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Evaluation of dietary coated omega-3 fatty acid supplementation on reproduction performance, growth performance, nutrient digestibility, and blood profiles in lactating sows and suckling piglets

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ABSTRACT

A total of 16 sows (Landrace × Yorkshire) were used in a 33-day trial (7 days before expected parturition) to determine the effects of dietary coated omega-3 fatty acid supplementation on reproduction performance, growth performance, nutrient

digestibility, and blood profiles in lactating sows and suckling piglets. Pigs were randomly allotted into two treatments with 8 replicates per treatment and the parity was 4.9. The dietary treatments were as follows: CON, corn-soybean meal based diet (omega-6:omega-3 polyunsaturated fatty acids (PUFA) ratio of 17:1) and TRT, CON + 0.9% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1). The supplementation of coated omega-3 increased piglet's body weight (BW) (day 7) and average daily gain (ADG) (day 0 to 7) ($P < 0.05$) from farrowing to weanling compared with control. No differences ($P > 0.05$) were observed on reproduction performance, nutrient digestibility, and blood profile in sows.

In conclusion, our study demonstrated that the dietary supplementation of 0.9% omega-3 PUFA in corn-soybean meal based diet (omega-6:omega3 PUFA ratio of 5:1) improved BW and ADG of suckling piglets during the first week.

Key words: omega-3 fatty acid, growth performance, lactating sows, suckling piglets

Introduction

The reproductive performance of sows is one of the key factors determining the profitability of the pig industry (Onteru et al., 2009). Improving sow nutrition is a potential way to improve sow fertility and improve embryo survival, fetal development and piglet survivability and survival rates (Henman, 2006). Polyunsaturated fatty acids (PUFA) are important nutrients for maintaining the

physiological health of animals. PUFA are essential fatty acid (FA) and cannot be synthesized by the body, but can be obtained from the diet. In the past two decades, some studies have evaluated the effect of supplementing gestation and lactation feed with PUFA, which is critical for fetal growth and development, and it has been suggested that the addition of omega-3 PUFA to the diet can improve sow productivity (Mateo et al. 2009; McAfee et al., 2019). Tanghe and De Smet, (2013) reported that dietary supplementation with omega-3 FA could enhance reproductive outcome. Particularly the omega-3 long chain PUFA (LC-PUFA) are important. Commercial pig diets are based on grain and protein feeds and contain almost no long-chain omega-3 FA. LC-PUFA are fatty acids with 18–20 carbons or more, which can be categorized into two main families — omega-6 and omega-3. Main omega-3 LC-PUFA in food sources are a-linolenic acid (ALA) (18:3 Δ9, 12, 15), docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), and docosapentaenoic acid. As mammals cannot synthesize ALA from the precursor oleic acid and the conversion efficiency of ALA to DHA, and EPA are low and hence direct uptake appears to be significantly more effective (Abedi and Sahari, 2014). Linseed oil and refined fish oil are often used as a source of omega-3 FA to be supplemented into feed (Jiang et al., 2017; Sun et al., 2019).

In addition, we hypothesis that the coated omega-3 FA can effectively protect the active ingredients of FA from being absorbed by the stomach, and enabling FA to be effectively delivered to the suitable location of animal's. Therefore, the objective of this study was to evaluate the effects of dietary supplementation of 0.9% coated

omega-3 FA from linseed oil and refined fish oil to corn-soybean meal-based diet on growth performance, nutrient digestibility, blood profiles, and FA composition in lactating sows and suckling piglets.

MATERIAL AND METHODS

The experiment was conducted at the swine experimental unit of Dankook University (Anseodong, Cheonan, Choongnam, Korea). The protocol for the current experiment was approved by the Animal Care and Use Committee of Dankook University (DK-4-1706).

Source of Coated Omega-3

The omega-3 PUFA used in this study was provided by a commercial company (Morningbio Co., Ltd., Cheonan, Korea). It was produced from linseed oil and refined fish oil. It was protected using matrix coating technology. According to the information provided by the suppliers, protected omega-3 FA contains 55.75% linolenic acid as active ingredient. Besides this it also contains 15.73% linoleic acid, 18.89% oleic acid, 5.22% palmitic acid and 4.41% stearic acid.

Experimental Design, Animals and Housing

A total of 16 sows (Landrace × Yorkshire) were randomly allotted into two treatments with 8 replicates per treatment. The dietary treatments were as follows: CON,

corn-soybean meal based diet (omega-6:omega-3 PUFA ratio of 17:1) and TRT, CON + 0.9% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1). Diets (pellet feed) were formulated to meet or exceed NRC (2012) recommendations for all nutrients (Table 1). On day 107 of gestation, sows were moved from gestation crates to farrowing crates (2.10 × 1.80 m) equipped with a feeder and water in farrowing room and randomly assigned to dietary treatments. The temperature in the farrowing house was maintained at a minimum of 20℃. Supplemental heat was provided to piglets using heat lamps. All diets of sows were provided in meal form, and sows and piglets were provided with free access to water throughout the experimental period. Gestation sows were fed twice per day. From day 107 of gestation to parturition, sows were fed 2.5 kg/day. Piglets were treated according to routine management practices that included teeth clipping, tail docking, and ear notching.

Sampling and Measurements

The backfat thickness of sows was measured 6 cm off the midline at the 10th rib using a real-time ultrasound instrument (Piglet 105, SFK Technology, Herlev, Denmark) 4 day before farrowing, 1 day after farrowing, 7 day after farrowing, and during weaning (day 26). The measurement of backfat was done as per the method described by Wang et al. (2008).

The feed consumed during the gestation and lactation periods was recorded and used to calculate the average daily feed intake (ADFI). Detection of estrus was conducted

twice per day from weaning onwards, at 8 am and 4 pm every day. A sow was considered to return to estrus when exhibiting a standing response induced by a back pressure test when in the presence of a boar. Litter size and litter size at weaning pigs was also recorded to calculate the survival rate.

Individual piglet body weight (BW) and litter weights were assessed on day 0, 7, 14, 21, and weaning to calculate average daily gain (ADG). Body condition scores of each sow were recorded 4 day before farrowing, 1 day after farrowing, 7 day after farrowing, and during weaning. A scale of 1 to 5 was used to visually evaluate the body condition; a value of 1 was assigned to a very thin sow and 5 to a very fatty sow, and the optimum score was given a value of 3.

To determine the ATTD for dry matter (DM), nitrogen (N), and gross energy (GE), sows were fed diets containing chromic oxide (0.2%) as an indigestible marker for 5 day followed by fecal grab sampling from 5 randomly selected sows per treatment via rectal palpation on farrowing and weaning day. Before the chemical analysis, the fecal samples were thawed and dried in an oven at 60°C for 72 h, after which they were ground to pass through a 1-mm screen. Then, all the feed and fecal samples were analyzed, following the procedures outlined by the AOAC (2000). N was determined using a Kjeltec 2300 Nitrogen Analyzer (Foss Tecator AB, Hoeganaes Sweden) and CP was calculated as N × 6.25. GE was analyzed using an oxygen bomb calorimeter (Parr 1600 Instrument Co., Moline, IL, USA). Chromium was analyzed by UV absorption spectrophotometry (Shimadzu, UV-1201, Japan) according to the methods of Hahn et al. (2006).

The ATTD was then calculated using the following formula:

Digestibility (%) = {1 - [(Nf × Cd)/ (Nd × Cf)]} ×100 where: Nf = nutrient concentration in the feces (%DM), Cd = chromium concentration in the diet (%DM), Nd is the nutrient concentration in the diet (%DM), and Cf = chromium concentration in the feces (%DM).

The fatty acids concentrations of the experimental diets were the mean of three replicated, and the fatty acids were analyzed by using a gas chromatography (GC–2010 Plus, Shimadzu, Kyoto, Japan). The FA methyl esters were separated using a SH–FameWAX fused silica capillary column (30 m × 0.32 mm × 0.25 mm; Shimadzu China Co., Ltd), with 0.8ml/min of helium flow. The oven temperature was increased from 205℃ to 240℃, at the rate of 1.5℃/min. temperatures of the injector and detector were 250℃ and 280℃ respectively. The peaks of FA were identified by comparing the retention time and peak area of each FA with the respective standard. FA content was expressed as a percentage of the total fatty acids and shown in Table 2.

Blood sample (5 mL) were collected via jugular venipuncture into vacuum tubes, (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ, USA) from 5 randomly selected sows per treatment at one day before farrowing and after weaning. After collection, blood sample were centrifuged at 3,000 x g for 15 min at 4℃, and samples were stored at -20℃. The total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), cholesterol in the serum samples were analyzed with

automatic biochemical analyzer (RA-1000, Bayer Corp., Tarrytown, NY) using colorimetric method, immunoglobulin G (IgG) using an automatic biochemistry analyzer (HITACHI 747; Hitachi, Tokyo, Japan).

Statistical Analysis

All data were subjected to the GLM procedures of SAS (2013) as a randomized complete block design (SAS Inst. Inc., Cary, NC). The individual sow or litter of piglets was used as the experimental unit. Differences among all treatments were separated by using the Tukey's test. The variability in the data was expressed as standard error (SE). A probability level of $P < 0.05$ was considered to be statistically significant.

RESULTS

Growth performance

No differences ($P > 0.05$) were observed on sow BW, backfat thickness and ADFI, as well as piglet survival, body condition score, and estrus interval between CON and TRT treatment (Table 3). At day 7, BW was higher ($P < 0.05$) in piglets fed TRT diet compared with CON. In addition, ADG was also higher ($P < 0.05$) in pigs fed TRT diet compared with CON at day 0-7 (Table 4).

Nutrient digestibility

No differences ($P > 0.05$) were detected on ATTD of nutrients in sows fed TRT diets

compared with CON during farrowing and at weaning (Table 5).

Blood profiles

No differences ($P > 0.05$) were detected on blood profile in sows fed TRT diets compared with CON during farrowing and at weaning (Table 6).

Discussion

Until now, research on the effect of increased dietary intake of omega-3 PUFA during gestation of sows and progeny is limited and has provided inconsistent results. In the study of Rooke et al. (2001a), increasing omega-3 FA intake (as salmon oil) from day 60 of gestation reduced total litter size, and the reason for this decreased litter size is unclear. However, Mateo et al. (2009) reported that feeding a diet rich in omega-3 LC PUFA for two subsequent gestations (both from day 60 of gestation until weaning) found no effect on number of piglets born (total, live or stillborn). Lauridsen and Danielsen (2004) report that a control diet without supplemental fat was compared to six diets containing 8% of either animal fat, rapeseed oil, fish oil, coconut oil, palm oil, or sunflower oil. The result showed that inclusion of fat at a level of 8% to lactation diets of sows improved their daily feed intake, and enhanced the weight gain of the progeny from birth until weaning. The inconsistent finding regarding growth performance in pigs could be due to the different doses of omega-3 added in the diet, FA source, different omega-3 FA, Coated fatty acids, different age or feed ingredients of pigs.

In the current experiment, feeding omega-3 PUFA to sows does not seem to affect the embryo number or development and that feeding omega-3 PUFA to sows during gestation does not apparently influence the number of piglets born (total, live or stillborn). However, we observed increase in piglets BW (day 7) and ADG (day 0 to 7) in the omega-3 diet from farrowing to weanling, and no significant difference in birth weight. Similarly, Mateo et al. (2009) reported that omega-3 PUFA during lactation improved the growth of nursing piglets, and improved piglet birth weight in the subsequent litter. It may be that the omega-3 PUFA reach the piglet through the colostrum and sow milk and affect the growth performance (Roszkos et al., 2020). Rooke et al. (2001c) suggested that dietary salmon oil increased the proportions of long-chain omega-3 PUFA in colostrum to a similar extent. In previous reports, it has been shown that FA composition of the diet influences FA composition in different tissues of pigs, milk and piglets (Peinado et al., 2009; Sampels et al., 2011: McAfee et al., 2019). Due to the transfer of dietary fatty acids from the diet to the fetus or provided to piglets through colostrum and sow milk, there are many influencing factors, such as duration, timing, and amount of supplements, as well as FA types (Rooke et al., 2001b; Amusquivar et al., 2010).

Cho and Kim (2013) and Upadhaya et al. (2017) reported that omega-3 PUFA have no effect on nutrient digestibility in finishing pigs. In our study, we demonstrated that omega-3 diet has no effect on nutrient digestibility in lactating sows. In contrast, Ueda et al. (2003) reported that lactating cows fed diets with 3% linseed oil had resulted in significant improvements in the digestibility of DM and organic matter. The

inconsistent reported could be caused by many reasons, such as whether the fatty acid is coated or not, the source of the fatty acid, etc., especially the differences between different species.

It has been reported that PUFA may also decrease LDL and total cholesterol by modifying the oxidation-reduction or phosphorylation state of a nuclear transcription protein that governs the synthesis of FA synthase, stearoyl-CoA desaturase, or acetyl-CoA carboxylase (Clarke et al., 1994; Clarke et al., 1996). Similarly, PUFA decrease total cholesterol, LDL cholesterol, and HDL cholesterol by decreased LDL apolipoprotein B production rates and increased HDL apolipoprotein A-I catabolism in monkeys (Brousseau et al., 1993; Brousseau et al., 1995). In addition, low cholesterol level in the blood can reduce the risk of arthritis, cardiovascular and neurodegenerative diseases (Lands 2012). So far, there have been limited reports on the effect of omega-3 FA supplementation on serum lipids in sows. In our study, we demonstrated that omega-3 diet has no effect on blood profiles in lactating sows.

Conclusion

In summary, our study demonstrated that the dietary supplementation of 0.9% coated omega-3 PUFA in corn-soybean meal based diet (omega-6:omega3 PUFA ratio of 5:1) improved BW and ADG of suckling piglets during the first week. Coated omega-3 fatty acids can be added to the feed to improve the growth performance of the piglets.

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Conflict of interest

All co-authors have no conflict of interest to declare.

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Table 1. Composition of gestation-lactation sow diets (as-fed basis)[1]

Item	Gestation		Lactation	
	CON	TRT	CON	TRT
Ingredients, %				
Corn	54.27	54.49	59.83	60.03
Wheat bran	11.00	11.00	2.00	2.00
Beet pulp	6.56	6.54	-	-
Corn gluten feed	6.00	6.00	-	-
Soybean meal	13.42	13.39	27.27	27.23
Tallow	2.01	0.95	3.38	2.26
Molasses	4.00	4.00	4.00	4.00
Limestone	1.25	1.25	1.20	1.20
Monodicalcium phosphate	0.84	0.84	1.46	1.46
Salt	0.30	0.30	0.50	0.50
Lys78%	-	-	0.0316	0.0322
Vitamin Premix[2]	0.10	0.10	0.10	0.10
Mineral premix[3]	0.10	0.10	0.10	0.10
Choline-50	0.1510	0.1510	0.1283	0.1283
Omega-3	0.00	0.90	0.00	0.95
Calculated composition				
Metabolizable energy, Mcal/kg	3.1	3.1	3.3	3.3
Crude protein, %	13.50	13.50	17.00	17.00
Crude fat, %	4.50	4.14	5.77	5.40
Crude fiber , %	5.00	5.00	3.04	3.05
Ash, %	4.69	4.69	5.19	5.19

Calcium, %	0.72	0.72	0.76	0.76
Phosphorus , %	0.55	0.55	0.65	0.65
Available phosphorus, %	0.24	0.24	0.36	0.36
Analyzed compositions, %				
Lysine	0.53	0.53	0.84	0.84
Methionine	0.20	0.20	0.24	0.24
Methionine+cysteine	0.41	0.41	0.48	0.48
Threonine	0.39	0.39	0.53	0.53
Tryptophan	0.12	0.12	0.18	0.18
omega-3	0.09	0.30	0.11	0.33
omega-6	1.55	1.51	1.69	1.64
omega-6/omega-3	16.42	4.98	15.59	5.01

[1] Abbreviation: CON, Corn-soybean based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

[2] Provided per kilogram of complete diet: vitamin A, 10 000 IU; vitamin D_3, 2000 IU; vitamin E, 48 IU; vitamin K_3, 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 B_6, 2 mg; and vitamin B_{12}, 28 mg.

[3] Provided per kilogram of complete diet: Fe (as FeSO4·7H2O), 90 mg; Cu (as CuSO4·5H2O), 15 mg; Zn (as ZnSO4), 50 mg; Mn (as MnO2), 54 mg; I (as KI), 0.99 mg; and Se (as Na2SeO3·5H2O), 0.25 mg.

Table 2. Analysed fatty acid profile of the experimental diet[1]

Items	Gestation		Lactationg	
	CON	TRT	CON	TRT
Fatty acid profiles				
Myristic acid (C14:0)	1.12	0.65	1.57	0.96
Palmitic acid (C16:0)	18.46	18.75	19.88	22.69
Stearic acid (C18:0)	5.77	9.28	9.80	10.60
Oleic acid (C18:1)	37.67	29.64	37.12	32.88
Linoleic acid (C18:2n-6)	34.02	35.00	28.50	25.92
α-Linoleic acid (C18:3n-3)	2.01	5.81	1.68	4.36
Docosahexaenoic acid (C22:6n-3)	-	0.23	-	0.24
Saturated fatty acid, %	25.35	28.68	31.25	34.25
Monounsaturated fatty acid, %	37.67	29.64	37.12	32.88
Polyunsaturated fatty acid, %	36.03	41.05	30.18	30.51
Total omega-3 PUFA, %	2.01	6.05	1.68	4.59
Total omega-6 PUFA, %	34.02	35.00	28.50	25.92
omega-6:omega-3 PUFA ratio	16.93	5.79	16.96	5.64

[1]Abbreviation: CON, Corn-soybean based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

Table 3. Effect of dietary supplementation of omega-3 on reproduction performance in lactation sows[1]

Items	CON	TRT	SEM[2]	*P*-value
Parity	5.0	4.8	0.3	0.621
Litter size, head				
Litter size at birth	13.4	13.6	0.5	0.587
Number of live birth	13.0	13.2	0.4	0.477
Litter size at weaning	11.8	12.0	0.4	0.542
SUR1[3], %	97.0	97.2	2.3	0.944
SUR2[3], %	90.4	91.0	1.7	0.819
Body weight, kg				
Before Farrowing	270.4	264.1	4.7	0.397
After Farrowing	249.2	244.5	5.4	0.578
Farrowing 7 days	245.5	241.2	5.3	0.598
Sow BW at weaning	231.6	227.7	5.6	0.647
Body weight difference 1[4]	21.2	19.5	1.1	0.331
Body weight difference 2[4]	3.7	3.3	0.4	0.610
Body weight difference 3[4]	13.9	13.5	0.9	0.789
ADFI, kg				
Gestation	1.93	1.93	-	-
Lactation	6.80	6.84	0.08	0.718
Backfat thickness, mm				
Before Farrowing	22.5	23.4	0.4	0.152
After Farrowing	22.5	23.4	0.4	0.152
Farrowing 7 days	22.0	22.7	0.2	0.080
Sow BW at weaning	20.2	19.7	0.3	0.266
Backfat thickness difference 1[5]	0.0	0.0	-	-

Backfat thickness difference 2[5]	0.5	0.7	0.2	0.587
Backfat thickness difference 3[5]	1.8	3.0	0.4	0.118
Body condition score				
Before Farrowing	3.5	3.5	0.2	1.000
After Farrowing	3.3	3.3	0.2	1.000
Farrowing 7 days	2.8	2.9	0.1	0.374
Sow BW at weaning	2.2	2.3	0.1	0.374
Estrus interval, d	5.0	4.8	0.4	0.748

[1] Abbreviation: CON, Corn-soybean meal based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

[2] Standard error of means.

[3] SUR1 : Survival rate of number of alived pig per number of total born pigs. SUR2: survival rate during lactation.

[4] Body weight difference : 1, Before farrowing to After farrowing; 2, After farrowing to Farrowing 7days; 3, Farrowing 7days to Weaning.

[5] Back fat difference : 1, Before farrowing to After farrowing; 2, After farrowing to Farrowing 7days; 3, Farrowing 7days to Weaning.

Table 4. Effect of dietary supplementation of omega-3 on growth performance in sucking piglets[1]

Items	CON	TRT	SEM[2]	*P*-value
Body weight, kg				
Birth weight	1.26	1.30	0.04	0.620
Day 7	1.59[b]	1.90[a]	0.06	0.045
Day 14	2.47	2.53	0.11	0.717
Day 21	4.80	4.93	0.13	0.500
Weaning	7.03	7.14	0.20	0.628
Average daily gain, g				
Day 0 to 7	49.1[b]	67.4[a]	2.5	0.006
Day 8 to 14	125.2	107.1	11.3	0.301
Day 15 to 21	329.6	342.2	11.5	0.382
Day 22 to 26	456.8	453.4	30.3	0.969
Overall	221.6	223.9	5.8	0.716

[1] Abbreviation: CON, Corn-soybean meal based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

[2] Standard error of means.

[a,b] Means in the same row with different superscripts differ (P<0.05).

Table 5. Effect of dietary supplementation of omega-3 on nutrient digestibility in lactation sows[1]

Items, %	CON	TRT	SEM[2]	*P*-value
Before Farrowing				
Dry Matter	69.31	69.70	0.94	0.776
Nitrogen	68.21	68.46	0.84	0.836
Energy	67.51	67.86	0.71	0.737
Weaning				
Dry Matter	67.99	68.31	1.08	0.841
Nitrogen	67.10	67.36	0.94	0.854
Energy	66.32	66.50	0.98	0.903

[1] Abbreviation: CON, Corn-soybean meal based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

[2] Standard error of means.

Table 6. Effect of dietary supplementation of omega-3 on blood profile in lactation sows[1]

Item	CON	TRT	SEM[2]	*P*-value
Before Farrowing				
Total cholesterol, mg/dL	72.2	73.6	7.0	0.895
LDL-C, mg/dL	33.0	33.8	4.5	0.906
HDL-C, mg/dL	31.2	30.6	1.4	0.781
IgG , µg/ dL	125.8	125.0	2.5	0.833
Fatty acid profile, uEq/L	617.0	616.2	12.0	0.965
Weaning				
Total cholesterol, mg/dL	91.0	86.8	3.6	0.458
LDL-C, mg/dL	41.6	39.4	3.2	0.648
HDL-C, mg/dL	45.6	49.8	3.0	0.379
IgG , µg/ dL	127.6	131.4	2.4	0.326
Fatty acid profile, uEq/L	112.4[b]	150.4[a]	9.8	0.048

[1] Abbreviation: CON, Corn-soybean meal based diet (omega-6:omega-3 PUFA ratio of 17:1); TRT, CON + 0.90% omega-3 PUFA (omega-6:omega-3 PUFA ratio of 5:1).

[2] Standard error of means.