Journal of Agricultural Science; Vol. 8, No. 1; 2016
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Healthy Pork Production through Dietary n6:n3 Ratio Regulation

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Received: September 15, 2015 Accepted: November 2, 2015 Online Published: December 15, 2015

doi:10.5539/jas.v8n1p25 URL: http://dx.doi.org/10.5539/jas.v8n1p25

Abstract

The meat fat fatty acid composition could influent consumer health. Thus, this study was though dietary n-6:n-3 ratio regulation to production healthy pork. The experiment was used eighty LYD pigs that average weight was 66.5 kg (half male and half female) divide into five groups, they are lard group (L), soybean oil group (SO), commercial fish product group (CFP), canola oil group (CO), and 50% fish oil and 50% canola oil group (FCO) with 4 replicates, this experiment was lasted for 90 days. Experimental results indicated that the growth performances was no difference among groups; serum cholesterol, LDL and LDL-C were lower, meanwhile HDL was higher ($P < 0.05$) in FCO group than in control group. Back fat thickness, pork color, water holding capacity and meat fat content show no difference among groups. TBARS test on pork storage for 15 days in SO group was significantly higher ($P < 0.05$) than CO group. The n-6:n-3 ratio of back and belly fat in CFP, FCO and CO groups were significantly lower ($P < 0.05$) than in lard group. Panel evaluation score in SO group was significantly better ($P < 0.05$) than CO group in flavor, texture, juicy and total acceptance in longissmus muscle, but no difference in belly meat. In conclusion, the pork n-6: n-3 ratio was decreased with CFP, FCO, and CO supplementation, feeding pigs with low n-6:n-3 ratio fat could production healthy pork for consumers.

Keywords: dietary fat, growth performance, carcass, fatty acid composition, n-6:n-3 ratio, pigs

1. Introduction

Meat products are important sources of dietary fat. The meat fat content and the fatty acid composition could deeply influent consumer health. In ordinary food, the much saturated fatty acid it contains, the better taste it does (Cameron & Enser, 1991), but saturated fatty acid is highly corrected with artery and heart disease (Enser, 2001).

Previous reports showed that consumption of n-3 polyunsaturated fatty acid (n-3 PUFA) significantly reduced plasma triacylglycerol, cholesterol and blood pressure (Jiang & Sim, 1992; Oh et al., 1994; Baik et al., 2010), and decrease atherogenic oxidative stress in vivo (Casós et al., 2010). In addition, Wan et al. (2010) indicated that the aortic lesion area was significantly reduced with lower ratio of n-6:n-3 fatty acids. A significant reduction of interleukin 6 and prostaglandin E-2 in both plasma and aorta culture medium was observed, this findings demonstrate that a decreased n-6:n-3 fatty acid ratio reduces atherosclerotic lesions in apoE(-/-) mice. This protective effect may be attributed to the antiinflammatory properties of n-3 fatty acids. The n-3 PUFA up-regulate several inflammation molecules including serum amyloid A (SAA), tumor necrosis factor-alpha (TNF-alpha) and interleukin-6 (IL-6) in hepatocytes and adipocytes. Actions of these inflammation mediators resemble those of n-3 PUFA in the modulation of many lipid metabolism-related genes (Tai & Ding, 2010). Among the fatty acids, the n-3 PUFA is of especially importance for infant and elder, because they have limited capacity to elongate and desaturation during fatty synthesis (Simopoulos & Salem, 1992).

Thus, lower ratio of n-6/n-3 PUFA meat products also good for consumer health. The Department of Health (UK) (1994) suggested that the ratio of polyunsaturated fatty acid: saturated fatty acid (P:S) should be higher than 0.4 and n-6/n-3 ratio should be under 4.

Commonly, the P:S ratios in pork could reach 0.58, but the n-6:n-3 is too high, and is necessary to be reduced. The factors that affected meat fatty acids composition including breed, diet and type of meat (Wood et al., 2004), among them, the dietary fat is the most effective factor. Because the body fatty acid composition is very sensitive to the dietary fat, for instance, linseed (Kouba et al., 2008) and fish oil supplementation diet (García-Rebollar et al., 2008) could significantly increase n-3 PUFA content, and thus reduced animal body fat n-6:n-3 ratio. It is

worth expecting, by using high PUFA and n-3 fatty acid rich feedstuffs to produce healthful meat via modifying meat fatty acid profile.

Fatty acid compositions would influence meat quality, such as firmness, color, antioxidant characters, flavor, tenderness and juiciness. The antioxidant capacity of fatty acid would influence the color of pork. For example, PUFA are easy oxidation and consequently, red oxymyoglobin change its color to brown metmyoglobin (Mottram, 1998).

The corn-soybean always is the basal diet of animals, corn contains 3-5% of fat, the fatty acid composition are C18:1 (45.6%) and C18:2 (45%), no C18:3; in addition, the supplemental lipid most is used soybean oil if the cost is low, soybean oil contains C18:1 (17%), C18:2 (54.4%) and C18:3 (7.1%), the n-6:n-3 ratio is 7.7, it is higher than the expect value of 4. Thus, it is need to seek for other dietary fat source to reduce the pork n-6:n-3 ratio.

Among all kind of lipid resources, the most abound n-3 PUFA are canola oil and fish oil; cod liver oil contains C18:2 (1.2%), C20:5 (EPA, 10.9%), C22:6 (DHA, 10.3%), the n-6:n-3 ratio is 0.06, but it is expensive, and may affect meat quality if adding at a high level. Canola oil contains C18:3 (9-11%), C18:2 (13%), n-6:n-3 ratio is 1.44, which is the most lower ratio in plant lipid sources. Thus, in this study we selected contains linseed product, canola oil and/or plus fish oil to reduce the pork n-6:n-3 ratio.

The purpose of this study was aimed at reducing n-6:n-3 ratio of pork, which is better for consumer health, and improving meat quality by supplemented dietary n-3 PUFA rich oils accompany with vitamin E in pigs.

2. Materials and Methods

2.1 Animal Treatment

Sixty Landrace×Yorkshire×Duroc (LYD) finishing pigs (average body weight was 66.5±5.2 kg) were allotted five dietary treatments with four replicates (pen), based on body weight and sex (half male and half female). They are (1) Lard (L), (2) Soybean oil (SO), (3) contain linseed commercial fish product, (CFP) (J. John, Co. Taiwan), (4) Canola oil (CO), (5) 50% Fish oil + 50% Canola oil, (FCO). Dietary divided to growing (under 80kg) and finishing periods. Pigs were allowed to consume feed (Table 1) (NRC, 1998) and water *ad libitum*. The fatty acids composition of each group was listed in Tables 2 and 3, calculated dietary n-6:n-3 ratio at growing period are 14.46, 9.03, 6.52, 7.79 and 4.36, at finishing period are 16.63, 8.69, 7.21, 7.38 and 4.23 in group 1, 2, 3, 4 and 5, respectively. All the dietary are added 200mg/kg of vitamin E. The experiment was conducted for 90 days. Blood samples were collected at the 60^{th} day, pigs were fast overnight before blood sampling; then at final of experiment 8 pigs of each group (4 male and 4 female) were selected for sacrificed and measured the carcass characteristics. Loin and belly muscle samples were used for meat traits analysis. Back fat and belly fat samples were used for fatty acids analysis. The experimental animals were reared following the guidelines in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching*.

Table 1. Composition of basal diet

	50-80 kg		80-120 kg	
	DO	CFP	DO	CFP
Ingredients (g/kg)				
Corn	684.7	661.7	746	713
Soybean meal	175	175	110	110
Fish meal (60% CP)	25	0	15	0
Commercial fish product	0	55	0	55
Wheat bran	50	50	70	70
Calcium phosphate monobasic	4.6	4.6	1	1
Limestone	9.2	9.2	8.5	8.5
Oil	46	39	44	37
Salt	5	5	5	5
Vitamin premix [a]	0.2	0.2	0.2	0.2
Mineral premix [b]	0.3	0.3	0.3	0.3
Total	1000	1000	1000	1000
Calculated value				
Metabolism energy (MJ/kg)	13.40	13.40	13.46	13.48
Crude protein (%)	16.11	16.17	13.46	13.69
Analyzed value				
Crude fat (%)	7.57	7.52	6.89	7.14

Note. [a] Vitamin premix supplied per kilogram contain: retinol 50,000,000 IU; cholecalciferol 6,250,000 IU; α-tocopherol 160 g; menadione 8 g; thiamine 10 g; riboflavin 20 g; pyridoxine 16 g; cyanocobalamin 0.16 g; niacin 95 g; pantothenic acid 60 g; biotin 0.5 mg; folic acid: 7.5 g.

[b] Mineral premix supplied per kilogram contain: Fe 150 g; Cu 30 g; Mn 60 g; Zn: 120 g; Se 0.15 g; Co 0.7 g; I 1.5 g.

DO = Different oil groups, CFP = Commercial fish product containing linseed group (31.82 % CP).

Table 2. Fatty acid composition of 50-80 kg BW basal diet

Fatty acids	Lard	SO	CFP	CO	FCO
	----------%				----------
C6:0	0.01	0.04	0.17	0.03	0.02
C8:0	0.01	0.02	0.11	0.02	0.02
C10:0	0.05	-	0.02	0.01	0.01
C12:0	0.07	0.01	0.03	0.04	0.06
C14:0	1.14	0.15	0.16	0.25	1.48
C15:0	0.11	0.03	0.04	0.04	0.12
C16:0	21.01	12.97	11.51	12.05	12.53
C17:0	0.34	0.12	0.09	0.11	0.18
C18:0	9.27	3.69	2.75	3.43	3.00
C20:0	0.28	0.38	0.68	0.42	0.44
C21:0	-	0.06	0.06	0.06	0.03
C22:0	0.09	0.30	0.40	0.31	0.22
C23:0	-	0.04	0.06	0.04	-
C24:0	0.07	0.17	0.23	0.18	-
SFA	32.45	17.98	16.31	16.99	18.12
C14:1	0.06	-	-	-	0.02
C16:1	1.45	0.19	0.28	0.29	1.9
C18:1	33.67	23.63	53.54	29.39	38.38
C20:1	0.51	0.26	0.96	0.34	1.18
C22:1	0.03	-	-	-	0.10
C24:1	-	-	0.11	0.03	0.14
MUFA	35.72	24.08	54.89	30.05	41.72
C18:2, n-6	29.51	51.92	25.54	46.58	32.23
C18:3, n-3	1.34	5.64	3.21	5.94	3.71
C20:2, n-6	0.31	0.04	0.05	0.04	0.26
C20:3, n-6	0.14	-	-	-	0.13
C20:4, n-6	0.12	0.01	-	0.02	0.15
C20:5, n-3	0.11	0.12	-	0.17	1.83
C22:2, n-6	-	-	-	-	0.02
C22:6, n-3	0.3	0.21	-	0.18	1.84
PUFA	31.83	57.94	28.80	52.96	40.17
n-6:n-3	17.19	8.71	7.97	7.41	4.44

Note. SFA: saturated fatty acids. MUFA: monounsaturated fatty acids.

SO = Soybean oil. CFP = Commercial fish product. CO = Canola oil. FCO = 50% Fish oil + 50% Canola oil.

Table 3. Fatty acid composition of 80-120 kg BW basal diet

Fatty acids	Lard	SO	CFP	CO	FCO
	----------%----------				
C6:0	0.03	0.03	0.03	0.02	0.02
C8:0	0.01	0.01	0.02	0.01	0.01
C10:0	-	-	0.01	0.01	0.01
C12:0	0.01	0.01	0.05	0.06	0.05
C14:0	0.16	0.16	0.12	0.25	1.49
C15:0	0.20	0.03	0.03	0.03	0.12
C16:0	20.35	12.73	12.43	11.79	12.06
C17:0	0.50	0.12	0.07	0.11	0.17
C18:0	8.90	3.71	2.06	3.27	2.75
C20:0	0.35	0.35	0.54	0.37	0.40
C21:0	0.07	0.07	0.05	0.07	0.06
C22:0	0.30	0.30	0.30	0.29	0.22
C23:0	-	0.05	0.04	0.05	-
C24:0	0.13	0.16	0.18	0.19	-
SFA	32.05	17.73	15.89	16.52	17.37
C14:1	0.16	-	-	-	0.02
C16:1	1.51	0.21	0.26	0.27	1.95
C18:1	31.97	22.65	50.62	28.7	37.12
C20:1	0.4	0.26	0.92	0.30	1.21
C22:1	0.04	-	0.05	-	0.12
C24:1	-	-	0.13	-	0.14
MUFA	34.08	23.12	51.98	29.27	40.56
C18:2, n-6	31.47	53.18	28.41	47.63	33.78
C18:3, n-3	1.81	5.56	3.3	6.16	3.82
C20:2, n-6	0.16	0.05	0.07	0.05	0.29
C20:3, n-6	0.06	-	-	-	0.14
C20:4, n-6	0.04	0.02	0.01	0.02	0.15
C20:5, n-3	0.11	0.12	0.11	0.18	1.92
C22:6, n-3	0.21	0.22	0.23	0.17	1.96
PUFA	33.86	59.15	32.13	54.21	42.08
n-6:n-3	14.90	9.03	7.83	7.33	4.46

2.2 Growth Performance

Pigs were weighed at the start and end of the experiment to calculate daily body weight gain. Feed consumption was recorded for calculating feed intake, and the feed conversion ratio.

2.3 Blood Traits

Serum cholesterol and triglyceride (TG) were determined by commercial enzymatic test kit (Roche/Hitachi) and determined photometrically using a serum biochemical auto-analyzer (Roche, Co. Switzerland).

Lipoprotein profile (including HDL, LDL and VLDL) was determined by electrophoresis method using TITAN GEL Lipoprotein Kit (3045, Helena Laboratories, Texas). After drying, the gels were stained, then destained, and then scanned with a densitometer at 525 nm (Helena Co. 8JF00105, US). Non-esterified fatty acid (NEFA) concentrations were determined using a commercial enzymatic kit procedure (Biovision, USA).

High-density lipoprotein cholesterol (HDL-C) determination was based on the method described by Dobiasova et al. (1991). Low-density lipoprotein cholesterol (LDL-C) was determined according to Dobiasova et al. (1991) method.

2.4 Carcass Characteristic

Carcass yield was calculated based on carcass measurements of carcass weight over live weight. Average back fat thickness (skinless) was measured at the shoulder, last costal and lumbar rib in the unit cm/100 kg. In the longissimus muscle area, the **c**arcass was straight cut between the tenth and eleventh rib of the longissimus muscle, and the area drawn on tracing paper, then the integral was used to calculate the area in the unit mm^2/100 kg.

2.5 Muscle Fat Content

Muscle fat content was determined follow the Folch et al. (1957) method. Muscle samples of 20 g were immersed in 200 mL solvent (chloroform:methanol = 2:1) overnight, and then filtered. Next, 40 mL 0.9% NaCl solution was added into a separating funnel. The lower layer of liquid was fat and chloroform. After drying, the samples were weighed and the fat content was calculated.

2.6 Color Difference

Meat Hunter L, a, b values were measured duplicate using a color difference meter (Model TC-1, Tokyo Denshoku Co., LTD.). L, a and b values represent light, amaranth and beige, respectively.

2.7 Water Holding Capacity

Water holding capacity (WHC) was determined duplicate using the Lesiak et al. (1997) method. 10 mL of a 1%-sodium chloride solution was added to 5 g samples of breast and thigh muscle, placed in a water bath at 70-75 °C for 30 min, cooled and centrifuged at 12235 × g (Himac SCR 20B, Hitachi, Japan). The supernatant was then collected and weighed. Water holding capacity was then calculated.

2.8 Fatty Acids Analysis

The samples esterification was added 5 ml 0.5N methanolic-NaOH and boiling for 5 mins with a cooling equipment, then added 5 mL BF_3-MeOH and boiled for 2 mins. Next, 5 mL heptane was added and boiled for 1 min. After cool then added saturated NaCl to let the esterified fatty acid-heptane layer separated and taken for fatty acids analysis (Prabhakara Rao et al., 2010).

Fatty acids analysis was carried out with a FID detector gas chromatography (Agilent 6890N, USA) with DB-23 column. The initial temperature was 60 °C and maintain for 2 mins then elevate to 210 °C maintain for 7 mins. FID detector temperature was 280 °C, carrier air was nitrogen, flow rate was 1.5 mL/min.

2.9 Sensory Evaluation

Samples of breast and thigh muscle, respectively, were cooked at 80 °C for 15 min, and a piece of 1 cm was cut off for evaluation of appearance, flavor, tenderness, juiciness and overall acceptability by 50 persons. Scoring was between 1 and 7, with 7 representing the best grade.

2.10 Meat Storage Test

Meat samples were stored at -20 °C for 15 days, then for antioxidation traits determine.

Thiobarbituric acid-reactive substances (TBARS) were determined based on the procedure reported by Fraga et al. (1988). The scavenging DPPH (a,a-diphenyl-β-picrylhydrazyl) radical ability was determined in triplicate, following the method reported by Chung et al. (2002). Peroxide value (POV) was determined following the procedure described by Sebranek (1978). Conjugated diene hydroperoxide contents were measured according the method described by Osawa et al. (1992).

2.11 Statistical Analysis

The experimental data was subjected to analysis of variance using general linear model procedures (PROC GLM) of SAS (1998). Tukey's test was used to determine significant differences between treatment means. According to the following model, $Y=\mu + T_i + P_j + e_{ijk}$, treatment (T) was the main effect. Where Y is the dependent variable, μ represents the mean, P is the pen (replicate) effect and e is the random residual error term.

3. Results and Discussion

3.1 Growth Performances of Finishing-Pigs in Response to Dietary Supplementation of Different Oils (Table 4)

Table 4. Growth performances of pigs in response to dietary supplementation of different oil

Items	Lard	SO	CFP	CO	FCO	SEM
Initial body weight (kg)	63.22	65.91	63.50	63.69	64.11	1.83
Final body weight (kg)	118.4	117.6	124.0	120.0	116.9	2.70
Average daily gain (kg/day)	0.61	0.59	0.65	0.63	0.59	0.04
Average feed intake (kg/day)	2.26	2.09	2.18	2.12	2.15	0.08
Feed efficiency (feed/gain)	3.68	3.64	3.25	3.39	3.67	0.16

Note. n = 4. SO = Soybean oil; CFP = Commercial fish product; CO = Canola oil; FCO = 50% Fish oil + 50% Canola oil.

The results showed that different dietary oils had no influence on final body weight, average feed intake and feed efficiency ($P > 0.05$) of finishing-pigs. Previous reports indicated that under similar nutritional concentrations, different oils supplementation did not affect average daily gain, average feed intake and feed efficiency of animals (Thacker, 1998; Teye et al., 2006; Mitchaothai et al., 2007).

3.2 Carcass Characteristics of Finishing-Pigs in Response to Dietary Supplementation of Different Oil (Table 5)

Table 5. Carcass characteristics of pigs in response to dietary supplementation of different oil

Items	Lard	SO	CFP	CO	FCO	SEM
Carcass weight (kg)	99.81	98.89	102.9	100.9	100.6	3.87
Carcass yield (%)	84.8	86.1	85.9	86.0	86.3	0.50
Back fat thickness (cm)	2.14	2.01	2.17	1.92	2.10	0.11
Lion-eye area (cm^2)	52.70	52.84	52.09	51.73	49.56	2.97
pH_1	6.51	6.28	6.36	6.30	6.50	0.10
pH_{24}	5.73	5.83	5.89	5.78	5.81	0.09

Note. n = 4. SO = Soybean oil; CFP = Commercial fish product; CO = Canola oil; FCO = 50% Fish oil + 50% Canola oil.

Different dietary oils had no influence on carcass weight, carcass yield, back fat thickness, meat pH value at 1h (pH_1) and 24h (pH_{24}) after been slaughtered of finishing-pigs (Table 5; $P > 0.05$). The results agreed with the observations in growing-pigs (Thacker, 1998; Teye et al., 2006), and finishing-pig (Mitchaothai et al., 2007). All these results indicated that different dietary oils supplementation would not influence the carcass quality and characteristics of finishing-pigs.

3.3 Plasma Parameters of Finishing-Pigs in Response to Dietary Supplementation of Different Oil (Table 6)

Table 6. Plasma parameters of pigs in response to dietary supplementation of different oil

Items	Lard	SO	CFP	CO	FCO	SEM
Total cholesterol (mg/dL)	138.7^{a}	125.1^{ab}	125.8^{ab}	132.7^{ab}	116.65^{b}	5.71
HDL-C (mg/dL)	8.30^{ab}	6.80^{b}	8.09^{ab}	8.77^{a}	9.25^{a}	0.48
LDL-C (mg/dL)	109.63^{a}	97.89^{ab}	99.04^{ab}	105.4^{ab}	89.27^{b}	5.03
Triglyceride (mg/dL)	621.5^{b}	1000.0^{a}	1003.9^{a}	708.2^{ab}	651.0^{b}	99.1
NEFA (μmol/L)	771.1^{ab}	639.1^{b}	600.6^{b}	824.7^{a}	738.9^{ab}	53.7
Lipoprotein Profile						
HDL (%)	49.06^{b}	46.64^{b}	47.32^{b}	49.08^{b}	55.84^{a}	1.16
VLDL (%)	8.75^{c}	14.95^{a}	14.62^{ab}	12.38^{abc}	10.97^{bc}	1.17
LDL (%)	42.13^{a}	38.40^{b}	38.04^{b}	38.55^{b}	33.26^{c}	0.95

Note. $^{a, b, c, d}$ Means within the same row without a common superscript differ significantly ($P < 0.05$). n = 4. HDL-C: high-density lipoprotein-Cholesterol; LDL-C: low-density lipoprotein-Cholesterol; NEFA: non-esterified fatty acids; SO = Soybean oil; CFP = Commercial fish product; CO = Canola oil; FCO = 50% Fish oil + 50% Canola oil.

Cholesterol content in FCO group was lower than that in lard group (Table 6; $P < 0.05$), lard group was tend to have higher cholesterol than SO and CGP groups, the results suggested that lard could increase the cholesterol in plasma while fish oil decreased. The data obtained in this trial did not agree with the Byoung et al. (1997) and Lien et al. (2003) reports, who indicated that there existed no difference in plasma cholesterol among different dietary oils supplementation.

Plasma HDL-C in CO and FCO groups was higher than in SO group (Table 6; $P < 0.05$), plasma LDL-C in FCO was lower than Lard groups ($P < 0.05$), the results were similar to the observations of Lien et al. (2003) and Riediger et al. (2008), who supplied fish oil into diets of hens and mice respectively. Chang et al. (2010) also reported that saturated fat (SAT) diets increased, but n-3 diets decreased the arterial low-density lipoprotein (LDL) cholesterol deposition.

Plasma TG in lard and FCO group were significantly lower than SO and CFP groups ($P < 0.05$). Concerning about the lipoprotein profile, FCO group had highest HDL and lowest LDL ratio than other groups ($P < 0.05$), which was similar to the report of Lien et al. (2003). Lard group had highest plasma LDL than other groups as well as cholesterol content ($P < 0.05$). The SO and CFP groups had lower NEFA concentrations than that in CO group ($P < 0.05$), and tend to be lower than FCO group.

From the plasma parameter indicated that the FCO group, the lower n-6:n-3 ratio PUFA are reduced plasma cholesterol, LDL and LDL-C, those bad factors for artery and heart disease; meanwhile enhanced HDL and HDL-C, the benefit factors for artery and heart disease. Thus, lower n-6:n-3 ratio PUFA is good for consumer health.

3.4 Fatty Acid Compositions of Back Fat and Belly Meat of Finishing-Pigs in Response to Dietary Supplementation of Different Oil (Tables 7 and 8)

Table 7. Back fat fatty acid composition of pigs in response to dietary supplementation of different oil

Fatty acids	Lard	SO	CFP	CO	FCO	SEM
	----------%----------					
C6:0	0.16	0.18	0.07	0.10	0.12	0.04
C8:0	0.14^{a}	0.12^{ab}	0.05^{b}	0.06^{b}	0.10^{ab}	0.03
C10:0	0.11	0.11	0.10	0.10	0.12	0.01
C12:0	0.14	0.12	0.13	0.12	0.13	0.01
C14:0	1.72^{a}	1.55^{ab}	1.47^{b}	1.41^{b}	1.71^{a}	0.06
C15:0	0.09^{a}	0.09^{ab}	0.06^{b}	0.08^{ab}	0.09^{ab}	0.01
C16:0	27.80^{a}	25.83^{a}	23.35^{b}	22.06^{b}	23.34^{a}	0.77
C17:0	0.45^{a}	0.40^{ab}	0.30^{b}	0.35^{ab}	0.38^{ab}	0.04
C18:0	13.99^{a}	12.8^{a}	10.79^{b}	10.61^{b}	10.69^{b}	0.47
C20:0	0.26^{ab}	0.26^{ab}	0.23^{b}	0.25^{ab}	0.27^{a}	0.01
SFA	44.86^{a}	41.45^{a}	35.56^{b}	35.14^{b}	36.95^{b}	1.31
C14:1	0.019^{a}	0.015^{b}	0.015^{b}	0.014^{b}	0.014^{b}	0.001
C16:1	1.71^{b}	1.97^{ab}	1.87^{ab}	2.04^{a}	1.70^{b}	0.10
C18:1	40.49^{a}	36.85^{b}	37.95^{b}	43.59^{a}	38.59^{ab}	0.90
C20:1	0.81^{b}	0.71^{c}	0.66^{c}	0.88^{a}	0.90^{a}	0.02
MUFA	43.29^{a}	39.29^{b}	40.50^{b}	46.54^{a}	43.20^{a}	0.96
C18:2, n-6	10.65^{c}	17.20^{ab}	20.83^{a}	15.01^{bc}	16.82^{ab}	1.54
C18:3, n-3	0.49^{c}	1.10^{bc}	1.83^{a}	2.04^{ab}	1.94^{a}	0.22
C20:2, n-6	0.43^{b}	0.62^{ab}	0.73^{a}	0.61^{ab}	0.43^{b}	0.06
C20:3, n-6*	0.048	0.048	0.075	0.054	0.068	0.01
C20:3, n-3**	0.09^{b}	0.14^{ab}	0.21^{a}	0.20^{a}	0.10^{b}	0.03
C20:4, n-6	0.10	0.10	0.15	0.15	0.09	0.03
C20:5, n-3	0.020^{c}	0.018^{c}	0.034^{bc}	0.136^{ab}	0.184^{a}	0.03
C22:6, n-3	0.05^{b}	0.06^{b}	0.07^{b}	0.12^{ab}	0.22^{a}	0.05
PUFA	11.88^{c}	19.29^{ab}	23.94^{a}	18.32^{b}	19.85^{ab}	1.89
n-6:n-3	17.18^{a}	13.63^{ab}	10.16^{b}	6.34^{c}	7.12^{c}	1.63

Note. $^{a, b, c}$ Means within the same row without a common superscript differ significantly ($P < 0.05$). n = 4.

* cis-8,11,14-Eicosatrienoic acid. ** cis-11,14,17-Eicosatrienoic acid.

SO = Soybean oil. CFP = Commercial fish product. CO = Canola oil. FCO = 50% Fish oil + 50% Canola oil.

Table 8. Belly meat fatty acid composition of pigs in response to dietary supplementation of different oil

Fatty acids	Lard	SO	CFP	CO	FO	SEM
	----------%----------					
C10:0	0.11	0.10	0.11	0.12	0.12	0.01
C12:0	0.12	0.10	0.12	0.11	0.11	0.01
C14:0	1.51^{a}	1.31^{b}	1.45^{ab}	1.43^{ab}	1.54^{a}	0.06
C15:0	0.056^{ab}	0.063^{a}	0.046^{b}	0.055^{ab}	0.059^{ab}	0.04
C16:0	24.46	22.36	23.46	22.62	23.50	0.96
C17:0	0.30^{a}	0.32^{a}	0.24^{b}	0.27^{ab}	0.27^{ab}	0.02
C18:0	12.59^{a}	12.40^{ab}	11.92^{b}	11.31^{b}	12.29^{ab}	0.34
C20:0	0.21	0.21	0.22	0.21	0.22	0.01
SFA	39.42^{a}	36.88^{ab}	37.27^{ab}	36.14^{b}	38.16^{ab}	1.07
C14:1	0.019^{a}	0.013^{b}	0.015^{ab}	0.016^{ab}	0.014^{ab}	0.002
C16:1	2.06^{a}	1.51^{b}	1.90^{a}	2.07^{a}	2.13^{a}	0.13
C18:1	39.71^{a}	34.56^{b}	35.58^{b}	39.92^{a}	39.72^{a}	0.70
C20:1	0.77^{a}	0.67^{b}	0.63^{b}	0.80^{a}	0.81^{a}	0.02
MUFA	42.66^{a}	36.78^{b}	38.14^{b}	42.82^{a}	42.69^{a}	0.70
C18:2, n-6	15.60^{b}	22.74^{a}	20.81^{a}	17.56^{b}	15.57^{b}	0.97
C18:3, n-3	1.12^{c}	2.00^{ab}	2.15^{a}	1.91^{ab}	1.68^{b}	0.14
C20:2, n-6	0.66^{bc}	0.82^{a}	0.74^{ab}	0.66^{bc}	0.60^{c}	0.03
C20:3, n-6*	0.10	0.11	0.10	0.10	0.11	0.01
C20:3, n-3**	0.16^{c}	0.22^{ab}	0.24^{a}	0.23^{ab}	0.19^{bc}	0.01
C20:4, n-6	0.27	0.24	0.29	0.29	0.24	0.03
C20:5, n-3	0.09^{b}	0.04^{b}	0.05^{b}	0.08^{b}	0.28^{a}	0.03
C22:6, n-3	0.15^{b}	0.14^{b}	0.11^{b}	0.21^{b}	0.48^{a}	0.04
PUFA	18.15^{c}	26.31^{a}	24.49^{ab}	21.04^{bc}	19.15^{c}	1.17
n-6:n-3	10.94^{a}	9.96^{a}	8.60^{b}	7.66^{b}	6.28^{c}	0.46

Note. $^{a, b, c}$ Means within the same row without a common superscript differ significantly ($P < 0.05$). n = 4.

* cis-8,11,14-Eicosatrienoic acid. ** cis-11,14,17-Eicosatrienoic acid.

SO = Soybean oil. CFP = Commercial fish product. CO = Canola oil. FCO = 50% Fish oil + 50% Canola oil.

In back fat, lard group obtained largest saturated fatty acid percentage, but was significantly higher CO group only (Table 7; $P < 0.05$). Lard, CO and FCO groups had higher monounsaturated fatty acids (MUFA) percentages than SO and CFP ($P < 0.05$). Among all types of PUFA, linoleic acid (C18:2) was the most abundant in n-6 fatty acid, while linolenic acid (C18:3) was the most abundant in n-3 fatty acid. Although the CFP group had highest contain of linolenic acid, but it also had relatively higher linoleic acid content to make a high n-6:n-3 ratio (10.16). CO group contained significantly ($P < 0.05$) lower linoleic acid than CFP group, and had lower n-6:n-3 ratio (6.34) than CFP group (10.16). However, which still could not meet the suggestion of Department of Health (UK), the n-6:n-3 ratio should be 4.

Total PUFA contains in back fat of SO, CFP, CO and FCO group were higher than those of lard group ($P < 0.05$). The n-6:n-3 ratio were also lower in CFP, CO and FCO groups than in lard group ($P < 0.05$). Scientists are suggested that high PUFA content was not certainly advantageous for human health, it is depend on the n-6: n-3 ratio.

In belly meat, total SFA contain in lard group was higher than that in CO group ($P < 0.05$), MUFA level in lard, CO and FCO groups were higher than those of SO and CFP groups ($P < 0.05$). SO group had higher PUFA than lard, CO and FCO groups ($P < 0.05$), The n-6:n-3 ratio were lower in CFP, CO and FCO groups than lard and SO groups ($P < 0.05$).

SO and CFP group had higher linoleic acid among all treatments ($P < 0.05$), lard group showed lowest linolenic acid level compared with each of the other four groups ($P < 0.05$). FCO group obtain highest EPA (C20:5, n-3)

and DHA (C22:6, n-3) than other groups ($P < 0.05$), which resulted in the lowest n-6:n-3 ratio of FCO ($P < 0.05$). These results were similar to the experiment of García-Rebollar et al. (2008), who supplied fish oil into pullet diet. The n-6:n-3 ratio of CEP, and CO group were also lower than lard and SO group.

The fatty acids composition is sensitive the dietary fat. West and Myer (1987) reported feeding animal with rich of C18:2 (n-6 FA) soybean oil or sunflower oil, the animal body C18:2 from 10-15% increased to 30%. In order to reduce n-6:n-3 ratio have some reports using canola oil and linseed (Wood et al., 2003), and have the good effective, however, can not using high level (no more than 3 %), otherwise will have bad effect on meat flavor, since high amount of C18:3 will result of bad odours (Shackelford et al., 1990). Warnants et al. (1999) reported using the dietary fat to modify animal body fat is quickly, the feeding time about 40 days could have the largest effective. This study also have the effective, but the feeding time is 90 days still not reach the expect n-6:n-3 value of 4. However, the effect would be more obvious as supplemental time more long.

3.5 Meat Quality and Sensory Evaluation of Finishing-Pigs in Response to Dietary Supplementation of Different Oil (Table 9, 10)

Table 9. Meat quality of pigs in response to dietary supplementation of different oil

Items	Lard	SO	CFP	CO	FCO	SEM
L	41.20	42.42	40.44	41.05	42.24	1.32
a	9.93	9.27	10.29	9.44	9.52	0.53
b	7.51	7.55	7.43	7.34	7.33	0.35
TBARS, MDA (μg/g)	0.27^{ab}	0.32^{a}	0.31^{ab}	0.24^{b}	0.29^{ab}	0.02
DPPH (%)	49.78	49.95	49.41	50.39	49.15	0.60
POV (%)	99.76	100.1	99.21	99.21	98.69	0.76
Water holding capacity (%)	87.87	87.08	84.61	85.66	87.27	0.33
Fat content (%)	2.36	2.34	2.39	2.23	2.98	0.36

Note. $^{a, b}$ Means within the same row without a common superscript differ significantly ($P < 0.05$). n = 4.

L: light; a: amaranth; b: beige; DPPH: a,a-diphenyl-β-picrylhydrazyl. POV: peroxide value.

SO = Soybean oil. CFP = Commercial fish product. CO = Canola oil. FCO = 50% Fish oil + 50% Canola oil.

Table 10. Sensory evaluation of meat from pigs in response to dietary supplementation of different oil

Items	Lard	SO	CFP	CO	FCO	SEM
Longissimus muscle						
Color	4.44	4.36	4.04	4.28	4.32	0.20
Smell	3.96	3.92	3.96	4.00	3.80	0.24
Flavor	3.80^{ab}	4.28^{a}	4.04^{ab}	3.40^{b}	4.04^{ab}	0.22
Texture	3.48^{ab}	4.04^{a}	4.12^{a}	3.08^{b}	3.80^{a}	0.23
Juiciness	3.36^{ab}	4.04^{a}	3.72^{a}	2.72^{b}	3.40^{ab}	0.26
Total acceptance	3.67^{bc}	4.46^{a}	4.08^{ab}	3.08^{c}	3.92^{ab}	0.23
Belly meat						
Color	4.64	4.60	4.60	4.60	4.64	0.21
Smell	4.16	4.56	4.40	4.36	4.24	0.22
Flavor	4.40	4.72	4.68	4.28	4.44	0.22
Texture	4.80	4.84	4.68	4.80	4.84	0.20
Juiciness	4.96	5.00	4.92	4.92	5.00	0.22
Total acceptance	4.58	4.83	5.00	4.79	4.50	0.24

Note. $^{a, b, c}$ Means within the same row without a common superscript differ significantly ($P < 0.05$). n = 4.

SO = Soybean oil; CFP = Commercial fish product; CO = Canola oil; FCO = 50% Fish oil + 50% Canola oil.

The meat quality such as firmness, color, flavor, tenderness and juiciness are affected by the meat fatty acids

composition. The firmness may influence by melting point of fatty acids, for instance, the melting point are 69.6 °C, 13.4 °C, -5 °C and -11 °C in C18:0, C18:1, C18:2 and C18:3, respectively, thus, the more PUFA, the less firmness (Enser, 1984). The tenderness and juiciness are concern with the amount of fatty acids, since fat could hold more water inside (Enser, 1984). The meat color will be affected by oxidation of fatty acids, which will change the red oxymyoglobin to the brown metmyoglobin (Mottram, 1998), thus, the meat more PUFA, when storage the more prone to oxidation and change color. Thus, antioxidant additives, including vitamin E, polyphenols and flavonoids are often supplied with PUFA to prevent oxidation (Lien et al., unpublished). The flavor of meat is associated with volatile compounds derived from fatty acid and peroxides from oxidation process. PUFA content in phospholipids was particularly associated with meat flavor (Mottram, 1998).

The L, a, b value, water holding capacity, fat content, POV, DPPH-scavenging ability were not affected by different dietary oils (Table 9; $P < 0.05$). TBARS of SO group was higher than CO group after been frozen storage for 15 days indicated that it had higher degree of oxidation ($P < 0.05$), but still no different with the lard group ($P > 0.05$). This result was in contrast with Bryhni et al. (2002). Which might be due to a short time of storage in this trial. Although the composition of PUFA between CO and SO diet were very similar, the TBARS of SO was higher than that of CO group ($P < 0.05$), the reason is needed further study. This study indicated that the different oil supplementation still no affect meat oxidation as storage meat for 15 days.

The flavor, texture, juiciness and total acceptance of longissmus muscle in SO was better than CO group (Table 10; $P < 0.05$), according to the opinion of Cameron and Enser (1991), this result might be due to the higher meat SFA contain in SO group (Tables 7 and 8), but it was difficult to explain the result obtained from lard group. All parameters of sensory evaluation in belly meat did not show any difference among groups ($P > 0.05$), it is consistence with the report of Lu et al. (2008). This study results indicated that feeding pigs with CEP and FCO did not significantly influence meat quality compare to control, CO group influent also slightly.

4. Conclusion

Different dietary oils did not influent the growth performances and carcass characteristics of finishing-pigs. Animal body fatty acids compositions could be influenced by different dietary oils supplementation. Saturated fatty acids would be reduced meanwhile PUFA would be increased followed CO and SO supplementation. CFP, CO and FCO diets could reduce meat n-6:n-3 ratio, and the effect would be much obvious as supplemental time became longer. They did not affect storage meat antioxidation traits and meat quality. FCO group could reduce plasma cholesterol, LDL and LDL-C and increase HDL and HDL-C contain, it is benefit for consumer health. Thus, feeding pigs with low n-6:n-3 ratio fat could production healthy pork for consumers.

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