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Evaluation of Soybean Oil as a Lipid Source for Pig Diets*

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ABSTRACT : An experiment was conducted to determine the effects of soybean oil supplementation replacing tallow in pig diets at different stages of growth. One hundred and twenty crossbred (Landrace×Yorkshire×Duroc) pigs weighing 18 kg on average were selected. Pigs were randomly allotted to 12 pens of 10 pigs (5 pigs of each sex) each. Three pens were assigned to each of the four treatments: TA; tallow diet, TA-SO-80; switched from tallow to soybean oil diet at 80 kg average body weight, TA-SO-45; switched from tallow to soybean oil diet at 45 kg average body weight, and SO; soybean oil diet. Treatment SO was significantly lower in ADG than tallow diets (TA, TA-SO-80 and TA-SO-45) during the grower period (18 to 45 kg). However, treatment SO showed greatest compensation in ADFI and ADG during the finisher-2 period (after 80 kg body weight). ADFI and ADG and Gain/Feed for the total period were not significantly different among treatments. Loin area, back fat thickness, firmness and melting point of back fat were not significantly different. The levels of total cholesterol and low density lipoprotein+very low density lipoprotein cholesterol in serum were significantly lower in treatment SO than in treatments TA-SO-45, TA-SO-80 and TA. The level of serum triglyceride linearly increased as the length of the tallow feeding period increased. Serum immunoglobulin-G (IgG) level was significantly higher in the soybean oil treatment than in other treatments. Major fatty acid composition of short rib muscle and back fat were significantly influenced by treatments. Contents of α-linolenic acid (C18:3) and docosahexaenoic acid (DHA, C22:6) linearly increased as the soybean oil feeding period increased. In conclusion, soybean oil can be supplemented to the diet of pigs without significant effects on growth performance and carcass characteristics. The level of polyunsaturated fatty acids (PUFA), especially ω-3 fatty acids in the carcass was increased by soybean oil supplementation. (**Key Words :** Cholesterol, Pig, Soybean Oil, Tallow, ω-3 Fatty Acid)

INTRODUCTION

Fats and oils such as lard, choice white grease, beef tallow, corn oil, and soybean oil contain about 2.25 times as much metabolizable energy as most of the cereal grains. Their nutritional importance is already well defined (Enser, 1984). Many feed manufacturers have been using fat in swine diets as an energy source and palatability promoter. Addition of 1 to 2% fat in the diet will reduce dust of diet and wear of mixing equipment and augurs (Ensminger et al., 1990). Researchers indicate that the addition of 1 to 5% fat to growing-finishing swine diets will improve feed conversion and average daily gain (Coffey et al., 1982). Animal fats such as beef tallow and lard are less expensive than vegetable oil and so used universally. Pig performed better on diets containing either soybean oil, choice white grease, or coconut oil than on diets containing tallow, however (Turlington, 1989). Dietary fat absorption depends on the fatty acids present in the diet, saturated fatty acids (SFA) being less well absorbed than unsaturated fatty acids (Renner and Hill, 1961). Therefore, performance of pigs is affected by the source of supplementary fat in the diet. Cera et al. (1990) reported that digestibility of tallow was improved when it was mixed with soybean oil and suggested that increased digestibility of the tallow might be resulted from factors, such as high polyunsaturated fatty acids (PUFA) content and phospholipids in soybean oil. Carcass characteristic of pigs are affected by dietary fat sources. It is generally known that feeding high level of vegetable oil which is rich in unsaturated fatty acids produces soft fat pork. But the extent to which tissue concentration of fatty acid are altered from dietary fats

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differing in the degree of unsaturation depends on the dietary level of energy in the diet (Bee et al., 2002). Recently, increasing attention is being paid to human health, especially regarding the adverse effects of high intake of saturated fatty acids and the role of long-chain ω-3 unsaturated fatty acids. Animal fat has higher SFA than vegetable oil. Too much consumption of SFA elevates the cholesterol level in blood which results in side effects, such as coronary disease, hypertension and heart disease in human (Azain, 2004). Some PUFA, such as linoleic acid and linolenic acid are essential for human and animals, therefore, must be incorporated into the diet. The present experiment was conducted to study the effects of supplementation of soybean oil replacing tallow in the pig diets on the growth performance, carcass characteristic and fatty acid composition of carcass fat.

MATERIALS AND METHODS

Experimental materials and procedures

One hundred and twenty crossbred (Landrace×Yorkshire×Duroc) pigs weighing 18 kg on average were

Table 1. Formula of diets fed to determine the effects of substituting soybean oil for tallow on performance and carcass traits of growing-finishing pigs

Ingredients (% of diet)	Grower		Finisher-1		Finisher-2	
	TA	SO	TA	SO	TA	SO
Corn	53.16	53.16	64.18	64.18	68.58	68.58
Soybean meal (44% CP)	25.00	25.00	18.70	18.70	12.42	12.42
Wheat bran	9.05	9.05	7.46	7.46	10.63	10.63
Animal fat (Tallow)	5.00	-	4.50	-	4.00	-
Soybean oil	-	5.00	-	4.50	-	4.00
Corn gluten meal	4.85	4.85	-	-	-	-
Rapeseed meal	-	-	3.00	3.00	3.00	3.00
Calphos-18	1.41	1.41	0.91	0.91	0.46	0.46
Limestone	0.53	0.53	0.45	0.45	0.48	0.48
Lysine HCl (78%)	0.26	0.26	0.10	0.10	-	-
Vitamin-mineral premix	0.25[1]	0.25[1]	0.25[2]	0.25[2]	0.25[3]	0.25[3]
Antibiotic premix	0.25	0.25	0.25	0.25	-	-
Salt	0.24	0.24	0.20	0.20	0.18	0.18
Total			100.00			
Calculated value (%)						
ME (kcal/kg)	3,250	3,250	3,250	3,250	3,250	3,250
Crude protein	20.0	20.0	16.0	16. 0	14.0	14.0
Crude fat	8.39	8.39	7.68	7.68	7.39	7.39
Crude fiber	3.63	3.63	3.46	3.46	3.44	3.44
Crude ash	5.03	5.03	4.29	4.29	3.69	3.69
Lysine (%)	1.15	1.15	0.85	0.85	0.65	0.65
Ca (%)	0.80	0.80	0.60	0.60	0.45	0.45
P (%)	0.70	0.70	0.58	0.58	0.50	0.50
Analyzed value (%)						
Moisture	13.18	13.65	13.40	13.51	13.35	13.63
Crude protein	20.28	19.61	15.20	15.84	14.41	13.50
Crude fat	7.68	6.87	6.37	6.80	6.77	6.31
Crude fiber	4.07	3.38	3.10	3.52	3.57	3.28
Crude ash	4.57	5.13	4.21	3.84	3.06	3.32

[1] Provides per kg of diet: Copper, 5 mg; Iodine, 0.14 mg; Iron, 80 mg; Zinc, 80 mg; Vitamin A, 1,750 IU, Vitamin D_3, 200 IU; Vitamin E, 11 IU; Vitamin K, 0.5 mg; Biotin, 0.05 mg; Choline, 0.4 g; Folacin, 0.3 mg; Niacin available, 12.5 mg; Panthothenic acid, 9 mg; Riboflavin, 3 mg; Thiamin, 1 mg; Vitamin B_6, 1.5 mg; Vitamin B_{12}, 15 μg; Linoeic acid, 0.1%.

[2] Provides per kg of diet: Copper, 3.75 mg; Iodine, 0.14 mg; Iron, 55 mg; Manganese, 2 mg; Vitamin A, 1,500 IU; Vitamin D_3, 150 IU; Vitamin E, 11 IU; Vitamin K, 0.5 mg; Biotin, 0.05 mg; Choline, 0.3 g; Folacin, 0.3 mg; Niacin available, 8.5 mg; Panthothenic acid, 7.5 mg; Riboflavin, 2.25 mg; Thiamin, 1 mg; Vitamin B_6, 1 mg; Vitamin B_{12}, 7.5 μg; Linoeic acid, 0.1%.

[3] Provides per kg of diet: Copper, 3.75 mg; Iodine, 0.14 mg; Iron, 40 mg; Manganese, 2 mg; Selenium, 0.15 mg; Zinc, 50 mg; Vitamin A, 1,300 IU; Vitamin D_3, 150 IU; Vitamin E, 11 IU; Vitamin K, 0.5 mg; Biotin, 0.05 mg; Choline, 0.3 g; Folacin, 0.3 mg; Niacin available, 7 mg; Panthothenic acid, 7 mg; Riboflavin, 2 mg; Thiamin, 1 mg; Vitamin B_6, 1 mg; Vitamin B_{12}, 5 μg; Linoeic acid, 0.1%.

selected. Pigs were randomly allotted to 12 pens of 10 pigs (5 castrated males and 5 gilts) each. Three pens were assigned to each of the four treatments: TA; tallow diet, TA-SO-80; switched from tallow to soybean oil diet at 80 kg of average body weight, TA-SO-45; switched from tallow to soybean oil diet at 45 kg of average body weight, and SO; soybean oil diet. Formula and fatty acid composition are shown in Table 1 and 2, respectively. Feeds and water were given *ad libitum* for 16 wk (grower feed 1 to 6 wk, finisher-1 feed 7 to 12 wk and finisher-2 feed 13 to 16 wk) to reach marketing weight (108 kg on average). Feed intake and body weight were measured every two weeks. ADFI, ADG and gain to feed intake ratio (Gain/feed) were calculated from the data obtained.

Sample preparation and analysis

After obtaining final weight on the last day of feeding, feeds were removed from feeders and pigs were fasted for 24 h. From each treatment, 12 pigs (4 pigs, 2 in each sex, per pen) with median body weight were selected and blood samples were taken from the vena jugularis interna using the Vacutainer system (Becton Dickinson Co., Ltd., USA). Pigs were sacrificed by cutting jugular vein after stunning in gas chamber at slaughter house. Loin area cut around 5th rib and thickness of back fat around 13th rib of all pigs were measured and samples of short rib muscle and back fat were taken from 18 pigs per treatment for fatty acid analysis. Short rib muscle samples were freeze-dried, ground and fat was extracted with petroleum ether. Loin area cut around 5th rib was measured with Plastic grid for quick measurement of loin eye, developed by Iowa State University. Firmness of back fat was measured by Rheometer (Compac 100, Japan) and melting point of back fat was measured with Thiele Apparatus (AOCS, 1967). Analysis of total-cholesterol, high density lipoprotein cholesterol (HDL-cholesterol) and triglyceride (TG) in serum were performed with analysis kits (Cholestezyme-V, HDL-C 555 and Triglyzyme-V manufactured by Shinyang

Table 2. Fatty acids composition of diets fed to determine the effects of substituting soybean oil for tallow on performance and carcass traits of growing-finishing pigs (% of total fatty acids)

Fatty acids	Grower		Finisher-1		Finisher-2	
	TA[1] diet	SO[1] diet	TA diet	SO diet	TA diet	SO diet
≤C6:0	2.01	1.07	0.31	0.44	2.17	0.47
C8:0	0.35	0.02	0.05	0.02	2.69	0.02
C10:0	0.07	0.16	0.08	0.07	-[2]	-
C12:0	-[2]	-	-	0.04	-	-
C13:0	-	-	-	0.16	-	-
C14:0	0.16	0.08	1.03	0.08	1.45	0.08
C14:1	-	-	0.19	-	0.33	-
C15:0	0.11	-	0.11	-	0.17	-
C16:0	22.08	11.53	16.97	11.37	18.74	11.55
C16:1	0.31	0.10	1.23	0.10	1.64	0.12
C17:0	0.18	0.08	0.38	0.09	0.42	0.09
C17:1	0.05	-	0.22	0.04	0.32	0.05
C18:0	6.77	3.38	9.13	3.60	8.80	3.44
C18:1	29.39	21.62	32.05	21.72	29.82	20.88
C18:2	31.42	55.27	34.25	55.31	30.49	55.79
C18:3,ω-3	2.20	4.73	2.10	5.40	2.14	5.78
C20:0	0.79	0.80	0.43	0.44	0.30	0.36
C20:1	2.38	0.25	0.43	0.28	0.52	0.28
C20:2	-	-	0.10	0.05	-	0.06
C20:4	-	-	0.04	-	-	-
C22:0	0.58	0.34	0.18	0.18	-	0.32
C22:1	0.48	0.44	0.39	0.23	-	0.43
C22:2	0.68	0.12	0.30	0.05	-	-
C23:0	-	-	-	0.07	-	0.09
Total SFA[3]	33.09	17.47	28.70	16.82	34.74	16.61
Total MUFA[4]	32.61	22.41	34.51	22.37	32.63	21.76
Total PUFA[5]	34.30	60.12	36.79	60.81	32.63	61.63
Total			100			

[1] TA = Tallow diet, SO; Soybean oil diet. [2] Trace (<0.001%). [3] SFA = Saturated fatty acids.
[4] MFA; monounsaturated fatty acids [5] PUFA; polyunsaturated fatty acids

Table 3. Feed intake, gain, and feed efficiency of pigs fed diets to determine the effects of substituting soybean oil for tallow

Constituents	Treatments[1]				SEM	p-value
	TA	TA-SO-80	TA-SO-45	SO		
Grower stage (17.99 to 45.54 kg)						
ADFI (g)	1,276	1,280	1,314	1,202	64.2	0.50
ADG (g)	664^{A}	683^{A}	683^{A}	593^{B}	22.1	0.001
Gain/feed	0.52	0.53	0.52	0.49	0.01	0.35
Finisher-1 stage (45.54 to 81.26 kg)						
ADFI (g)	2,283	2,239	2,211	2,263	83.2	0.98
ADG (g)	861	848	832	861	32.5	0.86
Gain/feed	0.38	0.38	0.38	0.38	0.01	0.92
Finisher-2 stage (81.26 to 108.05 kg)						
ADFI (g)	3,251^{a}	2,891^{b}	3,151^{ab}	3,337^{a}	58.5	0.02
ADG (g)	990^{ab}	865^{b}	966^{ab}	1,007^{a}	49.01	0.04
Gain/feed	0.31	0.30	0.31	0.30	0.02	0.99
Total period (17.99 to 108.05 kg)						
ADFI (g)	2,125	2,029	2,084	2,191	200.1	0.97
ADG (g)	819	790	810	797	21.0	0.66
Gain/feed	0.42	0.42	0.41	0.41	0.03	0.97

a, b, A, B Values in the same row with no common superscripts are significantly different (p<0.05 or p<0.01).
[1] TA = Tallow diet, TA-SO-80 = Switched from tallow to soybean oil diet at 80 kg of average body weight,
TA-SO-45 = Switched from tallow to soybean oil diet at 45 kg of average body weight, SO = Soybean oil diet.

Chemical Co., Ltd., Korea) using spectrometer (HITACHI U-3200, Japan) at 500 nm, 555 nm and 505 nm wavelength, respectively. Concentration of low density lipoprotein (LDL)+very low density lipoprotein (VLDL) was calculated by subtracting concentration of HDL-cholesterol from that of total-cholesterol. IgG concentration was determined by the method of single radical immuno-diffusion (RID) test developed by Mancini (1965). Fatty acids analysis was conducted in accordance with the method of Lepage and Roy (1986) using gas chromatography (Varian Star 3400, USA). Gas chromatograph was equipped with flame ionization detector, and fatty acid methyl ester was separated with a DB-FFAP column (30 m×0.25 mm internal dimension×0.25 μm film thickness). The injector and detector temperature was maintained at 230°C and 250°C, respectively. Column oven temperature was programmed from 120°C for 1 min and then increase to final 220°C at the rate of 3°C increase/min. Final temperature was held for 18.8 min. Helium carrier gas flow was 1.55 ml/min with a split ratio of 25:1. Sample size injected was 2 μl.

Statistical analysis

The data were analyzed by ANOVA using General Linear Model (GLM) procedure of SAS (SAS Institute, 1996). Performance data were presented as least square means using initial body weight as covariant. Significant differences between treatment means were determined at p<0.05 or p<0.01 using Tukey's test (1953).

RESULTS AND DISCUSSION

Growth performance

Results of growth performance are summarized in Table 3. ADG during grower stage was significantly (p<0.01) affected by treatments. Pigs on soybean oil diet (Treatment SO) gained less than those on tallow diets (Treatments TA-SO-45, TA-SO-80 and TA) during this period. However, ADFI, ADG and gain/feed were not significantly affected by treatments during finisher-1 stage. ADFI and ADG were significantly affected by treatments during finisher-2 stage. ADFI and ADG were highest in Treatment SO and lowest in Treatment TA-SO-80 during this period. Growth performances of pigs during the whole period were not significantly different among treatments. This result, as well as that of early research (Cera et al., 1989; Howard et al., 1990; Park et al., 2001), indicates that pigs on soybean oil diet may need adaptation period during which feed intake and growth is lower than those on tallow diet. Palatability of diet can be influenced by supplementary fat sources (Kendall, 1984). Tallow may have better palatability than soybean oil in young pigs of starter stage. After adaptation period, however, pigs on soybean oil ate more and grew faster, probably through compensation mechanism.

Carcass characteristics of pigs

Physical properties of carcass are shown in Table 4. Loin area and back fat thickness were not significantly different. These results are in agreement with those of

Table 4. Loin area, thickness, firmness, and melting point of back fat of pigs[1] fed diets to determine the effects of substituting soybean oil for tallow

Constituents	Treatments[2]				SEM	p-value
	TA	TA-SO-80	TA-SO-45	SO		
Loin area[3] (cm^2)	20.6	21.6	22.6	22.7	0.99	0.51
Back fat thick[4] (mm)	22.9	23.5	22.5	24.8	2.26	0.22
Firmness (g/cm^3)	22.3	21.9	21.5	18.5	3.39	0.51
Melting point (°C)	41.3	39.8	39.4	38.0	0.87	0.52

[1] In each treatment, samples were taken from 12 pigs, 4 pigs (2 pigs in each sex) per pen (3 pens).
[2] TA = Tallow diet, TA-SO-80 = Switched from tallow to soybean oil diet at 80 kg of average body weight.
TA-SO-45 = Switched from tallow to soybean oil diet at 45 kg of average body weight, SO = Soybean oil diet.
[3] Loin area cut around the fifth rib. [4] Back fat thickness around the thirteenth rib.

previous studies in which pigs were fed diets containing oil seed such as ground, roasted soybean (Wahlstorm et al., 1971; Skelly et al., 1975) or ground sunflower seeds (Hartman et al., 1985). It has been known that firmness and melting point of fat are influenced by fatty acid composition. The large amount of SFA in swine diet increased firmness of fat while PUFA increased softness of carcass fat (Morgan et al., 1994; Dupont, 1996; Lekanich et al., 1997). According to NRC (1998), richest fatty acid of soybean oil is C18:2 (55.39%) followed by C18:1 (22.08%), C16:0 (12.86%), C18:3, n-3 (5.35%), C18:0 (3.56%), C20:0 (0.69%) and others while that of tallow is C18:1 (36.30%) followed by C18:2 (24.92%), C16:0 (24.20%), C18:0 (12.26%), C18:3, n-3 (1.53%), C14:0 (0.58%) and others. It was also reported that soybean oil contained 60 percent of PUFA while tallow contained 44 percent (Theodore, 1980; Perez Rigau et al., 1995). Fatty acid composition of diets in the present experiment (Table 2) also shows that soybean oil diets are richer in PUFA (C18:2 and C18:3) while tallow diets are richer source of SFA (C16:0 and C18:0) and oleic acid (C18:1). As expected, firmness and melting point of back fat tended to increase as the length of tallow supplementation period increased. But the differences among treatments were not significant.

Serum lipid composition and IgG concentration

Compositions of serum lipids and IgG concentration are shown in Table 5. The levels of total-cholesterol and LDL+VLDL-cholesterol in serum were significantly lower in treatment SO than in treatments TA-SO-45, TA-SO-80 and TA. The level of serum TG linearly increased as the length of tallow feeding period increased. The level of HDL-cholesterol was not significantly affected but the ratio of total-cholesterol to HDL-cholesterol was lowest in treatment SO. Serum IgG concentration of treatment SO was significantly higher than those of others. Soybean oil consists of large amount of PUFA compared to tallow. It is known that PUFA decrease blood cholesterol level. Diets high in polyunsaturated fat (compared with those high in monounsaturated or saturated fat) significantly decreased plasma total and LDL-cholesterol levels in pigs. Although there are species differences, these data are in agreement with the study of Frenadez and McNamara (1991) who hypothesized that polyunsaturated fat-rich diets are hypocholesterolemic and decrease plasma LDL levels by increasing hepatic uptake of plasma LDL via the apo B/E

Table 5. Serum lipid composition and Immunoglobulin-G (IgG) concentration in pigs[1] fed diets to determine the effects of substituting soybean oil for tallow

Constituents	Treatments[2]				SEM	p-value
	TA	TA-SO-80	TA-SO-45	SO		
	---------- mg/dl (serum) ----------					
Total-cholesterol (TC)	86.7[a]	86.1[a]	85.8[a]	74.9[b]	4.18	0.05
HDL-cholesterol (HDL-C)	33.4	31.1	31.0	31.5	2.07	0.45
LDL+VLDL-C	54.2[a]	55.8[a]	54.5[a]	43.5[b]	4.85	0.05
Triglyceride	25.7[a]	24.4[ab]	22.2[ab]	20.9[b]	2.44	0.04
TC/HDL-C	2.62[ab]	2.76[a]	2.76[a]	2.38[b]	0.18	0.05
	---------- mg/ml (serum) ----------					
IgG	14.9[b]	16.0[b]	15.4[b]	18.1[a]	1.26	0.02

[a, b] Values in the same row with no common superscripts are significantly different ($p<0.05$).
[1] In each treatment, samples were taken from 12 pigs, 4pigs (2 pigs in each sex) per pen (3 pens).
[2] TA = Tallow diet, TA-SO-80 = Switched from tallow to soybean oil diet at 80 kg of average body weight.
TA-SO-45 = Switched from tallow to soybean oil diet at 45 kg of average body weight, SO = Soybean oil diet.

receptor pathway. PUFA of ω-3 series fatty acids decreased TG level in blood. Decrease of TG level lowers total-cholesterol/HDL-cholesterol ratio. And this ratio over 3.5 had an undesirable effect on cardiovascular disease (Harris et al., 1984; Harris, 1997). Soybean oil treatment showed significantly higher serum IgG level compared to tallow treatments. Lands (1986) explained possible action of ω-3 acids on immunity. Harbige (1998) stated that dietary ω-6 and ω-3 fatty acids may exert effects on the immune system and autoimmune disease, which is regulated by mechanism of gene expression, production of eicosanoids and cytokines, and the action of antioxidant enzymes. As soybean oil is a richer source of ω-3 fatty acids than tallow, the present result may be resulted from the differences of ω-6 and ω-3 composition of diets.

Fatty acid composition of carcass

Fatty acid compositions of short rib muscle and back fat are shown in Table 6 and Table 7, respectively. Major fatty acids compositions of short rib muscle and back fat were significantly influenced by treatments. Generally, fatty acid compositions of carcass followed those of the diets (Table 2) except stearic acid (C18:0) in back fat. Content of stearic acid in back fat was low in the tallow treatment even though the tallow diet has higher stearic acid compared to soybean oil diet. Greater amount of stearic acid may be coming from

Table 6. Fatty acid composition of short rib muscle of pigs[1] fed diets to determine the effects of substituting soybean oil for tallow (% of total fatty acids)

Fatty acids	Treatments[2]			
	TA	TA-SO-80	TA-SO-45	SO
C6:0	0.20	0.07	0.17	0.06
C8:0	0.14	0.08	0.08	0.96
C10:0	0.29	0.29	0.36	0.27
C11:0	0.01	0.05	0.03	-[3]
C12:0	0.01	0.001	0.01	0.12
C13:0	0.01	0.02	0.02	-
C14:0	0.71[a]	0.54[b]	0.61[ab]	0.54[b]
C14:1	-	-	0.03	-
C15:0	0.01[ab]	-	0.02[a]	0.01[ab]
C16:0	19.21	18.39	18.39	18.62
C16:1	1.46[a]	0.97[b]	0.95[b]	0.90[b]
C17:0	0.28	0.28	0.30	0.28
C17:1	0.11	0.93	0.02	0.44
C18:0	14.29	14.26	14.29	14.69
C18:1, ω-9	21.96[a]	16.75[b]	17.57[b]	17.57[b]
C18:2, ω-6	29.59[b]	34.89[a]	34.80[a]	34.12[a]
C18:3, ω-6	0.08	0.05	0.07	0.04
C18:3, ω-3	0.55[c]	0.86[b]	1.03[a]	1.00[a]
C20:0	0.04[b]	0.03[b]	0.11[a]	0.07[ab]
C20:1	0.33	0.29	0.27	0.30
C20:2	0.39[b]	0.55[ab]	0.64[a]	0.65[a]
C20:3, ω-6	0.80	0.87	0.74	0.75
C20:3, ω-3	-	-	-	0.08
C20:4	7.61	7.87	7.14	7.32
C20:5, EPA, ω-3	0.15	0.21	0.17	0.21
C21:0	-	0.01[b]	0.05[a]	0.02[ab]
C22:0	0.27	0.05	0.09	0.05
C22:1	-	-	-	-
C22:2	1.36	1.53	1.83	1.51
C22:6, DHA, ω-3	0.13[b]	0.15[b]	0.19[ab]	0.38[a]
DHA/EPA ratio (%)	86.67	71.43	111.76	180.95
Total SFA[4]	39.87	34.63	35.19	35.38
Total MUFA[5]	23.86	18.94	18.84	19.21
Total PUFA[6]	36.27	46.43	45.97	45.41

[a, b] Values in the same row with no common superscripts are significantly different ($p<0.05$).

[1] In each treatment, samples were taken from 12 pigs, 4 pigs (2 pigs in each sex) per pen (3 pens).

[2] TA = Tallow diet, TA-SO-80 = Switched from tallow to soybean oil diet at 80 kg of average body weight.
TA-SO-45 = Switched from tallow to soybean oil diet at 45 kg of average body weight, SO = soybean oil diet.

[3] Trace (<0.001%). [4] SFA = Saturated fatty acids. [5] MFA = Monounsaturated fatty acids. [6] PUFA = Polyunsaturated fatty acids.

Table 7. Fatty acid composition of back fat of pigs[1] fed diets to determine the effects of substituting soybean oil for tallow (% of total fatty acids)

Fatty acids	Treatments[2]			
	TA	TA-SO-80	TA-SO-45	SO
C6:0	0. 17^{a}	0.02^{b}	0.06^{ab}	0.08^{ab}
C8:0	0.02	0.01	0.01	0.01
C10:0	0.07	0.06	0.07	0.07
C11:0	-[3]	-	-	-
C12:0	0.07^{a}	0.06^{b}	0.06^{ab}	0.07^{ab}
C13:0	-	-	-	-
C14:0	1.39^{a}	1.18^{b}	1.12^{b}	1.10^{b}
C14:1	0.06^{a}	0.04^{b}	0.02^{c}	0.01^{d}
C15:0	0.10^{a}	0.07^{b}	0.06^{bc}	0.04^{c}
C16:0	21.79^{a}	20.76^{ab}	20.26^{b}	19.77^{b}
C16:1	2.05^{a}	1.72^{b}	1.31^{c}	1.24^{c}
C17:0	0.59^{a}	0.42^{b}	0.37^{b}	0.31^{c}
C17:1	0.62^{a}	0.33^{b}	0.25^{b}	0.19^{b}
C18:0	14.96^{b}	14.69^{b}	15.48^{b}	18.17^{a}
C18:1, ω-9	39.42^{a}	35.86^{b}	31.70^{c}	28.28^{d}
C18:2, ω-6	15.52^{c}	20.66^{b}	24.47^{a}	24.95^{a}
C18:3, ω-6	0.02^{b}	0.03^{a}	0.03^{a}	0.04^{a}
C18:3, ω-3	0.88^{c}	1.46^{b}	1.96^{a}	2.09^{a}
C20:0	0.21^{b}	0.21^{b}	0.25^{a}	0.27^{a}
C20:1	0.85	0.83	0.75	0.77
C20:2	0.61^{d}	0.83^{c}	0.93^{b}	1.05^{a}
C20:3, ω-6	0.10	0.11	0.11	0.12
C20:3, ω-3	-	-	-	-
C20:4	0.23^{b}	0.26^{ab}	0.28^{a}	0.29^{a}
C20:5, EPA, ω-3	0.05	0.05	0.05	0.07
C21:0	0.11^{c}	0.17^{b}	0.25^{a}	0.25^{a}
C22:0	-	0.01	0.01	0.02
C22:1	0.02	0.02	0.02	0.02
C22:2	0.11	0.10	0.08	0.12
C22:6, DHA, ω-3	0.02^{b}	0.03^{ab}	0.03^{ab}	0.04^{a}
DHA/EPA ratio (%)	40.00	60.00	60.00	57.14
Total SFA[4]	39.44	37.68	38.01	40.72
Total MUFA[5]	43.02	38.80	34.05	30.51
Total PUFA[6]	17.54	23.52	27.94	28.77

[a-d] Values in the same row with no common superscripts are significantly different ($p<0.05$).

[1] In each treatment, samples were taken from 12 pigs, 4 pigs (2 pigs in each sex) per pen (3 pens).

[2] TA = Tallow diet, TA-SO-80 = Switched from tallow to soybean oil diet at 80 kg of average body weight.,
TA-SO-45 = Switched from tallow to soybean oil diet at 45 kg of average body weight, SO = Soybean oil diet.

[3] Trace (<0.001%). [4] SFA = Saturated fatty acids. [5] MFA = Monounsaturated fatty acids. [6] PUFA = Polyunsaturated fatty acids.

de novo synthesis than from diet in soybean oil treatment. Content of linoleic acid (C18:2), which is generally called essential fatty acid, was significantly richer in the short rib muscle and back fat of the pigs fed soybean oil diets (Treatments SO, TA-SO-45 and TA-SO-80) than those of the pigs fed tallow diet (Treatment TA). Contents of ω-3 or n-3 fatty acids, such as α-linolenic acid (C18:3) and DHA (C22:6), significantly increased as the soybean oil feeding period increased. It is quite understandable because soybean oil contains approximately 3.5 times of α-linolenic acid compared to tallow as described earlier (5.35% vs. 1.53%). Usually, nonruminant animals are very susceptible to tissue fatty acid alteration through dietary modification (Thiel-Cooper et al., 2001; Wiegand et al., 2002; Averette Gatlin et al., 2002; Bee et al., 2002). The results of the present study are in good agreement with data from various authors, who reported significant changes in the composition of the fat after feeding different dietary fat source or different amounts of certain fatty acids. Among the various fatty acids, α-linolenic acid (C18:3 ω-3) from plant oils represents the parent fatty acid of longer chain ω-3 PUFA such as eicosapentaenoic acid (EPA, C20:5 ω-3) and DHA

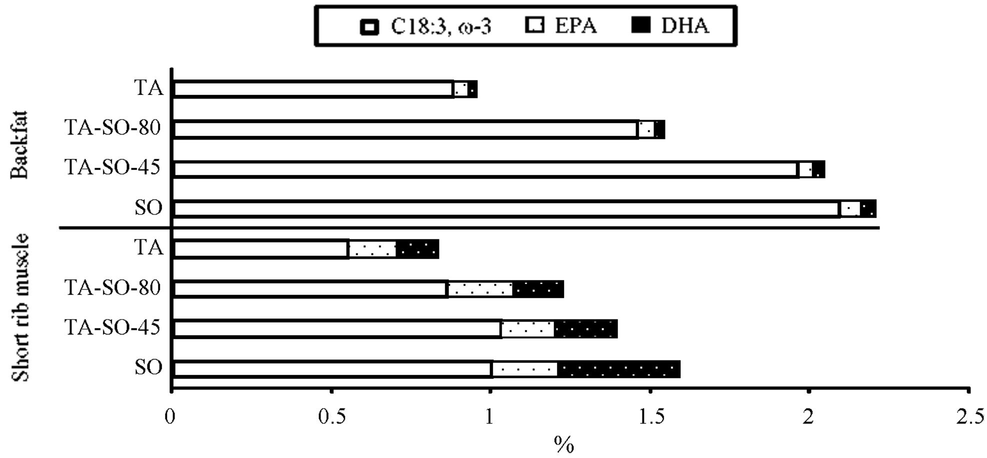

Figure 1. The ω-3 fatty acid composition of back fat and short rib muscle of pigs fed diets supplemented with different fat sources (TA; tallow diet, TA-SO-80; switched from tallow to soybean oil diet at 80 kg of average body weight, TA-SO-45; switched from tallow to soybean oil diet at 45 kg of average body weight, SO; soybean oil diet).

(C22:6 ω-3), via *de novo* synthesis through desaturation and elongation (Sprecher, 1981; Romans et al., 1995; Van Oeckel et al., 1996; Scollan et al., 2001; Azain, 2004). These long-chain ω-3 PUFA are an important component of the membrane phospholipid, where it is reported to be essential for maintaining membrane physicochemical properties (Stubbs and Smith, 1984). Especially, EPA and DHA play a major role in the control of cardiovascular disease (Conquer and Holub, 1998; Sanderson et al., 2002; Kouba, 2003) and in neural and retinal development (Alessandri et al., 1998). With an increased PUFA content of the diet, the synthesis of oleic acid (C18:1) in adipose tissue was depressed, possibly by a decreased stearoly-CoA desaturase activity (Klingenberg et al., 1995). Omega-3 PUFA, especially α-linolenic acid (C18:3 ω-3), EPA and DHA concentration in back fat was increased as the feeding period of α-linolenic acid rich oil source increased in pigs. This result was consistent with the early research (Romans et al., 1995). In the present experiment, it is interesting to note that concentrations of EPA and DHA are higher in short rib muscle than in back fat (Figure 1). Anatomical location is known to affect fatty acid composition (Irie and Sakimoto, 1992). This may be due to the different nature of depot fat in back fat and muscle fat in short rib muscle. Recently, fatty acids modified animal products are produced and marketed under various names such as designer pork or egg, omega pork or egg and so on. If ω-3 fatty acids enriched pork is deemed to grow at niche market, soybean oil can be safely used as a source of ω-3 fatty acids in pig diet. Same could be applied to the production of ω-3 fatty acids enriched eggs.

In conclusion, soybean oil can be supplemented to the pig diets without significant effect on growth performance and carcass characteristics. The content of PUFA, especially ω-3 fatty acids in the carcass can be linearly increased depending on the length of the feeding period of soybean oil supplemented diet.

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