The Effect of Dietary Oil Containing (*n*-3) Fatty Acids on the Fatty Acid, Physicochemical, and Organoleptic Characteristics of Pig Meat and Fat[1,2]

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ABSTRACT: An investigation was made to alter the fatty acid composition of pork and a pork product in line with human dietary advice while not adversely affecting factors controlling consumer acceptability. Pigs (n = 150) were assigned to three dietary treatments with 25 intact male-female pairs per treatment. Diet A (control) contained 3% of a 4:1 (wt/wt) tallow-soybean oil mixture. Diets B and C contained 2% rapeseed oil plus 1% fish oil. Diets A, B, and C were supplemented with 100, 100, and 250 mg of all-*rac*-α-tocopheryl acetate/kg of diet, respectively. Pigs were given ad libitum access to feed from 52 kg live weight until 95 kg (slaughter). Sausages were prepared from the resulting cuts. Tissues of pigs were evaluated in terms of fat firmness, color, fatty acid composition, and contents of α-tocopherol and thiobarbituric acid-reactive substances (TBARS). Organoleptic characteristics of chops and sausages were evaluated by a trained taste panel. Pigs fed Diets B and C had improved feed conversion ratios ($P < .05$) and ADG compared with control pigs. The levels of *n*-3 (omega-3) polyunsaturates were significantly increased in the tissues and sausage from pigs fed Diets B and C with associated alterations in *n*-6 to *n*-3 fatty acid ratios that accorded with contemporary human dietary recommendations. Levels of α-tocopherol and TBARS were significantly altered in the tissues. There were no appreciable differences between treatments in carcass characteristics, including color. The overall organoleptic acceptability of chops and sausages was not different between the treatments.

Key Words: Pigs, Fat, Pork, Fatty Acids, Vitamin E

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Introduction

Increasing attention is being paid to the dietary role of the long-chain *n*-3 (omega-3) polyunsaturated fatty acids, in particular eicosapentaenoic acid **[EPA**; 20:5(*n*-3)] and docosahexaenoic acid **[DHA**; 22:6(*n*-3); Galli and Simopoulos, 1989; BNF, 1992; DH, 1994]. A role for these acids in the amelioration of a number of diseases, including coronary heart disease, is well recognized. In addition, the essentiality of (*n*-3) fatty acids during neonatal and aging periods is receiving particular attention (Noble and Cocchi, 1989; Innis, 1991; Pénzes et al., 1993). As a result, there are increasing moves to enhance the levels of such acids in major human dietary components.

In pig tissues, enhancement of polyunsaturated fatty acid (**PUFA**) levels has largely been accompanied by unacceptable effects on attendant physicochemical properties (Whittington et al., 1986; Rhee et al., 1988b) and organoleptic quality (Oldfield and Anglemier, 1957). However, several investigations indicate that such changes can be limited even in the presence of high tissue PUFA levels (Irie and Sakimoto, 1992; Morgan et al., 1992; Leskanich et al., 1994). The objective of the present study was to increase the (*n*-3) fatty acid content of the major porcine tissues to an extent that could promote their

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Table 1. Ingredient composition (% wt/wt) of the control and experimental diets[a]

Component	Diet A (control)	Diet B	Diet C
Barley	36.0	36.0	36.0
Wheat	30.0	30.0	30.0
High-protein soybean meal	26.0	26.0	26.0
Fish meal	2.5	2.5	2.5
Mineral/vitamin supplement[b]	2.5	2.5	2.5
Tallow-soybean oil (4:1, wt/wt)	3.0	—	—
Rapeseed oil[c]	—	2.0	2.0
Fish oil[d]	—	1.0	1.0
All-*rac*-α-tocopheryl acetate, mg/kg diet	100	100	250

[a]Proximate composition of Diets A, B, and C, respectively (as analyzed): 16.8, 16.7, 16.9 MJ DE/kg DM; 24.2, 24.9, 23.7% CP; 9.9, 10.6, 9.7% NDF; 4.4, 4.4, 3.8% crude fiber; 6.3, 6.7, 6.2% ash; 5.5, 6.0, 5.8% acid hydrolyzed ether extract.
[b]Supplied per kg of diet: 109 mg Cu, .27 mg Se, 9.1 g Ca, 4.8 g P, and 1.5 g Na.
[c]Refined and deodorized; supplied by The White Sea and Baltic Company Ltd. (Leeds, U.K.); declared analysis: free fatty acid: .1% maximum, iodine value: 110, peroxide value: 1.0 mEq/kg maximum.
[d]Refined; supplied by Seven Seas Ltd. (Hull, U.K.); declared analysis: free fatty acid: .08%, iodine value: 204, peroxide value: .98 mEq/kg.

healthy image but in the absence of deleterious physicochemical and organoleptic effects that undermine consumer acceptability.

Materials and Methods

Animals and Diets. Pigs (n = 150) taken from five commercial genotypes (NPD, PIC, JSR, Cotswold, and Newsham) were divided equally among three dietary treatments. Each treatment group consisted of 25 mixed-sex pairs. From any one litter, an uncastrated male and a female were assigned to each of the three diets. At 20 to 25 kg live weight, pigs were fed a standard grower diet until a weight of approximately 50 kg was attained, from which point animals were given ad libitum access to one of the trial diets until slaughter. The weight of each pig was recorded at the beginning and at the end of the feeding period, and a record was kept of the total amount of feed consumed by each pair. All pigs of a litter were slaughtered on the same day, determined when the lightest pair of pigs had consumed a minimum of 175 kg of feed. Duration of feeding of the trial diets and slaughter weights were approximately 7 wk and 95 kg, respectively. During the growth phase, two pigs died.

The general composition of the control and experimental diets is shown in Table 1. The diets differed in the type of oil/fat and in the level of all-*rac*-α-tocopheryl acetate. The control diet (Diet A) contained a level and type of oil and a level of vitamin E (100 mg/kg) recommended for use in commercial practice (MLC, 1992). The oils added to Diets B and C were chosen specifically for the purpose of altering the (*n*-3) fatty acid composition of the carcass fat in line with current human dietary recommendations on the intake of fatty acids. Diets B and C contained vitamin E at levels of 100 and 250 mg/kg, respectively. Diets were prepared in meal form and were stored in paper bags before feeding.

The fatty acid composition of the control and experimental diets is shown in Table 2. Diet A was characterized by higher contents than Diets B and C

Table 2. The fatty acid composition (% wt/wt of total fatty acids) of the control and experimental diets[a]

Fatty acid[a,b]	Diet A (control)	Diets B and C[c]
14:0	1.54	1.19
16:0	19.3	17.4
16:1(*n*-7)	1.78	1.23
17:0	.46	ND
17:1(*n*-7)	.28	ND
18:0	8.55	2.12
18:1(*n*-9)	24.4	31.0
18:1(*n*-7)	2.48	2.52
18:2(*n*-6)	31.9	27.0
18:3(*n*-3)	3.56	5.42
20:0	.16	ND
18:4(*n*-3)	.19	.43
20:1(*n*-9)	.82	2.48
20:5(*n*-3)	.52	1.19
22:1(*n*-9)	.64	2.58
22:6(*n*-3)	.74	1.67
SAT	30	21
MUFA	30	40
PUFA	37	36
P:S ratio	1.2	1.7
18:2(*n*-6)/18:3(*n*-3)	9.0	5.0
Total (*n*-6)/total (*n*-3)	6.4	3.1

[a]The fatty acid X:Y(*n*-Z) represents a fatty acid with X carbon atoms and Y double bonds with the position of the first double bond being Z carbon atoms from the methyl end (*n*) of the molecule.
[b]SAT = total weight percentage of 14:0, 16:0, 17:0, 18:0, and 20:0; MUFA = total weight percentage of 16:1(*n*-7), 17:1(*n*-7), 18:1(*n*-9), 18:1(*n*-7), 20:1(*n*-9), and 22:1(*n*-9); PUFA = total weight percentage of 18:2(*n*-6), 18:3(*n*-3), 18:4(*n*-3), 20:5(*n*-3), and 22:6(*n*-3); P:S ratio = ratio of PUFA:SAT.
[c]ND = not detectable.

of all saturated fatty acids, especially stearic acid (18:0). The contents of oleic acid [18:1(*n*-9)], α-linolenic acid [18:3(*n*-3)], eicosenoic acid [20:1(*n*-9)] and erucic acid [22:1(*n*-9)] were higher in Diets B and C than in Diet A because of the elevated levels of these fatty acids present in rapeseed oil. The level of linoleic acid [18:2(*n*-6)] was similar between the diets but the levels of EPA and DHA were doubled in Diets B and C compared with Diet A as a result of the addition of fish oil, which characteristically contains high levels of these fatty acids. Summations of the fatty acids and their ratios also reflected differences between dietary fatty acids. Thus, total saturates were lower and total monounsaturates were higher in Diets B and C than in Diet A. Although the levels of total polyunsaturates were similar, the ratios of (*n*-6) to (*n*-3) fatty acids were markedly lower in the experimental diets than in the control.

Carcass Evaluation. Measurement of backfat thickness at a point 6 cm from the midline of the carcass at the head of the last rib (P_2 thickness) was undertaken using a probe and callipers. The firmness of fat was assessed subjectively by an experienced assessor and objectively using a hand-held Penetrometer (Dransfield and Kempster, 1988) at the split surfaces of the shoulder, the last rib, and at a point posterior to the gluteus muscle. The subjective assessments were made before the objective measurements in order to avoid the possibility of bias. The melting point of the inner backfat triacylglycerol was determined according to British Standard (1958). Carcass conformation at three sites and extent of marbling fat in the longissimus muscle were judged by an experienced assessor. Percentage of drip loss was determined by measuring the amount of fluid lost from a 20-mm-thick suspended loin chop (minus fat) after 48 h.

The colors of muscle and subcutaneous fat from loin chops and a sample of shoulder fat (3 cm × 3 cm) were assessed through over-wrap plastic film using a Minolta Chromameter (Minolta (UK) Ltd., Milton Keynes, U.K.). Measurements of L* (luminance), a* (redness), and b* (yellowness) values were undertaken in the CIELAB color space at 0, 48, and 120 h of storage in a retail display cabinet at 3°C under fluorescent light (36-W tubes supplying approximately 10,000 lx). Four readings were taken at each time interval on each of the muscle and shoulder fat samples. The degree of paleness on the cut surface and interior of the muscle was assessed using a Smokestain Reflectometer (EEL, Evans Electroselenium Ltd., supplied by Diffusion Systems Ltd., London, U.K.) and a fiber optic probe, respectively. Individual 20-mm loin chops (deboned) were taken from each half-carcass in a designated sequence, vacuum-packaged, and blast-frozen to –20°C for subsequent measurements of thiobarbituric acid-reactive substances (**TBARS**), total fat and fatty acid composition, vitamin E content, and organoleptic properties.

Sausage Preparation. Conventional 18-mm-thick pork sausages were prepared containing 42.5% by weight of meat and 25% fat taken primarily from the shoulder, water (20%), rusk (10%), and seasoning (2.5%). Seasoning (Spiceman's Ltd., Glasgow, U.K.) contained ascorbic acid (an antioxidant), sodium metabisulphite (a preservative), and color ('Red 2G') as well as salt, dextrose, spices, yeast extract, and herbs. Meat and fat portions were minced separately then mixed together with the water, rusk, and seasoning. The mixture was then minced again and added to sheep casings. Sausages were hang-dried for 16 h at room temperature before being stored individually in plastic bags at –20°C until analysis.

Chemical Analyses. All analyses were equally balanced with respect to sex and genotype. Before analysis, the chops and sausages were thawed for 16 h at 4°C. When required, chops and sausages were cooked evenly under an electric grill to internal temperatures of 70 and 96°C, respectively.

The fatty acid compositions of the total lipids extractable from the longissimus muscle and inner backfat were determined on the raw sample after 3 mo of frozen storage. The fatty acid composition of sausage was determined after grilling; sausage had been stored uncooked at –20°C for 6 mo. The total lipids were extracted with chloroform:methanol (2:1, vol:vol) according to Folch et al. (1957). Fatty acid methyl esters were generated by refluxing suitable aliquots of the total lipid extracts with a solution of methanol:toluene:sulphuric acid (20:10:1, (vol:vol:vol). The fatty acid composition was determined by capillary GLC in a CP 9001 Gas Chromatograph (Chrompack U.K., London, U.K.) using a Carbowax column (Alltech, Carnforth, U.K.) of length 30 m, i.d. .25 mm and film thickness .25 μm. Fatty acid methyl esters in hexane were injected via a CP 9010 Autosampler (Chrompack U.K., London, U.K.) and pentadecanoic acid was used as the internal standard. Quantification of the peaks was by electronic integration (EZ-Chrom Data Handling System supplied by Speck Analytical, Alloa, U.K.) after identification by comparison with known methyl ester standards.

Determination of TBARS in longissimus muscle, inner backfat, and sausage after grilling was based on the method of Ohkawa et al. (1979) as modified by Pikul et al. (1983). Surface regions of cooked muscle, inner backfat, and sausage were excluded from analysis. To the homogenates were added 40 μL of a .4% solution of butylated hydroxytoluene (**BHT**) as antioxidant to prevent TBARS formation during the assay. The method was calibrated using solutions of 1,1,3,3-tetramethoxypropane (Sigma Chemical, Poole, U.K.) that encompassed the range of concentrations expressed by the samples. The CV for the muscle TBARS determinations was 2.3%. To follow the development of TBARS during storage, the level of

TBARS in the muscle of cooked chops was determined initially and after storage for 24 and 48 h at 4°C.

The level of α-tocopherol in uncooked longissimus muscle and inner backfat was determined by HPLC based on the method of McMurray et al. (1980). The HPLC system consisted of a 3-μm Spherisorb ODS2 reverse phase column (Phase Separations Ltd., Deeside, U.K.), a Shimadzu LC-10AD liquid chromatographic pump (supplied by V.A. Howe & Co., Banbury, U.K.), and a JASCO 821-FP Spectrofluorometer (Mettler-Toledo Ltd., Beaumont Leys, U.K.). Extracts of α-tocopherol in methanol were injected via a Shimadzu SIL-9A Autoinjector, and results were processed on a Shimadzu C-R6A Chromatopac integrator. A solution of all-*rac*-α-tocopherol (3 μg/mL) was used as an external standard.

Organoleptic Assessment. Assessment of grilled chops and sausages was undertaken by trained taste panelists (Vipond et al., 1995) who were trained according to British Standard (1994). Meat and fat components of the chops were assessed. In addition, assessment of odor characteristics was undertaken on samples of the cooked fat. Panelists gave an overall acceptability rating for each chop. At each paneling session, half of the panelists made meat assessments first and the other half made fat assessments first to avoid an order effect. Organoleptic assessment of the cooked sausages was undertaken following storage of the uncooked sausages at –20°C for 3 mo. Before evaluation, panelists developed a range of relevant descriptive vocabulary to be used in the assessment of the sausages. Sausages were grilled evenly under a gas grill for 3.5 min. Sausages were judged for 15 individual sensory characteristics including both texture and flavor ratings and were rated for their overall acceptability. Cooking loss percentages were recorded for both chops and sausages.

Statistical Analysis. Differences between treatments were examined with one-way ANOVA using Genstat software (GEN, 1993). The fixed effects were diet, sex, and genotype and their interactions; the effect of diet was of primary interest. The Penetrometer and subjective fat firmness measurements were analyzed using the temperature of the shoulder fat taken at the time of measurement and P_2 fat thickness as covariates. The data for carcass characteristics and taste panel evaluations were analyzed using the REML model to allow for random effects of slaughter day and paneling session, respectively. The conformation score data were analyzed with the Kruskal-Wallis ranks test (Steel and Torrie, 1960) and the marbling score data with the GLM procedure. Measurements of performance, carcass characteristics, and sensory properties were obtained for each pig (i.e., n = 50 per diet). For chemical analyses, sample numbers were reduced based on power tests using standard error terms obtained from previous experiments while still maintaining balance with respect to diet, sex, and genotype.

Results

Growth Performance and Carcass Characteristics. As shown in Table 3, the ADG of pigs fed Diets B and C was higher than that of pigs fed the control diet; males had a higher ($P < .001$) rate of gain than females (.88 vs .78 kg/d, respectively; data not shown). Pigs receiving the experimental diets (Diets B and C) had an improved gain:feed ratio over pigs receiving the control diet ($P < .05$). The EEL Reflectometer measurement was higher for Diet A than for Diets B or C ($P < .05$), whereas the probe reflectance reading for Diet B was higher than for Diets A or C ($P < .05$). Marbling scores were significantly higher for males than for females, and females consistently exhibited a higher conformation score than males (data not shown). There were no differences in all other variables. As shown in Table 4, the shoulder fat from pigs fed Diet A was the most firm and fat from those fed Diet C the least firm; fat from pigs fed Diet B was more similar in firmness to fat from pigs fed Diet A than to that from pigs fed Diet C. The subjective measurements revealed fat firmnesses that were generally in the middle of the range for all treatments. The experimental groups exhibited lower firmnesses than the control group, although only the difference for the shoulder was significant. The melting points of the inner backfat triacylglycerols were not significantly different. The L*, a*, and b* measurements made on the muscle and fat samples (data not shown) failed to reveal any consistent differences between the three diets. Also, there were no differences between treatments in the standard deviations of the replicated L*, a*, and b* measurements on muscle and fat samples.

Lipid and Fatty Acid Compositions. The longissimus muscle, inner backfat, and grilled sausage contained approximately 1, 80, and 17 g of total lipid per 100 g of sample, respectively. There was no effect of diet on the total lipid contents (data not shown). The composition of the diet exerted marked changes in fatty acid composition of the longissimus muscle (Table 5). Although no changes in the proportions of total saturated (**SAT**), monounsaturated (**MUFA**), and PUFA fatty acids were observed between the diet groups, the levels of (n-3) fatty acids, most notably α-linolenic acid, EPA, and DHA, increased and the levels of (n-6) fatty acids, including linoleic and arachidonic acids, decreased in pigs fed Diets B and C. The percentage of EPA was nearly doubled in the experimental groups compared with the control. As a consequence of these changes, the ratio of linoleic acid to α-linolenic acid and the ratio of total (n-6) fatty acids to total (n-3) fatty acids were markedly reduced

Table 3. The performance and carcass characteristics of the pigs fed the control and experimental diets (n = 50 per diet)

Measurement	Diet A (control)	Diet B	Diet C	SED[a]	Significance[b]
ADG, kg/d	.81	.84	.84	.027	NS
Gain/feed (n = 25 per diet), kg/kg	.346	.372	.363	.009	*
Slaughter wt, kg	95.5	93.7	96.9	2.05	NS
Hot carcass wt, kg	72.8	71.0	74.3	1.74	NS
pH at 45 min[c]	6.30	6.39	6.33	.074	NS
Longissimus muscle temperature at 45 min., °C	35.3	35.2	34.9	.35	**
Rigor meter at 45 min[d]	11.0	11.0	11.0	.33	NS
Ultimate pH[c]	5.70	5.69	5.70	.033	NS
Ultimate longissimus muscle temperature, °C	1.43	1.44	1.45	.082	NS
EEL Reflectometer[c]	42.6	41.7	40.7	.77	*
Fiber optic probe (Biceps femoris)	44.3	44.5	43.6	1.41	NS
Probe muscle reflectance	32.4	35.6	33.0	1.29	*
Probe fat thickness, mm[e]	13.0	13.2	14.2	.59	NS
Probe muscle thickness, mm[e]	52.2	51.3	50.1	1.20	NS
Drip loss, %	4.4	5.0	4.5	.40	NS
Marbling score[f]	.30	.26	.18	.08	NS
Conformation score[g]					
Leg	6.8	6.6	6.9	.18	NS
Loin	6.8	6.9	7.0	.14	NS
Shoulder	6.4	6.4	6.3	.13	NS
Overall	6.7	6.8	6.7	.12	NS

[a]SED = standard error of the difference between any two means.
[b]NS: $P > .10$; *$P < .05$; **$P < .01$.
[c]Duplicate measurements on each carcass.
[d]Measurements on leg (gracilis) muscle in triplicate.
[e]Between third and fourth ribs.
[f]Scale of 0 (no marbling) to 8 (much marbling).
[g]Scale of 1 (very poor) to 10 (very good).

in the muscle of pigs fed the experimental diets ($P < .001$). The levels of eicosenoic acid and erucic acid were higher ($P < .001$) in the muscles of pigs fed Diets B and C. However, the absolute levels of erucic acid in the pigs fed these diets were low. The proportions of eicosenoic and erucic acids were higher in males than in females ($P < .05$; data not shown).

The fatty acid composition of the inner backfat was altered by diet (Table 6). Unlike the muscle, the proportions of total SAT and MUFA were reduced ($P < .05$) and increased ($P < .01$), respectively, in the pigs fed the experimental diets, although the level of total PUFA was unaffected. Female pigs exhibited a higher ($P < .01$) level of oleic acid than males (36.7 vs 35.3%, data not shown). As in the case of the muscle, the levels of (*n*-3) fatty acids were considerably higher in the experimental groups (all $P < .001$). The levels of EPA and DHA were approximately four and three times higher, respectively, in the experimental groups than in the control. The presence of rapeseed oil increased the levels of eicosenoic and erucic acids (both $P < .001$). Both the ratio of linoleic acid to α-linolenic acid and the ratio of total (*n*-6) fatty acids to total (*n*-3) fatty acids were reduced (both $P < .001$) in the inner backfat of the pigs fed the experimental diets. The fatty acid composition of the grilled sausage (Table 7) was primarily a reflection of the fatty acid composition of the inner backfat. However, the ratios of polyunsaturated:saturated fatty acids of the grilled sausage were slightly higher than those for the inner backfat, which was probably a result of the fatty acids of the muscle included in the sausage.

Vitamin E and TBARS. The level of vitamin E was higher in the fat than in the muscle at approximately 15 and 3 μg/g, respectively (see Table 8). In the muscle, vitamin E was lower for Diet B than for Diet A. Pigs fed Diet C contained the highest concentration and reflected the fact that this diet contained the highest level of vitamin E. The vitamin E levels within the inner backfat showed differences between diets similar to those seen in the muscle.

The level of TBARS in the cooked muscle was lowest in the chops from the control group and highest in the chops from pigs fed Diet B ($P < .001$). The level of TBARS in chops from pigs fed Diet C was intermediate between the levels for pigs fed Diets A or B. The levels of TBARS in the grilled muscle following 24 and 48 h of storage at 4°C are shown in Figure 1. From 0 to 48 h, the level of TBARS nearly doubled in all treatment groups. The level of TBARS in cooked muscle from pigs fed Diets B and C tended to be higher than in cooked muscle from pigs fed Diet A. There were no TBARS detectable within the fat or sausage after grilling. However, when BHT was excluded from the assay, artifactual formation of

Table 4. The selected physical properties of the subcutaneous fat from the pigs fed the control and experimental diets (n = 50 per diet)

Measurement	Diet A (control)	Diet B	Diet C	SED[a]	Significance[b]
Shoulder fat temperature at time of reading, °C	3.7	3.7	3.8	.13	NS
P_2 fat thickness with probe, mm	11.8	11.6	12.2	.54	NS
P_2 fat thickness with calliper, mm	9.1	9.3	10.0	.61	NS
Penetrometer firmness, units[c]					
Shoulder	667	645	607	18.1	**
Midback	541	533	516	18.1	NS
Gluteus medius	543	526	531	15.6	NS
Subjective firmness score[d]					
Shoulder	4.39	4.21	3.96	.128	**
Midback	3.80	3.56	3.60	.102	NS
Gluteus medius	3.68	3.60	3.53	.105	NS
Melting point[e], °C	34.6	32.1	31.4	1.54	NS

[a]SED = standard error of the difference between any two means.
[b]NS: $P > .10$; **$P < .01$.
[c]Penetrometer units from 0 (indicative of very soft) to 1,000 (indicative of very firm); values corrected to 4°C and 12 mm P_2 thickness.
[d]Scale of 1 (very soft) to 8 (very firm).
[e]Inner backfat triacylglycerol; n = 16 per diet.

TBARS was higher for samples from pigs fed Diets B or C than from pigs fed Diet A (data not shown). The muscle from males contained significantly higher TBARS than that from females ($P < .05$; data not shown).

Organoleptic Characteristics. Results of the organoleptic evaluation of the grilled loin chops are shown in Table 9. Muscle tenderness was higher for pigs fed Diet B than for those fed the control diet. Scores for other abnormal odor were higher ($P < .05$)

Table 5. The fatty acid composition (% wt/wt of total fatty acids) of the total lipid extractable from the longissimus muscle in the pigs fed the control and experimental diets (n = 16 per diet)

Fatty acid[a]	Diet A (control)	Diet B	Diet C	SED[b]	Significance[c]
14:0	.95	1.04	1.06	.090	NS
16:0	21.3	21.9	21.5	.591	NS
16:1(*n*-7)	2.82	2.81	2.75	.193	NS
17:0	.41	.35	.34	.030	*
18:0	12.5	12.3	12.1	.25	NS
18:1(*n*-9)	29.4	32.1	32.6	1.53	†
18:1(*n*-7)	4.32	4.37	4.29	.108	NS
18:2(*n*-6)	18.2	15.4	15.5	1.35	†
18:3(*n*-3)	.78	1.00	1.13	.053	***
20:0	.17	.11	.14	.015	**
20:1(*n*-9)	.67	.98	1.01	.043	***
20:3(*n*-6)	.69	.56	.55	.078	NS
20:4(*n*-6)	4.54	3.28	3.21	.557	*
20:5(*n*-3)	.68	1.13	1.18	.125	***
22:1(*n*-9)	.01	.09	.12	.013	***
22:5(*n*-3)	1.09	1.16	1.04	.158	NS
22:6(*n*-3)	.77	.99	1.00	.097	*
SAT	35	36	35	.8	NS
MUFA	37	40	41	1.8	NS
PUFA	27	24	24	2.4	NS
P:S ratio	.8	.7	.7	.08	NS
18:2(*n*-6)/18:3(*n*-3)	23.6	15.5	13.9	1.29	***
Total (*n*-6)/total (*n*-3)	7.3	4.6	4.5	.17	***

[a]SAT = total weight percentage of 14:0, 16:0, 17:0, 18:0, and 20:0; MUFA = total weight percentage of 16:1(*n*-7), 17:1(*n*-7), 18:1(*n*-9), 18:1(*n*-7), 20:1(*n*-9), and 22:1(*n*-9); PUFA = total weight percentage of 18:2(*n*-6), 18:3(*n*-6), 18:3(*n*-3), 18:4(*n*-3), 20:3(*n*-6), 20:4(*n*-6), 20:5(*n*-3), 22:4(*n*-6), 22:5(*n*-3), and 22:6(*n*-3); P:S ratio = ratio of PUFA:SAT. Not all fatty acids are presented.
[b]SED = standard error of the difference between any two means.
[c]NS: $P > .10$; †$P < .10$; *$P < .05$; **$P < .01$; ***$P < .001$.

Table 6. The fatty acid composition (% wt/wt of total fatty acids) of the total lipid extractable from the inner backfat in the pigs fed the control and experimental diets (n = 16 per diet)[a]

Fatty acid	Diet A (control)	Diet B	Diet C	SED	Significance
14:0	1.31	1.31	1.34	.051	NS
16:0	24.1	23.2	22.8	.49	*
16:1(*n*-7)	2.12	2.08	1.96	.121	NS
17:0	.52	.45	.44	.031	*
18:0	14.9	13.7	13.4	.52	*
18:1(*n*-9)	35.1	36.5	36.3	.50	*
18:1(*n*-7)	3.36	3.42	3.31	.091	NS
18:2(*n*-6)	14.9	14.1	14.6	.72	NS
18:3(*n*-3)	1.39	1.91	2.09	.077	***
20:0	.30	.17	.14	.021	***
20:1(*n*-9)	1.12	1.63	1.76	.064	***
20:3(*n*-6)	.08	.07	.08	.012	NS
20:4(*n*-6)	.21	.21	.21	.013	NS
20:5(*n*-3)	.06	.23	.26	.018	***
22:1(*n*-9)	.01	.19	.23	.018	***
22:5(*n*-3)	.21	.40	.42	.026	***
22:6(*n*-3)	.14	.40	.45	.028	***
SAT	41	39	38	.9	*
MUFA	42	44	44	.6	**
PUFA	17	17	18	.8	NS
P:S ratio	.4	.5	.5	.03	NS
18:2(*n*-6)/18:3(*n*-3)	10.8	7.4	7.0	.27	***
Total (*n*-6)/total (*n*-3)	8.5	4.9	4.6	.19	***

[a]See Table 5 for explanation of abbreviations.

Table 7. The fatty acid composition (% wt/wt of total fatty acids) of the total lipid extractable from grilled sausage prepared from the cuts taken from pigs fed the control and experimental diets (n = 16 per diet)[a]

Fatty acid	Diet A (control)[b]	Diet B	Diet C	SED	Significance
14:0	1.31	1.30	1.36	.053	NS
16:0	22.7	21.9	21.7	.37	*
16:1(*n*-7)	2.89	2.63	2.68	.117	†
17:0	.49	.43	.41	.025	*
18:0	11.8	11.0	10.8	.35	*
18:1(*n*-9)	36.7	38.1	37.8	.43	**
18:1(*n*-7)	3.42	3.44	3.37	.061	NS
18:2(*n*-6)	15.8	15.1	15.3	.68	NS
18:3(*n*-3)	1.56	1.88	2.06	.081	***
20:0	.31	.19	.16	.039	**
20:1(*n*-9)	1.02	1.41	1.52	.059	***
20:3(*n*-6)	.06	.02	.05	.024	NS
20:4(*n*-6)	.39	.36	.34	.019	NS
20:5(*n*-3)	.04	.26	.30	.028	***
22:1(*n*-9)	ND	.02	.11	.029	**
22:5(*n*-3)	.31	.48	.54	.035	***
22:6(*n*-3)	.22	.50	.54	.034	***
SAT	37	35	34	.7	**
MUFA	44	46	46	.4	**
PUFA	19	19	20	.8	NS
P:S ratio	.5	.6	.6	.03	NS
18:2(*n*-6)/18:3(*n*-3)	10.2	8.1	7.4	.31	***
Total (*n*-6)/total (*n*-3)	7.8	5.0	4.6	.30	***

[a]See Table 5 for explanation of abbreviations.
[b]ND = not detectable.

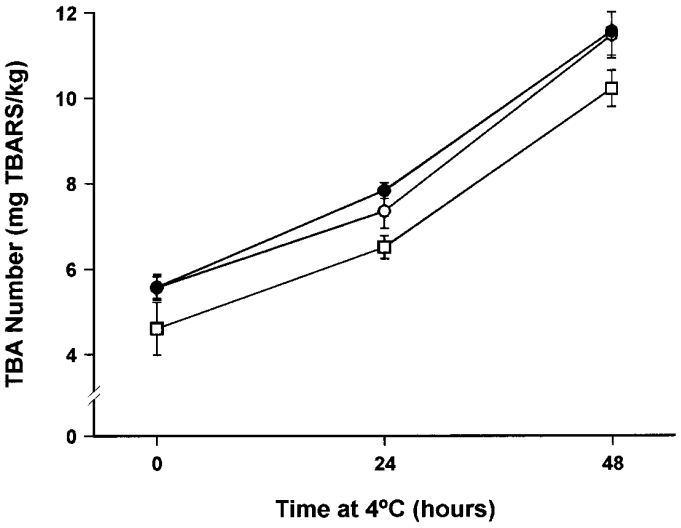

Figure 1. The increase in the formation of thiobarbituric acid-reactive substances (TBARS) in the muscle component of grilled chops (n = 6 per diet) during storage at 4°C; symbols: □, Diet A (control); o, Diet B; ●, Diet C; comparison between treatments at each storage time: $P > .05$; comparison between any two storage times: $P < .001$.

for Diet B pigs than for control pigs. There were no other significant effects of diet on organoleptic characteristics of the muscle or fat components. Abnormal odor/flavor scores for pigs fed Diet C tended to be lower than those for pigs fed Diet B. In the fat, males had higher scores for boar flavor and odor ($P < .05$ and $P < .001$, respectively; data not shown), whereas females had higher scores for pork odor ($P < .05$; data not shown). Evaluation of flavor and texture properties and overall acceptability in terms of the descriptors of the trained taste panelists revealed no significant differences in organoleptic characteristics of sausages from any of the dietary treatments (data not shown); scores for off-flavor and overall acceptability were lower for males (both $P < .05$). There were no differences in cooking loss in the sausages due to diet (data not shown).

Discussion

The present investigation was designed to enhance the (*n*-3) fatty acid content of major pig tissues and their products without causing deleterious effects on measures of consumer acceptability. The improvement in feed conversion efficiency and ADG in the pigs fed the rapeseed oil/fish oil diets could be related to the greater degree of unsaturation of these diets than of the control diet. Growth-enhancing effects of unsaturated oils have also been observed by Oldfield and Anglemier (1957) and Suomi et al. (1993). The relevance of the significant effects of diet on Smokestain Reflectometer and muscle reflectance measurements is not clear. There was some reduction in drip loss with the increased level of dietary vitamin E, as previously reported (Buckley et al., 1995). The absence of a diet effect on L*, a*, and b* values of the meat and fat accords with the observations of Specht-Overholt et al. (1993), who found no marked effects of various dietary flaxseed and(or) α-tocopheryl acetate additions on L*, a*, and b* measurements of pig muscles taken after different storage periods. Irie and Sakimoto (1992) observed no differences in the color of fat from pigs fed 0, 2, 4, or 6% fish oil. However, the inclusion of high levels of canola oil (10% diet; Miller et al., 1993) or fish oil (14%; Brown, 1931) adversely affected pig carcass color.

In terms of objective and subjective measures, a general trend was evident toward less firm subcutaneous fat in the experimental groups. The reduction in firmness was clearly related to the alterations in the levels of palmitic, stearic, and α-linolenic acid, all of which to varying extents have been shown to influence the firmness of fat (Enser et al., 1984; Whittington et al., 1986). Although some reductions in fat firmness were observed, the extent was such that they could well be tolerated in the commercial situation. In previous work, inclusion of long-chain PUFA increased

Table 8. The contents of vitamin E and thiobarbituric acid-reactive substances (TBARS) in the tissues/products from the pigs fed the control and experimental diets

Measurement	Diet A (control)	Diet B	Diet C	SED	Significance[a]
Vitamin E[b]					
Longissimus muscle	3.03	2.71	3.27	.113	***
Inner backfat	15.4	13.2	16.5	2.70	*
TBARS[c]					
Longissimus muscle	6.02	7.07	6.48	.338	***

[a]*$P < .05$; ***$P < .001$.
[b]μg α-tocopherol/g fresh tissue; longissimus muscle: n = 50 per diet; inner backfat: n = 22 per diet.
[c]mg TBARS/kg sample; determined at two separate sites on each grilled chop; n = 50 per diet.

Table 9. The organoleptic characteristics of the muscle and fat components of pork chops from the pigs fed the control and experimental diets as judged by the trained taste panelists (n = 50 per diet)[a]

Tissue characteristic	Diet A (control)	Diet B	Diet C	SED	Significance[b]
Muscle					
Tenderness	13.7	15.0	14.4	.65	*
Juiciness	15.5	16.1	15.4	.51	NS
Pork flavor	13.9	13.6	13.6	.48	NS
Abnormal flavor	4.4	5.1	4.5	.45	NS
Fat					
Pork flavor	11.3	11.5	11.0	.55	NS
Boar flavor	2.7	2.5	2.6	.26	NS
Other abnormal flavor	3.7	4.2	3.9	.43	NS
Fat odor					
Pork odor	11.3	10.8	10.9	.51	NS
Boar odor	4.0	3.2	3.4	.43	NS
Other abnormal odor	3.5	4.6	4.3	.44	*
Chop					
Overall acceptability	13.7	14.0	13.9	.52	NS
Cooking loss, %	25.5	24.1	25.6	.91	NS

[a]Scores rated on a pseudoline scale from 1 (low intensity) to 24 (high intensity) for each characteristic.
[b]NS: $P > .10$; $*P < .05$.

backfat firmness in the presence of high linoleic acid levels, an effect that was mediated by specific changes in the distribution of triacylglycerol molecular species (Leskanich, 1995). Similar effects would be expected to operate in the present study. In other investigations, marked changes in carcass fatty acid composition were associated with significant deleterious effects on the physical properties of the fat. For example, St. John et al. (1987) reported that total SAT in backfat decreased from 40% of total fatty acids in the control group to 15% after feeding a diet containing 20% by weight of canola oil. The changes were accompanied by significant increases in the oiliness and softness of the fat, probably making it unacceptable for retail or processing. Rhee et al. (1988a) observed deleterious effects of a similar magnitude on pig fat characteristics after feeding a diet that contained 12% of high-oleic sunflower oil. Unlike the findings of Anglemier and Oldfield (1957), there was no suggestion in the present study of a decrease in backfat thickness as a result of fish oil inclusion.

In the present study, the total lipid contents of the muscle and fat were not affected by treatment, an observation that accords with other work in which pigs received diets with different total fat and(or) fatty acid compositions (Allee et al., 1972; St. John et al., 1987; Rhee et al., 1988a). However, there were highly significant alterations in the fatty acid compositions of muscle and fat tissues. There were marked increases in the levels of α-linolenic acid on account of the higher levels of this fatty acid in the experimental diets. The higher level of oleic acid in the inner backfat of females compared with males accords with previous observations (Barton-Gade, 1987). The reduction in the level of arachidonic acid within the muscle observed in the pigs that received the experimental diets conforms with previous observations of an arachidonic acid-lowering effect of dietary fish oil (Morgan et al., 1992). As a result of the inclusion of fish oil in the experimental diets, the levels of EPA and DHA were increased in muscle and fat tissues according with previous observations (Leskanich et al., 1994). The increases in the levels of eicosenoic and erucic acids in the tissues, particularly within the adipose tissue, have been observed previously when rapeseed oil has been fed (Walker, 1972).

An amount of 200 mg of EPA plus DHA has been recommended for daily human intake (DH, 1994). Assuming a consumption of 100 g of meat plus 10 g of fat from chops of pigs fed Diets A, B, and C, intakes of EPA plus DHA would approximate to 33, 80, and 88 mg, respectively. Intakes of EPA plus DHA arising from the consumption of two grilled sausages from pigs fed Diets A, B, and C approximates to 24, 71, and 81 mg. A valuable contribution to the needs of the human diet could thus be made through the consumption of such meat/meat products. The importance of the dietary ratio of linoleic acid to α-linolenic acid and that of total (n-6) fatty acids to total (n-3) fatty acids in the human diet has been well emphasized (Galli and Simopoulos, 1989; BNF, 1992). In the present study, these ratios closely approached the stated optima of 6:1 and 4:1, respectively. The reductions in the levels of saturates in the inner backfat and sausage from the pigs on the experimental diets further contributes to their health value. The trend toward slightly higher levels of polyunsaturated fatty acids in pigs receiving Diet C compared with pigs receiving Diet B is probably due to the higher level of vitamin E in Diet C (Leskanich, 1995).

The fatty acid composition of the sausages after cooking was similar to that of the inner backfat for the respective diet, which indicated that the levels of long-chain fatty acids appropriate to the backfat were retained even after exposure to conditions favoring oxidative deterioration of PUFA. The required mincing of meat and fat in sausage preparation can be associated with the generation of heat coupled with exposure to atmospheric oxygen. No special care was taken in the present investigation to avoid such conditions. Sausages were also stored for 6 mo in a freezer before being thawed and then grilled to an internal temperature of approximately 96°C. In other work, the processing and(or) cooking of a variety of pork joints and pork products did not affect the levels of either monounsaturated (Rhee et al., 1990a,b) or polyunsaturated fatty acids (Fogerty et al., 1990; Romans et al., 1995).

In the longissimus muscle and inner backfat, vitamin E was lower in pigs fed Diet B than in those fed Diet A, even though the dietary levels were the same. This accorded with the observations of others who have reported lower levels of vitamin E in porcine tissues containing high PUFA levels (Meydani et al., 1987; Wang et al., 1996). The differences were probably due to increased metabolism of the vitamin as a result of the higher presence of the long-chain (*n*-3) PUFA, which have a greater susceptibility to peroxidation. Furthermore, Hollander (1981) proposed that polyunsaturated fatty acids may limit the intestinal absorption of vitamin E. These results show the importance of providing adequate levels of vitamin E in high PUFA diets. In the present study, feeding the higher level of vitamin E generated the highest tissue levels of the vitamin. However, the efficiency of deposition of vitamin E in muscle and fat in pigs fed Diet C was only half that in the muscle and fat in pigs fed either Diets A or B.

The oxidative stabilities of the tissues and sausages from the pigs fed the rapeseed oil/fish oil diets were lower than for the control, probably due to the higher content of polyunsaturates in the pigs fed the former diets. Under similar dietary circumstances, Rhee et al. (1988b) observed that TBA number in ground, raw muscle was higher for pigs fed 10 and 20% canola oil diets than for those fed a control diet. The present inclusion of a higher level of vitamin E in Diet C increased the oxidative stability of the grilled longissimus muscle, an observation that is consistent with the findings of Monahan et al. (1990) and Cannon et al. (1996). In contrast to these observations, Miller et al. (1993) reported that sausages prepared from pigs fed 10% of animal fat, safflower oil, or sunflower oil did not differ in terms of the resulting TBA values.

Despite the fact that TBARS were higher for the experimental oil diets, organoleptic evaluation of the cooked chops and sausages revealed no major differences in sensory quality. In the muscle components of the chops, a benefit in terms of tenderness was observed for the experimental diets. In the fat, the higher presence of abnormal odor for Diets B and C could be related to the presence of either the rapeseed oil or fish oil in the diets, as observed by Miller et al. (1990). Based on a wide range of measurements, all the products from the pigs fed the modified diets in the present study were acceptable in terms of major physicochemical and sensory traits.

Implications

The feeding of diets containing 2% rapeseed oil and 1% fish oil resulted in significant alterations in the fatty acid composition of porcine tissues and sausage prepared from the tissues. Fatty acid changes accorded with contemporary recommendations on lipid quality intake. Aspects of pig performance and carcass characteristics and the organoleptic properties of meat, fat, and sausages of the pigs were not adversely affected. The results show that the perceived health value of pig meat can be improved without significant deleterious effects on factors relevant to producer or consumer acceptability.

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