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Impact of adding eicosapentaenoic and docosahexaenoic acid-rich fish oil in sow and piglet diets on blood oxylipins and immune indicators of weaned piglets

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ABSTRACT

Weaning is a decisive event in piglets' life. This study aimed to evaluate whether the inclusion of fish oil, rich in eicosapentaenoic and docosahexaenoic acids (**EPA** and **DHA**), in sow and piglet diets, increased the concentration of anti-inflammatory molecules in the blood of weaned piglets and whether the effect was dependent on the pigs being born with either low or a high birth BW (**bBW**). Thirty-six sows in four consecutive batches were randomly distributed between a control diet with animal fat (15 g/kg in gestation and 30 g/kg in lactation) or a n-3 long-chain fatty acid diet (**LCFA**; totally or half replacing animal fat by fish oil during gestation and lactation, respectively) from service until weaning (ca. 28 days). At birth, the two lightest (**LBW**) and the two heaviest (**HBW**) piglets in each litter were identified and, at weaning, grouped in pens by pairs prioritising their bBW. Pens were further distributed into a control (30 g/kg animal fat) or n-3 LCFA diet (totally replacing animal fat by fish oil) for 28 days. At the end of the trial, blood was collected from piglets in the first batch (n = 48). Serum fatty acids (**FAs**) were quantified by GC, plasma oxylipins by ultra-HPLC-MS, and plasma immune indicators by ELISA. An interaction between piglet diet and bBW for average daily gain (P = 0.020) and average daily feed intake (P = 0.014) during the whole postweaning indicated that dietary n-3 LCFA–promoted LBW piglets to have a similar growth and intake than HBW piglets reaching 1.5 kg average BW more at the end of the postweaning period than LBW control piglets. Fish oil in piglet diets also increased the concentrations of total n-3 FA, EPA and DHA (all P < 0.001), their resultant oxylipins, particularly their hydroxy derivatives from lipoxygenase enzymatic pathway (all P < 0.001) and tended to increase immunoglobulin M (P = 0.067) in blood. Regarding the bBW category, LBW piglets tend to increase tumour necrosis factor α in plasma (P = 0.083) compared to HBW. It is concluded that fish oil in postweaning diets could enhance the daily gain and feed intake of LBW piglets, increasing the concentration of serum n-3 FAs and their derived oxylipins in plasma.

Implications

Weaning is one of the most critical events in the swine production system. The use of n-3 long-chain fatty acid as a nutritional strategy could modulate the immune status of piglets at this decisive point. The current study reveals that the inclusion of fish oil in postweaning diets could enhance the daily gain of low-birth-weight piglets, and increases serum n-3 fatty acids and their derived oxylipins. These changes could help piglets to overcome the weaning transition, in particular those of low birth weight.

Introduction

Weaning is considered as one of the most critical steps in swine production. The transition from the maternal milk to a diet based on cereals and soya is an abrupt change. Many piglets do not adapt to the new solid feed source and enter into a low feed intake state or directly stop eating (de Vries and Smidt, 2020). This is commonly associated with an intestinal atrophy and a consequent

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reduction in the digestibility and absorption of nutrients (Pluske et al., 1997). Moreover, weaning is a very stressful period (social and environmental changes) related with other problems, such as unspecific inflammatory response, which are associated with the appearance of diarrhoea (McCracken et al., 1999; Xu et al., 2000; Pie et al., 2004). On the other hand, the increased prolificity of sows increased the number of piglets born with a low birth weight (**LBW**) which are more unlikely to be robust at weaning, accentuating this critical step in the swine production cycle. For these reasons, studies on perinatal and early nutrition strategies that may impact piglet development and immune status during the postweaning period are nowadays a focus of interest.

Polyunsaturated fatty acids (**FAs**) in sow and postweaning diets have commonly been used for their role as an energy source (Rosero et al., 2016), but they can also play an important role as immune modulators (Calder, 2012). Their effects on the immune system vary depending on their nature. In this way, n-6 polyunsaturated FAs and their oxygenated derivatives, also known as oxylipins, are associated with more proinflammatory effects, while n-3 polyunsaturated FAs and their derived oxylipins are related with a less proinflammatory, anti-inflammatory and/or inflammation resolving role (Lauridsen and Jensen, 2007; Calder, 2010; Gabbs et al. 2015).

This study is part of a larger project evaluating the influence of a fish oil source rich in n-3 polyunsaturated FAs (mainly eicosapentaenoic acid (**EPA**) (C20:5 n-3) and docosahexaenoic acid (**DHA**) (C22:6 n-3)) on the robustness and health status of the piglets during suckling and postweaning period. Precisely, results about the effect of fish oil in sow diets on the performance of sows and the growth of piglets during lactation, and on the FAs profile, oxylipin composition and selected immune indicators of colostrum, milk, sows' and suckling piglets' blood have been previously published (Llauradó-Calero et al., 2021; Llauradó-Calero et al., 2022). The aim of the current study was to assess the impact of inclusion of fish oil in the maternal diet or in postweaning diets in piglets being born with low or high birth BW (**bBW**), hypothesising that the dietary inclusion of n-3 polyunsaturated FAs could increase total n-3 FAs and their derived oxylipins and modify immune indicators in the blood of piglets depending on their bBW category, also at this growing phase, providing the novelty of this study. Understanding the influence that this type of dietary fat may have on the selected parameters could contribute to the development of nutritional strategies based on n-3 polyunsaturated FAs to increase molecules with anti-inflammatory immune modulation capabilities. This manuscript has been published in a limited form as a part of a PhD thesis (Llauradó-Calero, 2023).

Material and methods

Animals, housing, and experimental design

At approximately 28 days of life, the two lightest (> 800 g) (LBW) and the two heaviest (high birth BW (**HBW**)) piglets per litter without considering their sex (total of 124 piglets [48, 32, 16 and 28 in each sows' batch, respectively]) were selected from 31 sows (16 control and 15 n-3 long-chain FA (**n-3 LCFA**)) previously described in the experimental set-up by Llauradó-Calero et al. (2021) and Llauradó-Calero et al. (2022). At weaning, these piglets were moved to the postweaning facilities. Due to farm management and piglets' availability in each batch, maintaining the effect of maternal diet in the postweaning distribution of piglets was not feasible. Therefore, piglets were distributed in pens by pairs prioritising to maintain the bBW category and when possible maternal dietary treatment (control or n-3 LCFA). Thereafter, each pen was administered a control or n-3 LCFA diet. The prestarter diet was offered from weaning until day 15 postweaning and the starter diet between day 15 and day 28 postweaning. Piglets were weighed at weaning, at 8-, 15- and 28-days postweaning. Daily feed intake was monitored for each pen and recorded on the same days of weighing. Piglets' average BWs, average daily gain, average daily feed intake, and gain−to−feed ratio were calculated per pen.

Postweaning facilities consisted of a room with 24 slatted pens of 1.7 m^2 (1.8 × 0.95 m). The inside of the building has natural light through three windows. Tubular fluorescent lights were programmed to 16 h of light and 8 h of darkness (lights were switched on between 0700 and 2300 h). The room was ventilated through single variable-speed fans linked to temperature sensors. The temperature was adjusted according to the standard program used at the farm, with a gradual decrease from 30 °C to 24 °C during the first 21 days postweaning, and from 24 °C to 23 °C from day 21 to day 28 postweaning. Piglets were fed via hoppers and water availability was *ad libitum* consumption via one nipple drinker per pen.

Experimental diets

Gestation and lactation diets for sows and postweaning diets for piglets were formulated according to FEDNA specifications (de Blas et al., 2013). In terms of ingredients, gestation diets were mainly based on barley and corn, and lactation diets on corn. Regarding nutrients, control and n-3 LCFA gestation diets contained 12.4 and 12.5 MJ/kg of metabolised energy, 131 and 132 g/kg of CP, and 56.0 and 56.0 g/kg of lysine, respectively. Control and n-3 LCFA lactation diets contained 13.7 and 13.6 MJ/kg of metabolised energy, 182 and 179 g/kg of CP, and 92.0 and 92.0 g/kg lysine, respectively. In reference to fat inclusion, control diets were formulated to contain 15 and 30 g/kg of animal fat during gestation and lactation, respectively. In the n-3 LCFA diets, 21.5 g/kg of solid fish oil (Lipomega®; V&S Asociados, Madrid, Spain) was used to totally replace (gestation diet) or half replace (lactation diet) animal fat in the control diets. Complete information about sow diets has been previously reported in Llauradó-Calero et al. (2021). Ingredient and nutrient composition of postweaning diets of piglets are presented in Table 1 and the FA composition in Table 2. The control diets were formulated to contain 30 g/kg of animal fat (both prestarter and starter specifications), and in n-3 LCFA diets, animal fat was totally replaced by an equivalent amount of solid fish oil (48.6 g/kg). Prestarter diets in mash form were also offered as a creep feed from day eleven of lactation until weaning. For all periods, diets were provided *ad libitum* consumption.

Sampling description

For the first batch of sows, blood was collected at the end of postweaning period from each piglet (48 piglets). Blood was obtained by jugular venepuncture in non-heparinised tubes for serum and in ethylenediaminetetraacetic acid tubes for plasma. Non-heparinised tubes were kept at ambient temperature and ethylenediaminetetraacetic acid tubes at 4 °C for a maximum of 120 min until centrifugation (300 rpm, 10 min). Aliquots of serum for FA analysis, and of plasma for oxylipins (in tubs containing 0.005% butylated hydroxytoluene as antioxidant (Merck, Darmstadt, Germany)), Ig and cytokines analyses were collected and quickly stored at −80 °C (maximum 30 min from centrifugation to storage).

Quantitative analysis of fatty acids

Fat was extracted from serum samples with chloroform (PanReac AppliChem, Barcelona, Spain) – methanol (Honeywell, Charlotte, NC, USA) according to Folch et al. (1957). Afterwards,

Table 1
Ingredient and nutrient composition of control and n-3 LCFA post-weaning piglet diets (as fed basis).

	Prestarter		Starter	
	Control	n-3 LCFA	Control	n-3 LCFA
Ingredients (g/Kg)				
Barley	226	220	150	150
Corn	314	315	514	509
Soybean 48%	150	150	235	236
Sweet whey (dehydrated)	110	110	–	–
Dicalcium phosphate	18.2	18.2	17.0	17.0
Animal fat (5 Sysfeed)[1]	30.0	–	30.0	–
Fish oil (Lipomega®)[2]	–	48.6	–	48.6
L-lysine HCL	5.50	5.50	5.20	5.20
L-threonine	2.50	2.50	2.30	2.30
DL-methionine	2.70	2.70	2.10	2.10
L-tryptophan	0.80	0.80	0.70	0.70
L-Valine	1.30	1.30	1.00	1.00
Calcium carbonate	2.00	2.70	2.60	3.30
Sodium bicarbonate	4.50	4.50	4.50	4.50
Sodium chloride	0.80	0.80	1.70	1.70
Sodium caseinate	20.0	20.0	–	–
Celite	15.0	–	15.5	–
HP 300[3]	88.8	89.3	12.1	12.4
Vitamin-Mineral Premix[4]	6.00	6.00	6.00	6.00
Antioxidant (Noxyfeed 56P)[5]	2.50	2.50	0.20	0.20
Analysed nutrient composition[6] (g/Kg)				
ME (MJ/Kg)	14.1	13.8	13.5	13.6
DM	88.7	88.7	86.1	86.2
Crude fibre	19.0	18.7	20.9	20.1
Ether extract	49.8	52.4	62.0	54.5
CP	204	205	177	176
Lysine	13.3	13.3	12.0	12.0

LCFA, long-chain fatty acid; ME, metabolisable energy.
[1] Product of Sysfeed SLU (Granollers, Spain). It contains myristic acid (C14:0) 1.50%, palmitic acid (C16:0) 18.0%, palmitoleic acid (C16:1 n-7) 2.00%, stearic acid (C18:0) 14.0%, oleic acid (C18:1 n-9 *cis*) 28.0%, linoleic acid (C18:2 n-6 *cis*) 12.0%, α-linolenic acid (C18:3 n-3 *cis*) 6.00%, saturated–unsaturated 0.7%.
[2] Product of V&S Asociados (Madrid, Spain). It contains 63.36% of fat, myristic acid (C14:0) 4.79%, palmitic acid (C16:0) 14.9%, stearic acid (C18:0) 3.77%, oleic acid (C18:1 n-9 *cis*) 12.3%, linoleic acid (C18:2 n-6 *cis*) 2.71%, α-linolenic acid (C18:3 n-3 *cis*) 1.21%, arachidonic acid (C20:4 n-6 *cis*) 0.75%, eicosapentaenoic acid (C20:5 n-3 *cis*) 7.92%, docosahexaenoic acid (C22:6 n-3 *cis*) 6.91% and 36.64% of inert excipients.
[3] Product of Hamlet Protein (Horsens, Denmark). It contains 56.0% of protein, 23.2% of carbohydrates, 8.0% of H_2O, 6.8% of ash, 3.5% of crude fibre and 2.5% of fat. Essential amino acids (g/16 g of N): lysine 6.1, methionine 1.3, cysteine 1.4, threonine 3.9, tryptophan 1.35, leucine 7.7, isoleucine 4.6, phenylalanine 5.0, tyrosine 3.7, valine 4.8, histidine 2.6 and arginine 7.2.
[4] Product of TecnoVit S.L. (Alforja, Spain). Supplied per kilogram of feed: vitamin A 10 000 UI, vitamin D_3 2 000 UI, vitamin E 25.0 mg, vitamin B_1 1.50 mg, vitamin B_2 3.50 mg, vitamin B_6 2.40 mg, vitamin B_{12} 0.04 mg, vitamin K_3 1.50 mg, calcium D-pantothenate 14.0 mg, nicotinamide 20.0 mg, folic acid 0.50 mg, biotin 0.05 mg, Fe (as $FeSO_4 \cdot H_2O$) 120 mg, I (as $Ca(IO3)_2$) 0.75 mg, Mn (as MnO) 60.0 mg, Se (as Na_2SeO_3) 0.37 mg.
[5] Product of Itpsa (Barcelona, Spain). It contains 56% of antioxidants substances (butylated hydroxytoluene + propyl gallate) and synergistic (Citric acid 14% + authorised support).
[6] Nutrient composition values correspond to the analysed values except for ME and lysine which were estimated according to INRA tables (Sauvant et al., 2004).

extracted fat was transmethylated with boron trifluoride (Sigma Aldrich, St. Louis, MO, USA) and methanolic potassium hydroxide 0.5 M (PanReac, Barcelona, Spain) according to Morrison and Smith (1964). Individual FAs were determined by GC (Agilent 6890 N, Boston, MA, USA) using the analytical procedure formerly described in Llauradó-Calero et al. (2021). FA quantifications were performed from C12:0, and the results are reported as mg of FA per g of serum.

Analysis of oxylipins

A total of fifty-three oxylipins were quantified from plasma samples. Aliquots of 0.25 mL of plasma were set up according to the previously described optimised process (Llauradó-Calero et al., 2022). The oxylipin concentrations were determined using an Ultra High Performance LC (UHPLC) 1290 Series coupled to a triple quadrupole mass spectrometer 6490 series instrument (Agilent, Santa Clara, CA, USA) with an analytical column Eclipse XDB C18 1.8 µL (2.1 × 150 mm) (Agilent, Santa Clara, CA, USA). The identification with standards or tentative identification of oxylipins was previously described in Llauradó-Calero et al. (2021). An extended version of the analysis of oxylipins is reported in Supplementary Material S1.

Immune indicators

Plasmatic concentrations of different immunoglobulins (immunoglobulin (**Ig**) G, A and M) and cytokines (interleukins (**IL**) 1β, 6, 10 and tumour necrosis factor α (**TNFα**)) were quantitatively determined throughout the sandwich ELISA kits previously reported in Llauradó-Calero et al. (2021). Precision values of ELISA kits are described in Supplementary Table S1.

Statistical analysis

The experimental treatments were analysed according to a 2 × 2 factorial arrangement (2 piglet diets and 2 piglets bBW categories) for the performance parameters, and a 2 × 2 × 2 factorial arrangement (2 maternal diets, 2 piglet diets and 2 piglets bBW categories) for the FA, oxylipins and immune indicator results.

Pen was used as the experimental unit. For the performance parameters, the model included the piglet diet, bBW category,

Table 2
Fatty acid composition of the control and n-3 LCFA postweaning piglet' diets.

	Prestarter		Starter	
	Control	n-3 LCFA	Control	n-3 LCFA
Fat (%)	4.53	5.21	5.38	5.55
Fatty Acids (mg FA/g fat)[1]				
C14:0	8.34	26.1	5.27	21.5
C15:0	0.63	2.10	0.33	1.68
C16:0	143	130	139	120
C16:1	11.7	26.5	10.9	24.6
C17:0	1.60	3.17	1.46	2.77
C18:0	47.8	30.1	47.0	26.6
C18:1 n-9 *cis*	228	139	242	149
C18:1 n-9 *trans*	1.29	0.66	0.96	0.47
C18:2 n-6 *cis*	214	167	239	185
C20:2 n-6 *cis*	2.58	1.04	2.46	0.96
C20:4 n-6	1.76	3.85	1.77	3.55
C20:5 n-3	ND	41.3	0.20	39.7
C24:0	1.11	1.20	1.18	1.07
C22:5 n-3	0.56	5.77	0.57	5.48
C22:6 n-3	0.53	36.0	0.72	34.9
Minor FA[2]	41.8	61.9	39.6	56.4
SFA	209	203	200	182
MUFA	260	196	272	202
PUFA	236	276	260	289
n-3	16.7	102	16.6	97.2
n-6	219	175	243	192
n-6:n-3	13.2	1.72	14.6	1.97

FA, fatty acid; LCFA, long-chain fatty acid; MUFA, monounsaturated fatty acid; ND, non-detected; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid.
[1] FA quantification results are reported from C12:0.
[2] Minor FAs include: C12:0, C14:1 n-9 *cis*, C17:1, C18:1 n-11 *cis*, C18:1 n-7, C18:2 n-6 *trans*, C19:0, C18:3 n-3 *cis*, C18:4 n-3, C20:0, C20:1 n-9 *cis*, C20:3 n3 *cis*, C20:3 n-6, C22:0, C22:1, C23:0, C22:4 n-6 and C24:1 n-9 *cis*. C13:0, C15:1, C18:3 n-6 cis, C21:0, C22:2 n-6 *cis* and C22:3 n-3 have not been detected.

and their interaction as fixed effects, and the batch as random effect. For the FAs, oxylipins and blood immune indicators, the individual piglets were used as observational units, and the model included maternal diet, piglet diet, bBW category and their interaction as fixed effects, and the pen and sow as random effects. Sex was initially introduced in the model as covariate. However, it had no significant effect, and it was removed from the statistical analysis. For the interactions, a Tukey test was performed to find differences between specific groups, and the differences between fixed effects were obtained from the ANOVA table. Statistical analyses were performed using the GLIMMIX procedure of SAS software (SAS/STAT 14.1; SAS Institute INC., Cary, NC, USA).

When the limit of detection was not reached in the analysis of FAs, oxylipins or immune indicators, missing values were replaced by 1/5 of the minimum positive value for each variable. Data suspected of being outliers were examined by Smirnov-Grubbs's test excluding the values if $P < 0.01$ (Grubbs, 1969). Data were checked for normality using the UNIVARIATE procedure of SAS using Kolmogorov-Smirnov test (confidence interval of 97%). To compare the oxylipin concentrations between treatments, a logarithmic transformation (log10(X+1)) of the data was performed. The original means are presented in the supplementary tables. The results of growth and feed intake, FAs and immune indicators are presented as least squares means ± RMSE, and the results of oxylipins are expressed as means ± RMSE (from transformed data). Significant differences and tendencies were considered at $P < 0.05$ and $P < 0.1$, respectively. The Principal Component Analyses (PCAs) included the results obtained for FAs and oxylipins and the heatmap the ones for oxylipins. Data were transformed to log10 and scaled by mean centering. For PCAs, individual values were grouped by sows' maternal diet, piglets' diet or bBW category. For the heatmap, mean values were used to assess the main factors (maternal diet, piglet diet and bBW). The scale ranged from −1.5 to 1.5 in relation to the mean value for each study variable, indicating a higher (1.5) or lower (−1.5) concentrations of the parameter analysed. Figures were performed using MetaboAnalyst 5.0 (https://www.metaboanalyst.ca, Alberta, CA, USA).

Results

Piglets' growth performance

Average BW, average daily weight gain, average daily feed intake, and gain to feed ratio of piglets during the postweaning period are reported in Table 3. Although no differences between treatments were observed in terms of the average BW, an interaction between piglet diet and bBW from 8 to 15 days postweaning ($P = 0.029$), weaning to 15 days postweaning ($P = 0.017$), 15 to 28 days postweaning ($P = 0.046$) and weaning to 28 days postweaning ($P = 0.020$) was detected for the average daily gain. Specifically, it was observed that the average daily gain in the control group was lower in LBW piglets compared to HBW piglets ($P = 0.031$). Contrary, in the n-3 LCFA group, there were no differences between bBW categories, and n-3 LCFA LBW piglets consistently presented numerically higher average daily gain than control LBW piglets in all the examined periods. An interaction between piglet diet and bBW category was also detected from weaning to 15 days postweaning ($P = 0.033$), 15 to 28 days postweaning ($P = 0.021$) and weaning to 28 days postweaning ($P = 0.014$) for average daily feed intake. Concretely, control LBW piglets had a lower average daily feed intake than control HBW piglets, while there were no differences between both bBW categories in the n-3 LCFA group. Regarding gain−to−feed ratio, an interaction between piglet diet and bBW category was also observed from weaning to 8 days or 15 days postweaning ($P = 0.021$ and $P = 0.035$, respectively) showing that LBW piglets fed n-3 LCFA diet presented a higher gain-to-feed ratio than the LBW piglets fed the control diet.

Fatty acid composition

As shown by the principal component analysis, there is a differential distribution of the samples according to the piglet's experimental diets (control *vs.* n-3 LCFA diet) (Supplementary Figure S1, B), while differentiation is not observed due to maternal

Table 3
Effect of dietary fish oil in postweaning diet and piglet birth BW on the growth performance of piglets during postweaning period (28 to 56 days of age)[1,2].

	Control LBW (n = 16)	Control HBW (n = 16)	n-3 LCFA LBW (n = 15)	n-3 LCFA HBW (n = 15)	RMSE	*P*−value PDiet	*P*−value bBW	*P*−value PDiet*bBW
Average BW (kg)								
At weaning	7.11	9.11	7.28	9.50	0.97	0.272	<0.001	0.679
8 days pw	7.83	10.0	8.24	10.2	0.96	0.217	<0.001	0.661
15 days pw	9.63	12.4	10.3	12.0	1.39	0.776	<0.001	0.137
28 days pw	15.2	19.6	16.7	18.4	2.65	0.805	<0.001	0.053
Average daily gain (kg)								
Weaning → 8 days pw	0.085	0.110	0.116	0.088	0.06	0.754	0.924	0.088
8 days pw → 15 days pw	0.256^{b}	0.340^{a}	0.288^{ab}	0.251^{b}	0.11	0.292	0.390	0.029
Weaning → 15 days pw	0.165^{b}	0.218^{a}	0.197^{ab}	0.164^{b}	0.07	0.519	0.557	0.017
15 days pw → 28 days pw	0.430^{b}	0.552^{a}	0.497^{ab}	0.496^{ab}	0.12	0.871	0.050	0.046
Weaning → 28 days pw	0.288^{b}	0.373^{a}	0.336^{ab}	0.318^{ab}	0.08	0.865	0.124	0.020
Average daily feed intake (kg)								
Weaning → 8 days pw	0.159	0.182	0.174	0.164	0.04	0.885	0.461	0.070
8 days pw → 15 days pw	0.620	0.734	0.662	0.623	0.16	0.416	0.369	0.072
Weaning → 15 days pw	0.223^{b}	0.269^{a}	0.248^{ab}	0.234^{b}	0.05	0.486	0.314	0.033
15 days pw → 28 days pw	1.21^{b}	1.47^{a}	1.37^{ab}	1.32^{ab}	0.25	0.935	0.111	0.021
Weaning → 28 days pw	0.405^{b}	0.485^{a}	0.451^{ab}	0.432^{ab}	0.08	0.865	0.123	0.014
Gain−to−feed ratio								
Weaning → 8 days pw	0.478^{b}	0.597^{ab}	0.653^{a}	0.497^{ab}	0.23	0.516	0.751	0.021
8 days pw → 15 days pw	0.374	0.500	0.504	0.366	0.32	0.983	0.940	0.113
Weaning → 15 days pw	0.700	0.801	0.798	0.672	0.21	0.773	0.814	0.035
15 days pw → 28 days pw	0.384	0.343	0.354	0.445	0.25	0.569	0.688	0.294
Weaning → 28 days pw	0.704	0.752	0.742	0.700	0.13	0.828	0.928	0.195

bBW, birth body weight; FA, HBW, high birth weight piglets; LBW, low birth weight piglets; LCFA, long-chain fatty acid; PDiet, piglet diet; pw, postweaning.
[1] Values are least squares means ± RMSE.
[2] Significantly different values according to the interaction ($P < 0.05$) are indicated using different letters (^{a,b}).

diet (Supplementary Figure S1, A) or piglet birth BW (Supplementary Figure S1, C). The influence of fish oil in maternal or piglet diets and piglet bBW on the weaned piglet's FAs concentrations in blood serum is shown in Table 4. Interactions between maternal diet and piglet diet, maternal diet and bBW, and piglet diet and bBW were observed by docosapentaenoic acid (C22:5 n-3), showing that HBW piglets fed LCFA had increased concentrations of this FA compared to the other treatments. No interactions between the main factors were observed for the other FAs. The addition of fish oil in the maternal diet did not change any of the individual FAs analysed. On the contrary, the inclusion of n-3 LCFAs in the piglet diets decreased or tended to decrease the saturated FAs pentadecylic acid (C15:0) ($P = 0.007$), palmitic acid (C16:0) ($P = 0.020$), margaric acid (C17:0) ($P < 0.001$), stearic acid (C18:0) ($P = 0.084$), heneicocylic acid (C21:0) ($P = 0.010$) and lignoceric acid (C24:0) ($P = 0.024$), the monounsaturated FA elaidic acid (C18:1 n-9 trans) ($P = 0.026$), the n-6 polyunsaturated FAs γ-linolenic acid (C18:3 n-6 cis) ($P = 0.063$), eicosadienoic acid (C20:2 n-6 cis) ($P = 0.003$) and arachidonic acid (C20:4 n-6) ($P = 0.031$), and the n-3 polyunsaturated FA docosatrienoic acid (C22:3 n-3) ($P = 0.018$). On the other hand, n-3 LCFAs in piglet diets increased or tended to increase the saturated FA myristic acid (C14:0) ($P < 0.001$), the monounsaturated FA palmitoleic acid (C16:1) ($P = 0.074$), and the n-3 polyunsaturated FAs EPA ($P < 0.001$) and DHA ($P < 0.001$). In addition, despite not detecting changes in the total amount of polyunsaturated FAs or the n-6 family, piglets offered the n-3 LCFA diet had a higher concentration of total n-3 FAs ($P < 0.001$) and a lower n-6:n-3 ratio ($P < 0.001$) than the piglets from the control diet. Regarding piglet bBW, LBW piglets tended to decrease the concentrations of the n-6 polyunsaturated FAs: γ-linolenic acid ($P = 0.058$) and eicosadienoic acid ($P = 0.062$).

Oxylipin profile

The principal component analysis revealed that there was a clear separation between samples from piglets fed the control or n-3 LCFA diet according to their plasma oxylipin concentration (Supplementary Figure S1, E), while maternal diet (Supplementary Figure S1, D) or piglets' bBW category (Supplementary Figure S1, F) had no effects on the sample distribution. The heatmap presented in Fig. 1 schematically shows that piglet diet is the main effect causing a substantial difference in terms of plasmatic oxylipin concentrations. The changes in the plasmatic oxylipin profile of weaned piglets as affected by the inclusion of fish oil in the maternal or piglet diets, and by the piglet bBW are shown in Supplementary Table S2. An interaction between piglet diet and bBW was observed for 11(12)-dihydroxy-eicosatrienoic acid and 14-hydroxy-DHA ($P = 0.043$ and $P = 0.015$, respectively). HBW piglets fed either control or n-3 LCFA had higher concentration of 11(12)-dihydroxy-eicosatrienoic acid compared with those LBW fed the control diet. The n-3 LCFA piglets, both, LBW and HBW, had higher concentration of 14-hydroxy-DHA compared to those of HBW and LBW fed the control diet. A triple interaction between maternal diet, piglet diet and bBW was also observed by 11-hydroxy-DHA ($P = 0.012$). In this case, piglets from sows fed the n-3 LCFA that also were fed n-3 LCFA during postweaning and those only fed the n-3 LCFA diet during postweaning had higher concentrations of this oxylipin compared to the other groups.

Similar to what it was observed for FA composition, the inclusion of n-3 LCFA on the maternal diet had little impact on the oxylipin profile. There was only one oxylipin affected by the addition of n-3 LCFA in the maternal diet. Piglets from sows fed n-3 LCFA presented increased concentrations of 16-hydroxy-DHA compared to piglets from the control sows ($P = 0.022$). Also, as for FAs, the inclusion of fish oil in the piglet diets was the factor causing most of the changes in the oxylipin concentrations. Up to a total of 27 oxylipins differed (or tended to differ) between the two piglet dietary treatments, where dietary n-3 LCFAs decreased the concentration of 5 of them and increased the concentration of another 22. Among the oxylipins that were decreased or tended to decrease by the addition of n-3 LCFAs in the piglet diets, there were the linoleic acid (C18:2 n-6 cis) derived oxylipins 9,10-dihydroxy-

Table 4
Influence of dietary fish oil in maternal or postweaning diets and piglet birth BW on blood serum fatty acid profile in postweaned piglets (56 days of age)[1,2,3].

	MDiet		Pdiet		bBW		RMSE	*P*−value MDiet	*P*−value PDiet	*P*−value bBW
	Control (n = 27)	n-3 LCFA (n = 20)	Control (n = 24)	n-3 LCFA (n = 23)	HBW (n = 24)	LBW (n = 23)				
Fatty acid (mg FA/g serum)[4]										
C14:0	0.024	0.024	0.018	0.030	0.023	0.025	0.01	0.934	<0.001	0.490
C15:0	0.013	0.013	0.015	0.011	0.012	0.014	<0.01	0.767	0.007	0.501
C16:0	0.63	0.60	0.70	0.52	0.63	0.59	0.21	0.671	0.020	0.571
C16:1	0.048	0.050	0.044	0.054	0.050	0.048	0.02	0.803	0.074	0.820
C17:0	0.054	0.047	0.067	0.034	0.051	0.050	0.02	0.468	<0.001	0.944
C18:0	0.40	0.39	0.43	0.35	0.41	0.37	0.12	0.812	0.084	0.470
C18:1 n-9 *cis*	0.65	0.69	0.74	0.60	0.70	0.63	0.21	0.767	0.161	0.530
C18:1 n-9 *trans*	0.020	0.012	0.023	0.009	0.015	0.017	0.02	0.187	0.026	0.672
C18:2 n-6 *cis*	0.73	0.85	0.82	0.76	0.86	0.72	0.22	0.466	0.621	0.248
C18:3 n-6 *cis*	0.021	0.022	0.023	0.020	0.023	0.020	<0.01	0.736	0.063	0.058
C20:2 n-6 *cis*	0.010	0.011	0.015	0.006	0.013	0.007	<0.01	0.626	0.003	0.062
C20:4 n-6	0.17	0.17	0.20	0.14	0.19	0.14	0.05	0.840	0.031	0.253
C20:5 n-3	0.12	0.12	0.024	0.21	0.11	0.12	0.10	0.993	<0.001	0.752
C21:0	0.011	0.013	0.015	0.009	0.014	0.011	<0.01	0.402	0.010	0.383
C22:3 n-3	0.016	0.023	0.024	0.015	0.022	0.017	0.01	0.302	0.018	0.264
C22:5 n-3*	0.055	0.051	0.033	0.073	0.046	0.060	0.02	0.755	0.001	0.232
C22:6 n-3	0.076	0.087	0.050	0.11	0.080	0.083	0.04	0.434	<0.001	0.763
C24:0	0.017	0.014	0.019	0.013	0.018	0.014	<0.01	0.149	0.025	0.169
Minor FA[5]	0.23	0.27	0.26	0.24	0.27	0.23	0.11	0.473	0.645	0.246
SFA	1.18	1.15	1.28	1.06	1.21	1.13	0.30	0.806	0.105	0.575
MUFA	0.83	0.90	0.89	0.85	0.92	0.82	0.16	0.574	0.640	0.457
PUFA	1.27	1.41	1.33	1.34	1.44	1.23	0.34	0.495	0.950	0.172
n-3	0.30	0.34	0.19	0.45	0.32	0.32	0.18	0.381	<0.001	0.953
n-6	0.96	1.08	1.06	0.97	1.12	0.92	0.23	0.527	0.465	0.234
n-6:n-3	5.87	4.91	8.63	2.15	5.99	4.78	3.72	0.386	<0.001	0.277

bBW, birth weight; FA, fatty acid; HBW, high birth weight piglets; LBW, low birth weight piglets; LCFA, long-chain fatty acid; MDiet, maternal diet; MUFA, monounsaturated fatty acid; PDiet, piglet diet; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid.
C20:3 n-6, C22:0, C22:1, C22:2 n-6 cis, C23:0, C22:4 n-6 and C24:1 n-9 cis. C13:0, C14:1 n-9 cis and C20:3 n3 cis have not been detected.
[1] Values are least squares means ± RMSE.
[2] *P*−values of the significantly different interactions are reported in the footnotes.
[3] During the analysis process, a sample corresponding to the control MDiet, n-3 LCFA Pdiet, and LBW was lost.
[4] FA quantification results are reported from C12:0.
[5] Minor FAs include: C12:0, C15:1, C17:1, C18:1 n-11 cis, C18:1 n-7, C18:2 n-6 trans, C19:0, C18:3 n-3 cis, C18:4 n-3, C20:0, C20:1 n-9 cis,
[*] *P*−value of the interaction PDiet*bBW was *P* = 0.026 where 0.046^{b} for control-LBW, 0.029^{b} for control-HBW, 0.055^{b} for n-3 LCFA-LBW, and 0.089^{a} for n-3 LCFA-HBW. Concentrations are expressed in mg FA/g serum.

octadecadienoic acid (*P* < 0.001) and 9(10)-dihydroxy-octadecenoic acid (*P* = 0.077), and the arachidonic acid−derived oxylipins thromboxane B2 (*P* = 0.065), prostaglandin E2 (*P* = 0.091) and 20-hydroxy-eicosatetraenoic acid (*P* = 0.012). Inversely, the plasma concentrations of 15(R)-Lipoxin A4/Lipoxin A4 (*P* < 0.001), 5,6-dihydroxy-eicosatrienoic acid (*P* = 0.002), 8- and 15(s)-hydroxy- eicosatetraenoic acids (*P* < 0.001 and *P* = 0.074, respectively) and 14,15-epoxy- eicosatrienoic acids (*P* = 0.017), which are derived from arachidonic acid; 5(s)-, 8-, 9-, 11-, 12(s)-, 15(s)- and 18-hydroxy-eicosapentaenoic acids (all *P* < 0.001) which are derived from EPA; and 4-, 7-, 8-, 10-, 13-, 16-, 17- and 20- hydroxy-DHA (all *P* < 0.001), which are derived from DHA, were increased or tended to be increased in the n-3 LCFA diet fed piglets. Little effect piglet bBW was observed on the plasma oxylipin concentration profile, only higher concentrations of 7- and 8-hydroxy-DHA (*P* = 0.025 and *P* = 0.010, respectively) were detected in the LBW piglets compared with those from the HBW category. Finally, an overview of all the oxylipins modified by the inclusion of fish oil in sow or piglet diets, or affected by piglet bBW category is summarised in Supplementary Figure S2 together with FA precursors and the enzymatic pathways involved in the synthesis of each oxylipin.

Immunological analysis

Immunoglobulin and cytokine concentrations in blood plasma are presented in Table 5. No interaction between the main factors were observed for the immune parameters analysed. The inclusion of n-3 LCFA in the maternal diet did not affect the immune parameters analysed in plasma. However, n-3 LCFA in piglet diet tended to increase IgM (*P* = 0.067), and LBW piglets tended to have a higher TNFα concentration than HBW piglets (*P* = 0.083).

Discussion

Weaning is a critical event in the pig production system, in particular to those piglets that are born with a low bBW which are also likely to be weaned with a lower BW. Milk FA composition or inclusion of dietary fat sources as an early feeding strategy to piglets may be a key tool to enhance pig performance and gut health during pre- and postweaning stages (Lauridsen, 2020), contributing to a production system more efficient and sustainable. Previous studies are evaluated the effect of the inclusion of n-3 LCFAs in piglet diets on productive parameters. Concretely, Li et al. (2014) described that an inclusion of 3% of marine n-3 PUFA in postweaning piglet diets did not result in a significant improvement of average daily gain, average daily feed intake or growth to feed ratio. However, they described that females consuming this n-3 PUFA-supplemented diet were lighter at week 4 postweaning than those consuming a vegetable oil-enriched diet. Another study reported by Lee et al. (2019) tested n-3 LCFA−rich diets with a low protein quality via the inclusion of fish oil or microalgae, and they did not observe differences in BW, average daily weight gain, or gain−to−feed ratio, but observed a reduced feed intake during

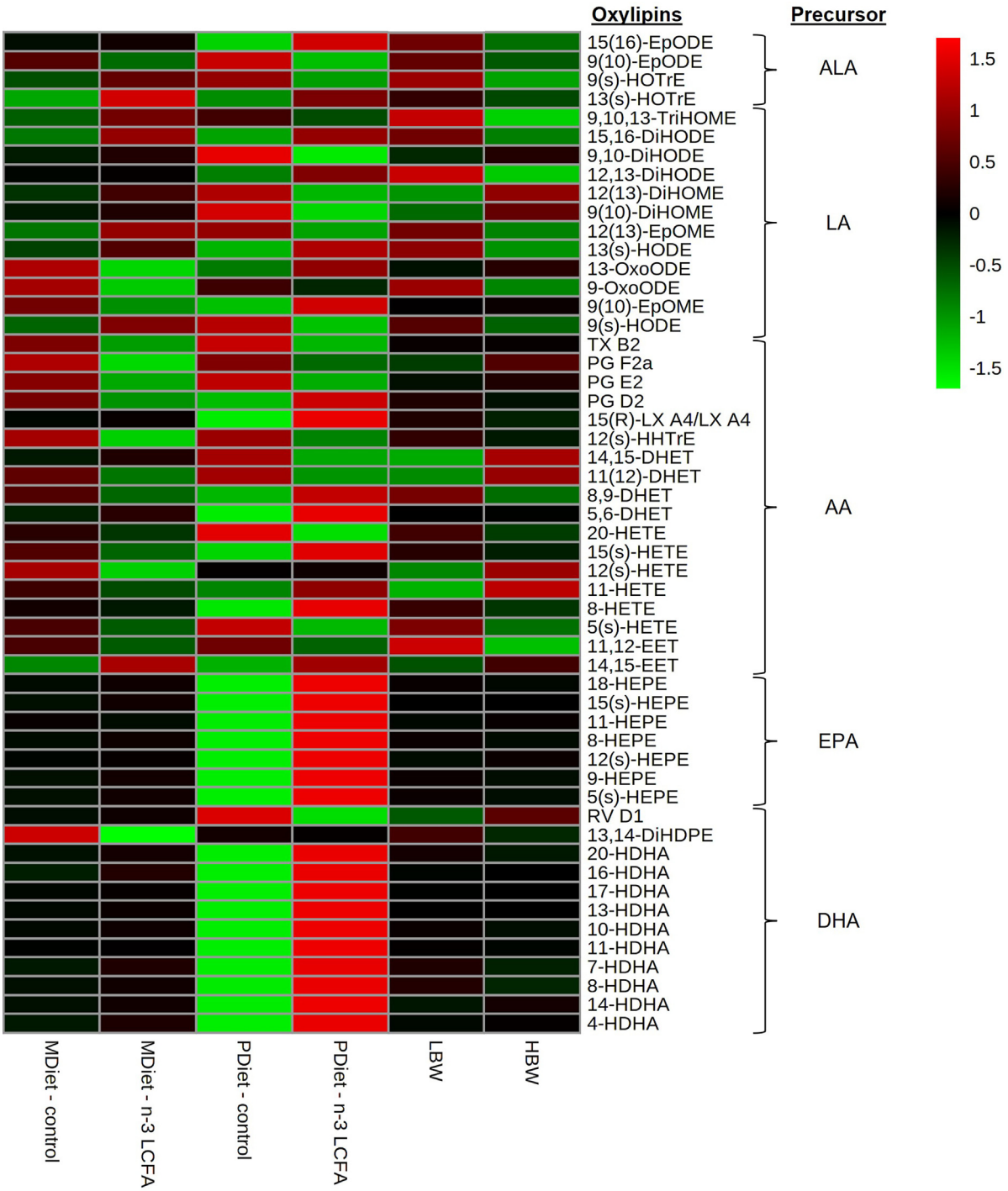

Fig. 1. Differential concentrations of plasma oxylipins by of the inclusion of a fish oil rich in eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in sow and piglet diets or piglet birth BW (bBW). Each coloured cell on the map corresponds to a concentration value being green lower concentrations and red higher concentrations. Values are means of 28 control and 20 n-3 LCFA samples for maternal diet, 24 control and 24 n-3 LCFA samples for piglet diet, and 24 LBW and 24 HBW samples for birth BW category. AA, arachidonic acid; ALA, α-linolenic acid; DiHDPE, dihydroxy- docosapentaenoic acid; DiHODE, dihydroxy-octadecadienoic acid; DiHOME, dihydroxy-octadecenoic acid; DHET, dihydroxy-eicosatrienoic acid; EET, epoxy-eicosatrienoic acid; EpODE, epoxy-octadecadienoic acid; EpOME, epoxy-octadecenoic acid; HBW, high birth weight; HDHA, hydroxy-docosahexaenoic acid; HEPE, hydroxy-eicosapentaenoic acid; HETE, hydroxy-eicosatetraenoic acid; HHTrE, hydroxy-heptadecatrienoic acid; HODE, hydroxy-octadecadienoic acid; HOTrE, hydroxy-octadecatrienoic acid; LA, linoleic acid; LBW, low birth weight; LCFA, long-chain fatty acid; LT, Leukotriene; LX, Lipoxin; MDiet, maternal diet; OxoODE, oxo-octadecadienoic acid; PDiet, piglet diet; PG, Prostaglandin; TriHOME, trihydroxy-octadecenoic acid; TX, Thromboxane.

the days 7 and 21 postweaning. Differently, Zhang et al. (2020) observed that piglets fed a diet supplemented with 5, 10, or 15 g/kg of coated n-3 LCFA during the postweaning period had greater BW (up to 0.43 kg more at week 6 postweaning), improved average daily gain (more than 8 g/day on week one and three of postweaning), and increased gain to feed ratio compared to control piglets (0.74 vs 0.75 ratio). In this way, previous studies reported inconsistency of the effects of n-3 LCFA on performance results and the effect of n-3 LCFA in piglets born with different BW has not been considered. In the present study, the interaction between

Table 5
Influence of dietary fish oil in maternal or postweaning diets and piglet birth BW on plasma immune indicators in postweaned piglets (56 days of age)[1,2].

	MDiet		PDiet		bBW		RMSE	*P*−value MDiet	*P*−value PDiet	*P*−value bBW
	Control (n = 28)	n-3 LCFA (n = 20)	Control (n = 24)	n-3 LCFA (n = 24)	HBW (n = 24)	LBW (n = 24)				
Plasma immune indicators										
Immunoglobulins (mg/mL)										
IgG	5.09	4.34	4.46	4.97	4.71	4.73	2.36	0.593	0.539	0.974
IgA	1.53	1.83	1.55	1.81	1.67	1.69	0.58	0.170	0.185	0.939
IgM	1.26	1.50	1.22	1.54	1.41	1.35	0.49	0.301	0.067	0.748
Cytokines (ng/mL)										
IL1β	14.4	24.9	19.0	20.4	18.6	20.8	8.01	0.287	0.575	0.375
IL6	8.50	64.4	36.2	36.7	30.9	42.0	33.8	0.171	0.973	0.388
IL10	0.068	0.067	0.068	0.067	0.067	0.068	<0.01	0.636	0.550	0.799
TNFα	0.13	0.16	0.13	0.17	0.12	0.17	0.10	0.692	0.171	0.083

bBW, birth weight; HBW, high birth weight piglets; IgA, immunoglobulin A; IgG, immunoglobulin G; IgM, immunoglobulin M; IL1β, interleukin 1β; IL6, interleukin 6; IL10, interleukin 10; LBW, low birth weight piglets; LCFA, long-chain fatty acid; MDiet, maternal diet; PDiet, piglet diet; TNFα, tumour necrosis factor α.
[1] Values are least squares means ± RMSE.
[2] Interactions were not detected between MDiet, PDiet and bBW.

piglet diet and bBW indicated that the n-3 LCFA diet promoted LBW piglets to have a similar average daily gain and average daily feed intake than the HBW piglets throughout all the postweaning period. In addition, LBW piglets fed the n-3 LCFA diet presented a greater gain−to−feed ratio compared to the LBW piglets fed with the control diet during the prestarter phase. Indeed, LBW form control diets had a lower average daily feed intake compared with those of HBW, while this difference between bBW was not observed in piglets fed the n-3 LCFA diets. This fact suggests that n-3 LCFA LBW piglets were more efficient during the postweaning period possibly by reducing the impact of early weaning stressors.

One of the aims of the study was to determine at what extent the changes in blood FA composition of weaned piglets are induced by the fish oil in the sow or in the piglet diet. Previously, Lauridsen and Jensen (2007) reported that the fatty acid profile of plasma and tissues of the progeny highly depends on the maternal dietary composition up to 3 weeks after the suckling period. Concretely, they described that an inclusion of 8% of rapeseed oil or fish oil in the maternal diet from late gestation and during lactation had a major impact on the n-6:n-3 FA ratio of the body lipids of the progeny pre- and postweaning being the fish oil the most efficient to provide the progeny with n-3 PUFA. Contrary, in the current study, with a lower inclusion of fish oil during gestation and lactation, the observed changes were mainly due to the presence of fish oil in the postweaning diet. Previous results within the same project describe that the inclusion of fish oil in the sow diets increases the EPA and DHA concentrations in blood from gestating and lactating sows, colostrum, milk, and blood from piglets during suckling (Llauradó-Calero et al., 2021, Llauradó-Calero et al., 2022). Therefore, increases in EPA and DHA are also expected in the blood of piglets at the end of the postweaning phase. In addition to the modifications related to n-3, a decrease of palmitic acid, stearic acid and arachidonic acid concentrations were also observed in the current study. These results are in line with those previously reported for colostrum and milk (Llauradó-Calero et al., 2021), and blood from sows and suckling piglets (Llauradó-Calero et al., 2022), where increases in total n-3 FAs, due to EPA and DHA, were linked to a decrease in arachidonic acid. The inhibition of arachidonic acid synthesis by EPA has also been previously reported (Rooke et al., 2001). In relation to the impact of bBW category, the observed changes involve n-6 FAs present at very low concentrations and they are not considered relevant.

Although the impact of dietary n-3 LCFAs on different immune indicators in suckling piglets has been a topic of interest, there is not much literature available on its effects during the postweaning period. Polyunsaturated FAs play a role in the coordination of inflammatory processes through different mechanisms. One of them is through their enzymatic or non-enzymatic oxidation and the formation of their derived oxylipins (Calder, 2010). Therefore, blood changes in the oxylipin profile could lead to changes in markers of immune response. Each oxylipin has its own immunomodulatory activity and those derived from n-6 FAs are commonly associated with pro-inflammatory activities while those derived from n-3 FAs are associated with less pro-inflammatory, anti-inflammatory and inflammation−resolving roles (Calder, 2010; Gabbs et al., 2015). In the current study, as for FA composition, the addition of fish oil in the maternal diets had virtually no effect on the oxylipin blood profile of piglets at day 28 postweaning, whereas all observed changes are due to the presence of fish oil in the postweaning diets. This could be explained because although FAs may be stored in different tissues, oxylipins are classically described as short half-life mediators that are not stored by the cells (Gabbs et al., 2015). Therefore, the effect of the maternal n-3 LCFA supplementation on postweaning plasma oxylipins may be diluted. Bearing in mind that the precise activity exerted by most of the oxylipins is not yet known, the increases in EPA and DHA concentrations have been reflected in increases of almost all their oxygenated derivatives. It is worth mentioning the increases of 12(s)-hydroxy-EPA, 15(s)-hydroxy-EPA, 18-hydroxy-EPA, 13-hydroxy-DHA and 17-hydroxy-DHA, all of which are formed via the lipoxygenase enzymatic pathway (Gabbs et al., 2015), and whose concentration was also increased in the same piglets at the end of the suckling period by the inclusion of fish oil in the sow diets (Llauradó-Calero et al., 2022). Concretely, 12(s)-hydroxy-EPA might contribute to the anti-inflammatory potential of dietary n-3 FAs through platelet-neutrophil interaction (von Schacky et al., 1990), 15(s)-hydroxy-EPA plays and important role in the resolution phase of inflammation (Miller et al., 1990), and 18-hydroxy-EPA, 13-hydroxy-DHA and 17-hydroxy-DHA are related with different anti-inflammatory roles such as the inhibition of the pro-inflammatory cytokine TNFα production in murine or human cell lines (Astarita et al., 2015; Gabbs et al., 2015). Luo et al. (2013) observed a significant decrease in TNFα and IL6 gene expression in longissimus dorsi muscle and a higher gene expression of TNFα in the spleen of weaned piglets from sows fed fish oil compared to piglets from sows fed lard during lactation. However, and in accordance with what was also reported at the end of the suckling period after the maternal inclusion of n-3 LCFAs (Llauradó-Calero et al., 2022), in the present study, TNFα plasma concentration was not affected by maternal or piglet n-3 LCFA diets. The decrease of 20-hydroxy-eicosatetraenoic acid and the trend to decrease thromboxane B2 and prostaglandin E2 observed

by the addition of n-3 LCFA in the diets are also in line with the reduction of the arachidonic acid concentration in serum resulted from the inclusion of dietary n-3 LCFA in postweaning diets. In addition, the decrease of 20-hydroxy-eicosatetraenoic and a trend to decrease thromboxane B2 were also described previously in the suckling piglets (Llauradó-Calero et al., 2022). The 20-hydroxy-eicosatetraenoic acid, formed via the cytochrome P450 enzymatic pathway, is defined as a potent vasoconstrictor and stimulator of proinflammatory cytokine production (Gabbs et al., 2015). Thromboxane B2 and prostaglandin E2 are final oxidative products formed via the cyclooxygenase enzymatic pathway (Astarita et al., 2015; Gabbs et al., 2015). Thromboxane B2 is also a potent vasoconstrictor and platelet aggregating agent (Gabbs et al., 2015), while prostaglandin E2, which is the most common and biologically active prostaglandin in mammals, can exert a variety of functions such as inducing fever, decreasing T-cell proliferation and lymphocyte migration, and promoting the secretion of interleukins related with inflammatory processes (Harizi and Gualde, 2006). Moreover, the reduction of prostaglandin E2 after an EPA– and DHA–rich diet is in line with previous results as reviewed by Calder (2010). However, although the reduced serum concentration of arachidonic acid, the blood concentrations of some derived oxylipins such 15(R)-Lipoxin A4/Lipoxin A4, 5,6-dihydroxy-eicosatrienoic acid, 8- and 15(s)-hydroxy-eicosatetraenoic acids and 14,15-epoxy-eicosatrienoic acids were increased. This differs from the results observed in the same piglets during suckling, where only a reduction of 8-hydroxy-eicosatetraenoic acids was observed (Llauradó-Calero et al., 2022). Shearer and Walker (2018) described that an increase in n-3 FA–derived oxylipins is commonly linked to a decrease in those derived from n-6 FAs. However, they also reported that in some cases n-6 oxylipins could be increased, which is in line with the results for these oxygenated derivatives of arachidonic acid in the current study. Lipoxin A4, as arachidonic acid oxygenated derivate, is defined as the main physiological lipoxin during inflammation in mammalian systems with a powerful anti-inflammatory role under many pathological conditions that trigger inflammation (Shi et al., 2017). Regarding immunoglobulins, only a trend to increase plasma IgM in piglets fed n-3 LCFAs was observed. Increases in blood IgM concentration in gestating and lactating sows fed diets with n-3 LCFA were reported in our previous studies in sows, but differences were not found in the Ig concentration in colostrum, milk, or the blood of suckling piglets (Llauradó-Calero et al., 2021; Llauradó-Calero et al., 2022). The mechanisms by which n-3 LCFA may regulate immunoglobulins remain unknown.

The two oxylipins modified by bBW are synthetised via lipoxygenase pathway. To the authors' knowledge, the functions of 8-hydroxy-DHA have not been described yet and only an association with activating peroxisome proliferator–activated receptor γ in a specific primate cell population had been reported for 7-hydroxy-DHA (Gabbs et al., 2015). Finally, the trend to increase TNFα in blood in LBW compared to HBW piglets may indicate a higher proinflammatory response.

Conclusion

This study attempted to provide a complete picture of the impact of n-3 LCFAs in the diets of sows and piglets on the blood concentrations of precursor FA, intermediate oxygenated molecules derived from them, and immune indicators in 28 days postweaned piglets. This study complements previous research carried out in our group describing the influence of n-3 LCFAs in sow diets on the same parameters in colostrum, milk, and blood from sows and the same piglets during suckling. In this study, the interaction between piglet diet and bBW category indicated that dietary fish oil could promote LBW piglets to have a similar average daily gain and feed intake compared with HBW piglets during postweaning. Moreover, the inclusion of fish oil in the piglet's diets increased EPA, DHA and total n-3 FAs, together with their derived oxylipins related with anti-inflammatory and inflammation–resolving roles.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101317.

Ethics approval

IRTA's Ethical Committee on Animal Experimentation approved the use of animals for this experiment in accordance with the Directive 2010/63/EU of 22 September 2010 and according to the recommendation of the European Commission 2007/526/CE, the Spanish guidelines for the care and use of animals in research (B. O.E. number 34, Real Decreto 53/2013) and the regional regulations on the use and handling of experimental animals (Decree 214/97, Generalitat de Catalunya) (project number: 10294).

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings are available upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

The authors report no conflict of interests.

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