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Coated omega-3 fatty acid from linseed oil positively affect sow immunoglobulin G concentration and pre-weaning performance of piglet

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ABSTRACT

A total of 45 multiparous sows (Landrace × Yorkshire, average parity is 4.2) and their piglets were used in a 35 days experiment to evaluate the effects of coated omega-3 polyunsaturated fatty acid (COF) on colostrum and milk immunoglobulin G (IgG) concentrations and fatty acid composition, and piglet growth performance. Sows were randomly allocated to three treatments with 15 replications per treatment. Dietary treatments were as follows: CON, basal diet; COF1, CON + 2.5 g/kg of COF; (3) COF2, CON + 5.0 g/kg of COF. No significant ($P > 0.05$) responses were observed for reproductive performance parameters such as litter size, lactating average daily feed intake, body weight (BW) loss, backfat thickness loss, and estrus interval days. A significant linear increase ($P < 0.05$) observed with an increasing COF supplementation at the IgG concentration in milk during 16 days. Nevertheless, the fatty acid compositions of colostrum, at 4 days and 16 days milk was not affected by the increased COF supplementation. Moreover, increasing dietary COF resulted in significant linear ($P < 0.05$) increase in piglet BW on days 21 and average daily gain during days 1−7, 8−14, 15−21, and 1−28. In summary, inclusion of COF in lactating sow diets improved the milk IgG concentrations, and suckling pig growth performance but had no effect on reproductive performance, and colostrum and milk fatty acid compositions.

1. Introduction

The genetic selection improves total litter size for the modern sow, which leads the increasing nutritional requirements during lactating (Prunier et al., 2010). Besides protein, vitamins, and minerals feed ingredients, fats and oils also supplemented into lactation diets because of the high energy and fatty acid (FA) constituents (Rossi et al., 2010). Omega-3 polyunsaturated fatty acid (PUFA) are part of PUFA series and are considered nutritionally essential FA because it cannot be synthesized in mammalian body (Yin et al., 2017). During the past years, many studies have reported that dietary inclusion of different sources of omega-3 PUFA could influence the growth performance, nutrient digestion and absorption, muscle and tissues FA profiles in different stages in pigs (Htoo et al., 2008;

Abbreviations: ADG, average daily gain; ADFI, average feed intake; ALA, α-linolenic acid; BW, body weight; COF, coated omega-3 fatty acid; FA, fatty acids; Ig, immunoglobulin; IgG, immunoglobulin G; LA, linoleic acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SEM, standard error of means; SFA, saturated fatty acids.

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Yeste et al., 2011; Liu and Kim, 2018; Upadhaya et al., 2019b). Moreover, it has also been demonstrated that the supplementation of omega-3 PUFA during gestation and lactation could modify the PUFA concentrations in plasma, milk, and reproductive organs of sows as well as modification of FA composition, structure, and physiology in intestinal tissues of newborn and weaning pigs (Bazinet et al., 2003; Binter et al., 2011; Boudry et al., 2009; Farmer and Petit, 2009; Leonard et al., 2010).

Omega-3 PUFA have also been reported to modulate mediators of humoral and cellular immunity (Calder, 2007). Immunoglobulin G (IgG) is the most common type of antibody found in blood circulation which protects the body from infection by binding many kinds of pathogens such as viruses, bacteria, and fungi (Kaneko et al., 2006). Moreover, colostrum of sows also has a high percentage of IgG which is beneficial for newborn piglet immune protection (Hasan et al., 2018). It has been hypothesized that dietary supplementation of omega-3 PUFA may have beneficial effects on sow performance and immunity, consequently improving the growth of suckling piglets.

Furthermore, it was reported that through the coated processing, the active ingredient could be released to the appropriate site for absorption (Upadhaya et al., 2017). Thus, the objective of this experiment was to investigate the effect of coated omega-3 PUFA (COF) on colostrum and milk IgG concentrations and fatty acid composition of sows', and piglet performance.

2. Materials and methods

The experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use Committee of Dankook University, Cheonan, South Korea.

2.1. Source of n-3 fatty acid

The coated omega-3 polyunsaturated fatty acid used in this study was provided by a commercial company (Morningbio Co., Ltd, Cheonan, Korea). The plant based omega-3 PUFA produced from linseed oil was protected using spray drying method as previously described by Watanabe et al. (2002). According to the information provided by the suppliers, the coated omega-3 PUFA product contains 352 g/kg of linolenic acid as active ingredient. Besides, it also contains 82.2 g/kg of linoleic acid, 362.7 g/kg of palmitic acid, and 82.2 g/kg of oleic acid.

Table 1
Composition of lactating sows diets (as fed-basis; g/kg).

	CON	COF1	COF2
Ingredients			
Corn	716.70	717.40	717.70
Soybean meal (480 g/kg of crude protein)	206.70	206.50	206.60
Tallow	17.20	14.20	11.30
Molasses	22.00	22.00	22.00
Coated omega-3 fatty acid	0	2.50	5.00
Dicalcium phosphate	16.30	16.30	16.30
Limestone	9.00	9.00	9.00
Salt	6.00	6.00	6.00
Methionine	0.60	0. 60	0. 60
Lysine	2.70	2.70	2.70
Vitamin premix[1]	1.00	1.00	1.00
Mineral premix[2]	1.00	1.00	1.00
Choline	0.80	0.80	0.80
Total	100.00	100.00	100.00
Calculated value			
Metabolisable energy, kcal/kg	3300	3300	3300
Analyzed value			
Dry matter	879.60	877.00	874.50
Crude protein	155.00	155.00	155.00
Lysine	9.50	9.50	9.50
Methionine	2.80	2.80	2.80
Crude fat	4.47	4.39	4.32
Neutral detergent fiber	82.30	82.30	82.30
Acid detergent fiber	31.60	31.60	31.60
Ash	55.70	55.70	55.70
Calcium	8.00	8.00	8.00
Phosphorus	6.00	6.00	6.00

[1] Provided per kilogram of complete diet: vitamin A, 12 100 IU; vitamin D3, 2000 IU; vitamin E, 48 IU; vitamin K3, 1.5 mg; riboflavin, 6 mg; niacin, 40 mg; D-pantothenic, 17 mg; biotin, 0.2 mg; folic acid, 2 mg; choline, 166 mg; vitamin B6, 2 mg; and vitamin B12, 28 mg.

[2] Provided per kilogram of complete diet: iron (as $FeSO_4 \cdot 7H_2O$), 90 mg; copper(as $CuSO_4 \cdot 5H_2O$), 15 mg; zinc(as $ZnSO_4$), 50 mg; manganese (as MnO_2), 54 mg; iodine (as KI), 0.99 mg; and selenium (as $Na_2SeO_3 \cdot 5H_2O$), 0.25 mg.

2.2. Experimental design, animals, diets, and housing

A total of 45 multiparous sows (Landrace × Yorkshire) with an average parity of 4.2 were used in this 35 days experiment. Sows were randomly allocated into one of three dietary treatments with 15 replications each. The dietary treatments included: (1) CON, basal diet treatment, (2) COF1, CON + 2.5 g/kg of COF; (3) COF2, CON + 5.0 g/kg of COF. Sows were fed their respective experimental lactation diets from day 108 of gestation until weaning (28 days after parturition). Dietary nutrients were formulated to meet or exceed National Research Council (NRC) (2012) recommendations (Table 1). All experimental diets of sows were provided in coarsely ground meal form and sows were fed 1.9 kg/day of a commercial gestation feed until farrowing. On the day of parturition, sows were not offered feed. All diets were provided in the mash form twice a day. Sows were housed in farrowing crates (2.1 × 0.6 m) with an area (2.1 × 0.6 m) for newborn piglets on each side. The temperature in the farrowing house was maintained at a minimum of 20 °C. Heat lamps were provided for piglets. Piglets were subcutaneously injected with iron dextran (1 mL/pig) within 24 h of birth. After farrowing, daily feed allowance was gradually increased. Sows were provided with a free access to drinking water throughout the experimental period. By day 6, sows were provided *ad libitum* access to feed. Piglets received no creep feed.

2.3. Sampling, and measurements

Sows were weighed and scanned for backfat thickness within 12 h after farrowing and at the day of weaning. Backfat thickness of sows (6 cm off the midline at the 10th rib) was measured using a real-time ultrasound instrument (Piglot 105; SFK Technology, Herlev, Denmark). During the experimental period, the numbers of piglets born alive and dead per litter were recorded to calculate survival ratio. Individual pig weight was recorded at birth. Cross-fostering was performed within 1 day of parturition and occurred only among sows of the same treatment. Each litter were standardized to 12 piglets per sow, and then at one-week intervals they were weighed to calculate the average daily gain (ADG) of piglets. After farrowing, daily feed allowance was increased by 1 kg/day until day 6 postpartum. During lactation, feed consumption was recorded for each sow to calculate average daily feed intake (ADFI).

Colostrum was collected within 12 h after farrowing, and milk was collected from all sows on 4 day and 16 day after parturition by hand-milking. The collected samples were stored in opaque plastic bottles at –20 °C until analysis. The immunoglobulin G (IgG) concentration of samples were analyzed by using nephelometry (Behring, Germany). The FA composition of colostrum and milk were determined according to the modified method of Kim et al. (2003). Lipids from the samples were extracted with hexane-isopropanol (3: 2, v: v). The extracted lipids was mixed with 0.5 mL of toluene and 2 mL of 50 mL/L KOH–MeOH, and heated at 70 °C for 8 min; then 2 mL of 140 mL/L BF_3–MeOH were added to the mixture, and heated at 70 °C for 2 min. The FA methyl esters was extracted with 3 mL of 5% NaCl and 1 mL of hexane. Samples were analyzed for total FA, using a gas chromatograph (GC-2010 Plus, Shimadzu, Kyoto, Japan) associated with a flame ionization detector. The FA methyl esters were separated using Omegawas-320 fused silica capillary column (30 m × 0.32 mm × 0.25 mm; Shimadzu China Co., Ltd, Shanghai, China), with 1.2 mL/min of helium flow. The oven temperature was increased form 180 °C–280 °C, at the rate of 1.5 °C/min. Temperatures of the injector and detector were 260 °C and 280 °C respectively. The peaks for FA were identified by comparing with the retention time and peak area with each respective FA standard. The content of each FA was expressed as a percentage of the sum of all of the FA analyzed.

Table 2
Effect of dietary supplementation of coated omega-3 fatty acid on reproduction performance in lactation sows.

Items	CON	COF1	COF2	SEM	P-value	
					Linear	Quadratic
Parity	4.0	4.3	4.3	0.30	0.513	0.705
Litter size						
Total birth, head	12.7	12.7	12.4	0.29	0.327	0.569
Total alive, head	11.9	12.1	11.7	0.32	0.763	0.386
Stillbirth, head	0.3	0.2	0.1	0.11	0.334	1.000
Mummification, head	0.2	0.1	0.3	0.11	0.350	0.111
Survival, %	96.3	97.7	96.4	1.06	0.924	0.247
Average daily feed intake, kg						
Lactation	6.8	6.7	6.8	0.06	0.891	0.229
Body weight, kg						
After farrowing	251.7	252.4	247.7	4.97	0.565	0.650
Weaning	234.6	237.9	233.2	5.40	0.840	0.524
Body weight loss	14.9	14.9	14.5	0.92	0.467	0.266
Backfat thickness, mm						
After farrowing	22.0	21.5	21.8	0.32	0.589	0.300
Weaning	19.5	19.3	19.6	0.29	0.828	0.478
Backfat thickness loss	2.4	2.2	2.1	0.24	0.356	0.858

Abbreviation: CON, Basal diet; COF1, CON + 2.5 g/kg of coated omega-3 fatty acid; COF2, CON +5.0 g/kg of coated omega-3 fatty acid. SME, Standard error of means.

2.4. Statistical analysis

All data were analyzed with a completely randomized design using a general linear model of SAS (2002). The sow was considered as the experimental unit. Orthogonal polynomials were used to assess the linear and quadratic effects of increasing levels of dietary supplemental COF. Variability in the data was expressed as the pooled standard error of means (SEM). Probability values less than 0.05 were considered significant.

3. Results

3.1. Reproductive performance of sows

The effects of COF supplementation on reproductive performance of sows are presented in Table 2. Litter size parameters such as total birth head, total alive head, stillbirth head, mummification head and survival rate were not affected ($P > 0.05$) by increasing levels of COF supplementation. Furthermore, increasing levels of COF had no significant ($P > 0.05$) effect on ADFI of lactating sows, body weight loss, backfat thickness loss and estrus interval days.

3.2. Colostrum, and milk IgG concentrations of sows

The data presented in Table 3 shows that colostrum as well as milk at 4 days after farrowing IgG concentrations were not affected significantly ($P > 0.05$) by dietary supplementation of COF. Whereas, significant linear increase ($P < 0.05$) due to increasing COF supplementation was observed for milk IgG concentrations at day 16 after farrowing.

3.3. Colostrum and milk FA compositions of sows

The effect of dietary supplementation of COF on colostrum and milk fatty acid compositions are described in Table 4. There were no significant effects ($P > 0.05$) in FA compositions due to increasing COF supplementation in colostrum as well as in collected milk and analyzed during days 4 and 16.

3.4. Growth performance of sucking piglet

As described in Table 5, dietary increasing levels of COF supplementation did not influence ($P > 0.05$) the weaned litter size, pre-weaning survival rate, body weight on days 7 and 14. Piglets BW increased ($P < 0.05$) linearly on days 21 follow increased supplementation of COF. There was a significant linear increase ($P < 0.05$) in ADG in response to increasing COF supplementation during days 1−7, 8−14, 15−21, and 1−28. Furthermore, with increasing level of COF supplementation trends in linear increases in BW ($P = 0.09$) at day 28 and ADG ($P = 0.06$) during days 22−28 were observed.

4. Discussion

The aim of the present study was to evaluate the influence of COF on reproduction performance, colostrum and milk IgG concentrations, colostrum and milk FA composition, and pre-weaning pig growth performance. Yin et al. (2017) reported that dietary supplementation with omega-3 PUFA did not influence the ADFI and backfat thickness loss which is in agreement with this study. Similarly, Upadhaya et al. (2019a) indicated that higher dietary omega-3 PUFA ratio did not affect BW, loss in BW or backfat thickness of sows. After farrowing, sows under many metabolic changes related to milk production, which leads a negative energy balance of sows. Moreover, lactation is a priority, fats are mobilized from tissues to maintain milk production (Boyd et al., 2000). It was suggested that the proportion of omega-3 PUFA may affected on several aspects of lipid metabolism to influence body fat mobilization (Lee et al., 2008). Furthermore, the addition of omega-3 PUFA may also affect feed intake; however, ADFI was not affected in this experiment. This maybe because that diets of this study met the nutrients recommendations for sows which could afford the milk production. On the other hand, the litter size parameters also remained unaffected by COF supplementation in the current study. Similar results was observed by Farmer et al. (2010), that sows fed flaxseed meal or flaxseed oil as omega-3 PUFA source did not influence born piglet number, stillborn number, and live born number. Moreover, Mateo et al. (2009) reported no effect of litter size for two subsequent

Table 3
Effect of dietary supplementation of coated omega-3 fatty acid on colostrum and milk IgG concentrations in lactation sows.

Items	CON	COF1	COF2	SEM	P-value	
					Linear	Quadratic
Colostrum, µg/mL	17,831	18,897	21,661	1779.0	0.154	0.704
Milk 4 day, µg/mL	674	856	1146	236.3	0.183	0.855
Milk 16 day, µg/mL	2089	2517	3378	376.9	0.030	0.641

Abbreviation: CON, Basal diet; COF1, CON + 2.5 g/kg of coated omega-3 fatty acid; COF2, CON +5.0 g/kg of coated omega-3 fatty acid. SME, Standard error of means.

Table 4
Effect of dietary supplementation of coated omega-3 fatty acid on colostrum and milk fatty acid composition in lactation sows.

Fatty acid composition	CON	COF1	COF2	SEM	P-value	
					Linear	Quadratic
Colostrum						
C14:0	2.82	2.99	2.57	0.237	0.474	0.341
C16:0	28.12	27.14	27.96	1.544	0.944	0.646
C16:1	4.11	4.77	4.41	0.561	0.715	0.477
C18:0	6.82	4.02	4.90	1.565	0.411	0.364
C18:1	28.69	31.85	32.21	2.056	0.261	0.595
LA[2]	19.53	19.24	21.18	2.210	0.610	0.690
ALA[2]	0.00	0.00	0.00	–	–	–
SFA[2]	38.20	34.54	35.43	3.184	0.556	0.577
MUFA[2]	32.60	37.81	36.61	2.519	0.292	0.329
PUFA[2]	18.40	20.35	21.59	3.160	0.496	0.929
Milk 4 day						
C14:0	2.56	2.60	2.26	0.192	0.305	0.436
C16:0	24.93	22.67	23.93	0.966	0.485	0.176
C16:1	6.23	5.96	6.13	0.289	0.820	0.545
C18:0	4.24	4.19	4.00	0.137	0.249	0.678
C18:1	43.22	44.77	44.62	1.467	0.518	0.650
LA	17.60	16.96	17.14	0.266	0.258	0.249
ALA	0.86	0.97	0.98	0.048	0.129	0.374
SFA	31.42	30.09	29.68	1.291	0.370	0.779
MUFA	49.45	50.72	51.06	1.230	0.384	0.760
PUFA	17.90	17.14	17.22	0.266	0.111	0.237
Milk 16 day						
C14:0	3.32	3.45	3.31	0.196	0.967	0.580
C16:0	27.33	28.57	27.99	0.670	0.503	0.298
C16:1	7.48	7.35	7.45	0.312	0.958	0.780
C18:0	4.75	4.90	4.86	0.148	0.607	0.597
C18:1	34.76	34.32	35.00	0.354	0.650	0.234
LA	18.85	18.07	18.48	0.626	0.873	0.772
ALA	1.17	1.00	1.02	0.062	0.119	0.259
SFA	37.02	37.47	36.86	0.104	0.913	0.681
MUFA	42.24	42.07	42.94	0.045	0.300	0.376
PUFA	19.92	18.87	19.50	0.167	0.861	0.692

Abbreviation: CON, Basal diet; COF1, CON + 2.5 g/kg of coated omega-3 fatty acid; COF2, CON +5.0 g/kg of coated omega-3 fatty acid. ALA, α-linolenic acid; LA, linoleic acid; SEM, standard error of means; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 5
Effect of dietary supplementation of coated omega-3 fatty acid on growth performance in sucking piglet.

Items	CON	COF1	COF2	SEM	P-value	
					Linear	Quadratic
Standardized litter size	12	12	12	–	–	–
Weaned litter size	11.7	11.8	11.5	0.33	0.671	0.169
Pre-weaning survival, %	96	98	97	1.16	0.605	0.253
Body weight, kg						
Initial	1.41	1.41	1.34	0.046	0.133	0.332
Day 7	1.91	1.96	1.87	0.051	0.453	0.098
Day 14	2.79	2.91	2.85	0.063	0.146	0.074
Day 21	4.47	4.69	4.69	0.069	0.013	0.093
Day 28	6.71	6.95	6.95	0.080	0.090	0.125
ADG, g						
1−7 days	69	74	74	1.2	0.002	0.085
8−14 days	126	138	141	3.1	0.001	0.330
15−21 days	240	255	262	5.2	0.005	0.336
22−28 days	426	452	453	9.1	0.057	0.033
1−28 days	203	213	216	3.0	0.007	0.149

Abbreviation: CON, Basal diet; COF1, CON + 2.5 g/kg of coated omega-3 fatty acid; COF2, CON +5.0 g/kg of coated omega-3 fatty acid. ADG, average daily gain; SEM, Standard error of means.

gestations with sows fed rich omega-3 PUFA diets. However, the uninfluenced results on litter size is not surprising, because the ovulation rate and prenatal death mainly occurs before day 30 of pregnancy (Edwards et al., 2012).

Newborn pigs are born antibody free and the passive immunization of neonatal depends entirely on maternal immunity from colostrum and milk, which mostly related with immunoglobulins (Ig) (Zanello et al., 2013). Particularly, IgG which existed at high percentage in colostrum, is a key factor in the passive immunity for newborn piglets against environmental infection during the first 24 h (Markowska-Daniel and Pomorska-Mol, 2010). In the current study, the concentration of IgG in colostrum and 4 days milk were not affected by COF supplementation; but IgG concentration in 16 days milk was linearly increased followed by the addition of COF. However, owing the lack of available literature, direct comparisons of response to COF supplemental in the sow IgG concentration is impossible. Contrary to this experiment, Yao et al. (2012) observed a great difference of colostrum IgG concentration in sows fed with different ratio of PUFA (linseed oil and corn oil) diets; whereas 21 days milk IgG concentration was not influenced. It was reported that colostrum IgG varies greatly between sows and there are many factors that could influence the colostrum IgG such as endocrine status, parity, vaccination, management, and fat composition of feed (Kielland et al., 2015; Nuntapaitoon et al., 2019). The inconsistent results for colostrum and milk IgG concentration are likely associated with differences in the source and levels of omega-3 PUFA and different parity of sows between experiments.

The results on colostrum and milk FA composition are inconsistent with those reported by De Quelen et al. (2010), who showed that linseed oil supplementation diets improved the content of PUFAs in colostrum and milk. Furthermore, Eastwood et al. (2014) indicated different dietary PUFA ratio also altered the colostrum and milk (4 days and 21 days) FA compositions. The contents of omega-3 PUFA in colostrum and milk reflect the nutritional status of sows during gestation and lactation. It was considered that dietary supplementation during last third of gestation with flaxseed or flaxseed oil changed the FA composition of sow milk (Farmer and Petit, 2009). Whereas, there was no changes about the FA compositions of milk and colostrum in the current experiment. The inconsistent finding regarding FA compositions could be due to the dose of COF in the diet, different feed ingredients or feeding period before parturition.

As a result of the current study, piglets BW were uninfluenced among treatments from birth to day 14; however, at day 21, weight of piglets was improved with COF supplementation. The ADG of piglets was linearly increased from day 1−7, 8−14, 15−21, and overall in response to COF supplementation. Previously, many studies have reported that supplementation of omega-3 PUFA in sows could affect the suckling piglets growth performance. For238 instance, Rooke et al. (2001) indicated that sows fed tuna oil as omega-3 PUFA source enhanced piglets growth may be due to the improvement of suckling behavior after birth by PUFA. As reported by Xiao et al. (2008), fish oil based omega-3 PUFA supplementation during lactation increased suckling piglets BW and ADG. Recently, Upadhaya et al. (2019a) proved that linseed oil as a source of omega-3 PUFA affected piglet growth which did not affect sow performance. These results showed that the supplementation of omega-3 PUFA may have various mechanism to influence the suckling pig growth such as improvement in sow performance and nutrient digestibility, alters the FA composition of milk, and suckling behavior. In combination with the results of this experiment, the enhanced suckling piglet growth may be more likely due to the improved immune status of sows. Because the antigenic specificity of IgG reflects the maternal perception of environmental antigens, immunity obtained from colostrum and milk can protect piglets from these antigens, which beneficial to piglet growth.

5. Conclusion

Dietary supplementation of coated omega-3 fatty acids in sow diets using linseed oil did not affect sow reproductive performance and milk fatty acids composition. However, the IgG concentrations in 16 days milk were linearly increased with the inclusion of increasing level of coated omega-3 fatty acids in the diet. The growth performance of suckling piglets were significantly improved in response to coated omega-3 fatty acids supplementation. It is suggested that the coated omega-3 fatty acids may have beneficial effects on sows during lactation at lower dose compared with non-coated ones.

Author statement

HYS and IHK contributed to conceptualization and methodology; HYS contributed to data collection and calculation; HYS has done the statistical analysis and wrote the original draft manuscript. Writing-review and editing by HYS and IHK. Supervision-IHK.

Declaration of Competing Interest

The authors confirm that there were no conflicts of interest associated with the publication.

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