Effect of Spray-Dried Porcine Plasma in Peripartum Sow Feed on Subsequent Litter Size

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Abstract

Background Nutritional strategies for sows designed to reduce stress around parturition are suggested to support postpartum recovery and longer-term productivity. Past studies using spray-dried plasma in sow feed reported productivity benefits in sow and litter performance. Other studies indicate stressed animals fed diets with spray-dried plasma have a more efficient immune response to the stress which supports animal recovery and health. The purpose of the present study was to determine if 0, 0.5 or 2.5% spray-dried porcine plasma (SDPP) in peripartum feed provided from entry in maternity through d 5 of lactation affects sow productivity and serological immune and oxidation status markers around parturition and if peripartum feed provided only during the initial parturition affected post-weaning sow productivity parameters including litter size of the next parturition. Results In the initial parturition, litter size for total born pigs was linearly reduced ($P < 0.05$) as dietary SDPP increased and percentage of stillborn pigs per litter decreased quadratically ($P < 0.05$) for sows fed 0.5% or 2.5% SDPP compared to 0% SDPP in peripartum feed. In the subsequent parturition, total born pigs from parity 1 and 2 sows linearly increased ($P < 0.05$) and live born pigs tended ($P = 0.09$) to linearly increase as level of SDPP increased. The change in total and live born litter size from the initial to the next parturition linearly ($P < 0.01$) increased as dietary SDPP increased for parity 1 and 2 sows. Diet did not differ ($P > 0.10$) for serum cytokine markers. Serum glutathione peroxidase activity linearly increased ($P < 0.01$) with increased dietary SDPP for both prepartum and postpartum sampling periods. Conclusions Inclusion of SDPP in peripartum sow feed reduced percentage of stillborn pigs during the initial parturition and increased litter size of parity 1 and 2 sows in the next parturition. The reduced oxidation stress around parturition as indicated by increased serum glutathione peroxidase activity for sows fed SDPP in peripartum feed suggests mitigation of oxidation stress can reduce stillborn rate and have a long-term benefit on subsequent litter size for parity 1 and 2 sows.

Background

Most sow farms typically use a single gestation feed from breeding to entry in maternity followed by a single lactation feed from entry in maternity to weaning to accommodate sow movement and management of feed delivery and storage capacity. Litter size has increased steadily over the past several years and the nutritional needs for high-prolific sows increases, especially during late gestation to support the rapidly growing litter and to maintain sow body condition in preparation for lactation. In commercial production, daily gestation feed is typically restricted, and the amount provided is adjusted to control individual sow body condition. Bump feeding or simply increasing the daily allotted amount of the common gestation feed during late gestation has been commonly used to provide more daily nutrient intake to support sow body condition and the rapidly growing litter. The benefits of bump feeding can be variable in commercial practice, but most report increased sow weight and a modest increase in pig birth weight, but an inconsistent effect on pig survival [1]. Amino acid, energy concentration, and(or) daily feed allowance in late gestation for sows with large litter size need to be adjusted to maintain sow body condition and support litter growth during late gestation and throughout lactation [2–7]. Also, other studies have demonstrated benefits from using ingredients with high fiber content in gestation and lactation feed to support satiety, sow body condition and physiology, colostrum production, and survival of progeny [8–11].

Parturition is often prolonged with larger litter size which drains sow energy during labor and can lead to increased stillbirths, constipation, mastitis, metritis, and agalactia that negatively affects postpartum uterine recovery, and subsequent lactation, progeny survival and growth [12–16]. A peripartum or transition feed should be considered to provide nutrients and ingredients that address needs for the prolific sow in late gestation to help mitigate early postpartum stress and prepare the sow for ad libitum consumption of lactation feed to support milk production, progeny growth and survival and subsequent sow reproductive performance. This targeted application of peripartum feed should be provided to sows as they are moved to maternity and continued for a few days after parturition to facilitate the management and logistics associated with sow movement, feed delivery and storage at the maternity facility.

Spray dried animal plasma (SDP) of porcine (SDPP) or bovine origin (SDBP) has been used in nursery pig diets because of its benefits on post-weaning growth, feed intake, morbidity, and survival [17, 18]. Sows fed SDP in lactation feed had several improvements in productivity measures including higher feed intake for young sows, heavier litter and average pig weight at weaning, improved pig survival, reduced wean to estrus interval, and improved farrowing rate to the next litter [19–23]. Spray dried plasma contains a diverse mixture of components including albumen, globulins, peptides, growth factors, and other components [18]. Research demonstrates that SDP supplementation in feed modulates the efficiency of the common immune systems, including the gastrointestinal, [24–26] respiratory, [27, 28] and reproductive systems, [29, 30] and restores homeostasis of lymphocytes Th-1 and Th-2 balance under an activated immune response initiated by various types of pathogen or environmental stress. More specifically, pregnant mice under transport stress and fed diets with SDP maintained higher pregnancy rates compared to control mice and after only 1 day of feeding exhibited a rapid restoration of Th-1/Th-2 balance in uterine tissue compared to control mice, which had elevated pro-inflammatory cytokines for a longer duration in early pregnancy [30]. In late pregnancy, dietary SDP attenuated inflammation in uterine and placenta tissue and reduced lethargic effects induced by injected lipopolysaccharide [29].

The objectives of the present study were: 1) to determine if titrated levels of 0%, 0.5% or 2.5% SDPP formulated in peripartum feed affected sow productivity and serology parameters around the initial parturition and 2) to determine if there were long-term effects from providing peripartum feed during the initial parturition on post-weaning sow productivity parameters including litter size of the next parturition.

Materials And Methods

Animal care statement

The experiment was done at a commercial sow farm that fulfilled animal housing standards and management by farm animal caretakers, trained to abide by authoritative animal welfare standards established by the *Law on Animal Welfare 2/2008* published by Diari Oficial de la Generalitat Catalunya [31].

Animals and Housing

The study was conducted at a commercial farm in Spain with 2000 sows. Maternity rooms were mechanically ventilated with high-flow fans and individual room temperature control. There were 27 maternity rooms, each with 16 crates. Each crate had individual sow feeders equipped with feed drop tubes and drinkers and supplemental heat pads for the piglets. There were 452 Naïma Choice Genetics sows (average parity 2.63 ± 0.08; parity 1 to 8) used for the study that had their initial parturition from November 2018 through March 2019 and the average age of pigs at weaning was 24.3 ± 0.23 d. Sows were managed using a continuous flow through maternity rooms, thus requiring a rolling random allotment of sows to peripartum diets with an attempt to balance diet allotment as evenly as possible across sow parity as they entered maternity.

Standard production parameters, including litter size of total pigs born, pigs born alive, stillborn pigs, mummified pigs, pigs after cross-fostering, and pigs weaned were recorded for the initial parturition. According to the study protocol, cross-fostering of litters during the initial parturition was only to be done within 48 h postpartum and only within room and within dietary treatment. However, cross-fostering was not successfully accomplished as requested due to the difficulty to manage piglet welfare yet maintain litter integrity within treatment groups throughout the lactation period at this highly prolific sow farm. Therefore, progeny data after cross-fostering to weaning was excluded from the final data analyses due to these uncontrollable, but confounding factors that make it difficult to manage sow studies, especially when having more than two dietary treatments.

Other parameters evaluated included sow mortality and culls prior to movement to breeding, percentage of sows moved to breeding, the intervals for wean to first estrus and wean to final service, percentage of sows completing their next parturition, and litter size at birth of the next parturition. In addition the change in total and live born litter size from the initial to next parturition was calculated, considering total born litter size of the initial parturition was established before peripartum diets were fed. Post-weaning sow reproductive performance and litter size information at birth for the next parturition was recorded to determine if prior feeding of the peripartum feed in the initial parturition impacted subsequent litter size in the next parturition.

Experimental peripartum sow diets

Three peripartum sow diets containing either 0, 0.5 or 2.5% SDPP were formulated to provide similar levels of net energy and amino acids with SDPP replacing soybean meal (Table 1). Sows were provided 3 kg/d of their assigned peripartum feed pellets from the day of entry in maternity to the day of parturition, and 4.5 kg/d from day 1 to 5 of lactation. Peripartum feed output and refusals were recorded during the peripartum period. Average days of the peripartum period and average daily feed intake per sow corrected for feed refusals are presented in Table 2. Sows were provided a common lactation feed for the remainder of the lactation period to weaning and common breeding-gestation feed to the next parturition, however feed consumption per sow was not recorded during these production periods.

Table 1
Ingredient and nutrient composition of peripartum sow diets.

Ingredient, %	0% SDPP	0.5% SDPP	2.5% SDPP
Barley	31.61	30.77	30.35
Corn	15.00	15.00	15.00
Wheat	10.00	10.00	14.00
Wheat bran	20.00	20.00	20.00
Soybean meal (47% CP)	10.30	10.70	5.70
Spray-dried porcine plasma[1]	0.00	0.50	2.50
Ligno-cellulose product[2]	2.50	2.50	2.50
Beet pulp	7.50	7.50	7.50
Soy oil	0.60	0.63	0.20
Calcium carbonate	1.65	1.70	1.70
Monocalcium phosphate	0.04	0.00	0.00
Salt	0.44	0.40	0.25
L-lysine HCL	0.05	0.00	0.00
L-threonine	0.015	0.00	0.00
VTM premix[2]	0.03	0.30	0.30
Analyzed nutrients			
Dry matter, %	87.2	87.3	87.9
Crude protein, %	14.4	15.2	14.6
Calculated net energy, kcal/kg	2101	2100	2100
Calcium, %	0.90	1.04	1.03
Phosphorus, %	0.43	0.45	0.46
Calculated digestible phosphorus, %	0.25	0.25	0.25

[1] APPETEIN GS, APC Europe S.L., Granollers, Spain.

[2] FibreCell 5, Agromed Austria GmbH, Kremsmünster, Austria. Ligno-cellulose product made from wood.

[3] ASN GESTATING SOWS 3 FIT; a commercial vitamin-trace mineral premix plus phytase. Provided the following per kg: vitamin A, 8500 UI; vitamin D3, 1500 UI; vitamin E, 30 total; vitamin E, 15 UI; moliphenol, 3 g, vitamin K3, 2 g; vitamin B1, 1.5 g; vitamin B2, 3 g; vitamin B6, 2 g; vitamin B12, 20 mg; pantothenic acid, 10 g; niacin, 15 g; folic acid, 2 g; biotin, 200 mg; choline, 300 g; Fe, 80 g; Cu, 10 g; Zn, 90 g; Mn, 60 g; selenium total, 0.25 g; organic selenium, 0.1; iodine, 2 g; phytase 750.

Ingredient, %	0% SDPP	0.5% SDPP	2.5% SDPP
Lysine, %	0.65	0.67	0.69
Methionine, %	0.23	0.22	0.22
Methionine + Cysteine, %	0.44	0.44	0.47
Threonine, %	0.56	0.53	0.57
Tryptophan, %	0.19	0.20	0.19
Isoleucine	0.59	0.61	0.57
Valine	0.64	0.68	0.68

[1] APPETEIN GS, APC Europe S.L., Granollers, Spain.

[2] FibreCell 5, Agromed Austria GmbH, Kremsmünster, Austria. Ligno-cellulose product made from wood.

[3] ASN GESTATING SOWS 3 FIT; a commercial vitamin-trace mineral premix plus phytase. Provided the following per kg: vitamin A, 8500 UI; vitamin D3, 1500 UI; vitamin E, 30 total; vitamin E, 15 UI; moliphenol, 3 g, vitamin K3, 2 g; vitamin B1, 1.5 g; vitamin B2, 3 g; vitamin B6, 2 g; vitamin B12, 20 mg; pantothenic acid, 10 g; niacin, 15 g; folic acid, 2 g; biotin, 200 mg; choline, 300 g; Fe, 80 g; Cu, 10 g; Zn, 90 g; Mn, 60 g; selenium total, 0.25 g; organic selenium, 0.1; iodine, 2 g; phytase 750.

Table 2
Peripartum feed intake and litter size during initial parturition by peripartum diet and sow class.

		Peripartum diet, % SDPP[2]			Statistics (F-test, *P* =)[3]					
Variable	Sow Class[1]	0	0.5	2.5	SEM	P	D	L	Q	P x D
Sows, n	A	147	167	138	—	—	—	—	—	—
	Y	94	111	90	—	—	—	—	—	—
	M	53	56	48	—	—	—	—	—	—
Peripartum days	A	10.95	11.42	11.11	0.19	0.03	0.17	0.97	0.06	0.03
	Y	10.46	11.02	11.29	0.23	0.31	0.05	0.04	0.19	0.24
	M	11.43	11.89	10.93	0.30	0.39	0.03	0.06	0.10	0.18
Feed intake, kg/d	A	3.72	3.67	3.69	0.02	0.03	0.07	0.41	0.03	0.02
	Y	3.77	3.70	3.68	0.02	0.41	< 0.01	0.01	0.05	0.04
	M	3.68	3.64	3.70	0.02	0.45	0.02	0.09	0.06	0.14
Total born pigs	A	14.68	14.69	13.82	0.30	< 0.01	0.06	0.02	0.62	0.42
	Y	14.23	14.10	12.83	0.35	0.11	< 0.01	< 0.01	0.73	0.32
	M	15.10	15.29	15.00	0.64	0.59	0.93	0.82	0.78	0.42
Live born pigs	A	12.65	13.12	12.28	0.29	0.07	0.10	0.14	0.12	0.16
	Y	12.68	12.93	11.56	0.34	0.02	< 0.01	< 0.01	0.26	0.21
	M	12.76	13.37	13.13	0.58	0.41	0.72	0.80	0.43	0.55
Stillborn pigs	A	1.84	1.40	1.34	0.17	< 0.01	0.06	0.08	0.09	0.71
	Y	1.45	1.06	1.13	0.16	0.23	0.18	0.35	0.10	0.27
	M	2.07	1.61	1.59	0.43	0.84	0.65	0.50	0.46	0.71

[1] Results for class A included data of all sows with parity categorized as Y for young (parity 1 and 2) sows and M for mature (parity 3 to 8) sows. Results for class Y included only data of young sows and class M included only data for mature sows.

[2] Values are least squares peripartum diet means by sow class.

[3] Each sow class was analyzed for the effects of P (A class, parity category Y or M; Y class, parity 1 and 2; M class, parity 3 to 8), D (peripartum diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet) and P x D (interaction of parity category per sow class by diet).

		Peripartum diet, % SDPP[2]				Statistics (F-test, *P* =)[3]				
Stillborn, %	A	11.78	8.77	9.29	1.01	0.03	0.06	0.23	0.04	0.46
	Y	9.98	7.04	9.04	1.14	0.20	0.14	0.98	0.05	0.12
	M	12.83	9.98	9.78	1.94	0.73	0.53	0.41	0.38	0.82
Mummified pigs	A	0.19	0.17	0.21	0.05	0.02	0.87	0.75	0.67	0.92
	Y	0.11	0.11	0.14	0.05	0.66	0.84	0.56	0.92	0.57
	M	0.26	0.31	0.28	0.14	0.29	0.96	0.99	0.77	0.54
Mummified, %	A	1.22	1.11	1.46	0.39	0.07	0.80	0.56	0.74	0.94
	Y	0.75	0.68	1.18	0.44	0.44	0.66	0.40	0.76	0.30
	M	1.58	2.13	1.82	0.87	0.28	0.88	0.96	0.61	0.36
Sows to breeding, %	A	94.4	92.8	97.8	2.05	0.23	0.20	0.12	0.37	0.69
	Y	92.6	92.8	95.6	2.60	0.76	0.65	0.36	0.90	0.34
	M	97.3	93.8	100.0	3.55	0.88	0.32	0.34	0.32	0.87

[1] Results for class A included data of all sows with parity categorized as Y for young (parity 1 and 2) sows and M for mature (parity 3 to 8) sows. Results for class Y included only data of young sows and class M included only data for mature sows.

[2] Values are least squares peripartum diet means by sow class.

[3] Each sow class was analyzed for the effects of P (A class, parity category Y or M; Y class, parity 1 and 2; M class, parity 3 to 8), D (peripartum diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet) and P x D (interaction of parity category per sow class by diet).

Blood sampling and analytical procedures

Blood samples were collected on day 2 before the expected parturition date and on day 4 after parturition from the tail vein of 57 randomly selected sows using vacutainer tubes without anticoagulant for a total of 78 samples collected. Samples were collected from 21 of the 57 selected sows at both sampling periods. Blood samples were kept at ambient temperature for 30 to 45 min until clot formation, then subjected to centrifugation at 2000 g for 10 min. The serum was pipetted into new tubes, labeled by date and sow number, then stored at -80 °C until analysis for cytokine and oxidation status parameters. Due to hemolysis some samples were discarded. The final number of sows used, and samples statistically analyzed per diet and sampling period are presented in Table 4.

Table 4
Serum cytokine and oxidation status of prepartum and postpartum sows fed peripartum diets with SDPP.

		Peripartum diet, % SDPP[1]				**Statistics (F-test, *P* =)[2]**				
Variable	Period	0	0.5	2.5	SEM	P	D	L	Q	P x D
Sows, n[3]	-2 d	11	13	11	—	—	—	—	—	—
	+ 4 d	14	9	14	—	—	—	—	—	—
IFN-α, pg/mL	-2 d	0.97 (10)	0.49 (9)	0.58 (9)	0.38	0.80	0.17	0.30	0.14	0.88
	+ 4 d	1.27 (13)	0.45 (6)	0.55 (11)	0.47					
IFN-γ, pg/mL	-2 d	1.67 (10)	1.60 (9)	1.69 (9)	0.06	0.73	0.72	0.86	0.44	0.63
	+ 4 d	1.71 (13)	1.67 (6)	1.63 (12)	0.08					
IL-10, pg/mL	-2 d	3.16 (10)	3.43 (9)	3.45 (9)	1.79	0.25	0.70	0.52	0.63	0.81
	+ 4 d	3.61 (13)	5.51 (6)	5.95 (12)	2.20					
IL-1β, pg/mL	-2 d	82.7 (10)	24.5 (9)	8.98 (9)	45.2	0.88	0.23	0.18	0.35	0.99
	+ 4 d	82.1 (13)	31.6 (6)	18.9 (12)	55.4					
IL-4, pg/mL	-2 d	1.68 (10)	1.30 (9)	1.25 (9)	0.29	0.81	0.19	0.18	0.27	0.99
	+ 4 d	1.77 (13)	1.36 (6)	1.28 (12)	0.35					
IL-6, pg/mL	-2 d	32.5 (10)	15.6 (9)	8.46 (9)	14.1	0.81	0.24	0.25	0.26	0.91
	+ 4 d	28.5 (13)	7.36 (6)	12.6 (12)	17.2					
IL-8, pg/mL	-2 d	26.0 (10)	27.9 (9)	13.5 (9)	15.0	< 0.01	0.35	0.21	0.38	0.84

[1] Values are least squares diet means and number (n) of serum samples analyzed by sampling period, 2 d before expected parturition (-2 d) and 4 d after parturition (+ 4 d).

[2] Probability values for P (period), D (diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet), and P x D (interaction of period and diet).

[3] Number of sows sampled by period and diet; number of samples analyzed per cytokine or oxidation status marker varied due to discarded samples affected by hemolysis.

		Peripartum diet, % SDPP[1]				Statistics (F-test, *P* =)[2]				
	+ 4 d	60.6 (13)	78.7 (6)	48.5 (12)	18.4					
TNF-α, pg/mL	-2 d	31.0 (10)	44.6 (9)	19.9 (9)	18.4	0.50	0.83	0.55	0.86	0.72
	+ 4 d	47.9 (13)	36.8 (6)	41.3 (12)	22.5					
IL-12, pg/mL	-2 d	146.2 (10)	89.9 (9)	63.9 (9)	33.5	0.91	0.15	0.22	0.17	0.59
	+ 4 d	122.6 (13)	69.4 (6)	98.9 (12)	41.1					
MDA, µM	-2 d	13.4 (11)	11.2 (13)	12.2 (11)	2.48	< 0.01	0.61	0.49	0.46	0.66
	+ 4 d	17.7 (12)	16.8 (8)	20.8 (13)	2.91					
SOD, U/mL	-2 d	0.97 (11)	0.62 (13)	0.75 (11)	0.15	0.07	0.12	0.20	0.11	0.75
	+ 4 d	1.17 (14)	0.97 (8)	0.87 (12)	0.18					
TAS, mmole/L	-2 d	0.47 (10)	0.61 (13)	0.65 (11)	0.07	0.57	0.15	0.13	0.23	0.66
	+ 4 d	0.56 (11)	0.63 (6)	0.63 (13)	0.09					
GPx, U/L	-2 d	7382 (11)	8188 (13)	9055 (11)	496	0.92	0.01	< 0.01	0.28	0.87
	+ 4 d	7599 (14)	8340 (9)	8806 (14)	548					

[1] Values are least squares diet means and number (n) of serum samples analyzed by sampling period, 2 d before expected parturition (-2 d) and 4 d after parturition (+ 4 d).

[2] Probability values for P (period), D (diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet), and P x D (interaction of period and diet).

[3] Number of sows sampled by period and diet; number of samples analyzed per cytokine or oxidation status marker varied due to discarded samples affected by hemolysis.

Cytokine serum levels were determined using a cytokine and chemokine panel (ProcartaPlex Pig, Luminex B.V, Hertogenbosch, The Netherlands) as specified by the manufacturer: interferon alpha (IFN-α), interferon gamma (IFN-γ), tumor necrosis factor alpha (TNF-α), interleukin (IL), IL-1β, IL-4, IL-6, IL-8, IL-10 and IL-12. Readings were performed on the Luminex MAGPIX system (Luminex B.V, Hertogenbosch, The Netherlands).

Total antioxidant status (TAS), superoxide dismutase (SOD) and glutathione peroxidase (GPx) activities were determined using a kit from RANDOX laboratories (Crumlin, UK) and readings were performed using an AU400 analyzer (Beckman Coulter, Germany). Malonaldehyde (MDA) levels were determined using a TBARS Assay Kit (Cayman Chemical, Michigan, USA) following the manufacturer protocol and readings were performed using the Multiskan Sky (ThermoFisher Scientific, Waltham, MA, USA).

Statistical analysis

All production data with sow as the experimental unit were statistically analyzed by ANOVA using the GLM procedure of SAS (version 9.4, SAS Inst. Inc., Cary, NC) for the effects of parity class, peripartum diet, and interaction of parity class x peripartum diet. Linear and quadratic contrasts were included in the model to test the significance of SDPP level in the peripartum diet. Parity of sows ranged from 1 to 8; however, parity distribution across dietary treatments was not evenly distributed, especially for sows within parity 3 to 8. Unequal parity distribution across treatments can significantly skew calculated least squares means when using parity in the model, so sows were designated into a parity class where Y = young sows (combined parity 1 and 2 sows) and M = mature sows (parity 3 to 8 sows). The designated parity class was used in the statistical model to test parity effects and the interaction of parity class and diet for all sows. The production data results from all sows using this model are designated as class A in Table 2 (initial parturition data) and Table 3 (postweaning to next parturition data).

Table 3

Subsequent postweaning performance and litter size of sows by previous peripartum feed and sow classification.

		Peripartum diet, % SDPP[2]				Statistics (F-test, *P* =)[3]				
Variable	Sow class[1]	0	0.5	2.5	SEM	P	D	L	Q	P x D
Wean to first estrus, d	A	8.63	8.65	8.96	0.64	0.92	0.92	0.68	0.96	0.36
	Y	8.47	8.04	9.59	0.84	0.15	0.38	0.22	0.53	0.26
	M	9.83	8.96	8.51	0.98	0.23	0.59	0.34	0.59	0.03
Wean to final service, d	A	11.43	10.97	10.69	1.00	0.88	0.87	0.64	0.80	0.76
	Y	10.77	10.84	11.14	1.27	0.23	0.98	0.82	0.99	0.03
	M	12.63	10.86	10.02	1.73	0.53	0.51	0.30	0.53	0.52
Sows farrowed, %[4]	A	94.4	92.8	97.2	2.08	0.18	0.29	0.19	0.40	0.61
	Y	92.6	92.8	94.4	2.67	0.58	0.86	0.58	0.96	0.35
	M	96.2	92.9	100.0	3.37	0.88	0.32	0.34	0.32	0.87
Total born pigs	A	14.20	14.53	14.53	0.29	< 0.01	0.64	0.54	0.47	0.04
	Y	14.14	15.09	15.49	0.36	0.11	0.02	0.02	0.12	0.82
	M	14.46	13.50	13.32	0.56	< 0.01	0.26	0.19	0.25	0.50
Live born pigs	A	12.85	12.92	13.08	0.30	< 0.01	0.86	0.58	0.94	0.21

[1] Results for class A included data of all sows with parity categorized as Y for young (parity 1 and 2) sows and M for mature (parity 3 to 8) sows. Results for class Y included only data of young sows and class M included only data for mature sows.

[2] Values are least squares peripartum diet means by sow class.

[3] Each sow class was analyzed for the effects of P (A class, parity category Y or M; Y class, parity 1 and 2; M class, parity 3 to 8), D (peripartum diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet) and P x D (interaction of parity category per sow class by diet).

[4] Percentage of sows having next parturition per sows having initial parturition.

[5] Total born change is total born litter size of subsequent parturition minus total born litter size of previous parturition. Live born change is live born litter size of subsequent parturition minus live born litter size of previous parturition.

		Peripartum diet, % SDPP[2]				Statistics (F-test, *P* =)[3]				
	Y	13.02	13.55	13.97	0.36	0.36	0.18	0.09	0.44	0.72
	M	13.05	11.99	11.83	0.55	< 0.01	0.20	0.16	0.20	0.79
Stillborn pigs	A	0.91	1.21	0.97	0.10	0.25	0.08	0.75	0.03	0.55
	Y	0.76	1.14	0.98	0.12	0.17	0.07	0.55	0.03	0.85
	M	0.96	1.14	1.01	0.22	0.20	0.78	0.97	0.48	0.13
Stillborn, %	A	6.81	8.05	6.93	0.74	0.16	0.40	0.75	0.19	0.87
	Y	5.93	7.47	6.60	0.88	0.40	0.42	0.88	0.19	0.55
	M	6.76	7.94	7.79	1.53	0.09	0.82	0.71	0.58	0.32
Mummified pigs	A	0.44	0.40	0.49	0.05	0.66	0.44	0.33	0.41	0.14
	Y	0.36	0.40	0.54	0.06	0.26	0.08	0.02	0.99	0.43
	M	0.45	0.37	0.48	0.10	0.40	0.60	0.60	0.43	0.43
Mummified, %	A	3.01	2.73	3.61	0.36	0.21	0.20	0.12	0.37	0.37
	Y	2.38	2.69	3.53	0.41	0.27	0.12	0.04	0.86	0.35
	M	3.10	2.64	4.24	0.80	0.54	0.22	0.15	0.45	0.31
Total born change[5]	A	-0.53	-0.30	0.61	0.42	< 0.01	0.13	0.04	1.00	0.05
	Y	-0.13	1.01	2.45	0.51	0.76	< 0.01	< 0.01	0.32	0.93
	M	-0.70	-2.03	-1.68	0.86	0.05	0.48	0.57	0.25	0.83
Live born change[5]	A	0.16	-0.31	0.68	0.41	< 0.01	0.22	0.18	0.26	0.06

[1] Results for class A included data of all sows with parity categorized as Y for young (parity 1 and 2) sows and M for mature (parity 3 to 8) sows. Results for class Y included only data of young sows and class M included only data for mature sows.

[2] Values are least squares peripartum diet means by sow class.

[3] Each sow class was analyzed for the effects of P (A class, parity category Y or M; Y class, parity 1 and 2; M class, parity 3 to 8), D (peripartum diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet) and P x D (interaction of parity category per sow class by diet).

[4] Percentage of sows having next parturition per sows having initial parturition.

[5] Total born change is total born litter size of subsequent parturition minus total born litter size of previous parturition. Live born change is live born litter size of subsequent parturition minus live born litter size of previous parturition.

		Peripartum diet, % SDPP[2]				Statistics (F-test, P =)[3]				
	Y	0.26	0.66	2.17	0.50	0.26	0.02	< 0.01	0.96	0.79
	M	0.27	-1.58	-1.31	0.82	0.045	0.19	0.30	0.11	0.95

[1] Results for class A included data of all sows with parity categorized as Y for young (parity 1 and 2) sows and M for mature (parity 3 to 8) sows. Results for class Y included only data of young sows and class M included only data for mature sows.

[2] Values are least squares peripartum diet means by sow class.

[3] Each sow class was analyzed for the effects of P (A class, parity category Y or M; Y class, parity 1 and 2; M class, parity 3 to 8), D (peripartum diet), L (linear contrast of % SDPP in diet), Q (quadratic contrast of % SDPP in diet) and P x D (interaction of parity category per sow class by diet).

[4] Percentage of sows having next parturition per sows having initial parturition.

[5] Total born change is total born litter size of subsequent parturition minus total born litter size of previous parturition. Live born change is live born litter size of subsequent parturition minus live born litter size of previous parturition.

Subsets of data using only young sows (class Y) or only mature sows (class M) were analyzed separately for the effects of actual parity (within data subset), diet, interaction of parity and diet, and with the linear and quadratic contrasts included to test significance of SDPP level in the peripartum feed. The least squares peripartum diet means ± SEM using this model to analyze the subsets of data for designated class Y and class M sows are also presented in Tables 2 and 3.

Serology results were analyzed by ANOVA using the GLM procedure of SAS for the effects of sampling period (2 days before and 4 days after parturition), peripartum diet, and interaction of sampling period x peripartum diet. Least squares peripartum diet means ± SEM by sampling period for cytokine and oxidation status markers are presented in Table 4.

For all performance and serology results significance was designated at $P < 0.05$, with significant trends at $P > 0.05$, $P < 0.10$.

Results

Production data results

Results of the peripartum feed intake and litter size data during the initial parturition by peripartum diet and sow class are presented in Table 2. The average peripartum period days for class A sows differed by parity and had a quadratic trend by SDPP level and a significant parity by diet interaction. For class Y sows there was a linear increase in peripartum days as SDPP level increased, while for class M sows there as a linear downward trend for peripartum days as SDPP level increased.

Daily peripartum feed intake corrected for feed refusals was affected by parity with a quadratic effect of SDPP level and a significant interaction of parity and diet for class A sows. For class Y sows, feed intake differed by diet with a linear reduction in intake by increased SDPP level and a significant interaction of diet and parity. Feed intake for class M sows was affected by diet with a quadratic trend for SDPP level with 0.5% SDPP having the lower feed intake.

During the initial parturition for class A sows, total born (sum of stillborn, mummified, and live born pigs) was affected by parity and presented a linear decrease ($P < 0.05$) as SDPP level increased with sows fed 2.5% SDPP having the lowest number of total and live born pigs per litter. For Y sows there was a linear ($P < 0.01$) reduction in total born pigs as SDPP level increased, whereas for M sows there were no significant effects of parity or diet for total born pigs per litter.

There was a trend for parity to affect live born pigs for class A sows and for Y sows live born pigs per litter was affected by parity, diet, and presented a linear reduction in litter size as SDPP level increased. There were no significant effects of parity or diet for live born pigs of M sows. Stillborn pigs per litter differed by parity with a downward trend as SDPP level increased in peripartum diets for class A sows. However, there were no significant parity or diet effects on stillborn pigs for Y or M sows.

When stillborn pigs were expressed as a percentage of total born pigs for class A sows, there were significant effects of parity, and a quadratic reduction of percent stillborn pigs as SDPP level increased. Similarly, for Y sows there was a quadratic ($P = 0.05$) reduction of percent stillborn pigs as SDPP level increased, but for M sows there were no significant effects of parity or diet for percent stillborn pigs.

Mummified pigs per litter significantly differed by parity and mummified pigs as a percentage of total born tended to differ by parity for class A sows, however there were no significant effects of parity or diet for number or percentage of mummified pigs per litter for Y or M sows.

During the initial parturition which used 452 sows, 20 died and 5 were culled postweaning. There were no significant effects of parity or diet on the percentage of sows that were moved to breeding for any of the sow classes.

Postweaning sow performance and litter size at birth in the next parturition by sow class and the previously fed peripartum diet during the initial parturition are presented in Table 3. Average wean to first estrus days and average wean to final service days did not significantly differ by diet or parity for all sow classes, however there was a significant parity by diet interaction for wean to first estrus days for M sows and a significant parity by diet interaction for wean to final service days for Y sows.

The percentage of sows that farrowed their next litter based on the number of sows that started in the initial parturition did not significantly differ by parity or diet. Only 1 sow fed the peripartum diet with 0% SDPP in the initial parturition that was mated postweaning, failed to farrow the next litter.

Total born pigs per litter in the subsequent parturition for class A sows was significantly affected by parity and had a significant parity by diet interaction. Total born pigs in the next litter was increased linearly ($P = 0.02$) for Y sows fed increased SDPP levels in the peripartum diet fed during the initial parturition. Total born pigs per litter in the next parturition for M sows was significantly affected by parity but was not significantly affected by diet.

Live born pigs per litter in the subsequent parturition for class A and M sows was significantly affected by parity, but not by diet. Live born pigs in the subsequent parturition for Y sows tended ($P = 0.09$) to present a linear increase in litter size relative to increased SDPP level fed in the previous parturition.

Parity or parity by diet interactions were not significant for number or percentage of stillborn or mummified pigs per litter in the subsequent parturition for any sow class. However, number of stillborn pigs increased quadratically and number and percentage of mummified pigs increased linearly with previously fed SDPP level in the peripartum diet for Y class sows. There were no significant diet effects in any sow class for percentage of stillborn pigs.

The change in total and live born pigs per litter from the previous to the next parturition was calculated considering that litter size for total born in the previous parturition was already established before the peripartum diet was fed, but that subsequent litter size could potentially be impacted by feeding SDPP in the peripartum diet. The change in total born pigs per litter for class A sows was significant for parity and the interaction of parity and diet and presented a linear increase ($P < 0.05$) with increasing SDPP level in the peripartum diet. Change in total born for class Y sows was linearly increased ($P < 0.01$) with increased SDPP level fed during the previous parturition, whereas there were not significant diet effects for M sows.

Change in live born litter size was significantly affected by parity for class A and M sows and there was a trend ($P = 0.06$) for a parity by diet interaction for class A sows. For Y sows there was a linear increase ($P < 0.01$) in change of live born pigs as SDPP level increased in the diet, whereas there were no significant diet effects in M sows.

Serology results

Serology results presented in Table 4 revealed no significant effect of diet on the various cytokines analyzed. Higher levels of IL-8 were detected ($P < 0.05$) during the postpartum period compared to the prepartum period. There was a linear increase ($P < 0.01$) for GPx as SDPP in peripartum feed increased. The other oxidation status markers were not different among peripartum diets, but sampling period differed ($P < 0.05$) for MDA and tended ($P < 0.10$) to differ for SOD, both of which were higher in the postpartum period (day 4 of lactation) compared to the prepartum period (2 days before expected parturition). There were no significant interaction of diet and sampling period for cytokine or oxidation status markers.

Discussion

Although peripartum feed intake significantly differed by diet, this was partially affected by the slightly variable duration of the feeding period and partially by variable amounts of feed refusal. Feed refusals can be common in individual sows, especially around parturition. Based upon the peripartum feed consumption and duration of feeding, sows fed 0.5% SDPP consumed 0.21 kg of SDPP/sow, while sows fed 2.5% SDPP consumed 1.03 kg of SDPP/sow.

At highly prolific sow farms, common management practices include split-suckling, continual cross-fostering throughout lactation, and movement of orphaned pigs, low birth weight pigs or fall-behind pigs to designated nurse sows to assure adequate colostrum and milk intake by piglets. After reviewing the production records from cross-fostering to weaning, it was clear that litter integrity within dietary treatment had been compromised such that results after cross-fostering were confounded. Thus, litter information from cross-fostering to weaning is not reported. Therefore, the inability to maintain litter integrity to weaning during the initial parturition and the inability to record the sow feed intake of the entire lactation period limited our ability to estimate the economic potential of the application.

Previous studies have reported higher ad libitum lactation feed intake by parity 1 and 2 sows and reduced wean to first estrus interval for parity 1 sows [20], increased subsequent parturition rate [21], increased pre-wean survival [19, 22–23], increased litter weight and average pig weight at weaning [20, 21] with more full-value pigs weaned per litter when sows were fed 0.5% SDP in lactation feed [20, 21]. The use of 0.5% SDP in both gestation and lactation feed provided for one year at a PRRSV unstable, 5550 sow farm increased parturition rate and produced 400 more live born and 400 more weaned pigs per 1000 sows serviced per week as determined by statistical process control analysis of weekly production records [32]. However, it is unknown if a similar magnitude of production improvements would be obtained after using SDPP in feed for current sow herds with PRRSV. Additionally, a study reported that 0.5% SDP fed only in gestation feed from day 14 of gestation to day of parturition resulted in increased pig weight at 18 d of age and more full-value pigs weaned per litter compared to a control gestation diet without SDP [33]. However, data is lacking to establish the optimum level and feeding duration of SDP in sow diets at strategic periods of the breeding herd lifecycle, especially when using current sow genetics that have been selected to produce larger litter size than those of the past decade.

The current study is the first known to evaluate the short-term feeding of variable levels of SDPP in peripartum feed for sows when provided from entry in maternity through day 5 postpartum. The production data results indicate that the application of a peripartum feed containing SDPP for sows has potential to benefit lifetime litter size produced per sow due to the reduced incidence of stillborn pigs during the initial parturition and the increased litter size in the next parturition, especially for the young sows which represented about 65% of the sow study population.

During the initial parturition, total and live born pigs per litter decreased as SDPP level in the peripartum diets increased (Table 2). The total born litter size at the initial parturition was already established during the previous breeding cycle, before peripartum diets were fed; thus, the statistical significance of diet for total born per litter do not reflect a physiological response to the consumption of SDPP in the peripartum sow diets. However, the downward quadratic response to SDPP level for percentage of stillborn pigs per litter could reflect a dietary response, because sows had consumed the peripartum diets for 5 to 7 days prepartum. Other studies have demonstrated reduced parturition time and stillbirths are associated with a higher energy status of the sow [34] and use of fiber in sow diets [35]. However, stillbirths were not affected by increased feeding levels in late gestation [4], but gilts with lower feed intake had a lower percentage of stillbirths than gilts fed higher feed intake in late gestation [5]. Other factors such as litter size, birth weight, sow weight, parity, and assisted births can also impact stillbirths [12]. Stillbirths occur during parturition and are highly associated with a prolonged parturition time [16]. In our study, parturition duration was not recorded, but future studies should be designed to understand if dietary SDPP can impact duration of parturition.

During late pregnancy under LPS-induced inflammation, mice fed diets with SDP had reduced overstimulation of pro-inflammatory cytokines in uterine mucosa and placenta and had lowered lethargic reactions to LPS [29]. Recently, sows fed SDP in last trimester gestation and lactation diets and their weaned progeny had lower serum TNF-α and cortisol than control sows and their progeny [36, 37]. However, in the current study there were no diet effects related to serum cytokine profiles of peripartum sows (Table 4) before or after parturition. Postpartum dysgalactic syndrome sows have more pronounced and significant changes in some hormone, metabolic and inflammatory serum markers than normal sows before and after parturition [14, 15]. The lack of detectable diet differences in our study for cytokine profiles may have been due to insufficient sample size or variable stress status of the sampled sows near parturition. However, there was a linear increase in serum GPx as SDPP level increased in both periods (Table 4) suggesting a better antioxidation status of SDPP fed sows. Studies with weaned pigs have reported improved serum antioxidant status when fed diets with SDP [38] and especially if diets contained mycotoxins [39].

In the next parturition there was a linear increase in litter size and litter size change for young sows that had been fed increasing SDPP levels in peripartum feed during the previous parturition, resulting in approximately 1 and 2.45 more change in total born pigs per litter for 0.5 and 2.5% SDPP, respectively (Table 3). In a past study there was a numerical trend ($P = 0.22$) for about 1 more live pig born for gilts in their next parturition when previously fed 0.5% SDP in lactation feed during their initial lactation [20]. Although it had been over 4 months since SDPP had been fed in the current study, prior feeding of SDPP during the initial 5 days postpartum of the previous lactation could have potentially impacted postpartum uterus recovery and possibly affected ovarian function. Small follicles (< 5 mm) are present in the ovaries of lactating sows and they undergo atresia or recruitment for further development in later lactation prior to ovulation 4 to 7 days post-weaning [40]. It is possible that the reduced oxidation status (increased serum GPx, Table 4) of postpartum sows fed SDPP may impact uterine recovery and possibly ovarian function. If so, this suggests the need for future research designed to understand the interacting effects of nutrition, immune system response, oxidation status, and reproductive function.

Reproductive performance can vary by individual sow within the same farm, especially in hot climates [41]. However, the number of pigs born alive per litter for parity 1 and 2 sows has been considered a good predictor for lifetime sow reproductive performance [42, 43]. Young parity sows with low litter size are often culled, while those with higher litter size are kept in the herd. In our study, the linear increase in total and live born litter size of the next parturition for the young parity sows previously fed increased levels of SDPP during their initial parturition suggest that SDPP in peripartum feed can benefit lifetime litter size produced per sow and potentially reduce the culling rate of young sows due to low litter size.

Conclusion

Strategic use of SDPP in peripartum sow feed may have merit for reducing stillborn pigs and have longer-term beneficial effects on litter size in the next parturition, which could lead to more lifetime production of pigs per sow.

Abbreviations

SDP: spray-dried animal plasma; SDPP: spray dried porcine plasma; SDBP: spray-dried bovine plasma; GPx: glutathione peroxidase; SOD: superoxide dismutase; MDA: malonaldehyde; TAS: total antioxidant status; SOD: superoxide dismutase; TNF-α: tumor necrosis factor alpha; IFN-α: interferon alpha; IFN-γ: interferon gamma; IL-1β: interleukin 1β; IL-4: interleukin 4; IL-6: interleukin 6; IL-8: interleukin 8; IL-10: interleukin 10; IL-12: interleukin 12.

Declarations

Ethics approval and consent to participants:Animal Care Statement: The experiment was done at a commercial sow farm that fulfilled animal housing standards and management by farm animal caretakers, trained to abide by authoritative animal welfare standards established by the *Law on Animal Welfare 2/2008* published by Diari Oficial de la Generalitat Catalunya.

Consent for publication: Not Applicable.

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Competing interests: Javier P, Joy C and Joe C are salaried employees of APC LLC, Ankeny, IA USA and Carmen R and Javier P are employed by APC-Europe S.L.A, Granollers, Spain. Both companies manufacture and sell spray dried blood products for use in animal feed. The remaining authors declare no competing interests.

Availability of data and materials: The data that supports the findings of this study are available from the corresponding author upon reasonable request.

Author's contributions: Joe C, LS, ST, CR, Joy C and JP designed the study; Joe C, LS, Joy C, ST and JP developed the nutritional strategy provided in this study; LL and LS conducted the experiment at the farm and collected the performance data and serum samples; DS and JG conducted the serum analysis; Joe C, CR, Joy C and JP provided statistical analysis and co-wrote the paper. All authors contributed to revisions and read and approved the final manuscript.

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