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Effect of dietary fish oil supplied to pigs from weaning to 60 kg liveweight on performance, tissue fatty acid composition and palatability of pork when slaughtered at 100 kg liveweight

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ABSTRACT

From weaning to approximately 60 kg liveweight, 24 castrated pigs were assigned to one of 4 diets. The diets were barley-wheat-soyabean meal based and contained either 6% animal fat (diet 1, control), 3% animal fat + 3% fish oil (diet 2), 6% fish oil (diet 3), or 6% of a mixture of fish oil and coconut oil (2/1) (diet 4). The fish oil was an unrefined sand launce oil. Thereafter, all pigs were switched to the finisher-diet added 2% tallow, which was fed until slaughter at approximately 100 kg liveweight. Subcutaneous fat and muscle samples of the loin were obtained by biopsy in the period 50-60 kg liveweight and analysed for fatty acid composition. In addition, samples of belly fat, the subcutaneous fat and the loin muscle obtained from the carcass were evaluated in terms of fatty acid composition and iodine values. There was no difference between the four experimental groups with regard to the growth performance. Fish oil supplementation increased particularly the concentration of C22:6n-3 (DHA), C20:5n-3 (EPA), and C22:5n-3 (DPA), and addition of coconut oil increased the concentration of the fatty acids C12:0 and C14:0 in the subcutaneous fat and muscle samples. The concentration of these fatty acids was lower in samples

obtained from the carcass than from biopsies, but the effect of the dietary oil treatments was still significant at slaughter. Thus, fish oil supplementation increased the level of DHA, EPA, and DPA in muscle and fat tissue, and decreased the n-6/n-3 ratio. However, feeding of 3-6% unrefined fish oil until approximately 60 kg liveweight caused off-flavour of the pork, which was therefore not suitable for human consumption.

KEY WORDS: fish oil, n-3 fatty acids, coconut oil, animal fat, pigs, performance

INTRODUCTION

Fish oil has been avoided to slaughter animals because of the risk for fishy taste and off-flavour. Danish pig-producers are therefore only allowed to include fish oil into the feed for pigs for no longer than 30 kg liveweight (LW). However, due to their high energy-value, fats and oils are important ingredients in the production of feed for fast-growing animals, and the pig-feed industry is a marketing possibility for producers of fish oil.

Fish oil is particularly rich in the polyunsaturated fatty acids (PUFA) eicosapentaenoic acid (EPA; C20:5n-3), docosapentaenoic acid (DPA, C22:5n-3), and docosahexaenoic acid (DHA, C22:6n-3). The n-3 fatty acids, especially EPA and DHA, are of interest as potential moderators of cardiovascular disease (Herold and Kinsella, 1986). A ratio of n-6 to n-3 fatty acids in the human diet above 1:10 is held responsible for a whole series of lifestyle diseases (Skjervold, 1993). In the organism, the n-3 fatty acids are formed through desaturation and chain elongation processes from the parent compound of the n-3 series of essential fatty acids, the alpha-linolenic acid (C18:3n-3). In farm animals, the conversion of α-linolenic acid to longer chain polyunsaturated fatty acids seems to be limited. Therefore C18:3n-3, and to a much lesser extent C20:5n-3, 22:5n-3 and 22:6n-3 are not deposited in skeletal muscles (and hence in meat), unless these PUFA are incorporated in the feed (Jakobsen, 1995).

The depot fat of pigs (Mortensen et al., 1983; Flachowsky et al., 1997) is very susceptible to dietary changes as fatty acids are incorporated unchanged into body fat. Irrespectively of the dietary source, there was a linear relationship between the dietary intake of α-linolenic acid and its concentration in the backfat of pigs (Østerballe et al., 1990). In an experiment with pigs fed diets containing 2, 4, and 6% fish oil for 4 weeks before slaughter, the concentration of EPA and DHA in subcutaneous fat began to increase during the first week and increased over time in relation to dietary intake (Irie and Sakimoto, 1992).

The objective of the present study was to investigate whether dietary provision of fish oil alone or in combination with coconut oil or animal fat for pigs until approximately 60 kg LW, would affect performance, fatty acid composition

of fat and meat and consumer acceptability of the pork, following slaughter at 100 kg LW.

MATERIAL AND METHODS

Animals

From weaning (28 days of age, approximately 9 kg LW) to approximately 60 kg LW, 24 alternating Landrace x Yorkshire castrated pigs from 6 litters (blocks) were assigned to one of 4 dietary treatments. Thereafter, pigs were fed the same finisher feed until slaughter at approximately 100 kg LW.

Pigs were housed individually at the plant of Research Centre Foulum. The animals were given *ad libitum* access to feed and water. Individual weight and feed intake were recorded weekly.

Diets

The composition of the four experimental diets differed with regard to the source of dietary fat:
Diet 1: 6% animal fat (control)
Diet 2: 3% animal fat + 3% fish oil
Diet 3: 6% fish oil
Diet 4: 6% of a mixture of fish oil and coconut oil (2/1).

The fatty acid composition of the dietary fat/oils is presented in Table 1. The fish oil used in this experiment was an unrefined sand launce oil (Tyborøn Andels Fiskeindustri A.m.b.a., Tyborøn, Denmark). The fish oil, manufactured originally for fish farming, contained 300 ppm ethoxyquine and had the following quality characteristics: free fatty acids (FFA), 2.7%; peroxide value, 1.1 meq/kg oil; and anisidine value, 13.2.

The pigs were provided with a starter feed during the first 4 experimental weeks and thereafter a grower feed until approximately 60 kg LW. Thereafter and until slaughter, pigs were fed a finisher feed. The chemical composition of the feed mixtures was determined according to the AOAC procedure (1990) and is given in Table 2.

Dietary lipids were extracted by the method of Stoldt (1952) using petroleum ether, and the long chain fatty acids (>C:8) were determined by gas-liquid-chromatography (GLC) after saponification and methylation as described by Rothenberg and Andersen (1980) with the modifications that a capillary column was used and that hexane was substituted with heptane, and with C17:0 as the internal standard. Results are shown in Table 3.

TABLE 1

Analysed fatty acid composition (g fatty acid/100 g) of supplemented fat/oils

Fatty acid	Animal fat	Fish oil	Fish/coconut oil
C8:0	–	–	2.20
C10:0	0.07	0.20	1.90
C12:0	0.14	0.21	13.92
C13:0	–	0.04	0.04
C14:0	1.97	5.44	8.93
C14:1	0.22	0.04	–
C15:0	0.25	0.34	0.26
C16:0	23.45	13.25	11.53
C16:1	2.77	4.88	3.23
C17:0	0.68	0.32	0.22
C17:1	0.44	0.21	0.13
C18:0	14.48	1.63	1.94
C18:1	39.94	7.99	7.27
C18:2n-6	6.80	1.76	1.69
C18:3n-3	0.87	1.43	0.95
C18:3n-6	0.07	0.08	0.05
C18:4	0.19	4.23	2.82
C20:0	0.19	0.10	0.10
C20:1	0.90	0.66	4.47
C20:2n-6	0.31	0.24	0.18
C20:3n-3	0.09	0.16	0.10
C20:3n-6	0.07	0.05	0.09
C20:4n-6	0.21	0.34	0.22
C20:5n-3	0.06	10.01	6.67
C22:0	0.10	–	–
C22:1	–	11.55	7.62
C22:5n-3	–	0.77	0.52
C22:6n-3	–	11.65	7.73
C24:1	–	0.76	0.51
Σ Fatty acids	94.27	78.34	85.29

Sampling and analytical procedures

At approximately 60 kg LW, a biopsy sample containing fat and skeletal muscle was taken in the *M. longissimus dorsi* above the last rib curvature with a biopsy spring instrument (Biotech, Nitra, Slovakia Republic) as described by Cheah et al. (1997). Samples of the inner layer of the backfat and the muscle were stored at –80°C until analysis.

Pigs were slaughtered at the plant at Research Centre Foulum at approximately 100 kg LW. Following evisceration of the carcasses, samples of the *Longissimus*

dorsi (above the last rib curvature), the belly, and the backfat (inner layer) were taken. For determination of fatty acid profiles of these samples and the biopsies, lipids were extracted from subcutaneous fat and intramuscular fat using chloroform, and long chain fatty acids were detected using GLC after esterification and

TABLE 2

Ingredient and chemical composition of the feed

	Pig Starter[1]	Pig grower[2]	Pig finisher[3]
Ingredients, %			
barley	31.6	42.8	56.3
wheat	31.5	20.0	20.0
soyabean meal	17.0	27.0	18.0
fish meal, LT[4]	11.0	0	0
molasses	0	1.0	1.0
L-lysine[5]	0.5	0.3	0.4
DL-methionine[6]	0	0.1	0.1
calcium carbonate	0.4	1.0	0.8
sodium chloride	0.3	0.4	0.4
dicalcium phosphate	1.3	1.2	0.8
mineral and vitamin premix	0.4[7]	0.2[8]	0.2[8]
fat[9]	6.0	6.0	2.0
Analysed chemical composition, %			
dry matter (DM)	89.6	89.7	87.6
In % of DM			
crude protein	26.2	21.7	20.5
crude fat	10.1	10.3	4.6
ash	7.1	6.7	6.0
crude fibre	3.9	3.9	4.5
EDOM[10]	89.5	90.8	88.3
MJ NE/kg DM	10.3	9.8	9.3

[1] fed from 28-56 days of age

[2] fed from 56 days of age and until 60 kg liveweight

[3] fed from 60 kg liveweight and until slaughter (100 kg liveweight)

[4] LT=low temperature

[5] L-lysine hydrochloride in wheat bran, containing 320 g pure L-lysine/kg

[6] DL-Methionine in wheat bran, containing 400 g pure DL-methionine/kg

[7] Sevit Mikro 4090 (Leo Pharmaceutical, Vejen, Denmark)

[8] Solivit Mikro 106 (Leo Pharmaceutical, Vejen, Denmark). Minerals and vitamins were mixed in calcium carbonate and wheat meal and provided per kilogram feed: Fe; 50 mg; Zn; 80 mg; I, 0.198 mg; Se, 0.3 mg; Cu, 20 mg; retinol, 4,400 IU; vitamin D_3, 1,000 IU; dl-α-tocopherol acetate, 60 mg; thiamine, 2.2 mg; riboflavine, 4 mg; pyridoxine, 3.3 mg; niacin, 22 mg; biotin, 55 µg; pantothenic acid, 11 mg; vitamin B_{12}, 22 µg; vitamin K_3, 2.2 mg

[9] experimental diets, 6% (Table 3). The 2% fat was provided as animal fat

[10] EDOM = Enzyme digestibility of organic matter (Boisen and Fernández, 1997)

methylation with boron trifluoridemethanol. The individual fatty acids were identified by means of a reference mixture of fatty acid methyl-esters (Nu-Check GLC 87).

The oxidative stability of the backfat samples obtained at slaughter was determined by the 2-thiobarbituric acid value method (AOCS Official Method Cd, 1990).

TABLE 3

Composition of fatty acids (g fatty acid/100 g fatty acids) of the experimental diets and the pig finisher

Fatty acids	Experimental diets[1]				Pig finisher[2]
	6% animal fat	3% fish oil + 3% animal fat	6% fish oil coconut oil	6% fish and	
C8:0	0	0	0	1.1	0
C10:0	0.2	0.2	0.2	1.3	0.1
C12:0	0.2	0.3	0.3	10.7	0.1
C14:0	1.6	3.0	4.5	7.5	0.9
C14:1	0.1	0.1	0	0	0.1
C15:0	0.2	0.3	0.4	0.3	0.2
C16:0	24.8	20.9	18.1	16.5	22.9
C16:1	2.1	3.1	4.2	2.8	1.1
C17:0	0.5	0.4	0.3	0.2	0.3
C17:1	0.4	0.2	0	0	0.2
C18:0	12.3	7.1	2.2	2.5	7.0
C18:1	32.8	23.0	9.8	10.7	22.5
C18:2n-6	20.7	19.1	18.0	17.6	38.9
C18:3n-3	2.3	2.6	3.0	2.5	4.2
C18:3n-6	0.2	0.1	0.1	0.1	0.1
C18:4n-3	0.1	1.6	3.4	2.3	0.1
C20:0	0.2	0.3	0.2	0.2	0.2
C20:1	0.8	3.3	5.8	4.0	0.7
C20:2n-6	0.3	0.2	0.2	0.1	0.2
C20:3n-3	0	0.1	0.1	0.1	0
C20:4n-6	0	0.2	0.3	0.2	0.1
C20:5n-3	0	3.8	8.1	5.4	0
C22:0	0	0.1	0.1	0.1	0.2
C22:1	0	4.8	10.0	6.7	0.2
C22:5n-3	0	0.5	0.6	0.4	0
C22:6n-3	0	4.4	9.3	6.2	0
C24:1	0	0.3	0.8	0.4	0
Σg fedtsyre/ 100 g Stoldt fat	83.8	80.1	77.4	81.3	85.7

[1] fatty acid profile of the pig grower diet

[2] diet provided from 60 kg liveweight until slaughter

Furthermore, samples of the belly, roasted and boiled, from pigs on each of the 4 dietary treatments were presented to a five-member taste panel at the Danish Meat Research Institute (Roskilde, Denmark).

Statistical analysis

Data were analysed statistically by the MIXED procedure in a statistical package from SAS®(1988). The effect of dietary treatment was analysed by the following model:

$$Y_o = \mu + \alpha_0 + U_{l(i)} + \varepsilon_o,\ \varepsilon_o = N(0,\sigma^2),\ o = 1,\ldots,4$$

where $U_{l(i)}$ refers to a random litter effect accounting for dependency among pigs from the same litter and α_0 refer to the effect of dietary treatment. If the dietary effect was statistically significant ($P<0.05$), treatment least-square means were estimated by the LSMEANS option.

The linear dependence between the tissue concentration of C22:6n-3 and the dietary concentration of C22:6n-3 provided by the fish oil was investigated by regression analysis according to the two following models, where Y_{wci} denotes the concentration of C22:6n-3 at the *w* (weight 60 (1) or 100 (2) kg LW), at the given dietary concentration, *c*, of C22:6n-3 of a pig, *i*:

For w = 1 (60 kg LW):

$$X_{1ci} \sim N\left(\mu^{(1)}_{ci}, \sigma^2_{1(i)}\right)$$

$$\mu^{(1)}_{ci} = \alpha^{(1)} + \beta^{(1)} c_i$$

For w = 2 (100 kg LW):

$$Y_{ci} \sim N\left(\mu^{(2)}_{c}, \sigma^2_{2(i)}\right)$$

$$\mu^{(2)}_{ci} = \alpha^{(2)} + \beta^{(2)} c_i + \gamma x_{1ci}.$$

RESULTS

No differences between dietary treatments were obtained with regard to the performance (daily body weight gain, feed utilisation) of pigs, and Table 4 shows therefore the pooled means of pigs' performance results within dietary treatment groups.

Tables 5 and 6 show the composition of fatty acids in the backfat and the *longissimus dorsi* muscle, respectively, obtained at approximately 60 and 100 kg liveweight. Dietary treatments differed with regard to the concentration of most fatty acids in samples obtained at 60 kg LW. The fatty acid profile of the backfat

TABLE 4
Performance of the experimental pigs from weaning at 28 days of age (approximately 9 kg LW) until slaughter at 100 kg LW (148 days of age)[1]

	Pig Starter	Pig Grower	Pig Finisher	Total
Number of pigs	22	22	22	22
Period, days	29	52	40	120
Accumulated body weight, kg	20.1	61.3	103.1	103.1
Average daily gain, g/day	391	796	1054	783
Feed conversion efficiency, kg/kg	1.57	2.15	2.79	2.36
MJ NE/gain	14.6	18.9	22.6	20.0

[1] no statistically significant differences between experimental diets were found, and means within experimental diets were therefore pooled

and the muscle obtained from the carcass differed in the same manner as the belly (Table 7). Addition of coconut oil (diet 4) increased the levels of lauric and myristic acid, and addition of fish oil increased the levels of DHA, EPA, DPA, and erucic acid (diet 2-4). The increase of those fatty acids was mainly at the expense of oleic acid. Provision of animal fat during the total experimental period resulted in the highest concentration of oleic acid, and thereby highest proportion of total monounsaturated fatty acids.

Figure 1 shows in detail the incorporation of C22:6n-3 in the backfat, the belly, and the muscle tissue as a function of the concentration of C22:6n-3 in the feed. As can be seen from the figure, the relationship between the concentration of the fatty acid in the tissue and in the feed is linear (R^2=0.83 to 0.99 for the 5 lines). Based on the intercepts and the regression coefficients (slope of the curves), the lines could be categorised into two groups, namely from weaning until 60 kg LW and from 60 kg to 100 kg LW. The incorporation of C22:6n-3 into tissues obtained at 60 kg LW depended directly on the concentration of C22:6n-3 in the feed ($P<0.001$). However, the variation of C22:6n-3 in samples obtained at 100 kg LW could be explained entirely ($P=0.001$) by the tissue concentration of C22:6n-3 at 60 kg LW. The estimate of the regression coefficient at 100 kg LW was 0.38, meaning that 62% of the concentration of C22:6n-3 disappeared from the tissues between 60 and 100 kg LW. This result indicates the influence of the animal fat provided by the finisher feed fed from 60 kg liveweight until slaughter.

The iodine value of the samples is shown in Table 8. Only results of the backfat obtained at 60 kg liveweight differed, i.e. the iodine value of pigs on diet 4 was lower than the pigs fed the other diets ($P<0.05$). The TBA-values of the backfat (results not shown), which was only determined on samples obtained at 100 kg liveweight, were generally low (range 0.016-0.021 μM malonealdehyde), and did not differ between dietary treatments ($P>0.05$).

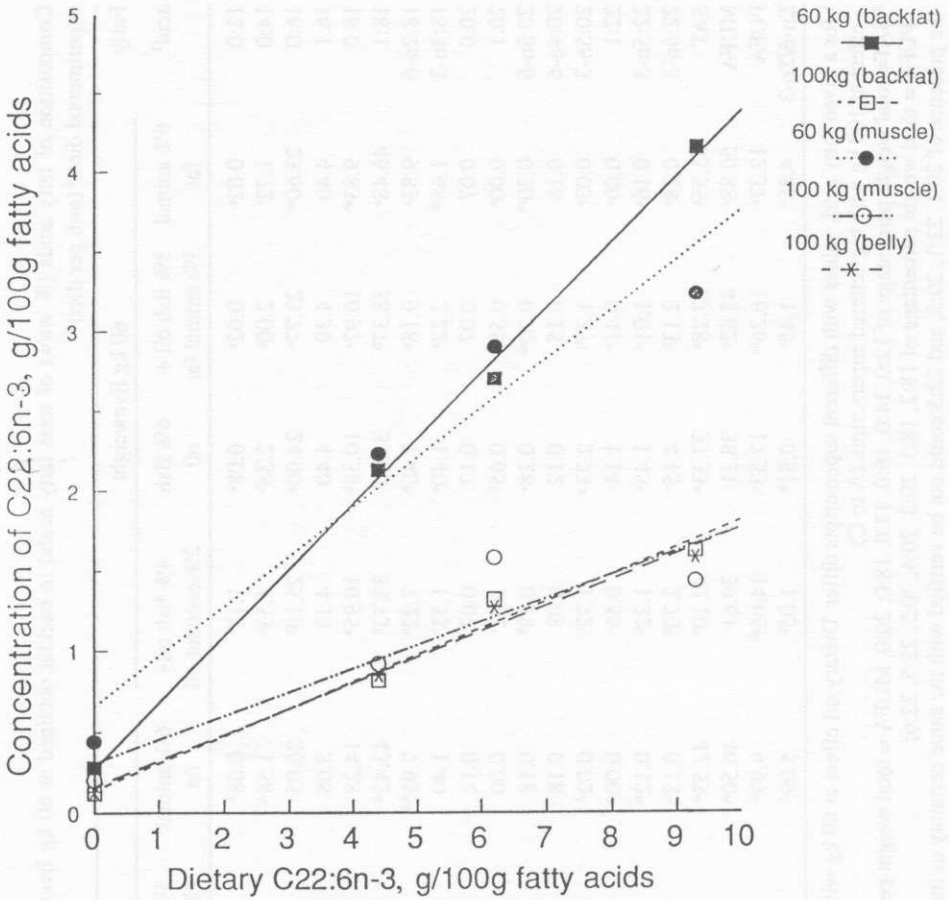

Figure 1. Plots of the concentration of C22:6n-3 in the belly, the backfat, and the muscle tissue at 60 and 100 kg liveweight against the dietary concentration of C22:6n-3, provided from weaning to 60 kg liveweight

Results from the sensory analyses showed that the dietary inclusion of fish oil caused off-flavour and off-odour of the belly. The off-flavour was characterised as an oily, rank, fishy or sweet taste. The off-flavour intensity of both boiled and roasted samples of pigs fed diet 3 was higher and samples of pigs fed diet 4 slightly higher compared with diet 1. In addition, the joint of the pork of diet 3 was greyish and liquid, and carcasses were not used for human consumption. Regarding samples of pigs fed diet 2, off-flavour was only detected in the boiled samples, not in the roasted ones.

TABLE 5

Composition of fatty acids (% wt/wt of total fatty acids) in backfat obtained at 60 kg liveweight and at slaughter (100 kg) of pigs fed the 4 experimental diets[1] (n=6 per diet)

Fatty acid[2]	60 kg liveweight				100 kg liveweight				SDE
	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil+ 2% coconut oil	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil + 2% coconut oil	
12:0	0.02^{a}	0.02^{a}	0.08^{a}	1.18^{b}	0.08^{A}	0.08^{A}	0.07^{A}	0.55^{B}	0.06
14:0	1.72^{a}	2.00^{a}	2.38^{b}	4.53^{c}	1.58^{A}	1.58^{A}	1.80^{A}	2.75^{B}	0.19
16:0	23.60^{ab}	23.77^{a}	24.00^{a}	25.10^{b}	26.05	25.18	26.17	26.00	0.79
16:1	4.40	4.30	4.40	4.30	3.08	2.98	2.92	2.97	0.24
18:0	9.83^{ab}	10.97^{a}	10.38^{b}	10.95^{b}	14.28	14.54	15.50	14.92	0.73
18:1	46.48^{a}	38.37^{b}	31.92^{b}	33.73^{b}	43.42^{A}	41.46^{AB}	36.85^{B}	37.75^{B}	1.21
18:2n-6	9.83^{a}	9.18^{a}	7.40^{b}	7.22^{b}	7.95^{AB}	8.00^{A}	7.80^{AB}	8.00^{B}	0.69
18:3n-3	1.68^{ab}	2.22^{a}	1.40^{b}	1.53^{b}	1.40	1.64	1.92	2.02	0.36
20:0	0.07	0.07	0.17	0.07	0.12	0.22	0.22	0.20	0.05
20:1	0.00^{a}	0.55^{b}	0.65^{b}	1.02^{c}	0.00	0.16	0.32	0.22	0.17
20:3n-6	0.20^{ab}	0.20^{ab}	0.28^{a}	0.18^{b}	0.18	0.20	0.23	0.25	0.04
20:4n-6	0.18	0.15	0.12	0.08	0.18	0.08	0.07	0.07	0.13
20:5n-3	0.03^{a}	1.37^{b}	2.73^{c}	1.72^{b}	0.02^{A}	0.42^{AB}	0.83^{B}	0.60^{B}	0.27
22:1	0.00^{a}	0.41^{b}	1.14^{c}	0.56^{b}	0.00^{A}	0.13^{AB}	0.43^{C}	0.18^{B}	0.08
22:5n-3	0.16^{a}	1.01^{b}	1.45^{c}	1.22^{b}	0.12^{A}	0.60^{B}	0.86^{C}	0.81^{C}	0.12
22:6n-3	0.28^{a}	2.13^{b}	4.15^{c}	2.70^{d}	0.12^{A}	0.82^{B}	1.62^{C}	1.32^{C}	0.19
SAT	35.55^{a}	37.28^{a}	37.33^{a}	42.10^{b}	42.53^{A}	42.04^{B}	44.13^{AB}	44.80^{B}	1.23
MUFA	50.88^{a}	43.62^{b}	38.11^{c}	39.61^{c}	46.50^{A}	44.73^{A}	40.52^{B}	41.11^{B}	1.32
PUFA	12.37^{a}	16.26^{bc}	17.53^{c}	14.66^{ab}	9.97^{A}	11.76^{AB}	13.32^{B}	13.06^{B}	1.29
Σn-6/Σn-3	4.85^{a}	1.45^{b}	0.81^{b}	1.05^{b}	5.09^{A}	3.48^{B}	1.56^{C}	1.80^{BC}	0.41

[1] for a given fatty acid, values with different superscripts differ. Dietary oil effect at 60 kg with small-lettered superscripts (a to c), and dietary oil effect at 100 kg with big-lettered superscripts (A to C)

[2] SAT= total weight percentage of 12:0, 14:0, 16:0, 17:0, 18:0, 20:0, MUFA = total weight percentage of 16:1, 18:1, 20:1, 22:1, PUFA = total weight percentage of 18:2, 18:3, 20:3, 20:4, 20:5, 22:5, 22:6;
the presence of 20:1, 22:1, 20:5, and 22:5 could not be verified with the same certainty as the other fatty acids presented

TABLE 6

Composition of selected fatty acids (% wt/wt of total fatty acids) in the longissimus dorsi muscle obtained at 60 kg LW and at slaughter (100 kg LW) of pigs fed the 4 experimental diets[1](n=6 per diet)

Fatty	60 kg liveweight				100 kg liveweight				SDE
acid[2]	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil+ 2% coconut oil	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil + 2% coconut oil	
12:0	0.00^{a}	0.00^{a}	0.00^{a}	0.60^{b}	0.02	0.00	0.00	0.00	0.06
14:0	1.34^{a}	1.80^{b}	1.48^{ab}	2.92^{c}	1.38	1.47	1.48	1.48	0.20
16:0	24.10^{a}	26.78^{b}	28.40^{b}	26.66^{b}	25.92	26.10	26.52	25.77	0.83
16:1	3.54^{ab}	3.33^{ab}	3.98^{a}	3.18^{b}	3.67^{A}	3.60^{AB}	3.45^{AB}	3.12^{B}	0.25
18:0	10.86^{a}	12.20^{b}	11.33^{ab}	11.74^{a}	11.05^{AB}	11.98^{A}	11.83^{B}	10.95^{B}	0.76
18:1	43.80^{a}	34.38^{b}	32.05^{bc}	30.96^{c}	44.90^{A}	43.57^{AB}	41.40^{B}	40.00^{B}	1.27
18:2n-6	10.86^{a}	11.68^{b}	8.58^{bc}	9.82^{ac}	7.90^{AB}	7.18^{B}	7.23^{B}	9.22^{A}	0.73
18:3n-3	1.36^{a}	2.25^{b}	2.15^{ab}	1.60^{ab}	0.83	1.23	1.32	0.77	0.73
20:0	0.04	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.38
20:1	0.00	0.00	0.35	0.12	0.00	0.02	0.00	0.00	0.18
20:3n-6	0.24^{a}	0.08^{b}	0.05^{b}	0.20^{a}	0.27	0.23	0.27	0.32	0.05
20:4n-6	1.06^{a}	0.45^{b}	0.33^{b}	0.58^{b}	1.25^{A}	0.53^{B}	0.48^{B}	0.73^{B}	0.05
20:5n-3	0.32^{a}	2.48^{b}	4.17^{c}	4.00^{c}	0.23^{A}	1.08^{B}	2.02^{C}	2.32^{C}	0.29
22:1	0.00^{a}	0.34^{b}	0.55^{c}	0.20^{b}	0.00	0.05	0.05	0.02	0.08
22:5n-3	0.38^{a}	1.13^{bc}	1.05^{b}	1.45^{c}	0.25^{A}	0.77^{B}	0.99^{C}	1.18^{C}	0.13
22:6n-3	0.44^{a}	2.23^{b}	3.23^{c}	2.90^{c}	0.20^{A}	0.92^{B}	1.43^{C}	1.58^{C}	0.14
SAT	36.52^{a}	40.78^{b}	41.28^{b}	41.92^{b}	38.43	39.70	39.83	38.20	0.20
MUFA	47.34^{a}	38.04^{b}	36.93^{bc}	34.16^{c}	48.77^{A}	47.23^{AB}	44.91^{BC}	43.14^{C}	1.38
PUFA	14.72^{a}	20.28^{b}	14.54^{b}	20.55^{b}	10.93^{A}	11.96^{A}	13.74^{AB}	16.11^{B}	1.34
Σn-6/Σn-3	5.21^{a}	1.52^{b}	0.96^{b}	1.10^{b}	6.63^{A}	1.99^{B}	1.39^{B}	1.77^{B}	0.43

[1] for a given fatty acid, values with different superscripts differ. Dietary oil effect at 60 kg with small-lettered superscripts (a to c), and dietary oil effect at 100 kg with big-lettered superscripts (A to C)

[2] SAT= total weight percentage of 12:0, 14:0, 16:0, 17:0, 18:0, 20:0, MUFA = total weight percentage of 16:1, 18:1, 20:1, 22:1, PUFA = total weight percentage of 18:2, 18:3, 20:3, 20:4, 20:5, 22:5, 22:6

the presence of 20:1, 22:1, 20:5, and 22:5 could not be verified with the same certainty as the other fatty acids presented

TABLE 7

Composition of selected fatty acids (% wt/wt of total fatty acids) in the belly in the pigs fed the 4 experimental diets (n=6 per diet)

Fatty acid[1]	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil + 2% coconut oil	SDE
12:0	0.07[a]	0.08[a]	0.07[a]	0.55[b]	0.06
14:0	1.65[a]	1.70[a]	1.83[a]	2.78[b]	0.19
16:0	25.57	25.08	24.90	25.13	0.79
16:1	3.77	3.55	3.68	3.60	0.24
18:0	11.72	12.87	12.58	12.77	0.73
18:1	46.08[a]	42.67[b]	40.25[c]	40.02[c]	1.21
18:2n-6	7.35	7.68	7.35	7.43	0.70
18:3n-3	1.38	0.72	1.55	1.50	0.36
20:0	0.12	0.13	0.15	0.12	0.05
20:1	0	0.02	0.28	0.30	0.17
20:3n-6	0.22	0.18	0.22	0.20	0.04
20:4n-6	0.18	0.15	0.15	0.13	0.13
20:5n-3	0.05[a]	0.53[ab]	1.07[c]	0.77[bc]	0.27
22:1	0.02[a]	0.24[b]	0.37[b]	0.24[b]	0.08
22:5n-3	0.16[a]	0.65[b]	0.94[c]	0.90[c]	0.12
22:6n-3	0.13[a]	0.85[b]	1.58[c]	1.27[c]	0.19
SAT	39.48	40.27	39.87	41.68	1.22
MUFA	49.85[a]	46.47[b]	44.59[b]	44.15[b]	1.32
PUFA	9.49[a]	10.77[ab]	12.86[b]	12.20[b]	1.29
Σn-6/Σn-3	4.57[a]	3.06[b]	1.53[c]	1.79[c]	0.41

[1] SAT = total weight percentage of 12:0, 14:0, 16:0, 17:0, 18:0, 20:0, MUFA = total weight percentage of 16:1, 18:1, 20:1, 22:1, PUFA = total weight percentage of 18:2, 18:3, 20:3, 20:4, 20:5, 22:5, 22:6 the presence of 20:1, 22:1, 20:5, and 22:5 could not be verified with the same certainty as the other fatty acids presented

[a, b, c] – $P<0.05$

TABLE 8

The iodine value of total lipids from the belly, the backfat, and the *longissimus dorsi* muscle in the pigs fed the 4 experimental diets (n=6 per diet)

Samples	6% animal fat	3% fish oil + 3% animal fat	6% fish oil	4% fish oil + 2% coconut oil	SDE
Belly	64.0	63.0	66.6	64.5	2.01
Backfat, 60 kg	70.9[a]	73.5[a]	73.4[a]	66.8[b]	2.01
Backfat, 100 kg	62.0	64.1	64.6	64.5	2.01
Significance[1]	***	***	***	NS	
Muscle, 60 kg	73.0	74.9	72.4	71.0	2.11
Muscle, 100 kg	66.9	66.2	67.1	69.6	2.11
Significance[1]	**	***	*	NS	

[1] level of significance between samples (only backfat and muscles) obtained at 50-60 and 100 kg of liveweight. NS: $P>0.05$; *$P<0.05$; **$P<0.01$;***$P<0.001$

[a, b] – $P<0.05$

DISCUSSION

The present study was designed to include fish oil into the diet for pigs without causing deleterious effects on the performance of the pigs and the consumer acceptability of the pork. An unrefined and non-deodorised fish oil was used because refinement and deodorization would increase the cost of the fish oil to an unrealistic level for practical use. Dietary inclusion of fish oil alone or in combination with animal fat or coconut oil had no significant effect on growth performance of the pigs. This result is in accordance with Øverland et al. (1996), and is probably a result of all diets containing the same level of added fat and thus having similar energy levels. However, the feeding of rapeseed oil/fish oil diet in the study by Leskanich et al. (1997) improved the feed conversion efficiency and ADG in pigs compared to the control diet, and this result was related to the greater degree of unsaturation of the experimental diets.

There were highly significant alterations in the fatty acid composition of muscle and fat tissues with the dietary treatments. Inclusion of coconut oil increased the level of C12:0 and C14:0 in the tissues. As a result of inclusion of fish oil in the experimental diets, a dose-dependent increase of DHA, and also a rise in EPA and DPA, was shown in the backfat, the muscle, and the belly according with previous studies (Irie and Sakimoto, 1992; Øverland et al., 1996). As also seen in those studies, the increase in DHA, EPA and DPA occurred mainly at the expense of C18:1, but also to some extent of C20:4n-6 and C18:2n-3.

As mentioned before, the conversion of 18:3n-3 to PUFA (EPA, DPA, DHA) in pigs seems to be limited (Jakobsen, 1995), and the accumulation of DHA, EPA, and DPA in tissues may therefore be due to the incorporation of those fatty acids in the feed. Although the concentration of DPA in the feed was much lower than the concentration of EPA and DHA (Table 3), a remarkably increase in the concentration in the muscle and fat tissue was obtained, which may be ascribed to the conversion of C20:5n-3 to C22:5n-3. Although pigs were switched to a control diet from 60 to 100 kg LW, there was still a linear relationship between the dietary proportion of C22:6n-3 and the proportion of C22:6n-3 in carcass samples of the pigs (Figure 1). This was also seen in the study by Øverland et al. (1996), in which the concentration of C22:6n-3, and also C20:5n-3 and C22:5n-3, was higher in tissues of pigs receiving 3% fish oil until d 112 (at about 60 kg LW), and thereafter a control diet until d 148 (at about 100 kg LW), compared with the feeding of the control diet during the whole experimental period. Apparently both the backfat, which consists mainly of triglycerides, and the muscle, which consists mainly of phospholipids, retained their high levels of C22:6n-3 which may be due to a low turnover rate of this fatty acid. In the present study, 62% of the concentration of C22:6n-3 in the tissues disappeared within the period from approximately 60 to 100 kg LW or within 42 days meaning that ap-

proximately 1.5% of C22:6n-3 disappeared per day. In the study by Øverland et al. (1996), approximately 45 and 34% of the concentration of C22:6n-3 in subcutaneus fat and muscle tissue, respectively, disappeared in pigs from day 112 to day 148 corresponding to 1.3% and 0.94% per day, respectively.

The ratio of n-6/n-3 fatty acids in fat and muscle tissue was calculated, based on the following fatty acids: C18:2n-6, C20:3n-6, C20:4n-6, C18:3n-3, C20:5n-3, C22:5n-3 and C22:6n-3. As expected, the ratio of n-6/n-3 decreased in tissues of pigs receiving fish oil. The n-6/n-3 fatty acid ratio in fat and muscle tissue obtained from the carcass was 5.1 and 6.6, respectively, in pigs fed the control diet (diet 1), and was reduced to 1.6 and 1.4, respectively, in pigs fed diet 3. The n-6/n-3 ratio in the fat from pigs on diet 1 can be considered as representative of common practice in Denmark due to the use of animal fat. Thus, inclusion of fish oil to the diet for pigs may improve the nutritional value of the pork with respect to the fatty acid composition.

Østerballe et al. (1990) claimed that the iodine value should be lower than 65, whereas values above 70 would not be acceptable because of depreciated quality (soft carcass, reduced technological value, and reduced stability). However, all iodine values of samples obtained from the backfat of the carcass were below 65, and of muscle lower than 70. In addition, the TBA-values of the backfat were generally low, and no indications of lower oxidative stability with the fish oil addition were observed. It cannot be excluded that differences between dietary treatments would turn up during more stressful conditions such as freezer storage or heating of the meat.

Despite the fact that dietary inclusion of fish oil did not affect the oxidative stability, addition of fish oil had a negative effect on the sensory profile of the belly. The increase in off-flavour and off-odour intensity was also reported in pigs receiving 1 or 3% fish oil until day 112 (Øverland et al., 1996), and in pigs receiving diets containing 2% rapeseed oil plus 1% fish oil from 52 kg LW until 95 kg (Leskanich et al., 1997). If the concentration of DHA, DPA and EPA gives rise to the negative sensory scores of the pork, it might be worthwhile to investigate the disappearance of these fatty acids if fish oil is applied for shorter time than until approximately 60 kg LW. On the other hand we cannot exclude that some or all off-flavour was caused by other fat-soluble components, because the fish oil used was unrefined and non-deodorised.

In conclusion, the results of the study reported herein show that pork fat can be easily enriched with n-3 fatty acids by feeding fish oil to pigs without negative effects on their performance. However, addition of 3 to 6% unrefined fish oil until approximately 60 kg liveweight causes off-flavour of the product, although a commercial diet including 2% animal fat is provided from 60 kg LW and until slaughter.

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STRESZCZENIE

Wpływ uzupełnienia olejem rybnym diety dla świń od odsadzenia do 60 kg masy ciała na wyniki produkcyjne, skład kwasów tłuszczowych w tkankach i smak mięsa świń ubijanych przy 100 kg masy ciała

Dwadzieścia cztery wieprzki, od odsadzenia do ok. 60 kg masy ciała (m.c.), otrzymywały jedną z 4 dawek, których podstawą była mieszanka jęczmienna, pszenicy i śruty sojowej poekstrakcyjnej. Do diet dodawano: 6% tłuszczu zwierzęcego (1 – kontrolna), 3% tłuszczu zwierzęcego + 3% oleju rybnego (dieta 2), 6% oleju rybnego (dieta) lub 6% mieszaniny (2:1) oleju rybnego i oleju kokosowego (dieta 4) Wszystkie zwierzęta żywiono mieszanką finiszer z dodatkiem 2% łoju aż do uboju przy ok. 100 kg m.c. Próby tłuszczu podskórnego oraz mięśni z polędwicy pobierano przez biopsję przy m.c. 50-60 kg, i oznaczano w nich skład kwasów tłuszczowych. Ponadto skład kwasów tłuszczowych oraz liczbę jodową oznaczano w próbach pobranych z tuszy: tłuszczu brzusznego i podskórnego oraz polędwicy.

Nie stwierdzono różnic między grupami w wynikach produkcyjnych. Dodatek oleju rybnego spowodował znaczne zwiększenie C22:6 n-3 (DHA), C20:5 n-3 (EPA) i C22:5 n-3 (DPA), a dodatek oleju kokosowego – zwiększenie stężenia kwasów tłuszczowych C12:0 i C14:0 w próbach tłuszczu podskórnego i mięśni. Stężenie tych kwasów było mniejsze w próbach pobranych z tuszy niż przez biopsję, lecz wpływ dodatku olejów był nadal istotny przy uboju.

W podsumowaniu stwierdzono, że dodatek oleju rybnego do diet zwiększał poziom DHA, EPA i DPA w tkance mięśniowej i tłuszczowej oraz obniżał stosunek n-6/n-3. Jednakże podawanie tucznikom do ok. 60 kg m.c. 3-6% nierafinowanego oleju spowodowało zły zapach i smak mięsa, co było przyczyną jego nieprzydatności do spożycia przez ludzi.