Effect of spray-dried porcine plasma protein and egg antibodies in diets for weaned pigs under environmental challenge conditions

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Summary

Objectives: To study the effects on performance of weaned pigs reared in an uncleaned nursery and fed diets containing either egg yolk antibodies (EYA) or spray-dried porcine plasma (SDPP) at one of two dietary inclusion rates.

Material and methods: Weaned pigs (21 days of age; 6.3 kg body weight) housed in an uncleaned nursery were fed diets containing 3% or 6% SDPP or 0.2% EYA for 14 days post weaning, then a common diet to day 28 post weaning (nine replicates, four pigs per pen).

Results: During the initial 14 days, in pigs fed diets with increasing levels of SDPP, there was a linear improvement ($P < .05$) in day 14 body weight and average daily weight gain (ADG) and a tendency ($P < .10$) for improved average daily feed intake (ADFI) and gain-to-feed ratio (G:F). In addition, pigs fed SDPP had greater ADG, ADFI, and G:F than pigs fed EYA ($P < .05$). Performance variables did not differ between pigs fed the EYA diet and those fed the unsupplemented control diet. During the common starter-diet phase (days 15 to 28), G:F was lower ($P < .01$) for pigs previously fed SDPP diets. Over the 28-day period, performance variables did not differ ($P > .05$).

Implications: Under the conditions of this study, while performance may not be better in pigs fed an EYA diet than in pigs fed a control diet, performance may be better in pigs fed SDPP diets than in controls during the initial 14-day period.

Keywords: swine, spray-dried porcine plasma, egg antibodies, environmental stress, post-weaning diets.

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Resumen - Efecto de la proteína de plasma secada por spray y los anticuerpos de huevo en dietas de cerdos destetados bajo condiciones medioambientales de reto

Objetivos: Estudiar los efectos en el desempeño de cerdos destetados criados en un destete sucio y alimentados con dietas conteniendo anticuerpos de yema de huevo (EYA por sus siglas en inglés) o plasma secado por spray (SDPP por sus siglas en inglés) en uno de dos porcentajes de inclusión en la dieta.

Material y métodos: Cerdos destetados (21 días de edad; 6.3 kg de peso corporal) alojados en un destete sucio fueron alimentados con dietas que contenían 3% ó 6% SDPP ó 0.2% EYA durante 14 días post-destete, seguido de una dieta común hasta el día 28 post-destete (nueve réplicas, cuatro cerdos por corral).

Resultados: Durante los primeros 14 días, en cerdos alimentados con dietas con niveles crecientes de SDPP, se observó una mejora linear ($P < .05$) en el peso corporal del día 14 (ADG por sus siglas en inglés), y una tendencia positiva en el consumo diario de alimento (ADFI por sus siglas en inglés) y la relación ganancia-alimento (G:F, por sus siglas en inglés). Además, los cerdos alimentados con SDPP tuvieron mayores ADG, ADFI, y G:F que los cerdos alimentados con EYA ($P < .05$). Las variables del desempeño no difirieron entre los cerdos alimentados con la dieta EYA y los alimentados con la dieta control no suplementada. Durante la fase común de inicio de dieta (días 15 a 28), la G:F fue más baja ($P < .01$) en los cerdos alimentados anteriormente con dietas SDPP. Durante el periodo de 28 días, las variables de desempeño no difirieron ($P > .05$).

Implicaciones: Bajo las condiciones de este estudio, mientras que el desempeño puede no ser mejor en los cerdos alimentados con una dieta con EYA comparado con en los cerdos alimentados con la dieta control, el desempeño durante el periodo inicial de 14 días puede ser mejor en los cerdos alimentados con la dieta SDPP que en los controles.

Résumé - Effet de protéines plasmatiques porcines séchées par jet et d'anticorps d'œufs chez des porcs sevrés dans des conditions environnementales délétères

Objectifs: Étudier les effets sur la performance de porcs sevrés élevés dans une pouponnière non-nettoyée et nourris avec des rations contenant soit des anticorps de jaune d'œuf (EYA) ou un des deux taux de protéines plasmatiques porcines séchées par jet (SDPP).

Matériels et méthodes: Des porcs sevrés (21 jours d'âge; 6,3 kg de poids corporel) logés dans une pouponnière non-nettoyée ont été nourris avec des rations contenant 3% ou 6% de SDPP ou 0,2% de EYA pendant 14 jours post-sevrage, puis avec une ration commune jusqu'au jour 28 post-sevrage (neuf réplications, quatre porcs par enclos).

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Résultats: Pendant les 14 premiers jours, chez les porcs nourris avec des rations ayant des quantités de SDPP croissantes, il y avait une amélioration linéaire ($P < 0,05$) du poids corporel au jour 14 et du gain de poids journalier moyen (ADG) et une tendance ($P < 0,10$) à une amélioration de la consommation quotidienne moyenne de nourriture (ADFI) et du ratio gain-consommation (G:F). De plus, les porcs nourris avec SDPP avaient des valeurs d'ADG, d'ADFI, et de G:F plus élevées que les porcs nourris avec EYA ($P < 0,05$). Aucune différence ne fut notée entre les variables de performance des porcs nourris avec la ration avec EYA et ceux nourris avec une ration témoin non-supplémentée. Pendant la période d'alimentation avec la ration de début commune (jours 15 à 28), le ratio G:F était inférieur ($P < 0,01$) pour les porcs nourris avec les rations contenant SDPP. Pour la période entière des 28 jours, les variables de performance ne différaient pas ($P > 0,05$).

Implications: Dans les conditions expérimentales de la présente étude, bien que les performances des porcs nourris avec une ration EYA n'étaient pas meilleures que celles des porcs nourris avec une ration témoin, les performances des porcs nourris avec des rations SDPP peuvent être meilleures que celles des animaux témoins durant la période initiale de 14 jours.

Weaning is one of the most stressful periods in the life of a pig, resulting in lower feed intake, poorer growth, and higher morbidity and mortality, particularly during the first weeks after weaning or until the immune system has become more fully developed. Weaning is a stress, independent of weaning age, caused by the abrupt separation from the sow and by other stressors related to changes in the physical and social environment, mingling with pigs from different litters, dietary transitions, and exposure to different pathogens or antigens.[1] Weaning stress causes intestinal inflammation and damage to mucosal barrier structure and function.[2-5] Therefore, it is crucial that the pig overcomes weaning stress rapidly to survive and be productive through the commercial production cycle.

Along with good husbandry and health management, dietary interventions may be a viable and practical way to help pigs adapt and transition through the complexities associated with weaning stress. Many studies have demonstrated consistently better performance with the use of spray-dried plasma (SDP) than with other protein sources, independent of its origin (porcine, bovine, or a blend), in diets for weaned pigs.[1,6,7] Several studies have also reported that SDP reduces the incidence of diarrhea during the post-weaning phase,[8,9] and improved performance has been described in pigs kept under less hygienic research conditions or commercial circumstances[10] or in younger pigs with less mature immune systems.[11] In addition, some studies also show that the intestinal mucosal immune response is better in animals fed diets containing SDP.[12-14] Taken together, these studies suggest that diets containing plasma proteins improve the immunological response to stress without compromising the response to pathogens, allowing the animal to use more nutrients for growth and other productive functions instead of for maintaining the immune response.

Spray-dried whole egg (SDE) without shells is an excellent nutrient source due to its high digestibility, favorable amino acid balance, fat content, and high metabolizable energy (ME).[15,16] In addition, SDE derived from hens not hyperimmunized against specific pig pathogens contains active components such as immunoglobulins (IgY),[17] lysozyme, and antimicrobial proteins.[18] Inclusion of SDE in nursery pig diets did not consistently promote better performance than did other high-quality protein ingredients, eg, SDP, milk proteins, and fish meal.[19]

Egg-yolk antibodies (EYA) from eggs produced by hens hyperimmunized against specific bacterial antigens have been suggested as a more efficient source of SDE and as an effective way to control diarrhea in post-weaned pigs.[20-23] Positive responses to EYA have been consistent when the microorganism used to challenge the pigs is the same as that used to hyperimmunize the hens.[20-23] However, limited published information is available about the use of EYA under commercial conditions when sanitation is suboptimal.

The purpose of this study was to investigate the effects on performance of weaned pigs reared under unsanitary conditions (pens not cleaned and sanitized after previously housing pigs) and fed diets containing either EYA or one of two dietary inclusion levels of SDP of porcine origin (SDPP).

Materials and methods

The experimental procedures with animals described in this study were conducted after approval from the Institut de Recerca i Tecnologia Agroalimentàries (IRTA) Ethical Committee on Animal Experimentation. The IRTA is a research institute belonging to the Catalonia government.

Animals and housing

The study was conducted in the post-weaning facility of the experimental farm of IRTA Animal Nutrition (Centre Mas de Bover, Constantí, Spain). The pigs were housed in two nursery rooms with 24 and 12 pens, respectively, each 1.7 m^2 (0.96 m × 1.77 m), with four pigs per pen. All pens were identically equipped with one single-sided hopper feeder with four eating spaces, and a cup-type drinker system. The rooms had automatic heating, forced ventilation, and completely slatted floors. The experimental facilities were not cleaned prior to the entry of the study animals in order to impose an environmental challenge.

One hundred and forty-four newly weaned intact male pigs (Duroc × Landrace), obtained from a commercial farm at 21 days of age, were used in the study. Average initial body weight (BW) was 6.3 kg (standard deviation [SD], 0.80 kg). At the start of the study, the pigs were sorted by BW and divided into 36 groups of four animals, so that the first four groups (ie, 16 animals) belonged to block 1, the next four to block 2 and so on, up to block 9. The four animals in a given group were randomly distributed, using the random number generator function in Excel (Microsoft Corporation, Redmond, Washington), among the four replicates (pens) in the corresponding block, and the same was done for the other groups in the same block. This was repeated for all blocks, so that nine blocks with four replicates (pens of four piglets) were generated. The four pens belonging to a block were adjacent to each other and in the same room, so that location was also considered within the block effect. Once the pigs had been assigned to the 36 replicates, the four experimental treatments were randomly assigned, using the random generator function in Excel, to the four replicates in each block.

Experimental design and treatments

The experimental diets (13.8 MJ metabolizable energy [ME]; 13.5 g per kg lysine) were offered for a period of 14 days (pre-starter phase). Between days 15 and 28, a common starter diet (without SDPP or EYA) was offered (13.6 MJ ME;

Table 1: Composition (%) of nursery-pig diets containing spray-dried porcine plasma (SDPP) or egg yolk antibodies (EYA) or an unsupplemented control diet (Control)*

Ingredients	Control	SDPP3	SDPP6	EYA	Starter
Wheat	25.00	25.00	25.00	25.00	0.00
Barley	20.00	20.00	20.00	20.00	38.43
Maize	15.00	15.00	15.00	15.00	25.00
Soybean meal (48% CP)	12.62	13.11	13.25	12.62	22.60
Sweet milk whey	10.00	10.00	10.00	10.00	6.86
Soy protein concentrate (65% CP)	6.00	3.00	0.00	5.80	0.00
SDPP†	0.00	3.00	6.00	0.00	0.00
EYA‡	0.00	0.00	0.00	0.20	0.00
Wheat middlings	4.00	4.00	4.00	4.00	0.00
Lard	3.50	3.50	3.55	3.50	3.39
Dicalcium phosphate	1.86	1.59	1.53	1.86	2.20
Calcium carbonate	0.53	0.71	0.74	0.53	0.18
L-lysine-HCl	0.49	0.40	0.32	0.49	0.40
DL-methionine	0.19	0.15	0.14	0.19	0.15
L-threonine	0.17	0.11	0.06	0.17	0.13
L-tryptophan	0.05	0.03	0.02	0.05	0.01
Salt	0.20	0.00	0.00	0.20	0.24
Vitamin-mineral complex§	0.40	0.40	0.40	0.40	0.40

* 144 weaned pigs (21 days of age; 6.3 kg body weight) were housed in two nursery rooms with 24 and 12 pens, respectively, and four pigs per pen. Pens had not been cleaned after the previous use. Experimental diets were fed during the first 14 days post weaning (pre-starter phase). Between days 15 and 28 post weaning, all animals were fed the Starter diet. Totals may not add to 100.00% because of rounding. Diets were formulated to meet the nutrient requirements of piglets (National Research Council [1998]).[24]

† SDPP used was AP-820P (APC Europe, SA, Granollers, Spain), included as either 3% (SDPP3) or 6% (SDPP6) of the diet.

‡ EYA used was Globigen (EW Nutrition GmbH, Visbek, Germany).

§ Provided per kg of diet: vitamin A, 10,000 IU; vitamin D3, 2000 IU; vitamin E, 15 mg; thiamine, 1.3 mg; riboflavin, 3.5 mg; vitamin B12, 0.025 mg; vitamin B6, 1.5 mg; calcium pantothenate, 10 mg; nicotinic acid, 15 mg; biotin, 0.1 mg; folic acid, 0.6 mg; vitamin K3, 2 mg; iron, 80 mg as iron sulfate; copper, 6 mg as copper sulfate; cobalt, 0.75 mg as cobalt sulfate; zinc, 185 mg as zinc oxide; manganese, 60 mg as manganese sulfate; iodine, 0.75 mg as potassium iodate; selenium, 0.10 mg as sodium selenite; ethoxyquin, 0.15 g.

CP = crude protein.

12.5 g per kg lysine). Diets were formulated to meet the nutrient requirements of the National Research Council (NRC; 1998).[24] Feed was presented in mash form and offered ad libitum. Ingredient and nutritive compositions of the diets are shown in Table 1 and Table 2, respectively.

The four feed treatments consisted of a control group (Control); two treatments containing SDPP (AP820P from APC Europe, SA, Granollers, Spain) at 3% and 6%, replacing soy protein concentrate in the Control diet (SDPP3 and SDPP6 groups); and a fourth treatment containing a commercial EYA product (Globigen; EW Nutrition GmbH, Visbek, Germany) at the manufacturer-recommended dietary inclusion rate (0.2%), also replacing soy protein concentrate (EYA group). According to the manufacturer's literature, the Globigen EYA product contains specific antibodies (immunoglobulins) against a number of pathogens described as "*Escherichia coli K88, E coli K99, E coli 987P, E coli Oedema, Salmonella typhimurium,* transmissible gastroenteritis virus*, Cryptosporidium, Rotavirus, Clostridium perfringens,* circovirus." The experimental feeds were offered from day 1 through day 14 post weaning, and a common starter diet was fed to all animals from day 15 through day 28.

Feed and piglets were weighed at the start of the study, at day 14, and at the end of the study (day 28). Initial and final BW, average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F) were calculated.

Statistical analysis

The experimental unit was the pen, and average pen values were used for the performance parameters. For statistical analysis (GLM procedure; SAS Inc, Raleigh, North Carolina), a randomized block design was used, with initial weight and pen location as block criteria. Least squares means, probabilities of differences, and standard errors of the mean were obtained to evaluate differences among treatment means.

In addition, orthogonal contrasts were used to compare production parameters in pigs in the Control or the EYA treatments versus the two SDPP treatments, and to determine

Table 2: Estimated nutritive compositions (%) of an unsupplemented nursery-pig control diet (Control) or the control diet supplemented with either spray-dried porcine plasma (SDPP) or egg yolk antibodies (EYA)*

Analyte	Control	SDPP3	SDPP6	EYA	Starter
Crude protein	19.12	19.34	19.43	19.08	19.50
Crude protein (analyzed)	19.53	19.55	19.62	19.67	18.51
Crude fiber	2.86	2.79	2.70	2.85	3.12
Fat	5.20	5.26	5.35	5.21	5.37
Ash	5.69	5.71	5.98	5.69	5.86
Lactose	7.29	7.29	7.29	7.29	4.32
Energy (MJ ME/kg)	13.8	13.8	13.8	13.8	13.6
Calcium	0.85	0.85	0.85	0.85	0.80
Phosphorous	0.70	0.70	0.74	0.70	0.78
Chloride	0.46	0.41	0.49	0.46	0.41
Sodium	0.15	0.19	0.30	0.15	0.15
Total methionine	0.47	0.43	0.41	0.47	0.43
Total methionine + cystine	0.81	0.81	0.83	0.81	0.75
Total lysine	1.35	1.35	1.35	1.35	1.25
Total tryptophan	0.27	0.27	0.27	0.27	0.23
Total threonine	0.88	0.88	0.88	0.88	0.81
Total valine	0.91	0.96	1.01	0.91	0.88
Total isoleucine	0.80	0.79	0.77	0.80	0.76
SID methionine	0.44	0.40	0.37	0.44	0.40
SID methionine + cystine	0.73	0.71	0.72	0.73	0.61
SID lysine	1.23	1.21	1.19	1.23	1.12
SID tryptophan	0.24	0.23	0.22	0.24	0.20
SID threonine	0.76	0.74	0.73	0.76	0.70
SID valine	0.79	0.83	0.86	0.79	0.72
SID isoleucine	0.71	0.69	0.67	0.71	0.65

* Study described in Table 1. Diets were formulated to meet the nutrient requirements of piglets (National Research Council [1998]).[24]

SID = standardized ileal digestible amino acids; ME = metabolizable energy.

the linear response to the increasing dose of SDPP supplementation. Results were considered statistically significant at $P < .05$ and a trend was defined at $P < .10$.

Results

During the pre-starter period (days 0 to14), four piglets died with signs of diarrhea (two in the Control group and two in the SDPP3 group). During the common starter phase (days 15 to 28), another four piglets died (one in the Control group, two in the SDPP6 group, and one in the EYA group). Four animals from the SDPP3 treatment group were culled due to extremely poor body condition. The data from these animals were considered missing values and were not used in the calculations. Their feed intake was calculated with a model that estimates the individual feed intake of pigs in group feeding,[25] and was subtracted from the total intake of the corresponding pen.

Between days 0 and 14 (Table 3), ADG was greater in the SDPP6 group ($P < .05$) than in the Control and EYA groups. For BW, ADG, and ADFI, performance in the SDPP3 group was intermediate between the Control and SDPP6 groups. Gain-to-feed ratio for EYA treatment was the lowest in this period. Linear improvements ($P < .05$) in BW and ADG and tendencies ($P < .10$) for higher ADFI and G:F were observed with increasing SDPP during this period. In addition, groups fed SDPP had greater ADG, ADFI, and G:F than the group fed EYA ($P < .05$), and tended to have greater ADG than the Control group ($P < .10$). Performance data did not differ between pigs fed the diet including EYA and those fed the Control diet.

During days 15 to 28 (Table 4), when a common starter diet was fed to all animals, no significant differences in ADG and ADFI were observed among treatments. However, pigs that had been previously fed SDPP had lower G:F than did the Control and EYA groups ($P < .01$).

For days 0 through 28, no differences for any parameters were observed among treatment groups. However, relative to the Control group, in pigs previously fed SDPP6, final BW was 0.46 kg higher, while in pigs previously fed the SDPP3 and EYA diets, final BW was 0.59 and 0.43 kg lower, respectively.

Discussion

In this study, pigs were subjected to challenging conditions by being weaned and housed in pens uncleaned since previous use. These conditions were effective in inducing post-weaning growth depression, as can be observed from the generally low growth rates of these animals, compared to normal production values in the industry or experience before and after the current trial in the same facilities. In the study facility, ADG of similar pigs on similar diets, but weaned into a clean environment, ranged from 175 to 250 grams per day at 0 to 14 days post weaning. The pathogens associated with these stressful conditions were not determined, but signs of watery diarrhea and poor feed conversion were observed.

Although the nutrient compositions of the experimental diets met the nutrient recommendations of the NRC (1998),[24] it could be argued that the diets were limiting for sodium and some essential amino acids, according to the values proposed more recently (NRC; 2012).[26] Even if some nutrients were limiting, the magnitude of their limitation cannot explain the poor performances observed. Instead, it is more likely that poor performance was driven mainly by the markedly lower feed intake of the study pigs. Under the conditions of the current trial, health status of the animals might have been compromised, resulting in the observed poor appetite.

The better performance observed with the inclusion of SDPP in the feed during the initial 14 days was consistent with previous publications indicating that formulating diets with SDPP improves post-weaning performance of pigs, especially when sanitary conditions are not optimal.[1,10] Several publications have demonstrated that when SDPP is included in the diet of animals challenged with a diversity of pathogens (*Escherichia coli*, *Salmonella*, rotavirus, porcine reproductive and respiratory syndrome, and porcine epidemic diarrhea virus [PEDV]), the animals had better health and more rapid recovery from these pathogens.[27-33] Enhanced performance provided by SDPP in diets for weaned pigs may be related to beneficial effects on intestinal barrier function, inflammation, and diarrhea.[13]

During the common starter phase (days 15 through 28), the two groups of pigs previously fed SDPP diets had lower G:F than did the Control or EYA groups. Over the entire study period (days 0 to 28), pigs previously fed the SDPP6 diet had numerically better final BW, ADG, and ADFI than did the Control group, but this was not the case for the SDPP3 and EYA groups. The reasons for these observations in the current study are unknown. However, it has been reported[13] that pigs fed a diet with 5% SDPP for 14 days post weaning had less secretory activity, lower diarrhea scores, and less pro-inflammatory cytokine (mRNA TNF-α) in colon tissue, resulting in less damage to gut barrier function than in pigs fed diets with either 0% or 2.5% SDPP.[13] In addition, a recent study[30] demonstrated that the dietary inclusion rate of SDPP and feeding duration post weaning is important for maintaining longer-term gastrointestinal tract function after SDPP is removed from the diet. In that study,[30] pigs were fed diets with either 0%, 2.5%, or 5.0% SDPP (5.0% SDPP in a diet fed for 14 days versus 2.5% SDPP in a diet fed for 7 days), and at day 34 in the nursery (50 days of age) pigs were transported to a different facility and challenged with *Salmonella* Typhimurium. At day 2 post challenge, distal ileum samples were collected and subjected to various chemical and physical measures. Results indicated pigs previously fed the 5.0% SDP diet for 14 days post weaning had lower histological scores, myeloperoxidase and IL-8 concentrations, and 4 kDa fluorescein isothiocyanate dextran (FD4) flux rates, along with higher concentrations of plasma and ileal TNF-α than in other groups, suggesting that inclusion rate and duration of feeding SDPP in diets can influence subsequent immunological and intestinal injury induced by *Salmonella* challenge. The data from the

Table 3: Productive parameters (least squares means) of pigs between 0 and 14 days of the experiment*

	BW (kg) Day 0	BW (kg) Day 14	ADG (g)	ADFI (g)	G:F ratio
Control	6.31	6.61[a]	21[a]	108	0.26
SDPP3	6.31	6.81[ab]	35[ab]	123	0.28
SDPP6	6.33	7.19[b]	62[b]	141	0.43
EYA	6.30	6.44[a]	9[a]	98	0.18
Root MSE	0.031	0.496	34.1	36.8	0.166
			***P* values**		
Treatment effect	> .10	< .05	< .05	< .10	< .10
Linear effect of SDPP dose	> .10	< .05	< .05	< .10	< .10
SDPP versus Control	> .10	< .10	< .10	> .10	> .10
SDPP versus EYA	> .10	< .05	< .05	< .05	< .05

* Study described in Table 1. Data were analyzed as a randomized block design with pen as the experimental unit using the GLM procedure (SAS Institute Inc, Cary, North Carolina). Values were considered significant at $P < .05$, and $P < .10$ was considered a trend.

[ab] Values in the same column with different superscript letters are significantly different ($P < .05$).

BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed ratio; SDPP = spray-dried porcine plasma, at 3% (SDPP3) or 6% (SDPP6) of the diet; EYA = egg yolk antibodies; MSE = mean square error.

Table 4: Productive parameters (least squares means) of pigs between 15 and 28 days of experiment*

	BW (kg)		ADG (g)	ADFI (g)	G:F ratio
	Day 15	Day 28			
Control	6.61[a]	9.82	229	357	0.64[a]
SDPP3	6.81[ab]	9.23	173	330	0.53[b]
SDPP6	7.19[b]	10.28	221	392	0.55[b]
EYA	6.44[a]	9.39	211	336	0.63[a]
Root MSE	0.496	1.151	53.5	76.8	0.060
			***P* value**		
Treatment effect	< .05	> .10	> .10	> .10	< .01
Linear effect of SDPP dose	< .05	> .10	> .10	> .10	< .01
SDPP versus Control	< .10	> .10	> .10	> .10	< .01
SDPP versus EYA	< .05	> .10	> .10	> .10	< .01

* Study described in Table 1. Data analyzed as a randomized block design with pen as the experimental unit using the GLM procedure (SAS Institute Inc, Cary, North Carolina). Values were considered significant at $P < .05$, and $P < .10$ was considered a trend.

[ab] Values in the same column with different letters are significantly different ($P < .05$).

BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed ratio; SDPP = spray-dried porcine plasma, at 3% (SDPP3) or 6% (SDPP6) of the diet; EYA = egg yolk antibodies; MSE = mean square error.

current study indicate that the inclusion rate of SDPP in the diet may need to be higher than 3% to maintain the performance benefits obtained during the initial 14 days post weaning.

Likewise, some studies suggest a growth-promoting effect of EYA in early-weaned pigs challenged with specific pathogens.[20-23] In most studies demonstrating improvements in animal performance when EYA has been fed, the animals had been challenged with the same pathogen for which the hens had been inoculated to produce the specific EYA. For example, a study[22] reported the effect on performance of pigs challenged with enterotoxigenic *Escherichia coli* (ETEC) K88 when a pea-protein-based diet was supplemented with EYA from hens immunized with ETEC K88 antigen. The results indicated that the pigs fed a diet with EYA had higher ADG than those fed a Control diet without EYA. In the same study,[22] pigs fed a diet with SDPP also had a higher ADG than the Control group, but no differences were observed between the groups supplemented with SDPP or EYA. In addition, the authors reported less severe diarrhea and lower mortality when either EYA or SDPP was included in the diets. Both the EYA and SDPP diets contained specific antibodies against ETEC K88 and F18, and therefore the authors suggested that the antibodies in these two products may have prevented ETEC K88 from binding to the mucosal receptors.[22] A different study[19] in weaned pigs fed diets containing SDE without antibodies against specific pathogens reported that pigs fed the SDE diet had higher ADFI during the first 7 days post weaning than did the pigs fed the control diet, but other performance parameters did not differ. However, pigs fed a diet containing SDP had significantly higher ADG, ADFI, and G:F than the control group. Similarly, in an earlier study,[34] weaned pigs were fed a diet containing egg-yolk powder with antibodies against *Salmonella* Typhimurium or a diet containing SDP, or were treated with antibiotics starting at day 3 of the trial. At day 7, all pigs were challenged with the strain of *Salmonella* Typhimurium used in the egg-yolk powder. The authors found that the percentage of pigs shedding *Salmonella* was lower in the antibiotic treatment group than in the other groups. However, *E coli* antibiotic resistance was greater in pigs fed antibiotics than in pigs in the other treatment groups. Health and performance indicators (weight gains, white blood cell counts, and plasma concentrations of *Salmonella* antibodies) did not differ among treatment groups, indicating that feeding those antibodies may not have been effective in reducing *Salmonella* shedding. Further, in another study,[35] weaned pigs challenged with K88$^+$ *E coli* and fed diets with 0.00%, 0.32%, or 3.20% EYA (IgY) developed watery diarrhea and became dehydrated, compared to an unchallenged Control group. No quantifiable concentrations of IgY were detected either in treated or Control pigs by testing small intestinal content using an enzyme-linked immunosorbent assay. According to the authors, the *E coli* challenge was successful in creating a clinical syndrome similar to field cases. The presence of chicken egg-yolk antibodies in the feed did not appear to be effective in preventing the disease.

During the process of manufacturing commercial spray-dried plasma, one single production lot of SDPP is derived from the pooled blood of 6000 to 10,000 pigs.[36] Each lot of SDPP contains antibodies against multiple pathogens circulating in the pig population at any time. Therefore, it is not surprising that SDPP may contain antibodies with neutralizing capacity against the unknown pathogens affecting the pigs used in our study, as it has been demonstrated that commercial SDPP contains neutralizing antibodies against common swine pathogens.[37] However, there is substantial literature demonstrating that the effects of dietary SDPP are due to the presence not only of immunoglobulins, but also other functional proteins, growth factors, cytokines, and biologically active compounds like functional peptides and amino acids that contribute to its beneficial effects on animal performance and health.[12,38] However, the exact roles of each of the functional components present in plasma that contribute to the physiological improvements of gastrointestinal barrier function have yet to be completely elucidated. These proteins can interact with immune cells in the mucosa, thus changing the cytokine environment. In addition to this luminal effect, spray-dried plasma also has systemic effects. For example, it can reduce the expression of pro-inflammatory cytokines in peripheral tissues of pigs challenged with lipopolysaccharides (LPS) from *E coli*[39] and prevent the increase in activated lymphocyte populations in an LPS-induced lung inflammation model.[40] In addition, it has been demonstrated that dietary SDP decreased the uterine concentrations of TNF-α and IFN-γ, and serum TNF-α, C-reactive protein, and cortisol, but increased uterine anti-inflammatory cytokine (TGF-β1) concentration in a pregnancy animal model study.[41] Since the organized gut-associated lymphoid tissue is an inductive site that connects with both local and peripheral effector sites (respiratory tract, glandular tissues, and the uterine mucosa), it can be further hypothesized that spray-dried plasma may favorably modulate the broader common mucosal immune system.

A recent study[33] evaluated a potential positive effect of SDPP or EYA on pigs challenged with PEDV. That EYA product consisted of a liquid egg formulation that, according to company specifications, was tested to contain anti-coronavirus antibodies. The pigs in all the infected groups (Control, SDPP, and EYA) began shedding PEDV in feces by day 3 post infection, and under the study conditions, SDPP or EYA addition did not significantly alter PEDV shedding or overall disease course after experimental challenge, except that the pigs in the SDPP group appeared more active during the acute PEDV disease stage, with less pronounced diarrhea. In addition, fecal PEDV shedding in treated pigs (SDPP or EYA) was lower than in the Control pigs in the early stage of infection, which could contribute to lower environmental PEDV loads and lower transmission rates to uninfected contact pigs. Furthermore, in the same study,[33] at day 3 post infection, adherent *E coli* in the intestine were detected in two of three pigs fed the Control diet and two of three pigs in the EYA group, but none (zero of three) in the SDPP-fed group, indicating that in the PEDV-challenged pigs fed the diet with SDPP, concurrent opportunistic pathogens like *E coli* were prevented.

In summary, the results of the current study indicate that, under the unsanitary conditions described, performance of pigs fed diets with SDPP during the initial 14 days after weaning was better than that of the EYA and Control groups, but longer-term performance (days 0 to 28) did not differ among groups. In this study, challenge pathogens were not identified and antibodies against those specific pathogens were not identified in the EYA fed. Under these conditions, better pig performance was not observed when diets were supplemented with EYA.

Implications

- Under the conditions of this study, spray-dried porcine plasma linearly increases performance in weaned pigs reared in an unknown challenge environment during the period that the ingredient is fed.
- Under the conditions of this study, the performance benefit of feeding spray-dried porcine plasma from day 0 to 14 post weaning is maintained to day 28 when the inclusion rate is 6%, but not when the inclusion rate is 3%.
- Under the conditions of this study, egg-yolk antibodies from eggs of hens hyperimmunized with specific bacterial antigens do not benefit performance in a non-specific pathogenic environment.

Conflict of interest

Javier Polo is employed by APC Europe, SA, Granollers, Spain, a company that manufactures and sells spray-dried plasma. However, APC Europe did not have any additional role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. David Torrallardona has no conflict of interest.

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