.98 kg), five diets, four pigs per pen, and 12 replicate pens per diet was used. Pigs were fed experimental diets for 14 days post-weaning, whereas a common phase 2 diet was fed to pigs from day 15–42 post-weaning. Results indicated that from day 1–14, fully replacing SPC with SDBP or H-SDBP increased ($P < 0.05$) average daily gain (ADG), gain to feed ratio (G:F), and ending body weight of pigs. During this period, linear ($P < 0.01$) increases in ADG, G:F, and body weight of pigs were also observed as dietary concentrations of SDBP increased. When pigs were fed the common diet from day 15–42, final body weight of pigs increased (linear, $P < 0.05$) for pigs fed SDBP or H-SDBP in phase 1. For the overall experimental period, ADG of pigs linearly increased ($P < 0.05$) as dietary concentration of both plasma sources increased in phase 1 diets. From day 8–14, and from day 1–14, fecal scores of pigs were reduced (linear, $P < 0.05$) as the concentration of SDBP increased in the diet. Partially replacing SPC with H-SDBP also reduced ($P < 0.05$) fecal scores of pigs from day 8–14. In conclusion, both plasma sources were effective for increasing pig growth performance and reducing diarrhea in the post-weaning period.

1. Introduction

Weaning is one of the most stressful periods that results in behavioral, immunological, and intestinal changes (Pluske et al., 1997; Campbell et al., 2013). At weaning, young pigs are exposed to a myriad of stressors, which results in reduction in growth performance. Therefore, weanling pigs are susceptible to infections, diseases, and villous atrophy in the gut. Inclusion of soybean meal is restricted in

Abbreviations: ADFI, average daily feed intake; ADG, average daily gain; G:F, gain to feed ratio; H-SDBP, hydrolyzed spray-dried bovine plasma; SDBP, spray-dried bovine plasma; SDP, spray-dried plasma protein; SPC, soy protein concentrate.

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diets for weanling pigs due to the presence of anti-nutritional factors (e.g., trypsin inhibitors, lectins, antigens, oligosaccharides, allergens) in soybean meal, which negatively affects nutrient availability, immune response, and health of the animals (Smiricky-Tjardes et al., 2003; Palacios et al., 2004; Stein et al., 2008). Therefore, highly digestible protein sources have been used at the expense of soybean meal to avoid its negative effects on growth performance of weanling pigs.

Spray-dried plasma protein (SDP) is obtained from the industrial fractionation of blood from slaughtered animals (e.g., pigs, poultry, cattle). An anticoagulant is added to the collected whole blood, which is then centrifuged to separate blood plasma and blood cells (Almeida et al., 2013). Plasma is concentrated and spray-dried under high pressure that results in a high protein-containing feed ingredient (Pérez-Bosque et al., 2016). Spray-dried plasma protein is often used in weanling diets due to its high concentration of digestible amino acids (Van Dijk et al., 2001). Spray-dried plasma protein also contains functional components (e.g., immunoglobulins and biologically active peptides) that may reduce intestinal inflammation of pigs exposed to bacterial pathogens (Campbell et al., 2019).

Enzymatically hydrolyzed spray-dried bovine plasma (H-SDBP) is a new source of SDP that may be used as a protein source in diets for weanling pigs. Hydrolyzed spray-dried bovine plasma may contain bioactive peptides with biological function that can partially provide health benefits similar to spray-dried bovine plasma (SDBP). There are, however, no data to demonstrate the efficacy of this novel ingredient. Pigs fed diets containing SDP have increased growth performance when exposed to a challenge model (Coffey and Cromwell, 1995; Bosi et al., 2004); therefore, it is possible that H-SDBP improves performance of pigs similarly to other sources of SDP, but this hypothesis has not been experimentally verified. Therefore, an experiment was conducted to test the hypothesis that dietary inclusion of H-SDBP is as effective as SDBP for increasing growth performance of weanling pigs housed in uncleaned pens.

2. Materials and methods

The protocol for this experiment was submitted to the Institutional Animal Care and Use Committee at the University of Illinois, Urbana-Champaign, USA, and was approved prior to initiation of the experiment. Pigs used in the experiment were the offspring of Line 359 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

2.1. *Diets, animals, housing, and experimental procedure*

Both plasma products (i.e., H-SDBP and SDBP) were produced from the same lot of raw plasma. Both plasma products originated from concentrated bovine plasma and were spray-dried under high pressure. The H-SDBP is produced by enzymatic hydrolysis under controlled pH, temperature, time, and specific substrate-to-enzyme ratio. A bacterial endopeptidase with a broad specificity for peptide binding and crucial to peptide production under the appropriate conditions was utilized. The powder is tan in color and highly soluble

Table 1
Analyzed nutrient composition of soy protein concentrate (SPC), spray-dried bovine plasma (SDBP), and hydrolyzed spray-dried bovine plasma (H-SDBP), as-fed basis.

Item	SPC	SDBP	H-SDBP
Gross energy, MJ/kg	18.1	20.2	18.4
Dry matter, g/kg	915.7	972.6	951.7
Ash, g/kg	73.4	76.1	145.8
Crude protein, g/kg	643.2	822.8	772.0
Acid-hydrolyzed ether extract, g/kg	18.0	16.5	20.0
Ca, g/kg	4.1	1.2	1.2
Total P, g/kg	8.2	15.6	13.6
K, g/kg	21.9	1.7	47.0
Na, g/kg	0.1	24.0	24.2
Cu, mg/kg	14.9	28.3	31.8
Zn, mg/kg	55.0	39.2	55.5
Indispensable amino acids, g/kg			
Arg	45.6	48.2	41.3
His	16.5	26.2	23.2
Ile	32.2	26.6	22.6
Leu	49.9	79.0	68.0
Lys	40.0	76.8	65.7
Met	8.6	10.2	9.0
Phe	33.3	44.6	38.3
Thr	23.7	52.7	45.5
Trp	8.4	15.9	13.6
Val	33.4	61.1	52.6
Dispensable amino acids, g/kg			
Ala	27.6	41.2	36.0
Asp	71.7	83.8	72.3
Cys	9.1	28.4	24.1
Glu	116.4	114.1	98.4
Ser	25.5	44.8	39.4
Tyr	22.4	42.3	32.8

containing low molecular weight proteins with an increased amount of free amino acids and a degree of hydrolysis greater than 15 %.

A 2-phase feeding program was used with day 1–14 as phase 1 and day 15–42 as phase 2. During phase 1, 240 pigs that were weaned at approximately 21 days of age (initial body weight: 6.52 ± 0.97 kg) were allotted to one of five dietary treatments in a randomized complete block design. Pigs were blocked by weight and weaning group. Each replicate pen in all dietary treatments had 4 pigs per pen (i.e., 2 gilts and 2 barrows) and gender of pigs was balanced within treatments. All pigs were fed a common diet in phase 2. Therefore, a total of 6 diets were prepared. There were 12 replicate pens per treatment with 4 pigs per pen for a total of 60 pens. For phase 1 diets, a basal diet was formulated based on corn, soybean meal, and 90 g/kg soy protein concentrate (SPC; Tables 1–3). Four diets containing either SDBP or H-SDBP that partially or fully replaced SPC were also formulated. The analyzed concentration of amino acids in the two plasma sources were used to formulate diets, and because of the reduced amino acid concentration in H-SDBP, dietary inclusion of H-SDBP was greater compared with SDBP. As a result, four diets were formulated by adding 25 or 50 g/kg SDBP or by adding 28 or 56 g/kg H-SDBP to the diets at the expense of SPC. A common phase-2 diet was also formulated. Vitamins and minerals were included in all diets to meet or exceed current nutritional requirement estimates of weanling pigs (NRC, 2012).

Pigs were allowed free access to feed and water throughout the experiment. Pigs were placed in uncleaned pens using a sanitation challenge model and pens remained uncleaned throughout the experiment. The uncleaned pens were not disinfected or cleaned after a previous occupation by pigs (Le Floc'h et al., 2006). Temperature, relative humidity, lighting, water, and feed were checked and recorded daily. The barn was on a 12 h light - 12 h dark cycle. Heating was provided as needed to maintain a temperature between 27 and 30 °C and the facility maintained a 65–80 % relative humidity. Diarrhea scores were assessed visually every day for the first 14 days (i.e., phase 1) of the experiment using a score from 1 to 5 (1 = normal feces; 2 = moist feces; 3 = mild diarrhea; 4 = severe diarrhea; and 5 = watery diarrhea). Individual pig weights and feed left in the feeders were weighed and recorded at the beginning of the experiment, on days 7, 14, 28, and at the conclusion of the experiment (day 42). Daily feed allotments were also recorded.

2.2. Chemical analyses

At the conclusion of the experiment, diets and ingredients (i.e., SPC, SDBP, and H-SDBP) were analyzed for dry matter (Method 930.15; AOAC Int, 2019) and ash (Method 942.05; AOAC Int, 2019). Minerals (i.e., Ca, P, K, Na, Cu, Zn) in ingredients were analyzed using inductively coupled plasma-optical emission spectrometry (Avio 200, PerkinElmer, Waltham, MA, USA). Sample preparation included dry ashing at 600 °C for 4 h (Method 942.05; AOAC Int, 2019) and wet digestion with nitric acid. Diets and ingredients were also analyzed for nitrogen (Method 990.03; AOAC Int, 2019) on a LECO FP628 nitrogen analyzer (LECO Corp., Saint Joseph, MI, USA), and crude protein was calculated as nitrogen × 6.25. Amino acids were analyzed in diets and ingredients on a Hitachi amino acid analyzer (Model No. L8800; Hitachi High Technologies America, Inc., Pleasanton, CA, USA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Acid-hydrolyzed ether extract was also analyzed via acid hydrolysis using 3 *N* HCl (AnkomHCl, Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (AnkomXT15, Ankom Technology, Macedon, NY, USA). Diets and ingredients were analyzed for gross energy using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL, USA).

Table 2
Ingredient composition of experimental diets.

Item	Phase 1 Diets					Phase 2
	SPC[a]	25 g/kg SDBP[a]	50 g/kg SDBP	28 g/kg H-SDBP[a]	56 g/kg H-SDBP	
Ingredient, g/kg						
Corn	453.9	475.4	496.7	472.4	490.6	556.6
Soybean meal	200.0	200.0	200.0	200.0	200.0	255.0
Whey powder	200.0	200.0	200.0	200.0	200.0	100.0
SPC	91.3	45.7	–	45.7	–	35.0
SDBP	–	25.0	50.0	–	–	–
H-SDBP	–	–	–	28.0	56.0	–
Soybean oil	20.5	20.5	20.5	20.5	20.5	20.0
Limestone	10.5	11.7	13.0	11.7	12.7	9.6
Dicalcium phosphate	8.2	6.5	5.0	6.5	5.4	8.5
L-Lys HCL, 780 g/kg Lys	3.8	3.7	3.7	3.7	3.7	3.8
DL-Met, 980 g/kg Met	1.9	1.7	1.5	1.7	1.5	1.5
L-Thr, 990 g/kg Thr	0.9	0.8	0.6	0.8	0.6	1.0
Sodium chloride	4.0	4.0	4.0	4.0	4.0	4.0
Vitamin-mineral premix[b]	5.0	5.0	5.0	5.0	5.0	5.0

[a] SPC, soy protein concentrate; SDBP, spray-dried bovine plasma; H-SDBP, hydrolyzed spray-dried bovine plasma.
[b] Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1660 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

Table 3
Analyzed nutrient composition of experimental diets.[a]

Item	Phase 1 Diets SPC[b]	25 g/kg SDBP[b]	50 g/kg SDBP	28 g/kg H-SDBP[b]	56 g/kg H-SDBP	Phase 2
Gross energy, MJ/kg	16.6	16.5	16.5	16.3	16.4	16.6
Dry matter, g/kg	909.3	904.1	904.3	901.5	901.4	867.4
Ash, g/kg	73.8	64.1	65.0	68.3	67.5	50.7
Crude protein, g/kg	215.1	204.7	204.9	206.0	203.8	207.4
Acid-hydrolyzed ether extract, g/kg	45.9	44.6	43.5	49.1	47.7	50.4
Amino acids, g/kg						
Arg	13.6	12.3	12.4	12.0	11.9	11.7
His	5.6	5.3	5.6	5.2	5.3	4.9
Ile	10.9	9.6	9.8	9.8	9.3	8.4
Leu	18.9	18.1	19.2	18.2	18.3	15.8
Lys	16.4	15.7	16.7	16.1	16.6	13.8
Met	5.2	4.5	4.7	4.4	4.5	4.0
Phe	10.7	9.9	10.3	9.8	9.9	9.2
Thr	10.5	9.4	10.0	9.5	9.7	7.2
Trp	2.7	2.7	3.0	3.0	3.0	2.1
Val	11.6	11.1	12.0	11.2	11.6	9.4
Ala	10.6	10.1	10.7	10.1	10.2	9.1
Asp	23.4	21.2	22.0	21.4	21.1	18.6
Cys	3.6	3.9	4.5	3.8	4.3	3.0
Glu	39.6	35.8	36.5	35.6	34.6	32.8
Gly	8.8	7.9	8.1	7.8	7.7	7.6
Ser	8.5	8.2	8.6	8.1	8.4	7.2
Tyr	7.2	7.0	7.4	6.8	7.2	6.3

[a] Diets were formulated to contain 14.2 MJ/kg of metabolizable energy, 14.2 g/kg standardized ileal digestible Lys, 4.1 g/kg standardized ileal digestible Met, 8.3 g/kg standardized ileal digestible Thr, 2.3 g/kg standardized ileal digestible Trp, and 9.0 g/kg standardized ileal digestible Val.
[b] SPC, soy protein concentrate; SDBP, spray-dried bovine plasma; H-SDBP, hydrolyzed spray-dried bovine plasma.

2.3. Calculations and statistical analyses

Data were summarized to calculate average daily feed intake (ADFI), average daily gain (ADG), and gain to feed ratio (G:F) within each pen and treatment group. Data were summarized for day 1–7, day 8–14, day 15–28, day 29–42, for each phase, and for the entire experiment. Data were analyzed using the MIXED procedure in SAS (SAS Institute Inc, 2016) with pen as the experimental unit. Homogeneity of the variances was verified, and data were tested for outliers using the UNIVARIATE and BOXPLOT procedures, respectively. The model included diet as main effect, whereas block and replicate within block were considered random effects. Least squares means were calculated using the LSMEANS statement. Means were separated using the PDIFF option of SAS. Linear effect of increasing levels of SDBP or H-SDBP in diets on growth performance and fecal score was also determined using polynomial CONTRAST statements. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

3. Results

Diet analyses indicated that the intended concentration of crude protein and amino acids was present in all diets. All pigs consumed their diets without apparent problems; however, one pig fed the diet containing 56 g/kg H-SDBP was removed from the experiment due to health condition during phase 2, and therefore, values for growth performance in the pen this pig was housed in were adjusted.

From day 1–14, fully replacing SPC with SDBP or H-SDBP increased ($P < 0.05$) ADG, G:F, and body weight of pigs (Table 4). During this period, linear ($P < 0.01$) increases in ADG, G:F, and body weight of pigs were also observed as dietary concentrations of SDBP increased. When pigs were fed the common diet from day 15–42, final body weight of pigs increased (linear, $P < 0.05$) as concentration of SDBP or H-SDBP in the phase 1 diet increased. Overall, ADG of pigs linearly increased ($P < 0.05$) as dietary concentration of both plasma sources increased in the phase 1 diet. From day 8–14, as well as for the entire phase 1, fecal scores of pigs were reduced (linear, $P < 0.05$) as concentration of SDBP increased in the diet (Table 5). Partially replacing SPC with H-SDBP also reduced ($P < 0.05$) fecal scores from day 8–14.

4. Discussion

At weaning, pigs must cope with abrupt withdrawal of sow milk, and this often causes diarrhea due to the lack of endogenous enzymes by weanling pigs to hydrolyze polysaccharides and proteins from cereal grains and soybean meal (Friesen et al., 1993). Therefore, strategies to prevent occurrence of infections and diseases must be identified to reduce mortality during this period. Spray-dried plasma protein (i.e., porcine or bovine) has greater concentrations of digestible amino acids than soybean meal and fish meal (Kim and Easter, 2001), and therefore, SDP is commonly used as a protein source in diets for weanling pigs (Campbell et al., 2019). Hydrolysis of protein results in increased production of bioactive peptides due to molecular change in the secondary and

Table 4
Growth performance of pigs fed experimental diets[a].

Item	SPC[b]	25 g/kg SDBP[b]	50 g/kg SDBP	28 g/kg H-SDBP[b]	56 g/kg H-SDBP	SEM	P-values Diet	SDBP, Linear	H-SDBP, Linear
day 1–7									
Initial body weight, kg	6.51	6.53	6.51	6.52	6.52	0.2911	0.847	0.730	0.709
ADG[c], kg	0.063[b]	0.093[ab]	0.113[a]	0.071[b]	0.083[ab]	0.0112	0.024	0.005	0.309
ADFI[c], kg	0.130	0.142	0.158	0.130	0.135	0.0102	0.226	0.098	0.830
G:F[c]	0.478[y]	0.656[x]	0.719[x]	0.546[xy]	0.610[xy]	0.0687	0.053	0.004	0.171
Final body weight, kg	6.95[c]	7.19[ab]	7.30[a]	7.01[bc]	7.09[abc]	0.3034	0.034	0.006	0.324
day 8–14									
ADG, kg	0.158[c]	0.163[bc]	0.212[a]	0.144[c]	0.199[ab]	0.0185	0.007	0.097	0.450
ADFI, kg	0.283[abc]	0.276[bc]	0.324[a]	0.250[c]	0.298[ab]	0.0184	0.039	0.391	0.682
G:F	0.560	0.593	0.656	0.576	0.666	0.0568	0.327	0.299	0.418
Final body weight, kg	8.06[c]	8.34[bc]	8.79[a]	8.02[c]	8.48[ab]	0.3792	< 0.001	0.003	0.231
day 15–28									
ADG, kg	0.502[xy]	0.497[xy]	0.477[y]	0.488[y]	0.528[x]	0.0180	0.095	0.360	0.683
ADFI, kg	0.686[ab]	0.691[ab]	0.646[b]	0.658[b]	0.721[a]	0.0308	0.037	0.423	0.878
G:F	0.734	0.728	0.738	0.749	0.738	0.0199	0.907	0.965	0.609
Final body weight, kg	15.06[b]	15.29[ab]	15.45[ab]	14.85[b]	15.87[a]	0.5609	0.034	0.286	0.302
day 29–42									
ADG, kg	0.601[b]	0.659[a]	0.621[ab]	0.654[a]	0.626[ab]	0.0182	0.027	0.027	0.027
ADFI, kg	0.854	0.892	0.893	0.911	0.910	0.0268	0.390	0.169	0.046
G:F	0.702[y]	0.744[x]	0.698[y]	0.719[xy]	0.690[y]	0.0228	0.079	0.245	0.889
Final body weight, kg	23.46	24.51	24.15	23.99	24.61	0.7485	0.104	0.032	0.038
day 1–14									
ADG, kg	0.110[c]	0.128[bc]	0.162[a]	0.107[c]	0.141[ab]	0.0112	< 0.001	0.003	0.226
ADFI, kg	0.207[b]	0.208[b]	0.243[a]	0.189[b]	0.216[ab]	0.0127	0.025	0.183	0.760
G:F	0.532[c]	0.614[ab]	0.668[a]	0.569[bc]	0.655[a]	0.0388	0.011	0.005	0.067
day 15–42									
ADG, kg	0.551	0.578	0.549	0.570	0.577	0.0156	0.114	0.297	0.073
ADFI, kg	0.771	0.792	0.771	0.783	0.814	0.0217	0.199	0.556	0.119
G:F	0.715	0.729	0.713	0.727	0.707	0.0097	0.345	0.566	0.878
day 1–42									
ADG, kg	0.403	0.428	0.420	0.416	0.431	0.0122	0.120	0.037	0.041
ADFI, kg	0.583	0.597	0.594	0.587	0.616	0.0169	0.313	0.369	0.194
G:F	0.694	0.718	0.708	0.709	0.700	0.0093	0.239	0.051	0.261

[a-c]Means within a row lacking a common letter are different ($P < 0.05$).
[x-y]Means within a row lacking a common letter tend to be different ($P < 0.10$).
[a] Data are least squares means of 12 observations for all treatments.
[b] SPC, soy protein concentrate; SDBP, spray-dried bovine plasma; H-SDBP, hydrolyzed spray-dried bovine plasma.
[c] ADG, average daily gain; ADFI, average daily feed intake; G:F, gain to feed ratio.

Table 5
Fecal scores of pigs fed the experimental diets during phase 1.[a,b]

Item	SPC[c]	25 g/kg SDBP[c]	50 g/kg SDBP	28 g/kg H-SDBP[c]	56 g/kg H-SDBP	SEM	P-values Diet	BP, Linear	H-BP, Linear
day 1–7	2.01	1.90	1.95	2.11	2.19	0.1133	0.392	0.551	0.327
day 8–14	2.36[a]	1.94[b]	1.96[b]	1.98[b]	2.25[ab]	0.1098	0.026	0.004	0.076
day 1–14	2.19[xy]	1.92[z]	1.95[yz]	2.04[xyz]	2.22[x]	0.0902	0.086	0.032	0.627

[a-b]Means within a row lacking a common letter are different ($P < 0.05$).
[x-z]Means within a row lacking a common letter tend to be different ($P < 0.10$).
[a] Data are least squares means of 12 observations for all treatments.
[b] Fecal score, 1, normal feces; 2, moist feces; 3, mild diarrhea; 4, severe diarrhea; 5, watery diarrhea.
[c] SPC, soy protein concentrate; SDBP, spray-dried bovine plasma; H-SDBP, hydrolyzed spray-dried bovine plasma.

tertiary structure of protein (Jin et al., 2020). These bioactive peptides are believed to contain anti-inflammatory, antioxidant, and antimicrobial activities that may be beneficial in reducing infections and mortality during the post weaning period (Hu et al., 2011; Jin et al., 2020). Therefore, this experiment was conducted to determine if hydrolyzing plasma protein exerts positive effects on growth performance of young pigs.

Le Floc'h et al. (2006) demonstrated that modifications in the environment and sanitary status can stimulate an immune response of young pigs housed in conventional facilities. Pigs exposed to unclean housing conditions are susceptible to bacterial pathogens that stimulate the immune system, and consequently, reduces pig growth performance. Hence, unsanitary housing conditions can change the homeostasis of nutrients since pigs will have increased needs for nutrients to meet requirements for metabolic and immunological functions (Suchner et al., 2000). Therefore, the observed increase in ADG and G:F of pigs fed diets with H-SDBP or SDBP agrees with data indicating that SDP increased growth performance of pigs kept under less sanitary conditions (Coffey and Cromwell, 1995), and this is possibly a result of the beneficial effects of functional components (e.g., bioactive peptides and growth factors) in H-SDBP or SDBP on gastrointestinal health and immune function (Bah et al., 2013). Spray dried plasma sources also contain immunoglobulins that are hypothesized to be essential during periods of increased stress (Torrallardona, 2010). Therefore, the observed improvement in growth performance of pigs placed in uncleaned pens upon dietary inclusion of H-SDBP or SDBP indicates that the functional components in these plasma sources were able to alleviate the negative effect of the sanitary challenge on pig growth performance. In this experiment, SPC was replaced by H-SDBP or SDBP; therefore, the greater growth performance of pigs fed the plasma protein diets than pigs fed the SPC diet indicates that SPC is not as effective as plasma protein in increasing growth of pigs exposed to a sanitary challenge.

Infection of *Escherichi coli* is one of the main causes of post weaning diarrhea, which reduces intestinal barrier function of pigs (Heo et al., 2013). Therefore, the observed reduction in fecal scores of pigs fed H-SDBP or SDBP diets during phase 1 indicates that plasma protein may influence community structure of microorganisms in the intestinal tract of pigs. The ability of H-SDBP or SDBP in reducing fecal scores of pigs is also likely due to the presence of immunoglobulins in these feed ingredients that could identify and neutralize pathogenic bacteria, viruses, and parasites that consequently enhance the immune response of pigs (Pierce et al., 2005). However, because we did not determine concentrations of microbes in the intestinal tract of pigs in this experiment, we are unable to identify the mechanism for the reduced fecal score. Nevertheless, results of the experiment indicate that inclusion of H-SDBP or SDBP in diets for weaned pigs can be used as a strategy to reduce severity and occurrence of diarrhea of pigs during the initial post weaning period.

5. Conclusion

Fully replacing soy protein concentrate with hydrolyzed spray-dried bovine plasma or spray-dried bovine plasma increased average daily gain, feed efficiency, and final body weight of pigs housed in unsanitary conditions. Both sources of spray-dried bovine plasma also reduced fecal scores of pigs during the initial 2-weeks post weaning. Therefore, both plasma sources were effective in increasing growth performance and reducing fecal scores of pigs.

CRediT authorship contribution statement

JMC and HHS conceptualized the experiment. CDE summarized and analyzed the data. CDE, JMC, and HHS interpreted data. CDE wrote the first draft of the manuscript. CDE, JMC, and HHS edited the final version of the manuscript. HHS supervised the project.

Conflict of interest

JMC is an employee at APC, LLC (Ankeny, IA 50021, USA), a global supplier of plasma protein to the feed industry. CDE and HHS have no conflicts of interest.

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