https://doi.org/10.17221/98/2022-CJAS

Dietary brown seaweed and plant polyphenols in hyperprolific sows: Productive performance, blood parameters and antioxidant status

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Citation: Rossi R., Tucci T., Giordano A., Moretti P., Corino C. (2022): Dietary brown seaweed and plant polyphenols in hyperprolific sows: Productive performance, blood parameters and antioxidant status. Czech J. Anim. Sci., 67: 493–502.

Abstract: This study evaluated the productive performance, blood parameters and antioxidant status of hyperprolific sows fed control diet or diet supplemented with brown seaweed and polyphenol mixture (SPM). Ninety-six farrowing highly prolific sows (Topigs 20) were assigned to two dietary treatments from day 107 ± 2 days of gestation until weaning: control diet and the same diet containing 15 g/day of SPM. Sows fed SPM diet tended to have lower backfat losses ($P = 0.06$) than control sows. No difference was observed in daily feed intake. No difference in litter birth weight or number of piglets per litter was observed. In sows fed SPM, average daily gain and weaning body weight of piglets were increased ($P < 0.05$). Haematochemical parameters, haptoglobin and blood total antiradical activity were not affected ($P > 0.05$) by dietary treatment. The paraoxonase-1 activity was higher ($P < 0.05$) in SPM sows than in the control. At the subsequent farrowing, the total number of piglets born was higher ($P < 0.05$) in sows fed SPM than in the control. Overall, these data suggest that dietary plant polyphenols and brown seaweeds improved the weaning weight of piglets and the total number of piglets born at the subsequent farrowing, modulating oxidative stress in lactating highly prolific sows.

Keywords: haematochemical parameters; lactating sow; *Laminaria* spp; performance; oxidative stress markers; natural antioxidant

To improve production efficiency in the pig industry, the dam selection is focused on hyperprolific sows. In the last three decades the litter size has almost doubled. However, an increase in the litter size may be adverse for sow and piglet health and welfare; litter sizes from 14 to 20 piglets can be classified as 'large', influencing the welfare (Baxter et al. 2013). The within-litter variations in piglet weight at birth and the number of piglets with low birth weight have increased, reducing productive performance and posing the risk of piglet preweaning morbidity and mortality (Fix et al. 2010).

The advances in reproductive performance boost sows' metabolic demands during lactation. In the sows, nutrient requirements for milk synthesis increase with litter size and this causes considerable losses of sow's body reserves with problems in productivity and longevity. The modern genotype is faster-growing and has a lower amount of adipose tissue, limiting the sow's opportunity to store

Supported by the University of Milan Department's funds (No. FFABR).

https://doi.org/10.17221/98/2022-CJAS

fat reserves for use in the lactation phase (Tokach et al. 2019). Moreover, hyperprolific sows showed high oxidative stress in late gestation and lactation that negatively affected productive and reproductive performance (Berchieri-Ronchi et al. 2011).

Close attention to the nutrition of hyperprolific sows has an essential role in the improvement of their body condition and therefore of the health of piglets born from large litters. It is thus important to develop new feeding strategies to maintain healthy sows to express their genetic potential.

The plant contains a high amount of active principles that act as antioxidant, antimicrobial, anti-inflammatory and immunostimulant, enhancing the nutrient absorption and improving the microbiota (Valenzuela-Grijalva et al. 2017). Moreover, dietary polyphenols improve antioxidant and immune parameters in lactating sows (Long et al. 2021). Brown seaweeds have gained interest due to their sulphated polysaccharides, phlorotannins, diterpenes, minerals and vitamins content (Corino et al. 2019). Typical molecules such as laminarin and fucoidan exhibit antimicrobial and immunomodulatory properties and play also a role as prebiotics with beneficial outcome on the gut health and immune status (Corino et al. 2021).

The aim of the present research was to explore the impacts of integration with plant polyphenols and brown seaweed mixture in the lactation diet of hyperprolific sows on productive performance, blood parameters and antioxidant status.

MATERIAL AND METHODS

Animals, experimental design and diets

The animal-related procedures were done according to Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes (Article 1, Paragraph 1, Letter b) and approved by the Italian Ministry of Health (D. L. No. 26/2014, Article 2, Paragraph 1, Letter b).

The study was performed in a commercial farrow-to-wean farm with 700 sows, located in northeastern Italy. Ninety-six Topigs 20 pregnant sows from two successive batches were stratified by parity (average parity of 4.15 ± 0.38), and within outcome groups, randomly assigned to two dietary treatments. Sows were moved to the farrowing rooms on day 107 ± 2 of gestation and kept in 1.80 × 2.60 m farrowing crates in an environmentally controlled room. The temperature was kept in the optimal range for the farrowing phase (temperature ranged from 24.4 °C to 28.3 °C) and heat lamps were provided to the newborn piglets.

Sows were randomly assigned to one of the two dietary treatments: a control group (C) fed a commercial diet (Ferraroni Mangimi SpA, Bonemerse, Italy) and a group fed the same diet integrated in top-dressing with 15 g/day of a mixture containing prebiotic polysaccharides from brown seaweeds (*Laminaria digitata* and *L. hyperborea*, ratio 1 : 1) and phenolic acid, hydroxycinnamic acids, tannins, and flavonoids from plant extracts (SPM). The dietary supplementation lasted 28 days, from seven days before farrowing until 21 days post farrowing. The sows received a basal diet formulated to meet or exceed the requirements for nutrient standards (NRC 2012). The diet composition is reported in Table 1.

The phenolic compounds of the supplement were analysed by HPLC-UV–DAD and the beta-carotene quantification was performed by HPLC-UV method. The chemical composition, carotenoid content and the polyphenol composition content of the feed supplement are reported Table 2.

Sows were fed a liquid feed (water to concentrate ratio of 3 : 1) twice daily (at 09:00 and 18:00), with free-choice access to drinking bowls. Animals were fed initially 1.5 kg, and this amount was daily increased by 0.5 kg of feed until day 7 postpartum in relation to the feed consumption of sows. After day 7 postpartum, sows had free access to their diets until weaning. Sows had *ad libitum* access to water. During the trial 12 sows were removed from the trial and the data were removed from the analyses.

Data collection

The sow backfat thickness in P2 (65 mm from the dorsal mid-line at the last rib) was recorded at farrowing and at 21 days of lactation using an ultrasonic apparatus (Piglog 105; SFK-Technology, Herlev, Denmark). The daily feed intake of sows was registered and the average daily feed intake (ADFI) was calculated.

At farrowing the total number of piglets born, piglets born alive, stillborn piglets and mummies were collected. Cross-fostering, to standardize the piglets/litter, was carried out within the same dietary treatment, 24 h after farrowing. The weight

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Table 1. Ingredients and composition of basal diet (as-fed basis)

Ingredient (g/kg)	
Corn	492.3
Barley	110
Soybean meal	180
Wheat bran	100
Beet molasses	40
Soybean oil	20
Fish meal	20
Vitamin mineral premix[1]	10
Calcium carbonate	10
Dicalcium phosphate	10
Sodium chloride	5
L-Lysine HCl	2
L-Threonine	0.5
L-Tryptophan	0.2
Calculated nutrients[2]	
NE (MJ/kg)[3]	10.02
NDF	13.39
ADF	4.41
SID lysine (%)	0.86
SID methionine + cysteine (%)	0.49
SID threonine (%)	0.55
SID tryptophan (%)	0.17
Calcium (%)	0.81
Total phosphorus (%)	0.61

ADF = acid detergent fibre; NDF = neutral detergent fibre; NE = net energy; SID = standardized ileal digestibility

[1]Provided the following per kg of complete diet: vitamin A, 6 000 IU; vitamin D_3, 2 000 IU; vitamin E, 50 IU; vitamin K_3, 2.0 mg; thiamine, 2.0 mg; riboflavin, 6.0 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.2 mg; niacin, 30 mg; pantothenic acid, 20 mg; folic acid, 3.6 mg; biotin, 0.4 mg; choline chloride, 0.8 mg; iron, 96 mg; copper, 20 mg; zinc, 120 mg; manganese, 40 mg; iodine, 0.56 mg; selenium, 0.4 mg

[2]Nutrient contents of diets were calculated according to INRA chemical composition and the nutrient values of feed materials

Table 2. Chemical composition and polyphenol content of the dietary supplement (n = 4)

Item (% on dry matter)	
Dry matter	93.58 ± 5.05
Crude Protein	7.21 ± 0.99
Ether extract	0.32 ± 0.01
Crude fibre	11.20 ± 1.02
Carbohydrates	49.64 ± 3.18
Ash	32.68 ± 1.38
Compounds (mg/kg dry weight)	
β-Carotene	402 ± 30.89
Phenolic acid	
Dihydroxybenzoic acid	≤ LOD
Syringic acid	1 059.79 ± 62.82
Hydroxycinnamic acids	
Neochlorogenic acid	7 979.23 ± 468.11
Rosmarinic acid	126.54 ± 8.67
Trans sinapic acid	105.54 ± 8.09
Chlorogenic acid	21.45 ± 3.65
Tannins	
Ellagic acid	2 440.88 ± 148.29
Rutin	272.37 ± 20.82
Flavonoids	
Myricetin	53.88 ± 5.68
Kaempferol	≤ LOD

LOD = limit of detection

Data are reported as means ± standard deviation

of litters was recorded within 12 h from birth, after cross-fostering, and at 21 days of lactation. The data were used to calculate the piglet average weight, average daily gain (ADG) and mortality rate. A commercial pre-starter feed was offered to the piglets from 10 days of lactation until weaning. The sow reproductive performance was registered: weaning-to-service interval (WSI), fertility, weaning-to-oestrus interval (WEI), farrowing interval (FI), farrowing rate (FR), number of piglets born and born alive at the subsequent farrowing.

Blood sampling

From 42 sows per treatment, randomly selected (n = 21), the blood samples were collected by a puncture of the anterior vena cava at entry to the farrowing room and at 21 days of lactation. The samples were collected in two 10 ml vacutainer glass tubes (Venoject®; Terumo Europe N.V., Leuven, Belgium) containing or not ethylenediaminetetraacetic acid (EDTA) and immediately stored at 4 °C. In the laboratory, samples from EDTA tubes were then centrifuged at 8 500 × g for 5 min at 4 °C to obtain plasma. Samples for serum assays (plain tubes) were left at room temperature until clot formation and then centrifuged at 3 500 × g for 10 min at 4 °C. Harvested serum and plasma samples were then transferred into Eppendorf tubes and stored at −80 °C until they were assayed.

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Haematochemical parameters

Haematochemical parameters were analysed on serum or plasma using an automated spectrophotometer (ILAB300 plus and ILAB600; Instrumentation Laboratory S.p.a., Milan, Italy). The following parameters were measured (in brackets the acronyms and methods used): alanine aminotransferase (ALT, kinetic IFCC), aspartate aminotransferase (AST, kinetic IFCC), total cholesterol (cholesterol oxidase), HDL cholesterol (HDL-C, cholesterol esterase/oxidase reaction after precipitation of LDL and VLD), non-esterified fatty acids (NEFA; ACS-ACOD; Wako Chemicals GmbH, Neuss, Germany), urea (urease), and triglycerides (GPO-PAP).

Paraoxonase-1 activity

The serum paraoxonase-1 activity (PON1) was measured with an automated spectrophotometer (Cobas Mira™, Roche Diagnostics, Indianapolis, IN, USA) using an enzymatic method (Ferre et al. 2002). Serum samples (6 µl) were incubated at 37 °C with 89 µl distilled water and 100 µl 0.05 M glycine buffer (pH 10.5) containing 1 mM paraoxon-ethyl (purity > 90%, Sigma-Aldrich, St. Louis, MO, USA) and 1 mM $CaCl_2$. The rate of paraoxon hydrolysis to p-nitrophenol was measured by recording the increase in absorbance at 504 nm using a molar extinction coefficient of 18 050 l/mol/cm. The PON1 activity, expressed as IU/ml, is defined as 1 nmol of p-nitrophenol formed per minute.

Serum haptoglobin

Serum haptoglobin (Hp) concentration was measured with a colorimetric assay based on the haemoglobin (Hb) binding method (PHASE Haptoglobin assay, Tridelta Development Ltd, Kildare, Ireland), using a microplate reader.

Total antiradicalic activity

The blood total antiradicalic activity was evaluated within 24 h from the sample collection, using the Kit Radicaux Libres (KRL™) test. The whole blood and red blood cells (RBCs) antiradical potential was evaluated using a KRL™ test, which tests blood resistance based on free radical-induced haemolysis. The samples, under orbital shaking, were each submitted in an isotonic saline solution to organic free radical aggression (AAPH) produced at 37 °C. All the antioxidant defences (extracellular and intracellular) contribute to maintaining the blood cell membrane integrity and function till cell lysis. Haemolysis was recorded using a 96-well microplate reader (KRL Reader™ – Kirial International, Couternon, France) by quantifying the optical density decay at 450 nm. Data were reported as the time required to reach 50% haemolysis. Half-haemolysis times (HT_{50}), expressed in minutes, referred to the blood and RBC resistance to free radical damage. The HT_{50} value is representative of the global defences against free radicals (KRL value). Intra- and inter-assay coefficients of variation of the KRL test were 2.5% and 4%, respectively.

Statistical analyses

The data analyses were performed with SPSS v26.0 (IBM Corp., Armonk, NY, USA). The data on sow and piglet performance were analysed by two-way analysis of variance (ANOVA) to evaluate the effects of the dietary treatment and batch. Haematochemical parameters and KRL values were analysed by one-way ANOVA and the values measured at time zero (before treatment) were used as covariates to evaluate the effects of dietary treatments. Data on reproductive performance at the successive farrowing did not show a normal distribution, therefore the nonparametric Mann-Whitney *U*-test was used. The sow was considered as the experimental unit for the productive performance and blood analyses. Data were reported as means ± pooled SEM. Differences were considered significant at $P < 0.05$ and as tendencies at $0.05 > P < 0.10$.

RESULTS

Productive performance

The data on hyperprolific sow performance in relation to the dietary integration are reported in Table 3. The sow parity did not change between experimental groups and resulted higher ($P < 0.01$) in the second batch than in the first. Dietary sup-

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Table 3. Effect of brown seaweed plus polyphenol mixture supplemented to the sow diet during lactation on reproductive performance of sows (n = 42)

Items	Dietary treatment		Batch		SEM	P-value	
	C	SPM	1	2		treat	batch
Parity	3.8	4.5	3.5	4.9	0.29	0.132	0.002
Backfat thickness (mm)							
At farrowing	21.7	20.0	20.5	21.3	0.80	0.157	0.462
At 21 days	16.2	15.6	15.5	16.4	0.65	0.583	0.320
Delta P2 (mm)	–5.5	–4.4	–5.0	–4.9	0.43	0.066	0.922
Piglets/litter (n)							
Total born	14.61	14.55	14.36	14.85	0.45	0.938	0.397
Stillborn	0.93	0.73	0.73	0.95	0.15	0.539	0.388
Mummified	0.55	0.53	0.49	0.54	0.12	0.951	0.675
Born alive	13.14	13.30	13.13	13.31	0.46	0.765	0.951
At cross-fostering	12.65	12.52	12.37	12.84	0.10	0.406	0.002
At 21 days	11.50	11.15	11.02	11.69	0.14	0.120	0.002

C = control diet; SPM = diet supplemented with 15 g/day of brown seaweed plus polyphenol mixture
Data are reported as mean ± pooled standard error of the mean (SEM)

plementation did not affect backfat thickness at 21 days of lactation, however the backfat losses tended to be lower (P = 0.06) in sows fed SPM compared with the control. The sow ADG did not differ between dietary treatments (3.32 ± 0.11 kg/day C vs 3.26 ± 0.12 kg/day SPM; P = 0.725).

The total number of piglets born, stillborn and mummified did not differ (P > 0.05) between dietary treatments. In the second batch, the number of piglets at cross-fostering and at 21 days of lactation was higher than in the first batch (P < 0.01). No interactions between batch and dietary treatment were observed for any of the considered parameters (P > 0.05).

The data on piglet performance in relation to SPM supplementation are shown in Table 4. Piglet weight at 21 days of lactation was higher in SPM group than in control group (P < 0.05). As expected, the ADG was higher (P < 0.05) in piglets from sows fed SPM than in control group (+9.8%). No differ-

Table 4. Effect of brown seaweed plus polyphenol mixture supplemented to the sow diet during lactation on piglet performance (n = 42)

Item	Dietary treatment		Batch		SEM	P-value	
	C	SPM	1	2		treat	batch
Piglets' weight (kg)							
At birth	1.36	1.38	1.36	1.39	0.03	0.706	0.551
At cross-fostering	1.39	1.42	1.40	1.41	0.03	0.491	0.726
At 21 days	5.38	5.80	5.51	5.65	0.12	0.014	0.338
ADG (g/day)	199.5	219.0	205.5	212.0	5.50	0.014	0.353
Mortality (%)	9.04	10.86	10.85	8.82	0.99	0.228	0.246
Litter' weight (kg)							
At birth	17.92	18.28	17.88	18.34	0.68	0.725	0.650
At cross-fostering	17.60	17.84	17.30	18.19	0.43	0.738	0.162
At 21 days	62.00	64.48	60.60	66.17	1.52	0.236	0.011

ADG = average daily gain; C = control diet; SPM = diet supplemented with 15 g/day of brown seaweed plus polyphenol mixture
Data are reported as mean ± pooled standard error of the mean (SEM)

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ences in litter weight at birth, cross-fostering and at 21 days of lactation were observed. The litter weight at 21 days of lactation was higher ($P = 0.01$) in the second batch than in the first. No interactions between batch and dietary treatment were observed for any of the considered parameters ($P > 0.05$). The mortality rate of piglets during the lactation period was unaffected by dietary treatment and batch ($P > 0.05$).

Reproductive performance

After weaning, four sows from the group fed control diet and one sow from the group fed SPM diet were culled before the subsequent mating due to management and reproductive reasons. In Table 5 are reported the effects of SPM supplement during sow lactation on the reproductive performance. The fertility, farrowing rate and farrowing interval were not affected ($P > 0.05$) by dietary treatment. The number of piglets born at subsequent farrowing was higher (+7.3%; $P < 0.05$) in sows fed SPM than in control sows.

Haematochemical and oxidative stress parameters

Data on blood antiradical activity and haematochemical parameters of sows fed control and SPM diet are shown in Table 6. The antiradical activity of whole blood and RBC was unaffected by dietary supplement. The same results ($P > 0.05$) were detected for ALT, AST, total, HDL, and LDL cholesterol, NEFA, triglyceride, urea and haptoglobin concentrations. As shown in Figure 1, the PON1 activity was higher ($P < 0.05$) in sows fed SPM than control sows.

DISCUSSION

The hyperprolific sow productive and reproductive performance is a key factor for maintaining the pig production efficiency (Koketsu et al. 2017). It is observed that around farrowing, sows deal with oxidative stress, negatively affecting their performance (Berchieri-Ronchi et al. 2011). Therefore, to have healthy piglets and good reproductive performance in hyperprolific sows, new nutritional approaches are needed (Hossain et al. 2015). In our study, sows fed SPM supplement tended to have lower backfat losses than control sows, however, the feed intake was the same in both experimental groups. These data suggest that the SPM supplement improves nutrient digestibility and absorption and could lessen the body reserve depletion in lactating sows, according to Long et al. (2021), who reported that *Forsythia suspensa* extract supplementation improved nutrient digestibility. Comparable data were reported in lactating sows fed a mixture of natural extracts (Matysiak et al. 2012). In disagreement, silymarin extract supplementation did not affect backfat losses in lactating sows (Farmer et al. 2017).

Even if the haptoglobin concentration did not differ between experimental groups and no other inflammatory markers were measured, the decreased backfat losses in SPM sows should also be related

Table 5. Effect of brown seaweed plus polyphenol mixture supplemented to the sow diet during lactation on reproduction data at the subsequent farrowing ($n = 40$)

Item	Dietary treatment		SEM	*P*-value
	C	SPM		
Weaning-to-estrus interval (day)	4.40	4.43	0.08	0.996
Fertility (%)	90	95	4.22	0.675
Farrowing Rate (%)	88	95	4.45	0.432
Farrowing interval (day)	148.4	148.1	0.85	0.473
Piglets total born (*n*)	14.43	15.46	0.45	0.044
Piglets born alive (*n*)	12.80	13.60	0.40	0.182

C = control diet; SPM diet supplemented with 15 g/day of brown seaweed plus polyphenol mixture
Four sows from the control group and one sow from the treated group were culled before the subsequent mating due to reproductive reasons. Data are reported as mean ± pooled standard error of the mean (SEM)

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Table 6. Effect of brown seaweed plus polyphenol mixture supplemented to the sow diet during lactation on antioxidant status and blood haematochemical parameters (n = 21)

Item	Dietary treatment		SEM	P-value
	C	SPM		
KRL value (min)				
Whole blood	89.83	95.52	2.93	0.881
Red blood cells	48.89	49.09	0.78	0.946
Haematochemical parameters				
Alanine aminotransferase (IU/l)	61.69	59.15	3.24	0.523
Aspartate aminotransferase (IU/l)	52.58	50.77	2.63	0.954
Cholesterol (mg/dl)	66.40	65.64	2.745	0.851
HDL cholesterol (mg/dl)	30.64	31.05	1.155	0.841
LDL cholesterol (mg/dl)	35.76	34.59	2.394	0.702
NEFA (mmol/l)	0.22	0.16	0.025	0.151
Triglycerides (mg/dl)	18.94	15.08	1.515	0.121
Urea (mg/dl)	28.19	25.63	1.395	0.131
Haptoglobin (mg/ml)	1.36	1.51	0.100	0.136

C = control diet; NEFA = non-esterified fatty acids; SPM = diet supplemented with 15 g/day of brown seaweed plus polyphenol mixture

Data are reported as mean ± pooled standard error of the mean (SEM), n = 21

to a reduction in inflammation processes that decrease energy expenditure. In fact, lower production of pro-inflammatory cytokines was observed in sows fed *Forsythia suspensa* (Long et al. 2021).

The literature on improving piglet growth during the lactation in sows fed brown seaweeds and/or polyphenols is not conclusive. In our study, piglet performance was positively influenced by maternal dietary treatment. The main factor of pig performance seems to be weaning weight; in fact, light pigs at weaning have been found to have slow growth rates and to need more days to reach the commercial weight at slaughter (Wolter et al. 2002). We found that piglets suckling from SPM sows had higher ADG and final weight than control piglets. This suggests an enhancement in the milk amount or quality, as these parameters are major determining factors of litter performance (King'ori 2012). It is well known that nutrients in milk come from the feed and body reserves (Noblet et al. 1998), and the lower loss of backfat in sows fed SPM should be related to the improved sanitary state of the animals. In fact, brown seaweeds enhance the immune function and decrease pathogens in the digestive tract due to their prebiotic and immunomodulatory activities (Makkar et al. 2016). Previous studies have shown that dietary integration with seaweed-derived polysaccharides improves piglet gut health and immune status without affecting the growth performance (Heim et al. 2015). An improvement of piglet average daily gain and weight when the sow diet was supplemented with capsicum, carvacrol, and cinnamaldehyde was also observed (Matysiak et al. 2012). In contrast, other studies did not show an enhancement

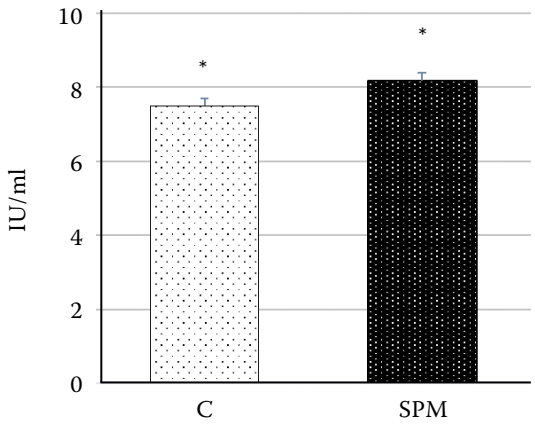

Figure 1. Effect of brown seaweed plus polyphenol mixture supplemented to the sow diet during lactation on paraoxonase-1 serum concentration (PON-1) at 21 days of lactation

C = control diet; SPM = diet supplemented with 15 g/day of brown seaweed plus polyphenol mixture

*P < 0.05

https://doi.org/10.17221/98/2022-CJAS

in piglet performance when the lactating sow diet was supplemented with brown seaweeds (Corino et al. 2019) or polyphenols (Farmer et al. 2017).

The data on sow fertility and mating success are in line with Lipinski et al. (2019), who reported the same reproductive performance in sows fed polyphenols. In sows fed brown seaweeds plus polyphenols, an improvement in the total number of piglets born at the subsequent farrowing was observed. This data is consistent with another study that showed that sows fed *Origanum vulgare* extract and essential oil had improved liveborn rates at subsequent farrowing (Allan and Bilkei 2005). In agreement with previous studies, sows that presented a reduced backfat loss during lactation had a high total number of piglets born alive at the subsequent farrowing (Houde et al. 2010). Based on these data, it is reasonable to suppose that the antioxidant, antibacterial and anti-inflammatory activities of brown seaweeds and polyphenols affect the sow health. In fact, if the natural dietary mixture can decrease gut pathogens, it increases feed digestibility and modulates the immune response, thereby enhancing the sow health.

The haematochemical parameters were unaffected by dietary treatment. To our knowledge, no previous studies have evaluated the effects of dietary supplementation of brown seaweed and plant polyphenol mixture on haematochemical parameters in sows. Our data agree with the outcomes of Vizzarri et al. (2020), who observed no effects of the same dietary supplements on cholesterol, triglyceride, AST and ALT concentrations in rabbit does.

Previous study has reported the natural extract ability to prevent or reduce oxidative stress markers (Rossi et al. 2013). Total antioxidant activity was unaffected by *Ascophillum* spp. supplementation in piglets (Michiels et al. 2012). Previous data reported that a plant extract (*Lippia* spp.) supplement increased blood antioxidant activity of pigs, determined by the KRL^{TM} test (Rossi et al. 2017). The present results showed that dietary integration with SPM did not affect the blood total antioxidant defence in sows, in agreement with Wang et al. (2019), who reported no difference in serum malondialdehyde and total antioxidant capacity in sows receiving different dosages of grape seed polyphenols. The discrepancy from the present data could be explained by different dosage and bioactive principles employed and the short length of the dietary supplementation with natural extracts.

The PON1 is an enzyme synthesized primarily by the liver and although its function has not been fully elucidated, it is believed to protect HDL and LDL from oxidation catalyzed by copper and show anti-inflammatory activity (Litvinov et al. 2012). PON1 has recently been suggested as a negative acute phase protein (APP) in pigs whose activity in serum decreases during inflammation (Escribano et al. 2015). The authors showed for the first time in pigs that PON1 activity diminishes in response to an inflammatory stimulus and hypothesized that its reduction is related to the oxidative status induced by inflammation.

To the best of our knowledge, no data were reported on PON1 activity in lactating sows. We found that PON1 activity was higher in sows receiving the SPM supplement. Despite the fact that none of the groups had overt inflammation, based on the lack of clinical signs and no fluctuations in the concentration of the positive acute phase protein haptoglobin, the decrease in PON1 at 21 days of lactation in control pigs, coupled with the increase of PON1 at same time in treated animals, suggests that oxidative stress possibly develops over time in control pigs but not in treated animals in which, conversely, the magnitude of oxidative stress seems to be lower. In an *in vitro* study, dietary resveratrol stimulated PON1 transcription activation in primary hepatocyte cultures (Gouedard et al. 2004). It is thus possible that in our study, dietary seaweeds and polyphenols exerted an antioxidant activity, enhancing PON1 activity and protecting LDL from oxidation.

Due to the lack of studies on PON1, additional studies are needed to better explain the function of this enzyme in pigs. Despite no significant differences between the dietary treatments and sampling time in KRL values, higher PON1 activity in the treated group compared to the control group may indicate that different mechanisms are involved in the protection from oxidation.

CONCLUSION

Overall, the present data revealed that dietary integration with brown seaweeds plus polyphenols in hyperprolific lactating sows enhanced the piglet weight at weaning and the total number of piglets born at the subsequent farrowing. Blood parameters were unaffected by dietary treatment, however

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an improvement in PON1 activity was observed, which was consistent with a reduction in oxidative stress. Coupling KRL™ and PON1 evaluation in studies aimed at verifying the antioxidant properties of dietary supplementation may be worth considering.

Conflict of interest

The authors declare no conflict of interest.

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Received: June 6, 2022
Accepted: November 20, 2022
Published online: December 19, 2022