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Effect of pan-frying in different culinary fats on the fatty acid profile of pork

Lindsey Haak [a], Isabelle Sioen [b,c], Katleen Raes [a,*], John Van Camp [b], Stefaan De Smet [a]

[a] *Department of Animal Production, Laboratory for Animal Nutrition and Animal Product Quality, FBW, Ghent University, Proefhoevestraat 10, 9090 Melle, Belgium*
[b] *Department of Food Safety and Food Quality, FBW, Ghent University, Coupure Links 653, 9000 Ghent, Belgium*
[c] *Department of Public Health, Ghent University, UZ-2 Blok A, De Pintelaan 185, 9000 Ghent, Belgium*

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Abstract

This study was set up to determine how pan-frying either without culinary fat or with different culinary fats (polyunsaturated fatty acids (PUFA)-enriched culinary fat, olive oil and margarine) affects the fatty acid (FA) composition of pork. The meat samples (*longissimus thoracis* (LT)) originated from pigs fed different dietary fat sources (animal fat, soybean oil or linseed oil) and thus had different FA compositions before frying. Pan-frying resulted in considerable increases in the meat total-FA content, although this was not always significant and highly variable, despite standardisation of the frying process. The FA composition of the pan-fried meat tended to become similar to that of the culinary fat used, and the extent of changes in the content of a particular FA was relative to the FA gradient from the culinary fat to the meat. However, this was also dependent on the culinary fat used, since frying in olive oil appeared to affect the FA composition of the meat more than did frying in the other culinary fats. Differences in FA composition of meat resulting from different animal feeding treatments remained unchanged after pan-frying without fat, they became smaller after frying in margarine and PUFA-enriched culinary fat, whereas frying in olive oil largely masked the initial FA profile differences. Long chain PUFA (LCPUFA) in the meat were not significantly lost by the frying process, but their proportion was influenced by the uptake of the culinary fat.

Keywords: Pan-frying; Culinary fat; Fatty acids; Pork

1. Introduction

The regular consumption of polyunsaturated fatty acids (PUFAs), and, more specifically, $n-3$ PUFA, is considered to be important because of their roles in the prevention of numerous diseases common to Western populations, including cardiovascular and inflammatory disorders, cancer and stroke (Din, Newby, & Flapan, 2004; Kris-Etherton, Harris, & Appel, 2003; Ruxton, Reed, Simpson, & Millington, 2004). For this reason, many efforts have been made to increase the $n-3$ PUFA concentration in pig tissues by dietary manipulation (see review, e.g. Raes, De Smet, & Demeyer, 2004; Wood et al., 2003). However, the goal is hampered by the higher susceptibility of the $n-3$ fatty acids (FA) toward oxidative deterioration in pork (Monahan, Buckley, Morrissey, Lynch, & Gray, 1992; Nurnberg, Kuchenmeister, Nurnberg, Ender, & Hackl, 1999) with a possible reduced sensory and nutritional quality of such foods and because of processing problems due to 'soft' fat. Studies on improving the fatty acid composition of pork usually do not take into account the influence of culinary processing, which often includes a heat treatment and a fat addition. Pan-frying is a common way of culinary preparation of pork in Western countries.

* Corresponding author. Tel.: +32 9 264 90 02; fax: +32 9 264 90 99.
E-mail address: Katleen.Raes@UGent.be (K. Raes).

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During pan-frying, exchange of FA between the food item and the culinary fat takes place (Nawar, 1984; Ramirez, Morcuende, Estevez, & Lopez, 2005; Sioen et al., 2006), and this exchange might differ according to the culinary fat used. In addition, PUFA are subject to oxidation during heating. The $n-3$ long chain PUFA ($n-3$ LCPUFA) (e.g., EPA (eicosapentaenoic acid, C20:5 $n-3$) and DHA (docosahexaenoic acid, C22:6 $n-3$)) are the most heat-labile and oxidation-sensitive FAs. Therefore, a determination of the extent of their decrease during pan-frying is important because this might reflect a reduction of the nutritional value of $n-3$ LCPUFA-enriched meat.

This study was aimed to investigate how pan frying, either without or with a culinary fat affected (1) the FA composition of pan-fried pork and (2) differences in FA profile of the pork as achieved by different feeding strategies.

2. Materials and methods

2.1. Samples

The meat used for this experiment originated from a pig trial in which the effect of the dietary fat source (soybean oil (SO): C18:2$n-6$-rich, linseed oil (LO): C18:3$n-3$-rich or animal fat (AF), rich in saturated FA) (added at 5 g/kg feed) on the FA composition of the meat was investigated. The trial lasted for 16 weeks and the mean start weight of the pigs was 30 (SD 8.5) kg. Pigs were slaughtered at a mean live weight of 121 (SD 14) kg. The carcasses had a mean meat yield of 61.7 (SD 4.4)%. pH-drop was normal (i.e. $pH_{40\ min} = 6.15$ (SD 0.25) and $pH_{24\ h} = 5.53$ (SD 0.10)). The LT muscle (*longissimus thoracis*; 6–14th rib) of 2 animals of each group was sampled 24 h *post mortem*, cut into 2.5 cm thick slices, vacuum-packed and stored at −18 °C until the moment of pan-frying or FA analysis.

The choice of culinary fats was conditioned by their claimed FA composition, i.e. PUFA enriched culinary fat, and olive oil and a margarine, being high in monounsaturated fatty acids (MUFA) and saturated fatty acids (SFA), respectively. The FA composition of the culinary fats is given in Table 1.

2.2. Frying procedure

The thawing of the meat took 1 h, during which the meat was turned every 5 min to prevent the thawing moisture from being located at one side of the meat and thus preventing a homogeneous heat transfer through the sample. Meat slices were cut into pieces of 5 × 5 cm before pan-frying. For all the frying experiments, preheated Tefal frying pans (∅ = 20 cm) were used. After each frying process, the pans were cleaned with a scraper and a kitchen paper to recover the fat as much as possible and were washed with detergent. During the frying process, the temperature was monitored continuously and only samples with a final core temperature of 70–72 °C were withdrawn for analysis.

The amount of culinary fat used for frying was exactly 10% of the weight of the raw meat. At the start of the frying process, the meat slice was fried for 1 min on each side and was subsequently turned every 30 s until the desired core temperature of 70–72 °C was reached. Both meat and fat were weighed after frying and stored at −18 °C prior to the FA analysis. For each treatment (combination of one of four culinary fat treatments and one of three animal feeding backgrounds), the pan-frying process was repeated until four samples with the desired final core temperature were obtained.

2.3. Analytical procedures

Before extraction of the total lipids for FA analysis, all samples were minced. Extraction of the total lipids was done using chloroform/methanol (2/1; v/v) according to the method of Folch, Lees, and Stanley (1957) and methylated as described by Raes, De Smet, and Demeyer (2001). Nonadecanoic acid (C19:0) was used as internal standard. The fatty acid methyl esters (FAME) were analysed by gas chromatography as described by Raes et al. (2001). Briefly, a GC HP 6890 (Agilent, Belgium) with a CP-Sil88 column for FAME (100 m × 0.25 mm × 0.20 μm) (Chrompack, The Netherlands) was used with an injector temperature of 250 °C, a detector temperature of 280 °C, H_2 as carrier gas and the following temperature programme: 150 °C for 2 min, followed by an increase of 1.5 °C/min to 200 °C, then 5 °C/min to 215 °C. Peaks were identified by

Table 1
Fatty acid composition of the different fresh and fried culinary fats (g/100 g of product) ($n = 2$)

	Analysed fresh			Analysed fried		
	PUFA enriched	Olive oil	Margarine	PUFA enriched	Olive oil	Margarine
SFA	8	8	25	5	7	17
MUFA	28	52	31	19	40	22
PUFA	38	19	12	24	3	9
$n-6$	34	14	10	21	2	7
$n-3$	4	4	3	2	0.2	2
Total	75	80	69	49	50	49

SFA = C12:0 + C14:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0; MUFA = C14:1 + C16:1c + C16:1t + C17:1 + C18:1t9 + C18:1t11 + C18:1c9 + C18:1c11; $n-6$ = C18:2 $n-6$ + C18:3 $n-6$ + C20:3 $n-6$ + C20:4 $n-6$ + C22:4 $n-6$; $n-3$ = C18:3 $n-3$ + C20:5 $n-3$ + C22:5 $n-3$ + C22:6 $n-3$; PUFA = $n-6$ + $n-3$ + C20:2 $n-6$.

comparing the retention times with those of the corresponding standards (Sigma, Belgium).

2.4. Recoveries

For each FA, the recovery was calculated as follows:

$$\%\text{recovery} = 100 \cdot (C_F \cdot g_F + C_{\text{fatres}} \cdot g_{\text{fatres}}) / (C_R \cdot g_R + C_{\text{fat}} \cdot g_{\text{fat}})$$

C_R and C_F are the concentrations of the FA (g/100 g) in the raw sample (R) and the fried sample (F), respectively and C_{fat} and C_{fatres} are the concentrations of the FA (g/100 g) in the culinary fat before (fat) and after pan-frying (fatres), respectively. These concentrations are multiplied by the mass of the raw or fried sample (g_R and g_F) and the mass of the culinary fat before or after pan-frying (g_{fat} and g_{fatres}).

2.5. Statistical analyses

Within feeding group and type of culinary fat, the effect of frying on the change in individual FA content was evaluated using a paired *t*-test ($P < 0.05$). The effects of type of culinary fat and feeding group on the FA composition of the meat samples after frying were compared separately by one-way analysis of variance (ANOVA), because the interaction between feeding group and culinary fat was highly significant. Comparison of means was done by the *post hoc* Duncan test. Statistical analyses were performed using SPSS 10.0 software package (SPSS Inc., USA).

3. Results and discussion

3.1. Fatty acid profile of fresh culinary fats

Table 1 shows the FA composition of the culinary fats. In all Tables, only the major FA are listed, representing more than 90% of total FA content of the samples.

Olive oil was rich in MUFA and margarine was rich in SFA. The $n-6$ PUFA content was markedly higher in the PUFA-enriched culinary fat than in the other culinary fats. In all culinary fats, the $n-3$ PUFA contents were equal.

3.2. Fatty acid profile of culinary fats after frying

The pan-frying process altered the FA content and composition of the culinary fats (Table 1). This might be important for the FA intake profile in case the residual fats are consumed together with the fried meat.

For all types of culinary fat, the FA content was reduced to a level of about 50 g/100 g of culinary fat. The fat absorption in the meat, together with oxidation of the FA during pan frying, and uptake of water from the meat during frying, could be responsible for these changes in FA content.

Table 2
Mean values (SD) (mg/100 g product unless stated otherwise) and recoveries (%) of the fatty acid content in pork fried without fat ($n = 2$ and 4 before and after frying, respectively)

Fatty acid	Pork AF				Pork SO				Pork LO			
	Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)
C12:0	1.6 (0.2)	3.1 (0.9)	0.024	151 (35.2)	0.4 (0.2)	0.9 (0.4)	0.079	201 (37.6)	1.9 (0.9)	1.8 (0.9)	0.488	83.1 (20.4)
C14:0	24.8 (1.9)	43.6 (8.9)	0.022	133.4 (23.4)	5.2 (2.4)	7.5 (4.3)	0.215	133 (19.5)	18.4 (7.1)	25.4 (14.6)	0.118	117 (37.3)
C16:0	453 (39.7)	725 (122.3)	0.022	118 (12.1)	148 (48.5)	215 (97.0)	0.199	135 (16.8)	410 (135)	549 (280)	0.121	112 (34.3)
C18:0	208 (10.1)	292 (58.4)	0.092	99.0 (4.4)	79.4 (30.5)	123 (63.6)	0.168	140 (20.1)	202 (55.3)	277 (116)	0.092	115 (33.6)
C18:1c9	636 (79.5)	1129 (285)	0.023	134 (25.1)	171 (67.3)	254 (136.4)	0.203	136 (20.5)	596 (222)	812 (463)	0.127	114 (36.6)
C18:2$n-6$	158 (14.2)	253 (39.8)	0.039	124 (24.4)	130 (23.7)	176 (42.4)	0.193	129 (22.1)	160 (3.4)	223 (55.6)	0.119	109 (29.6)
C18:3$n-3$	6.3 (1.2)	10.2 (2.3)	0.104	139 (54.1)	4.3 (0.9)	5.3 (1.8)	0.461	120 (28.6)	51.1 (7.1)	75.9 (27.6)	0.104	119 (38.2)
C20:4$n-6$	26.1 (2.0)	45.9 (11.3)	0.031	127 (27.3)	33.0 (7.4)	45.8 (9.0)	0.073	128 (6.5)	23.0 (2.1)	34.7 (7.7)	0.091	117 (33.6)
C20:5$n-3$	2.2 (1.9)	3.0 (2.2)	0.632	68.3 (24.8)	1.6 (0.4)	1.7 (0.3)	0.695	101 (39.7)	15.8(1.2)	18.9 (4.1)	0.214	93.2 (20.6)
C22:5$n-3$	4.2 (0.4)	6.7 (1.6)	0.027	117 (24.1)	6.1 (1.6)	6.9 (1.6)	0.338	99.1 (11.2)	13.5 (2.0)	17.4 (3.5)	0.252	98.9 (28.7)
C22:6$n-3$	1.3 (0.4)	2.6 (1.1)	0.101	119 (26.8)	2.2 (0.8)	2.4 (1.0)	0.566	98.3 (9.0)	2.4 (0.6)	3.3 (0.5)	0.148	102.4 (25.6)
$n-6/n-3$	11.2	12.00			8.89	9.58			2.20	2.03		
Total(g/100 g)	1.79 (0.15)	2.92 (0.57)	0.026		0.67 (0.17)	0.97 (0.40)	0.174		1.70 (0.48)	2.28 (1.07)	0.118	

Table 3
Mean values (SD) (mg/100 g product unless stated otherwise) and recoveries (%) of the fatty acid content in pork fried in PUFA-enriched culinary fat ($n = 2$ and 4 before and after frying, respectively)

Fatty acid	PUFA- enriched(g/100 g)	Pork AF				Pork SO				Pork LO			
		Before frying	After frying	*P*	Recovery	Before frying	After frying	*P*	Recovery	Before frying	After frying	*P*	Recovery
C12:0	0.04 (0.0002)	1.6 (0.2)	2.8 (0.6)	0.030	57.2 (30.5)	0.4 (0.2)	1.0 (0.3)	0.013	70.4 (27.0)	1.9 (0.9)	2.0 (0.3)	0.736	87.9 (5.6)
C14:0	0.06 (0.001)	24.8 (1.9)	37.9 (8.7)	0.075	102 (26.1)	5.2 (2.4)	8.4 (2.7)	0.052	91.2 (7.0)	18.4 (7.1)	26.6 (6.9)	0.073	110 (12.9)
C16:0	4.15 (0.08)	453 (39.7)	696 (141.9)	0.056	90.0 (22.7)	148 (48.5)	247 (43.4)	0.019	74.2 (18.0)	411 (135)	640 (89.4)	0.047	106 (5.6)
C18:0	3.06 (0.04)	208 (10.1)	307 (58.7)	0.060	67.5 (19.8)	79.4 (30.5)	138 (29.8)	0.017	66.1 (17.4)	202 (55.3)	318 (17.4)	0.057	96.8 (2.5)
C18:1c9	24.6 (0.62)	636 (79.5)	1164 (249)	0.029	81.8 (38.6)	171 (67.3)	428 (81.0)	0.003	60.2 (26.2)	596 (222)	1072 (115)	0.018	97.8 (8.8)
C18:2$n-6$	33.2 (0.59)	158 (14.2)	473 (87.1)	0.006	26.8 (27.2)	130 (23.7)	380 (42.3)	0.002	52.6 (26.4)	160 (3.4)	593 (152)	0.037	90.5 (10.2)
C18:3$n-3$	3.85 (0.04)	6.3 (1.2)	35.6 (8.0)	0.004	22.3 (26.4)	4.3 (0.9)	28.0 (4.3)	0.002	46.9 (24.4)	51.1 (7.1)	126 (12.3)	0.019	90.1 (10.4)
C20:4$n-6$	ND	26.1 (2.0)	49.2 (3.3)	0.001	151 (17.6)	33.0 (7.4)	49.1 (11.4)	0.008	128 (6.7)	23.0 (2.1)	38.9 (14.9)	0.188	152 (34.3)
C20:5$n-3$	ND	2.2 (1.9)	1.8 (0.5)	0.682	114 (75.0)	1.6 (0.4)	2.5 (0.6)	0.007	204 (31.7)	15.8 (1.2)	25.3 (6.4)	0.138	140 (27.3)
C22:5$n-3$	ND	4.2 (0.4)	6.3 (1.3)	0.049	60.5 (13.7)	6.1 (1.6)	8.0 (2.1)	0.151	64.8 (10.9)	13.5 (2.0)	22.8 (5.8)	0.052	135 (57.0)
C22:6$n-3$	ND	1.3 (0.4)	2.2 (0.5)	0.008	180 (87.5)	2.2 (0.8)	3.1 (1.4)	0.055	207 (189)	2.4 (0.6)	4.3 (1.7)	0.104	191 (98.1)
$n-6/n-3$	8.62	11.2	9.63			8.89	9.56			2.20	3.42		
Total (g/100 g)	75.0 (1.37)	1.79 (0.15)	3.20 (0.61)	0.027		0.67 (0.17)	1.51 (0.12)	0.001		1.70 (0.48)	3.32 (0.10)	0.026	

(ND: not detected).

Table 4
Mean values (SD) (mg/100 g product unless stated otherwise) and recoveries (%) of the fatty acid content in pork fried in olive oil ($n = 2$ and 4 before and after frying, respectively)

Fatty acid	Olive oil (g/100 g)	Pork AF				Pork SO				Pork LO			
		Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)
C12:0	ND	1.6 (0.2)	1.5(1.1)	0.879	921(492)	0.4(0.2)	3.1(3.0)	0.185	878(502)	1.9(0.9)	4.1 (1.2)	0.053	109(36.5)
C14:0	0.04 (0.01)	24.8 (1.9)	21.2 (18.5)	0.714	476 (513)	5.2(2.4)	49.3 (51.3)	0.192	1911 (2125)	18.4 (7.1)	42.3 (18.6)	0.035	195 (51.9)
C16:0	4.57 (0.11)	453 (39.7)	553 (361.0)	0.605	125 (72.9)	148(48.5)	941 (817)	0.154	258(135)	411 (135)	924 (367)	0.031	140 (36.1)
C18:0	2.18 (0.04)	208 (10.1)	283 (160)	0.408	112 (62.0)	79.4 (30.5)	425 (357)	0.162	213(120)	202 (55.3)	437 (165)	0.037	126 (33.5)
C18:1c9	44.8 (0.52)	636(79.5)	1180 (665)	0.179	68.6 (36.2)	171 (67.3)	1707 (1371)	0.117	116 (27.4)	596 (222)	1787 (700)	0.020	86.3 (51.7)
C18:2$n-6$	12.8 (0.25)	158 (14.2)	266(53.1)	0.036	50.4 (31.5)	130 (23.7)	336 (126)	0.034	55.6 (22.7)	160(3.4)	332 (55.6)	0.010	31.9 (14.0)
C18:3$n-3$	4.13 (0.09)	6.3 (1.2)	50.6 (54.1)	0.206	38.2 (39.3)	4.3(0.9)	13.2 (7.2)	0.077	28.7 (24.0)	51.1 (7.1)	101 (34.5)	0.048	22.7 (7.62)
C20:4$n-6$	0.16 (0.003)	26.1(2.0)	40.2(4.6)	0.022	94.5 (13.7)	33.0 (7.4)	64.4(5.4)	0.010	114(12.6)	23.0(2.1)	42.6(6.8)	0.019	89.7(16.7)
C20:5$n-3$	ND	2.2(1.9)	12.3 (12.0)	0.154	197 (137)	1.6(0.4)	3.2(0.4)	0.016	34.9 (15.0)	15.8(1.2)	17.7 (10.9)	0.752	50.1 (39.9)
C22:5$n-3$	ND	4.2(0.4)	13.9 (8.8)	0.108	83.1 (53.8)	6.1(1.6)	10.6(1.2)	0.014	52.3 (7.86)	13.5(2.0)	21.4(2.3)	0.016	73.4 (10.3)
C22:6$n-3$	ND	1.3(0.4)	3.1 (1.2)	0.025	260 (146)	2.2(0.8)	4.8(0.5)	0.010	189(68.8)	2.4(0.6)	4.0(0.7)	0.084	133 (51.2)
$n-6/n-3$	3.14	11.2	4.37			8.89	14.3			2.20	2.62		
Total(g/100g)	79.6 (12.1)	1.79(0.15)	2.71 (1.46)	0.277		0.67 (0.17)	4.00 (3.08)	0.126		1.70 (0.48)	4.17 (1.48)	0.091	

(ND: not detected).

Table 5
Mean values (SD) (mg/100 g product unless stated otherwise) and recoveries (%) of the fatty acid content in pork fried in margarine ($n = 2$ and 4 before and after frying, respectively)

Fatty acid	Margarine (g/100 g)	Pork AF				Pork SO				Pork LO			
		Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)	Before frying	After frying	*P*	Recovery (%)
C12:0	6.73 (0.21)	1.6 (0.2)	99.3 (20.9)	0.003	38.3 (33.0)	0.4 (0.2)	65.0 (41.5)	0.053	13.8 (14.2)	1.9 (0.9)	42.3 (15.8)	0.014	65.6 (10.1)
C14:0	2.73 (0.10)	24.8 (1.9)	87.9 (14.3)	0.004	50.3 (32.6)	5.2 (2.4)	35.0 (19.0)	0.045	17.6 (18.9)	18.4 (7.1)	42.4 (20.2)	0.030	75.2 (8.06)
C16:0	11.0 (0.41)	453 (39.7)	995 (137)	0.005	77.7 (18.8)	148 (48.5)	358 (144)	0.044	52.7 (2.79)	411 (135)	627 (368)	0.126	84.5 (14.9)
C18:0	3.93 (0.14)	208 (10.1)	407 (49.4)	0.006	84.3 (19.4)	79.4 (30.5)	171 (98.4)	0.112	55.7 (10.6)	202 (55.3)	286 (141)	0.112	84.0 (13.7)
C18:1c9	27.0 (0.98)	636.0(79.5)	1697 (292)	0.005	82.2 (26.2)	170.8 (67.3)	574 (249)	0.033	98.5 (45.0)	596 (222)	1043 (670)	0.113	80.9 (14.8)
C18:2$n-6$	9.31 (0.40)	158 (14.2)	434 (53.4)	0.003	129 (127)	130 (23.7)	279 (93.2)	0.069	38.9 (8.13)	160 (3.4)	294 (62.9)	0.028	75.4 (11.2)
C18:3$n-3$	2.55 (0.10)	6.3 (1.2)	48.6 (10.8)	0.004	76.4 (52.4)	4.3 (0.9)	31.6 (15.9)	0.044	19.6 (10.5)	51.1 (7.1)	91.7 (37.2)	0.068	73.5 (14.8)
C20:4$n-6$	0.12 (0.004)	26.1 (2.0)	57.1 (4.7)	0.001	130 (6.9)	33.0 (7.4)	50.0 (8.5)	0.041	89.4 (23.5)	23.0 (2.1)	37.4 (6.9)	0.047	111 (26.0)
C20:5$n-3$	ND	2.2 (1.9)	2.9 (0.2)	0.488	263 (186)	1.6 (0.4)	2.7 (0.8)	0.057	129.2 (38.4)	15.8 (1.2)	21.6 (3.5)	0.038	224 (27.3)
C22:5$n-3$	ND	4.2 (0.4)	9.2 (3.4)	0.051	93.0 (30.9)	6.1 (1.6)	8.1 (1.3)	0.037	64.3 (10.7)	13.5 (2.0)	19.9 (2.7)	0.078	90.6 (22.9)
C22:6$n-3$	ND	1.3 (0.4)	4.8 (4.3)	0.220	336 (385)	2.2 (0.8)	3.0 (1.1)	0.168	113 (40.2)	2.4 (0.6)	3.8 (0.1)	0.029	117 (26.1)
$n-6/n-3$	3.70	11.2	7.21			8.89	7.17			2.20	2.46		
Total(g/100 g)	69.0 (2.65)	1.79 (0.15)	4.36 (0.62)	0.005		0.67 (0.17)	1.79 (0.71)	0.044		1.70 (0.48)	2.81 (1.19)	0.048	

(ND: not detected).

The FA composition of olive oil profoundly changed after pan-frying compared to the other culinary fats; i.e. only 25% of the initial PUFA proportion and, moreover, hardly anything of the initial $n-3$ PUFA proportion remained. Together with this decline in PUFA, the SFA and MUFA proportions increased. For the other culinary fats, the FA composition did not change as profoundly in the frying process.

3.3. Fatty acid composition of the raw meat as affected by animal feeding

The FA content of the raw LT of the three feeding groups is shown in Tables 2–5. Quantitatively, the most important FA in raw LT were oleic acid (C18:1c9), palmitic acid (C16:0), stearic acid (C18:0) and linoleic acid (C18:2 $n-6$). In the meat of the two animals of the SO group, a considerably lower total FA content was found than in the meat of the other groups. This should not be interpreted as an effect of the feeding oil, but is due to random animal variability. For this study, two animals were randomly selected from a larger group of animals, wherein the average meat FA content was similar across feeding groups (1.21, 1.24 and 1.31 g/100 g for the AF, LO and SO groups, respectively). The SFA proportion was similar for the three dietary groups (36–38% of FAME), the proportion of MUFA was significantly lower for the SO group (25% compared to 35–36% in other groups) and the proportion of PUFA was significantly higher in meat of the SO-fed animals (27% compared to 12–15% in the other groups) (Figs. 1–3). The lower total FA content, together with a higher LA supplementation via the feed for the SO group, explains the higher AA (arachidonic acid, C20:4 $n-6$) proportion in the meat.

The $n-6/n-3$ PUFA ratio in the meat were 9, 2 and 11 for the SO, LO and AF groups, respectively and thus, only the LO group was below the recommended value of 5 (Voedingsaanbevelingen voor België, 2003).

3.4. Fatty acid composition of fried meat

3.4.1. Pan-frying without fat

The FA profile of the pork samples after pan frying without fat is shown in Table 2. Pan-frying without fat resulted in an increase in the absolute amount of each of the reported FAs as a consequence of water loss during the frying process. PUFA, and in particular LCPUFA, were still detectable after the frying process. This reflects an incomplete oxidation of the LCPUFA during frying; if at all, there is a measurable loss of FA due to oxidation. It also implies that there is no selective leaching of these LCPUFAs out of the meat. This is in accordance with the finding that modifications in FA composition of fried samples are due to the exchange between the neutral lipids and free fatty acids of the frying oils and the meat. The phospholipids fraction of the meat, in which LCPUFAs are mainly present, remained unchanged after frying, due

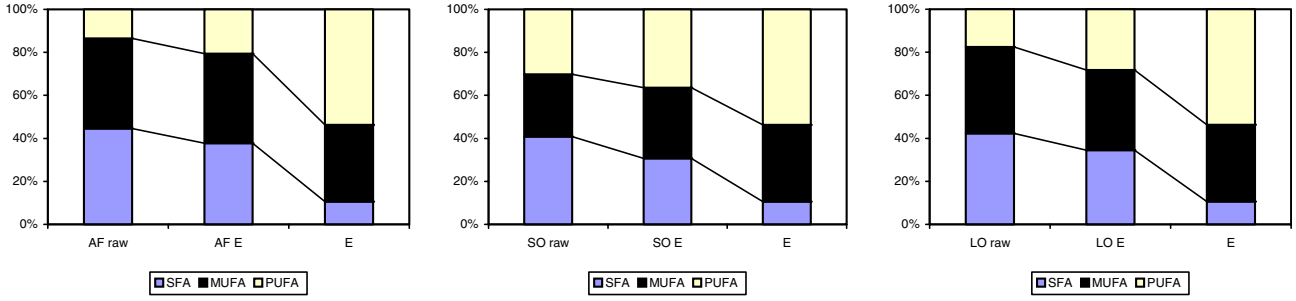

Fig. 1. SFA, MUFA and PUFA proportions of pork fried in PUFA-enriched culinary fat (E) (left to right: FA in raw meat, FA in fried meat, FA in culinary fat).

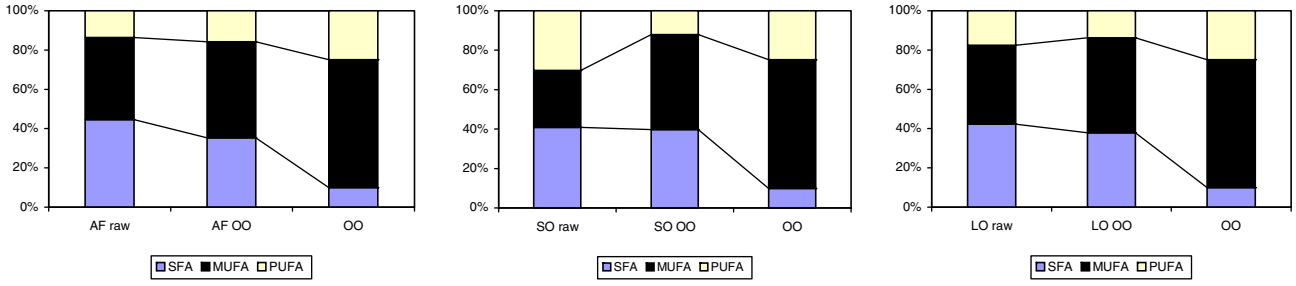

Fig. 2. SFA, MUFA and PUFA proportions of pork fried in olive oil (OO) (left to right: FA in raw meat, FA in fried meat, FA in culinary fat).

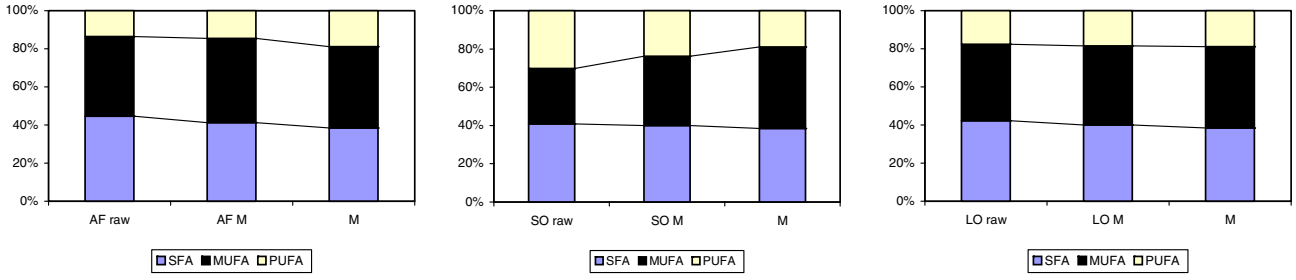

Fig. 3. SFA, MUFA and PUFA proportions of pork fried in margarine (M) (left to right: FA in raw meat, FA in fried meat, FA in culinary fat).

to the fact that this lipid fraction makes up the cell membrane structure in which FAs are not easily exchanged (Ramirez et al., 2005).

3.4.2. *Pan-frying in different culinary fats*

The FA content of the pork samples before and after pan-frying in the different culinary fats is shown in Tables 3–5. Frying in the three culinary fats resulted in an increased total FA content of the meat (g/100 g LT), irrespective of the feeding group. This increase was not significant for the meat fried in olive oil, due to high variations in FA uptake of the meat (Table 4). The increase of the FA content in the meat fried in the PUFA-enriched culinary fat or the margarine was significant and may be explained by two mechanisms, namely the loss of water during frying and the absorption of culinary fat. The increase in the absolute amounts of EPA, DPA and DHA after frying can only be explained by water loss during frying, because none of the culinary fats contains any of these FA.

The absorption of culinary fat, and especially FA of the culinary fat, into the meat was different for the three culinary fats used. As can be seen in Fig. 1, frying in PUFA-enriched culinary fat caused a decline in the proportion of SFA, while the proportion of MUFA remained unchanged and the proportion of PUFA markedly increased. Particularly, the proportions of linoleic (C18:2 $n-6$) and linolenic acid (C18:3 $n-3$) were increased. Compared to the other frying processes, frying in the PUFA-enriched culinary fat resulted in the highest proportion of PUFA and the highest P/S ratio in the meat.

Pan-frying in olive oil resulted in a decline in the proportion of SFA and an increased proportion of MUFA in the fried meat, while the effect on PUFA was variable (Fig. 2). The proportion of oleic acid (C18:1c9) in meat was highest

after pan frying in olive oil (Table 4). Pan-frying in margarine hardly changed the FA profile of the meat. It caused a slight decline in the proportions of SFA and PUFA, while the proportion of MUFA increased slightly (Fig. 3). A switch in the profile of the SFA was observed after pan-frying in margarine, i.e. the proportion of lauric (C12:0) and myristic acid (C14:0) were increased whereas the proportion of palmitic (C16:0) and stearic acid (C18:0) were decreased (Table 5).

The results indicate that the FA composition of the fried meat tended to be similar to that of the culinary fat that was used. This reflects the development of a FA gradient equilibrium between the culinary fat and the samples being fried. These results agree with findings previously reported by Sioen et al. (2006) for pan-fried fish (salmon and cod), by Candela, Astiasaran, and Bello (1998) for deep-fried sardines and by Ramirez et al. (2005) for deep-fried pork.

After frying and irrespective of the type of culinary fat used, differences in the FA profile of the meat obtained by animal feeding strategies could still be observed.

3.5. Recoveries of fatty acids

The weight losses of the meat samples due to frying in the different culinary fats were not dependent on the type of culinary fat and, moreover, were equal to the weight loss after frying without fat (±22% of the raw meat weight). This weight loss may consist mainly of water losses. However, the mass recoveries of the fats after frying differed very much between the different culinary fats (96%, 121% and 91% for PUFA-enriched culinary fat, olive oil and margarine, respectively). A mass recovery for olive oil exceeding 100% means that olive oil retained more water lost by the meat during frying than did the other culinary fats.

Tables 2–5 show the recoveries of the individual FAs after the frying process. This recovery was subject to a large variation. The recoveries below 100% can be explained by fat losses and analytical errors. The fat losses can be caused by oil-spraying during the frying process, by incomplete recovery of the fat residue in the pan after the frying process or by oxidation processes. Accurate recoveries are more difficult to obtain when analysing relatively low FA concentrations. Another factor causing variability in the recoveries is the inherent small differences in FA content between those meat slices that were used for FA analysis of the raw meat and those used for frying and analysing the FA profile after frying. Although originating from the same animal and the same muscle, small anatomical differences cannot be excluded. Recoveries of FA after frying without fat are usually closer to 100% and the variability in these recoveries is smaller than that in the recoveries obtained after frying in the culinary fats, which illustrates the additional errors caused by fat losses when using a culinary fat. It is clear that errors are accumulating in the recoveries as they are calculated here, and that it is difficult to deduce any meaningful interpretation.

4. Conclusion

The FA composition of the pan-fried meat tended to become similar to that of the culinary fat. The extent of the increase or decrease of a particular FA during frying was relative to the FA gradient from the culinary fat to the meat. Pan-frying without fat is preferable when aiming at a lower fat uptake in the human diet and preserving the differences in initial FA profile of the meat obtained from different feeding strategies. Frying in the PUFA-enriched culinary fat increased the PUFA proportion in the meat but had a negative effect on the $n-6/n-3$ ratio for the SO and LO meat. Frying in margarine gave rise to a significantly higher proportion of the atherogenic lauric (C12:0) and myristic acids (C14:0), although resulting in a better $n-6/n-3$ ratio compared to frying in PUFA-enriched culinary fat. After frying, and irrespective of the type of culinary fat used, differences in FA profile of the meat obtained by animal feeding strategies could still be observed. LCPUFAs were not significantly lost by the frying process, but their proportions were influenced by the uptake of the culinary fat.

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