n-3 Enrichment of Chicken Meat. 1. Use of Very Long-Chain Fatty Acids in Chicken Diets and Their Influence on Meat Quality: Fish Oil

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ABSTRACT We assessed the effect of a diet supplemented with fish oil (FO) on the performance, fatty acid (FA) composition, quality, and sensory traits of broiler meat. Diets enriched with 0, 2, or 4% FO plus tallow (T) up to 8% added fat (T1, T2, and T3, respectively) were given to the birds throughout a 38-d growth period. T3 was replaced by a mixture of FO, linseed oil (LO), and T (1, 3, and 4% respectively) for 1 wk (T4) or 2 wk (T5) before slaughter. Meat quality, taste, and FA profile were determined. Higher final weights were recorded for birds fed T3, although feed efficiency was not affected. Other performance or objective meat quality parameters did not show significant differences among treatments. High FO concentrations decreased the saturated and monoenoic FA contents in the thigh samples. The amount of polyunsaturated fatty acids (PUFA) increased when added to the diet (FO diets), mainly as long-chain n-3 FA [eicosapentaenoic fatty acid (EPA), docosapentaenoic fatty acid (DPA), and docosahexaenoic fatty acid (DHA)]. On the other hand, levels of total n-6 FA resulted in slight changes, mostly in linoleic acid (LA). By replacing the FO diet with the experimental mixture (T4, T5), the n-3 and n-6 FA contents increased, mainly in the form of linolenic acid and LA, respectively, only 1 wk later. After 1 wk of T4, the DHA levels in chicken decreased. Sensory panelists could not identify the meats from T4 and T5 as being different from the control diet (T1).

(*Key words*: chicken meat, fish oil, n-3, n-6, fatty acid)

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INTRODUCTION

The lipid composition of broiler meat can be modified by adding linoleic (LA) and linolenic (LNA) acids, vegetable oils (López-Ferrer et al., 1999a), fish meal (Hulan et al., 1984), and fish oils (Scaife et al., 1994; López-Ferrer et al., 1999b).

When meat is enriched with polyunsaturated fatty acid (PUFA, particularly with n-3 long-chain fatty acids ($C \geq 20$), all vegetable fat sources seem to be less effective than marine fats. This effect results from the content of n-3 fatty acids (FA), because marine oils are composed of eicosapentaenoic acid ($C_{20:5\ n-3}$, EPA) and docosahexaenoic acid ($C_{22:6\ n-3}$, DHA), in a variable but generally high proportion, whereas vegetable oils contain LNA, whose conversion to longer-chain derivatives and deposition in peripheral tissues is not sufficient to give nutritionally valuable modified products (Caston and Leeson, 1990; Cherian and Sim, 1991).

Our previous findings show that chickens modify their lipid profile shortly after 1 wk of replacement of the dietary fat source. However, the correlation between the nature and magnitude of the change in deposition of each FA in chicken meat and its amount in the diet is unclear. A linear response to increasing amounts of EPA and DHA in the diet would ensure high levels of such FA in meat. However, the use of fish oils at concentrations greater than 1 to 2% in poultry diets entails several organoleptic problems in the final product that compromise meat (Edwards and May, 1965; Fry et al., 1965; Miller and Robisch, 1969; Hargis and Van Elswyk, 1993).

With a view toward increasing the nutritional quality of poultry meat while preventing deterioration of sensory quality, the present study assessed several feeding regimens based on fish (FO) or linseed oil (LO) plus FO in the rations of broiler chickens.

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Abbreviation Key: AA = arachidonic acid; DHA = docosahexaenoic fatty acid; DPA = docosapentaenoic fatty acid; EPA = eicosapentaenoic fatty acid; FA = fatty acid; FO = fish oil; LA = linoleic acid; LC = long chain; LNA = linolenic acid; LO = linseed oil; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; T = tallow; T1, etc. = Treatment 1, etc.

MATERIALS AND METHODS

Animals and Diets

Two hundred fifty unsexed, 1-d-old chicks of a Cobb cross, randomly arranged in 25 replicates (10 birds per replicate), were assigned to one of five dietary treatments (five replicates per treatment). The birds were studied in a controlled environment farm at the Unterer Lindenhof research station, which belongs to the University of Hohenheim. The birds were given access to water and diets ad libitum that were formulated by adding 8% of fat to a basal diet (Table 1), which met the requirements recommended by the National Research Council (1994).

Two plans were designed to evaluate the effect of FO. Plan 1 included three experimental treatments, which consisted of variable amounts of the following n-3 long-chain (LC) PUFA: EPA, DPA (docosapentaenoic fatty acid), and DHA (Σ n-3 LC-PUFA), in order to determine the relationship between content in the diet and in the chicken meat. The FO used were at 0% (Diet 1, T1, control diet, Σ n-3 LC-PUFA: 0.06% of the total fatty acids), 2% (Diet 2, T2, Σ n-3 LC-PUFA: 4.83% of the total fatty acids), and 4% (Diet 3, T3, Σ n-3 LC-PUFA: 9.48% of the total fatty acids) plus tallow (T) up to 8% added fat.[2]

The T3, T4, and T5 were designed to define a feeding system that permitted a withdrawal of FO from the diet (Plan 2). Our aim was to improve the sensory quality of the meat while trying to preserve the nutritional benefits provided by FO. In this design, the diet given in T3 (Diet 3), which was enriched with 4% FO oil plus 4% T and was administered throughout the experimental period, was replaced by a diet enriched with 3% LO plus 1% FO plus 4% T (Diet 4, Σ n-3 LC-PUFA: 2.62%, LNA: 23.83%) for 1 wk (T4) or 2 wk (T5) before slaughter. The lipid profiles of the experimental diets are shown in Table 2.

All 5-wk-old birds were weighed, wing-banded, sex-identified, slaughtered, and eviscerated in the poultry slaughterhouse at the Unterer Lindenhof research station of the University of Hohenheim. The birds were bled, scalded, plucked, and eviscerated (removal of lungs and gastrointestinal tract), and air-chilled carcasses were weighed after removal of the head, neck, feet, and abdominal fat (considered the fat extending within the ischium, surrounding the cloaca, and adjacent to the abdominal muscle) to obtain ready-to-cook carcasses. Carcasses were stored in a cool chamber at 0 to 2 C until the next day, when weight was again recorded, and they were hand-cut into their various parts. In order to reduce variability in the cutting procedure, all dissections were carried out by only one operator. Each carcass was then portioned into commercial cuts as back, two leg-thighs, two wings, and breast (Hudspeth et al., 1973; Orr et al., 1984). Breast was obtained after removing wings by cutting through the shoulder joint at the proximal end of the humerus and by cutting through the ribs, thereby separating the breast from the back (excluding skin). The resulting cuts (breast meat, wings, and thighs with drumsticks) were then weighed to the nearest gram. After being quartered, thighs from T1, T4, and T5 were separated and frozen at –20 C until the appropriate sensory evaluation tests.

The tissue samples for FA analysis (five thighs, excluding skin, per treatment) were freeze-dried (FTS Systems model Alpha 1/6[3]). The total diet lipids and tissues were extracted following Folch et al. (1957) and were methylated with 20% boron trifluoride methanol complex in methanolic solution (Morrison and Smith, 1964). The

TABLE 1. Percentage composition of experimental control diet

Ingredients[1]	%
Extruded soybean (48% CP)	35.800
Wheat	31.467
Oats	11.600
Wheat starch	8.667
Added fat[2]	8.000
Dicalcium phosphate	1.867
Calcium propionate	0.800
Limestone	0.667
DL-Methionine	0.253
Salt	0.247
Vitamin premix[3]	0.200
Sodium bicarbonate	0.163
Choline chlorate	0.100
Trace elements premix[4]	0.080
Monensin-sodium	0.050
Antioxidant buthylhydroxytoluol	0.020
Vitamin E	0.013
Vitamin C	0.007
Calculated nutrient content	
ME, kcal/kg	3,200
Calcium	1.03
Available P	0.47
Methionine + Cysteine	0.93
Lysine	1.26
Chemical analyses of diet	
Dry matter	89.1
CP	23.4
Ash	5.3
Crude fat	9.2
Crude fiber	3.8
Nitrogen-free extracts	47.4
Sugar	6.8
Starch	30.6

[1]Vitamin and mineral content of diets was as follows per kilogram of diet: vitamin A, 13,500 IU; vitamin D3, 3,375 IU; vitamin E,34 mg; riboflavin, 6 mg; pantothenic acid, 16 mg; nicotinic acid, 56 mg; choline, 2,000 mg; folic acid, 1.13 mg; vitamin B_{12}, 34 μg; Mn, 72 mg; Zn, 48 mg.

[2]Eight percent tallow as added fat (control diet, T1).

[3]Composition of vitamin premix was as follows per kilogram of premix: vitamin A, 6,000,000 IU; vitamin D_3, 1,500,000 IU; vitamin E, 15,000 mg; riboflavin, 3,000 mg; pantothenic acid, 7,000 mg; nicotinic acid, 25,000 mg; folic acid, 500 mg; vitamin B_{12}, 15,000 μg (Vit-Vorm 6/1.5) supplied by Animedica, Horb, Germany.

[4]Composition of trace element premix was as follows per kilogram of premix: Mn, 120,000 mg; Zn, 80,000 mg; Fe, 90,000 mg; Cu, 15,000 mg; I, 1,600 mg; Se, 500 mg; Co, 600 mg (SpürElevor SG1, supplied by Animedica, Horb, Germany).

[2]Fish oil provided by Nagel Co., D-20095 Hamburg, Germany. EPA/DHA: 5/10. Linseed oil was provided by Graf Co., D-90489 Nürnberg, Germany. Tallow was provided in form of Bergafat HTL-106 by Berg and Schmidt, D-20099 Hamburg, Germany.

[3]Co. Christ, D-37520 Osterode, Germany.

TABLE 2. Fatty acid composition of experimental diets[1,2]

Fatty acid[3]	Diet[4] T1	Diet 2 T2	Diet 3 T3/4/5	Diet 4 T4/5
	(% of total methyl esters of fatty acids)			
$C_{10:0}$	0.01	0.00	0.02	0.00
$C_{12:0}$	0.14	0.16	0.15	0.15
$C_{13:0}$	0.00	0.00	0.02	0.00
$C_{14:0}$	0.95	1.44	2.44	1.19
$C_{15:0}$	0.04	0.15	0.17	0.08
$C_{16:0}$	47.02	38.70	30.26	21.97
$C_{16:1\ n-7}$[5]	0.02	0.02	0.00	0.00
$C_{16:1\ n-7}$	0.04	0.91	1.90	0.62
$C_{17:0}$	0.14	0.17	0.21	0.11
$C_{17:1\ n-7}$	0.00	0.03	0.04	0.07
$C_{18:0}$	36.69	26.78	17.15	12.93
$C_{18:1\ n-9}$[5]	0.04	0.03	0.00	0.00
$C_{18:1\ n-9}$	4.76	7.93	12.26	14.74
$C_{18:1\ n-7}$	0.04	0.81	0.00	0.29
$C_{18:2\ n-6}$[5]	0.23	0.49	0.22	0.14
$C_{18:2\ n-6}$	7.76	9.09	9.81	16.32
$C_{18:3\ n-6}$	0.06	0.03	0.08	0.20
$C_{18:3\ n-3}$	0.99	1.03	1.37	23.83
$C_{18:4\ n-3}$	0.00	0.45	0.93	0.16
$C_{20:0}$	0.13	0.25	0.26	0.20
$C_{20:1\ n-9}$	0.1	1.86	3.56	1.20
$C_{21:0}$	0.00	0.07	0.07	0.06
$C_{20:2\ n-6}$	0.00	0.00	0.02	0.00
$C_{20:3\ n-6}$	0.00	0.00	0.04	0.00
$C_{20:4\ n-6}$	0.00	0.18	0.35	0.10
$C_{20:3\ n-3}$	0.00	0.04	0.09	0.06
$C_{20:5\ n-3}$	0.00	1.66	3.35	0.94
$C_{22:0}$	0.06	0.07	0.03	0.14
$C_{22:1\ n-9}$	0.02	3.15	6.07	1.93
$C_{22:2\ n-6}$	0.00	0.02	0.02	0.00
$C_{23:0}$	0.01	0.10	0.20	0.09
$C_{24:0}$	0.00	0.02	0.05	0.00
$C_{22:5\ n-3}$	0.04	0.37	0.64	0.24
$C_{22:6\ n-3}$	0.02	2.80	5.49	1.44
$C_{24:1\ n-9}$	0.09	0.11	0.28	0.18
Saturated	85.19	67.90	51.03	36.93
MUFA	5.06	14.81	24.13	19.03
Trans fatty acid	0.29	0.54	0.22	0.14
PUFA	8.87	15.65	22.21	43.30
Total n-6	7.82	9.31	10.33	16.62
Total n-3	1.05	6.34	11.87	26.68
n-6/n-3	7.48	1.47	0.87	0.62

[1]The values presented are means of duplicate determinations.

[2]Fish oil was provided by Fa. BASF, Ludwigshafen, Germany. Cold-pressed linseed oil was provided by Fa. Graf, Nürnberg, Germany; tallow was provided as Bergafat HTL-106 by Berg and Schmidt, Hamburg, Germany.

[3]MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid.

[4]Diet 1 = 8% tallow (T); Diet 2 = 2% Fish oil (FO) + 6% T; Diet 3 = 4% FO + 4% T; Diet 4 = 1% FO + 3% LO + 4% T.

[5]*Trans* fatty acid.

lipid composition was determined at the Animal Nutrition and Feeding Unit of the Universitat Autònoma de Barcelona by gas chromatography in a Shimadzu GC-14A chromatograph[4] equipped with a BPX70 fused silica capillary column (SGE capillary column, length 30 m, i.d. 0.53 mm, 0.5 mm; 70% cyanopropyl polysilphenylene-siloxane stationary phase) film and a flame ionization detector. The operating conditions of the gas chromatograph were as follows; the initial temperature was 75 C, increasing by 4 C/min to 148 C; from 148 to 158 C, the temperature was increased by 2.5 C/min; from 158 to 225 C the temperature was increased at the rate of 5 C/min. The temperature of the injector and the detector remained stable at 280 C. The column head pressure of the conductor gas (Helium) was 1.30 g/cm^2. The FA percentage was integrated and calculated using the CLASS-Unipac Program,[5] by means of direct normalization of the peak areas. Each FA was identified in the form of a methyl ester by comparing the retention times with the standard acquired from Sigma.[6]

The sensory analysis of the samples of chicken thighs of treatments T1 (control diet, as positive control), T4, and T5, which had been prepared according to the World's Poultry Science Association (1987) methodology, was carried out by six trained individuals who are part of a regular sensory panel at the Department of Poultry Science of the University of Hohenheim. Training of the panelists in sensory evaluation had been conducted following Norm DIN 10959/10961 (Fliedner and Wilhemi, 1993) to teach them to identify the fishy taint in the poultry products. Similar amounts of meat were weighed and wrapped in two layers of aluminum foil before grilling in a double-plated grill at 200 C. The internal temperature of edible portions was controlled, and samples were kept inside the grill until an internal temperature of 85 C was reached. Time between cooking and serving was kept constant at less than 15 min. The panel assessed the meat in a triangular test (Seemann,1981) in which flavor of the meat and general impression were evaluated. Contrasts were made two by two among the three treatments, and each of the three resulting contrasts was conducted in different sessions (one session per day). In each session, only one tissue (thigh) was evaluated and contrasted twice in accordance with the procedures of Seemann (1981). The panelists assessed the samples as follows: typical poultry flavor (5), acceptable (4), indifferent (3), poor (2), or very poor (1).

The objective parameters were conducted 48 h after slaughter of the birds on each left breast of seven individuals per treatment. We calculated the water-holding capacity (juiciness), following Grau and Hamm (1953) and using the modified Braunschweiger Model technique (Grashorn, 1995). Grill losses were determined by difference in weight of all the left breasts of the samples, before and after cooking them wrapped in aluminum foil, in a double-plated grill at 200 C. The internal temperature of the portions was controlled, and samples were kept inside the grill until and internal temperature of 85 C was reached. Tenderness was estimated on cooked samples of breast (circular portions of 2 cm in diameter, prepared as described by Seemann, 1985) by following Ehinger (1977). Texture was measured using the Warner-Brazler shear tool in an Instron Model 4301.[7] Maximum shear force and total energy required were

[4]Shimadzu Europe GmbH, D-47269 Duisburg, Germany.
[5]IZASA, C/Calàbria, 168–174, E-08015, Barcelona, Spain.
[6]Sigma, St. Louis, MO 63103.
[7]Instron Wolpert GmbH, Landwehrstrasse 55, 64293, Germany.

TABLE 3. Performance parameters[1] of chicks according to different amounts of fish oil in diets (1 to 38 d)

Variable	T1	T2	T3[2]	Pooled MSE	*P*
Weight gain, g per bird per day	48.15[b]	51.24[a]	50.67[a]	3.117	*
Feed intake, g per bird per day	82.1	91.51	88.05	44.658	NS
Feed efficiency, g:g	1.71	1.79	1.74	0.0178	NS
Final weight, kg per bird	1.85[b]	1.97[a]	1.94[a]	0.00345	*

[a,b]Values in the same row with no common superscript are significantly different.

[1]Values are the means of five observations per treatment and their pooled mean square of error (MSE).

[2]T1 = 8% tallow (T); T2 = 2% fish oil (FO) + 6% T; T3 = 4% FO + 4% T.

*$P < 0.05$.

calculated with the Software Series IX of Instron (Version 4.09a, Software Automated Materials Testing System).[7]

Statistical Analysis

Data were analyzed by variance and simple regression analyses using the procedure described by the SAS Institute (1996). Significant differences among treatments were determined according to an ANOVA test. For significant differences ($P < 0.05$) means were compared by using the least significant difference method of the same statistical package. The sensory data were analyzed as per Seemann (1981). All treatments were compared two by two, and contrasts for a panel of six individuals were established as follows: NS (not significant differences in flavor between the two treatments), only none, one, or two individuals were able to isolate the different sample in both exposed dishes; $P < 0.05$, three individuals identified the single sample; $P < 0.01$, four individuals were able to identify the single sample; and $P < 0.001$, at least five individuals detected the single sample in both dishes of the conducted contrast.

RESULTS AND DISCUSSION

Productive Performances

The values corresponding to the productive parameters, as well as the performances of the carcasses and the percentages of the breast and thigh cuts of the birds, are shown in Tables 3 to 6.

Feeding of diets that deviate in composition from a standard diet raises the question of whether such diets confer a reduced growth performance, thus causing subsequent economic losses for the producer. Significant differences due to dietary treatment are almost absent from the production parameters throughout the experimental period. In any case, the weight increase in grams per bird per day was higher ($P < 0.05$) in birds fed the diets with the highest content of FO than in those fed the control diet, which showed the highest T content (Table 3). The resulting final weights for T2 and T3 were higher than those for T1, although better feed efficiency was not observed. The use of higher PUFA levels in diets and the effect on the performance parameters of broiler chickens, e.g., higher feed intake and feed:gain ratio has been described elsewhere (Zollitsch et al., 1997), although other authors have reported contradictory results (Ajuyah et al., 1993). In agreement with previous results (Phetteplace and Watkins, 1989; Huang et al., 1990; Nash et al., 1995), the inclusion of FO as an ingredient in the diets did not cause adverse effects on mortality or final weight or feed conversion ratios, as compared with the inclusion of saturated fats throughout the experimental period (T1). However, Hulan et al. (1988) reported that diets enriched with isoenergetic and isonitrogenous redfish meal and redfish oil led to lower feed consumption and body weights and poorer feed conversion efficiency than the control diet. They attributed this result to lower palatability and higher calcium levels, although no palatability problem as a result of FO supplementation in the diet was found in the present study.

The withdrawal plan, established as treatments T4 and T5 (more polyunsaturated feed for a longer period), did not result in statistically significant differences in any performance parameter when compared to T3. A synergistic effect was detected on mixing different kinds of fats, which resulted in better feed transformation and higher final weights as reported elsewhere (Garrett and Young, 1975; Sibbald and Kramer, 1978).

The carcass yield values (Table 5), based on the carcass weight after removal of feet and head, were similar in

TABLE 4. Performance parameters[1] of chicks after withdrawal of fish oil from diets (1 to 38 d)

Variable	T3[2]	T4	T5	Pooled MSE	*P*
Weight gain, g per bird per day	50.67	48.95	51.09	3.231	NS
Feed intake, g per bird per day	88.05	83.31	86.81	15.913	NS
Feed efficiency, g:g	1.74	1.7	1.7	0.006	NS
Final weight, kg per bird	1.94	1.88	1.95	0.00482	NS

[1]Values are the means of five observations per treatment and their pooled mean square of error (MSE).

[2]T3 = Diet 3 for 5 wk; T4 = Diet 3 for 4 wk and Diet 4 for 1 wk; T5 = Diet 3 for 3 wk and Diet 4 for 2 wk.

TABLE 5. Carcass yield parameters of broiler chicks according to different levels of fish oil in diets[1]

Variable	Carcass yield[2] at slaughterhouse (%)	Cold carcass yield[2] (%)	Abdominal fat[3] (%)	Thigh[3] (%)	Breasts[3] (%)	Wings[3] (%)
Treatment × sex						
T1[4] Male	65.29[ab]	63.57	1.00	33.26	26.03	11.93[b]
T1 Female	65.82[ab]	64.20	1.35	32.55	26.91	11.73[b]
T2 Male	65.83[ab]	64.16	1.16	32.97	25.14	11.62[b]
T2 Female	64.68[b]	62.97	1.45	32.23	25.18	12.59[a]
T3 Male	66.58[a]	64.46	0.80	33.89	25.60	12.20[ab]
T3 Female	64.13[b]	62.32	1.79	33.39	24.51	12.19[ab]
Pooled MSE	1.922	2.136	0.235	1.246	2.228	0.301
Treatment						
T1	65.56	63.88	1.17	32.90	26.47	11.83
T2	65.26	63.56	1.31	32.60	25.16	12.11
T3	65.36	63.39	1.30	33.64	25.05	12.20
Sex						
Male	65.90	64.06	0.99	33.37	25.59	11.92
Female	64.88	63.16	1.53	32.72	25.53	12.17
P						
Treatment	NS	NS	NS	NS	NS	NS
Sex	*	NS	NS	NS	NS	NS
Treatment × sex	*	NS	NS	NS	NS	*

[a–d]Values within the same column and section with no common superscript are significantly different.

[1]Values are the means of 15 observations per treatment and their pooled mean square of error (MSE).

[2]Carcass yield, without head, neck, or feet.

[3]Percentage of carcass.

[4]T1 = 8% tallow (T); T2 = 2% fish oil (FO) + 6% T; T3 = 4% FO + 4% T.

*$P < 0.05$.

**$P < 0.01$.

all treatments and ranged from 65.0 to 65.6%. The differences in the relative weight of each cut of the carcass in the two experimental plans were not significant. Therefore, increasing levels of polyunsaturation in the diet, i.e., in the meat, did not result in a higher abdominal fat percentage, as reported by Zollitsch et al. (1997), who found higher levels than we did (2.3 vs. 1.3%). As expected, the carcass yield registered at the slaughter-

TABLE 6. Carcass yield parameters of broiler chicks according to the plan of withdrawal of fish oil from diets[1]

Variable	Carcass yield[2] at slaughterhouse	Cold carcass yield[2] (%)	Abdominal fat[3] (%)	Thigh[3] (%)	Breasts[3] (%)	Wings[3] (%)
Treatment × sex						
T3[4] Male	66.58	64.46	0.80	33.89	25.60	12.20
T3 Female	64.13	62.32	1.79	33.39	24.51	12.19
T4 Male	65.18	63.44	1.09	33.98	24.65	12.18
T4 Female	64.76	63.11	1.11	33.11	24.90	12.39
T5 Male	65.21	63.33	0.95	33.59	23.76	12.44
T5 Female	64.96	63.48	1.54	32.54	24.95	12.11
Pooled MSE	2.319	2.537	0.26	0.912	1.730	0.286
Treatment						
T3	65.36	63.39	1.30	33.64	25.05	12.20
T4	64.97	63.28	1.10	33.55	24.78	12.29
T5	65.08	63.41	1.25	33.06	24.35	12.28
Sex						
Male	65.66	63.75	0.95	33.82	24.67	12.27
Female	64.62	62.97	1.48	33.01	24.78	12.23
P						
Treatment	NS	NS	NS	NS	NS	NS
Sex	*	NS	**	*	NS	NS
Treatment × sex	NS	NS	NS	NS	NS	NS

[1]Values are the means of 15 observations per treatment and their pooled mean square of error (MSE).

[2]Carcass yield, without head, neck, or feet.

[3]Percentage of carcass.

[4]T3 = Diet 3 for 5 wk; T4 = Diet 3 for 4 wk and Diet 4 for 1 wk; T5 = Diet 3 for 3 wk and Diet 4 for 2 wk.

*$P < 0.05$.

**$P < 0.01$.

TABLE 7. Meat quality parameters according to different levels of fish oil in diets[1]

Variable[2]	Juiciness	Grill losses (%)	Tenderness: Maximal kraft (N)	Tenderness: Toughness cut (N)	Tenderness: Energy in cut (J)	Tenderness: Total energy (J)
Treatment × sex						
T1[3] Male	0.84	21.54	13.58	8.93	134.0	255.3
T1 Female	0.88	20.50	11.87	7.99	119.8	222.8
T2 Male	0.80	21.10	14.47	8.22	123.4	257.5
T2 Female	0.81	20.24	19.01	9.22	138.3	349.2
T3 Male	0.75	20.26	9.93	6.54	98.0	173.9
T3 Female	0.92	23.02	17.44	8.28	124.2	291.4
Pooled MSE	0.007	6.596	30.896	4.827	1,087.16	6,539.38
Treatment						
T1	0.86	21.02	12.73	8.46	126.9	239.06
T2	0.81	20.67	16.74	8.72	130.8	303.32
T3	0.84	21.64	13.69	7.41	111.1	232.64
Sex						
Male	0.80	20.97	12.66	7.90	118.4	228.9
Female	0.87	21.25	16.11	8.50	127.5	287.78
P						
Treatment	NS	NS	NS	NS	NS	NS
Sex	*	NS	NS	NS	NS	NS
Treatment × sex	NS	NS	NS	NS	NS	NS

[1]Values are the means of seven observations per treatment and their pooled mean square of error (MSE).

[2]Juiciness = Water-holding capacity. Proportion of area of liquid in relation to the area of meat; maximal kraft = highest force value during shearing; toughness cut = mean force applied to shear the meat; energy in cut = integration of applied energy between start and maximum force; total energy = integration between limits of the stated shear determinations.

[3]T1 = 8% tallow (T); T2 = 2% fish oil (FO) + 6% T; T3 = 4% FO + 4% T.

*$P < 0.05$.

house in males was higher than in females (65.9% for males vs. 64.9% for females; $P < 0.001$), although this finding was not significant after cooling ($P < 0.10$). The abdominal fat percentage in male chicks was lower than in female chicks (0.99% for males vs. 1.53% for females; $P < 0.001$).

Meat Quality Parameters

Tables 7 and 8 show the objective quality meat parameters of the breast samples of chicks at various concentrations of FO and with withdrawal plan of FO, respectively.

Different amounts of FO in diet did not result in significant differences among treatments for each experimental plan, unlike the differences in juiciness between sexes. The breasts of females had more juiciness, irrespective of the experimental dietary treatment ($P < 0.05$ for Plan 1 and $P < 0.01$ for Plan 2). Juiciness is associated with the retention of water within the muscular fibers of raw meat (Grashorn, 1995). On the other hand, the grill losses of the breast meat samples from female chicks were not significantly increased. In Plan 2 (withdrawal of FO, Table 8), the female chicks were not significantly different from males in tenderness values. Consistent differences were not significant and almost never exceeded 25% of difference when compared to the male chick values.

Fatty Acid Composition

Many studies have examined the effects of dietary LC-PUFA, supplied as FO or fish meal, on the FA composition of the broiler carcass (Miller and Robisch, 1969; Hulan et al., 1988; Phetteplace and Watkins, 1989; Nash et al. 1995; López-Ferrer et al., 1999b), to encourage the human dietary intake of long chain n-3 PUFA, which have beneficial effects on human health and resistance to various inflammatory diseases. These studies have clearly established that n-3 PUFA-rich diets increase the deposition of these fatty acids in muscle and adipose tissues.

In the present experiments, the presence of FO in the added fat increased the accumulation of n-3 LC-PUFA in muscle, especially that of EPA, DPA, and DHA, as compared with the other two FA sources (T, LO + FO + T). Tables 9 and 10 show the FA content in the chicken thigh samples. No FA with more than 22 carbon atoms was detected.

Plan 1. Increasing Levels of FO. As expected according to the FA profile of the diets, the saturated fatty acid content of the meat was slightly lower when T was replaced by progressively more FO, the predominant FA being palmitic acid ($C_{16:0}$), followed by stearic acid ($C_{18:0}$). The monounsaturated FA (MUFA) content of the thigh samples also decreased with increasing levels of FO in the diet. The highest values were obtained when T was the highest, i.e., in the control diet (T1), as reported

by Yau et al. (1991) and Scaife et al. (1994). It was mainly in the form of oleic acid ($C_{18:1\ n9}$), although T1 had a lower level than T3. This effect could be due to the dual origin of oleic acid in meat (direct depot from diet and de novo synthesis in liver and tissue). The high palmitic acid ($C_{16:0}$) content in T1 could account for the high level of oleic acid in meat, through elongation and desaturation.

The PUFA content increased ($P < 0.01$) with increasing levels of FO in the diet (T2, T3). However, each type of PUFA must be analyzed. The precursors of the n-3 and n-6 families, LNA and LA, respectively, increased slightly with addition of FO to the T diet. LA was the main PUFA in thighs. All n-3 LC-PUFA clearly increased ($P < 0.01$) with progressively increasing amounts of FO to almost 5% of the total FA in the tissue. The prevailing FA was DHA (2.42 and 0.93% for T3 and T2, respectively). However, in comparison with results reported elsewhere (Chanmugam et al., 1992; Scaife et al., 1994) and previous findings (López-Ferrer et al., 1999b), we observed less of all the n-3 LC-PUFA content in thighs, particularly EPA. This result must be due to the special kind of FO used in the present experiment, with less EPA, as well as more gondoic ($C_{20:1\ n-9}$) and erucic ($C_{22:1\ n-9}$) acids. In addition, the FO used was mixed with T, which diluted the LC-PUFA percentage of the dietary fat.

The increase in the different n-6 LC-PUFA due to FO was not as dramatic as the increase in n-3 PUFA. Arachidonic acid (AA, $C_{20:4\ n-6}$) remained unchanged, and all the other n-6 FA showed little variation when T was replaced by FO. The exception was $C_{20:3\ n-6}$, the only n-6 FA that slightly increased in T3, the treatment with the highest FO content. The slight n-6 response to increasing levels of FO in the diet could result from the increase in the total n-3 LC-PUFA content when FO was added. The competition between precursors from both PUFA families (Sprecher, 1989) could have been enhanced after replacing T with FO. High levels of n-3 LC-PUFA might have decreased the desaturation and elongation of LA to its derivatives, as reported by Bézard et al. (1994) in mammals. The AA content in the tissues was higher than in the diet, although this finding was not closely associated with the LA content in the diet, as suggested by Scaife et al. (1994) and Yau et al. (1991). A minimum of AA might remain constant in tissues to ensure certain metabolic processes.

The regression analysis of the FA profile of the thigh samples according to the relative content in the diet provided useful data. The saturated fatty acid and MUFA contents in the tissue depended less on their respective contents in the diet than the PUFA tissue content ($R^2 = 0.93$, $P < 0.001$), which was the most dependent, probably because of the close relationships among liver conversion from diet, tissue deposition, and de novo synthesis from carbohydrates. The PUFA content was also obtained from direct deposit from dietary fat and, to a much lesser extent, from de novo synthesis

TABLE 8. Quality meat parameters according to the plan of withdrawal of FO from diet[1]

			Tenderness			
Variable[2]	Juiciness	Grill losses (%)	Maximal kraft (N)	Toughness cut (N)	Energy in cut (J)	Total energy (J)
Treatment × sex						
T3[3] Male	0.75	20.26	9.93	6.54	98.00	173.90
T3 Female	0.92	23.02	17.44	8.28	124.18	291.38
T4 Male	0.78	19.57	14.22	8.02	120.23	274.67
T4 Female	0.82	21.63	11.58	7.03	105.41	226.71
T5 Male	0.81	20.63	10.30	6.71	100.63	178.42
T5 Female	0.85	22.23	15.83	9.56	143.43	298.98
Pooled MSE	0.007	8.861	25.665	3.440	774.670	7,509.540
Treatment						
T3	0.84	21.64	13.69	7.41	111.09	232.64
T4	0.80	20.60	12.90	7.52	112.82	250.69
T5	0.83	21.43	13.06	8.14	122.03	238.70
Sex						
Male	0.78	20.15	11.48	7.09	106.29	208.99
Female	0.86	22.29	14.95	8.29	124.34	272.36
P						
Treatment	NS	NS	NS	NS	NS	NS
Sex	**	NS	NS	NS	NS	NS
Treatment × sex	NS	NS	NS	NS	NS	NS

[1]Values are the means of seven observations per treatment and their pooled mean square of error (MSE).

[2]Juiciness = Water-holding capacity. Proportion of area of liquid in relation to the area of meat; Maximal kraft = highest force value during shearing; toughness cut= mean force applied to shear the meat; energy in cut = integration of applied energy between start and maximum force; total energy = integration between limits of the stated shear determinations.

[3]T3 = Diet 3 for 5 wk; T4 = Diet 3 for 4 wk and Diet 4 for 1 wk; T5 = Diet 3 for 3 wk and Diet 4 for 2 wk; T5 = 4% fish oil (FO) + 4% tallow (T) for 3 wk and 1% FO + 3% linseed oil + 4% T for 2 wk.

**$P < 0.01$.

TABLE 9. Fatty acid composition of thigh samples of chickens according to different levels of fish oil in diets[1]

Fatty acid[2]	T1[3]	T2	T3	Pooled MSE	*P*	R^2	*P* (regression) model
	—(% of methyl esters of fatty acids) —						
$C_{10:0}$	0.00	0.00	0.00	0.000	NS		
$C_{12:0}$	0.00	0.00	0.00	0.000	NS		
$C_{14:0}$	0.77[c]	1.26[b]	1.47[a]	0.015	***		
$C_{14:1\ n-5}$	0.02[b]	0.03[b]	0.12[a]	0.002	**		
$C_{15:0}$	0.50[b]	0.66[b]	0.54[a]	0.007	*		
$C_{16:0}$	33.82[a]	32.11[b]	28.99[c]	0.412	***		
$C_{16:1\ n-7}$[4]	0.04	0.07	0.11	0.002	NS		
$C_{16:1\ n-7}$	3.60	3.68	4.33	0.408	NS		
$C_{17:0}$	0.09[b]	0.13[ab]	0.26[a]	0.008	*		
$C_{18:0}$	8.54	9.42	8.54	0.788	NS		
$C_{18:1\ n-9}$	34.66[a]	31.76[b]	29.26[c]	0.829	***		
$C_{18:1\ n-7}$	2.60	1.95	2.28	0.919	NS		
$C_{18:2}$[4]	0.07[b]	0.07[b]	0.27[a]	0.003	***		
$C_{18:2\ n-6}$	11.66[b]	11.40[b]	12.87[a]	0.365	**	0.28	NS
$C_{18:3\ n-6}$	0.11	0.13	0.18	0.002	NS		
$C_{18:3\ n-3}$	1.63[c]	2.46[b]	2.98[a]	0.074	***	0.64	***
$C_{18:4\ n-3}$	0.03[c]	0.20[b]	0.34[a]	0.001	***	0.97	***
$C_{20:0}$	0.04	0.02	0.05	0.000	NS		
$C_{20:1\ n-9}$	0.34[c]	0.94[b]	1.44[a]	0.011	***		
$C_{20:2\ n-6}$	0.16	0.18	0.18	0.002	NS		
$C_{20:3\ n-6}$	0.11	0.14	0.15	0.001	NS		
$C_{20:4\ n-6}$	0.63	0.52	0.57	0.008	NS	0.07	NS
$C_{20:4\ n-3}$	0.01[c]	0.08[b]	0.14[a]	0.000	***		
$C_{20:5\ n-3}$	0.20[c]	0.77[b]	1.33[a]	0.008	***	0.93	***
$C_{22:1\ n-9}$	0.04[b]	0.36[a]	0.16[ab]	0.011	**		
$C_{22:4\ n-6}$	0.10	0.06	0.08	0.002	NS		
$C_{24:1\ n-9}$	0.00	0.00	0.01	0.000	NS		
$C_{22:5\ n-3}$	0.12[c]	0.56[b]	0.93[a]	0.006	***	0.96	***
$C_{22:6\ n-3}$	0.10[c]	1.03[b]	2.42[a]	0.040	***	0.94	***
Saturated	43.77[a]	43.61[a]	39.84[b]	1.441	***	0.36	*
MUFA	41.26[a]	38.72[b]	37.60[b]	2.308	**	0.36	*
PUFA	14.86[c]	17.53[b]	22.18[a]	0.686	***	0.93	***
Trans fatty acid	0.11[b]	0.14[b]	0.38[a]	0.084	***		
Total n-6	12.77[b]	12.43[b]	14.04[a]	0.423	**	0.29	*
Total n-3	2.09[c]	5.10[b]	8.14[a]	0.211	***	0.98	***
n-6/n-3	6.11[a]	2.50[b]	1.73[c]	0.100	***	0.97	***

[1]Values are the means of five observations per treatment and their pooled mean square of error (MSE). R^2 = coefficient of determination of the regression of fatty acid tissue on fatty acid in the diet.

[2]MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acids.

[3]T1 = 8% tallow (T); T2 = 2% fish oil (FO) + 6% T; T3 = 4% FO + 4% T.

[4]*Trans* fatty acids.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

through elongation and desaturation from the other groups.

As expected according to FA analyses, not all PUFA in tissue showed the same regression response. All of the n-3 LC-PUFA (C_{20} and C_{22}) showed higher R^2 than their precursor, LNA, which was present at low levels in all of the dietary treatments that included FO. The EPA, DPA, and DHA had the highest R^2 of all the FA analyzed, and so their content in tissues was more dependent on their dietary content than on conversion from their precursor. Their presence in tissues at high levels can be considered a marker of the use of fish products in formulated diets.

This experiment and our previous study (López-Ferrer et al., 1999b) were combined, in a regression analysis, for a range of total FO dietary content between 0.0 to 8.2% and, consequently, the dietary levels of EPA from 0.0 to 15.8% and DHA from 0.0 to 9.1%. These dietary levels were highly correlated with the n-3 LC-PUFA content in thigh meat ($R^2 = 0.99$, $y = 0.51x - 0.06$, $P < 0.001$ for EPA; $R^2 = 0.91$, $y = 0.71x - 0.57$, $P < 0.001$ for DHA), without reaching a plateau of deposition of the n-3 LC-PUFA in this specific peripheral tissue.

Although conversion to longer-chain FA is not high, the final content of LNA in tissues suggests that it is related less to the amount present in the diet ($R^2 = 0.64$) than to its content in the diet and the first derivative ($C_{18:4\ n-3}$) in tissue as independent variables ($R^2 = 0.92$, data not shown). The LNA may thus convert into its derivatives in tissue, as reported by Scaife et al. (1994).

The high conversion of LNA in liver (López-Ferrer et al., 2001) may also allow, at least, the creation and deposition of sufficient amount of the first derivative in peripheral tissues.

On the other hand, all n-6 FA in tissues seem to be less linked to their content in diets than n-3 FA (R^2 = 0.29 vs. 0.98). The very limited range of the n-6 precursor (LA) in the dietary treatments compromised the linear response of the n-6 group. Increased amounts of LO (López-Ferrer et al., 2001) and a broad range of LNA and LA in diets provided a clear linear response of the n-3 and n-6 families FA in tissue, which resulted in higher R^2 values. In our experimental conditions, the ranges of LA and LNA in the diets did not allow us to observe such gradual changes. Moreover, most of the n-3 FA are given as LC-PUFA in the diet (EPA, DHA), which inhibits n-3 elongation, desaturation, and, especially, the metabolism of LA, as shown in rats (Grønn et al., 1992; Muriana et al., 1992). Unlike the n-3 content, the n-6 content in tissues is far more dependent on the n-6:n-3 ratio than on the n-6 FA content in the diet. These n-3 LC-PUFA were almost independent of the n-6 concentration in the diet.

Plan 2. Withdrawal of FO from the Diet Before Slaughtering. When Diet 4 replaced Diet 3 for 1 wk before slaughter, the saturated fatty acid content decreased. This decline was proportional to the decrease that took place after 2 wk on Diet 4. The lower level of saturated fatty acid, mainly as palmitic acid, followed by stearic acid, in Diet 4 was responsible for that change. The MUFA content was also higher in the samples from birds fed T3 in the form of oleic acid.

TABLE 10. Fatty acid composition of thigh sample of chickens according to the plan of withdrawal of fish oil from diets[1]

Fatty acid[2]	T3[3]	T4	T5	Pooled MSE	*P*
	(% of methyl esters of fatty acids)				
$C_{10:0}$	0.00	0.00	0.00	0.000	NS
$C_{12:0}$	0.00^{b}	0.07^{a}	0.08^{a}	0.000	**
$C_{14:0}$	1.47^{a}	1.38^{b}	1.05^{c}	0.003	***
$C_{14:1\ n-5}$	0.12	0.17	0.15	0.001	NS
$C_{15:0}$	0.53^{b}	0.74^{a}	0.74^{a}	0.004	***
$C_{16:0}$	28.99^{a}	24.98^{b}	20.78^{c}	3.221	***
$C_{16:1\ n-7}$[4]	0.11^{b}	0.34^{a}	0.33^{a}	0.001	***
$C_{16:1\ n-7}$	4.33^{a}	4.33^{a}	3.82^{b}	0.036	***
$C_{17:0}$	0.26^{a}	0.20^{ab}	0.12^{b}	0.003	***
$C_{18:0}$	8.54^{a}	7.46^{b}	6.21^{c}	0.270	***
$C_{18:1\ n-9}$	29.26	28.12	29.52	0.987	NS
$C_{18:1\ n-7}$	2.28	2.07	1.99	0.126	NS
$C_{18:2}$[4]	0.27	0.31	0.25	0.004	NS
$C_{18:2\ n-6}$	12.87^{c}	14.31^{b}	17.77^{a}	0.170	***
$C_{18:3\ n-6}$	0.18	0.21	0.23	0.002	NS
$C_{18:3\ n-3}$	2.98^{c}	7.28^{b}	10.28^{a}	0.132	***
$C_{18:4\ n-3}$	0.34^{b}	0.44^{a}	0.42^{a}	0.000	***
$C_{20:0}$	0.05^{c}	0.22^{a}	0.17^{b}	0.000	***
$C_{20:1\ n-9}$	1.44^{a}	0.93^{b}	0.73^{c}	0.006	***
$C_{20:2\ n-6}$	0.18	0.17	0.19	0.001	NS
$C_{20:3\ n-6}$	0.15	0.16	0.16	0.000	NS
$C_{20:4\ n-6}$	0.57^{b}	0.62^{ab}	0.65^{a}	0.001	*
$C_{20:4\ n-3}$	0.14	0.05	0.06	0.005	NS
$C_{20:5\ n-3}$	1.33^{c}	1.88^{a}	1.52^{b}	0.008	***
$C_{22:1\ n-9}$	0.16^{c}	0.47^{a}	0.30^{b}	0.006	***
$C_{22:4\ n-6}$	0.08^{c}	0.41^{a}	0.26^{b}	0.003	***
$C_{24:1\ n-9}$	0.01^{b}	0.07^{a}	0.03^{ab}	0.001	*
$C_{22:5\ n-3}$	0.93^{a}	0.79^{b}	0.79^{b}	0.003	**
$C_{22:6\ n-3}$	2.42^{a}	1.72^{b}	1.42^{c}	0.008	***
Saturated	39.84^{a}	35.05^{b}	29.14^{c}	3.515	***
MUFA	37.60	36.26	36.54	1.371	NS
PUFA	22.18^{c}	28.04^{b}	33.74^{a}	0.581	***
Trans fatty acid	0.38^{b}	0.65^{a}	0.58^{a}	0.006	***
Total n-6	14.04^{c}	15.88^{b}	19.26^{a}	0.170	***
Total n-3	8.14^{c}	12.17^{b}	14.48^{a}	0.294	***
n-6/n-3	1.73^{a}	1.30^{b}	1.33^{b}	0.004	***

$^{a-c}$Values in the same row and variable with no common superscript are significantly different.

[1]Values are the means of five observations per treatment and their pooled mean square of error (MSE).

[2]MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid.

[3]T3 = Diet 3 for 5 wk; T4 = Diet 3 for 4 wk and Diet 4 for 1 wk; T5 = Diet 3 for 3 wk and Diet 4 for 2 wk.

[4]*Trans* fatty acids.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

The level of PUFA in the meat scored the highest values when FO was withdrawn from the added fat of the diet (T5), mainly as a result of the high LNA level in Diet 4. As with changing FO levels, all PUFA were studied according to the families: when FO was replaced by Diet 4, the relative proportion of the total n-3 FA was significantly affected. Although a high LNA content ($P < 0.01$) was observed in the meat when LO was used, which resulted in the rise in total n-3 FA, almost all of the n-3 LC-PUFA decreased, especially DHA in the T5 samples. This change was clear in T4 samples, after just 1 wk of replacement. The relative proportion of DHA and DPA in tissues decreased by more than 60%. The 2-wk FO withdrawal had the same effect. However, EPA increased and scored the highest values after 1 wk of replacement of the FO diet (T4). Because Diet 4 had a significantly lower EPA content, the increase could have resulted from desaturation and elongation from the precursor, LNA, or as stated by Grønn et al. (1991), from retroconversion from DHA in the tissues, which could account for the above-mentioned decline in DHA during the FO withdrawal plan. Diet 4, used in T4 for 1 wk and in T5 for 2 wk, contained 1% of FO (with especially low EPA) but much higher amounts of LNA. Nevertheless, the total EPA amount never exceeded 1.9% of the total chicken fat, and differences in the values, although significant, were never greater than 0.5 percentage points.

Differences in all n-3 LC-PUFA contents in chicken meat between T4 and T5 were minimal, especially in T5, which included FO at 1% of the diet for a longer period. However, the proportion of the LC n-3 depot was much higher when Diet 3, with 4% FO, was given throughout experiment (T3). The administration of LNA does not ensure efficient synthesis of its C_{22} family, which rules out meat enrichment strategies and suggests, as pointed out elsewhere (Hawrysh et al., 1980, 1982; Chanmugam et al., 1992; López-Ferrer et al., 2001), that in broiler chickens, desaturation and elongation of LNA does not ensure the enrichment of peripheral tissues. Direct supplementation is thus more appropriate than conversion from precursors.

The relative proportion of the n-6 FA, mainly as LA, increased ($P < 0.01$) when 3% LO was added to the diet at the expense of their derivatives, which remained almost unchanged on Diet 4. Arachidonic acid was present in the samples from birds fed Diet 4 for 1 or 2 wk (T4, T5), at higher levels than those found in samples from birds fed 4% FO throughout the whole trial (T3). Because AA was clearly lower in the FA profile of Diet 4, this result must be from the desaturation and elongation of its precursor, LA.

In terms of meat enrichment with n-3 LC-PUFA, withdrawal design—use of 4% FO for 3 or 4 wk, followed by a mixture of LO (minimum 3%) and FO (up to 1%)—is more efficient than the use of 2% FO throughout the experimental period (T2). Higher EPA, DPA, and DHA levels and organoleptic quality are achieved.

TABLE 11. Eating quality traits: contrasts

Contrasts[1]	Thigh
T1 × T4	NS
T1 × T5	NS
T4 × T5	NS

[1]T1 = 8% tallow. T4 = Diet 3 for 4 wk and Diet 4 for 1 wk; T5 = Diet 3 for 3 wk and Diet 4 for 2 wk.

Sensory Quality of Meat

Results of the chicken meat sensory tests are shown in Table 11. Because unacceptable odors were detected in carcasses of chickens fed FO up to 4% (Dansky, 1962) and 2% (Edwards and May, 1965), we did not compare T3 with the other treatments. Instead, T4 and T5 (1% FO) were compared with the positive designed control (T1). Sensory quality of the meat from T4 and T5 did not have a fishy taint when compared to the control diet (T1), which did not include FO. The panel did not find differences in flavors between T4 and T5 samples or when these samples were compared to those from T1.

The chickens fed 4% FO and then a diet with 1% FO (1 wk before slaughtering) did not efficiently retain DPA and DHA in thigh tissues. The EPA content increased slightly only when 1% FO and 3% LO were added to the diet. However, EPA is among the most biologically important FA included in the human diet. A high EPA content would improve not only the meat but also the regulation of human lipid metabolism (Kinsella et al., 1990; Knapp, 1991). This improvement requires assessment of the oxidative control of the n-3 LC-PUFA-enriched meat; highly polyunsaturated meat is highly susceptible to oxidative processes, which may harm human health (Hamilton, 1989).

Low amounts of DHA in the diet resulted in decreased content in the meat. Meat enrichment in n-3 LC-PUFA can only be achieved by adding high proportions of marine products to chicken diets. The conversion of LNA to n-3 LC-PUFA and late deposition in peripheral tissues is rather limited in chicken, although results from viscera such as liver are far more controversial and need further research (López-Ferrer et al., 2001). Enrichment of chicken meat with LNA could be achieved without significant sensory losses, which may improve nutritional content because of its influence on the human lipidic metabolism, if the above-mentioned oxidative control is assessed. Meat from T4-fed chickens would contain more n-3 (in the form of LC-PUFA and LNA) than controls (T1), thus meeting most of the human daily requirements (International Life Sciences Institute, 1995) in n-3 LC-PUFA (160 mg of EPA and 1,100 mg of total n-3 in 200 g of meat, taking 4% of fat in thigh as a reference), without sensory losses.

In a time of major changes in the poultry market, we should satisfy the nutritional demands of the consumer. Scientists, researchers, and poultry producers should combine their efforts in order to provide nutritionally improved products. However, further research should

be carried out to understand the FA metabolism in chicken and thus optimize the use and efficiency of n-3 ingredients in poultry diets.

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