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Fatty acid, protein and energy gain of broilers fed different dietary vegetable oils

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Abstract

The objective of this study was to assess energy, nitrogen, fat and fatty acid deposition in broilers fed diets containing different vegetable oil sources. Forty female broiler chickens were fed five diets, with different fats [coconut, palm, olive, soybean (SO) and linseed oil (LO)] at 10% from 30 to 50 days of age. The animals consuming the LO diet presented the lowest body fat content. There were no differences among treatments regarding nitrogen balance. The greater percentage of apparent metabolizable energy was obtained with the LO diet. All animals deposited more saturated and monounsaturated fatty acids than digested, however the amount of polyunsaturated fatty acids deposited in the SO and LO treatments was lower than the amount digested. These results indicate that chickens that consumed the highly polyunsaturated diets deposited less fat due to a lower gain of polyunsaturated fatty acids.

Additional key words: chicken, energy balance, fatty acids, polyunsaturated fatty acids.

Resumen

Composición en ácidos grasos, proteína y energía de broilers alimentados con diferentes aceites vegetales

El objetivo de este estudio fue evaluar el efecto de la fuente de grasa dietética sobre el depósito de energía, nitrógeno, grasa y ácidos grasos en pollos broilers. Cuarenta pollos broiler hembras fueron alimentados de los 30 a los 50 días de edad con cinco tratamientos que diferían en el tipo de grasa añadida (10%): aceite de coco, palma, oliva, soja (SO) y linaza (LO). Los animales que consumieron la dieta LO presentaron el menor contenido en grasa corporal. En el balance de nitrógeno no se observaron diferencias entre tratamientos. Sin embargo, en el balance de energía, el mayor porcentaje de energía metabolizable aparente se obtuvo con el pienso LO. En el balance de ácidos grasos, en todos los tratamientos se produjo un aumento en la concentración de ácidos grasos saturados y mono-insaturados retenidos con respecto a los digeridos. En cuanto a los ácidos grasos poliinsaturados, en los tratamientos SO y LO se depositaron menos de los que se digirieron. Estos resultados indican que los pollos que consumieron las dietas altamente poliinsaturadas depositaron menos grasa y que esta disminución fue causada por una menor retención de los ácidos grasos poliinsaturados.

Palabras clave adicionales: ácidos grasos poli-insaturados, balance energético, pollo.

Introduction[1]

It is widely accepted that dietary manipulation, especially dietary lipid modifications, can alter lipid composition of different tissues of animals (Mourot and Hermier, 2001). The chicken has been considered an appropriate model in lipid nutrition studies, since it is quite sensitive to dietary modifications and many of the studies done with chickens deal with the degree of saturation of the dietary added fat and how does it

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[1] Abbreviations used: AME (apparent metabolizable energy), AOAC (Association of Official Analytical Chemists), BW (body weight), CO (coconut oil), DN (digested nutrients or energy), EN (excreted nutrients or energy), FBC (final body composition), FID (flame ionization detector), GE (gross energy), GN (gained nutrients or energy), IBC (initial body composition), IN (ingested nutrients or energy), LO (linseed oil), MUFA (monounsaturated fatty acids), OO (olive oil), NL (nutrient or energy losses), PO (palm oil), PUFA (polyunsaturated fatty acids), RSD (residual standard deviation), SFA (saturated fatty acids), SO (soybean oil).

influence the fatty acid profile of the animal (Rymer and Givens, 2005).

The fat ingested by monogastric animals undergoes relatively few modifications in the intestinal tract, in such a way that dietary fatty acid profile is reflected in their body composition (Mourot and Hermier, 2001). Being chicken a type of meat of great consumption in our society, not only the amount but also the quality of its body fat are of great importance for the producers and the consumers. For this reason, currently the industry tries to produce chickens with a lower accumulated abdominal fat, and, the ability of the animals to modify and to deposit the fatty acids that receive through the diet is being studied.

It has been also observed that the consumption by chickens of diets with different fatty acid composition not only changes the degree of saturation but also modifies the amount of fat deposited in chicken tissues. In particular, the intake of polyunsaturated fatty acids (PUFA) compared to the intake of saturated fatty acids (SFA) causes a lower fat deposition in the animal (Villaverde *et al.*, 2005).

The objective of this study was to determine the influence of the consumption of diets with different fatty acids profile from vegetable oils (varying in their degree of saturation and chain length) on body composition and efficiency of deposition of energy, nitrogen, fat and fatty acids.

Material and Methods

Animals and diets

The experiment was performed at the experimental farm of the Hohenheim University (Germany) and received prior approval from the Ethics Committee of Hohenheim University. The treatment, housing, husbandry and slaughtering conditions conformed to the European Union Guidelines (EEC, 1986).

A total of 46 female broiler chickens of the Ross 308 strain were selected from a total of 100 birds by weight. From day 1 to 23 of life, animals were raised in floor pens and fed a pre-experimental diet (Table 1). On day 23, 7 days before the experimental period started, 40 of the animals were distributed in individual metabolic cages for adaptation. The six remaining animals stayed in the floor until day 30, day of the beginning of the experimental period, when they were sacrificed as control animals to provide the initial body composition data. Animals in cages were distributed into five dietary treatments to obtain the same initial body weight and standard deviation in each group. The experimental diets were formulated following the recommendations of the NRC (1994) based on wheat, soybean extracted and corn gluten, as main ingredients. The five diets contained five types of added fat (coconut, palm, olive, soybean, and linseed oils), representing different profiles of fatty acids (short chain SFA, long chain SFA, MUFA, PUFA from n-6 and n-3 series) were used to conduct this experiment. Composition and nutritive value of the experimental diets are presented in Tables 1 and 2.

The experimental diets were fed to the animals between 30 and 50 days of age. During the experimental period,

Table 1. Ingredients and nutrient composition of experimental diets (as-fed basis)

Ingredients	Pre-experimental diet	Experimental diet[1]
Wheat, g kg^{-1}	690.0	639.0
Corn gluten, g kg^{-1}	170.0	208.4
Soybean meal 44, g kg^{-1}	65.0	—
Soybean oil, g kg^{-1}	20.0	—
Added fat[2], g kg^{-1}	—	100.0
Dicalcium phosphate, g kg^{-1}	20.5	16.7
Limestone, g kg^{-1}	11.5	11.7
Sodium bicarbonate, g kg^{-1}	4.00	5.00
Choline chloride, g kg^{-1}	2.00	1.67
Salt, g kg^{-1}	1.00	1.00
Methionine, g kg^{-1}	1.00	0.83
L-lysine HCl, g kg^{-1}	11.0	11.7
Vit. Min. Premix[3], g kg^{-1}	4.00	4.00
Analyzed composition of the diets		
Dry matter, %	90.36	90.72
Crude protein, %	21.28	22.49
Lipid content, %	4.02	10.32
Crude fiber, %	2.67	2.43
Calculated lysine, %	1.44	1.33
GE[4] (kcal kg^{-1})	4,517	4,938
AME[5] (kcal kg^{-1})	2,983	3,300

[1] Obtained values of an average of five treatments, each one with 10% of added fat (coconut oil, palm oil, olive oil, soybean oil and linseed oil). [2] 10% coconut oil, 10% palm oil,10% olive oil, 10% soybean oil, 10% linseed oil. [3] Composition of vitamin and mineral premix, expressed by kilogram of weight: vitamin A: 12000 UI; D3 vitamin: 2400 UI; alpha-tocopherol: 200 mg; K3 vitamin: 3 mg; B1 vitamin: 2.2 mg; B2 vitamin: 8 mg; B6 vitamin: 5 mg; B12 vitamin: 11 mg; folic acid: 1.5 mg; biotin: 150 mg; calcium pantotenate: 25 mg; nicotinic acid: 65 mg; Mn: 60 mg; Zn: 40 mg; I: 0.33 mg; Fe: 80 mg; Cu: 8 mg; Se: 0.15 mg. [4] GE: gross energy. [5] AME: apparent metabolizable energy (calculated from GE).

Table 2. Fatty acid profile of experimental diets (g/100 g fat)[1]

Fatty acid	Pre-exp	CO	PO	OO	SO	LO
C 8:0	0.19	4.88	0.01	0.07	0.06	0.07
C 10:0	1.26	0.30	0.22	0.27	0.24	0.36
C 12:0	1.19	36.59	0.38	0.06	0.03	0.02
C 14:0	0.13	13.79	0.94	0.07	0.10	0.07
C 16:0	16.22	12.12	38.42	14.14	12.26	8.18
C 18:0	1.89	4.14	3.90	2.45	3.21	3.20
C 18:1 n-9	19.48	10.68	33.62	55.73	21.93	18.87
C 18:1 n7	0.77	0.31	0.72	2.11	1.35	0.74
C 18:2 n-6	54.53	15.72	19.53	21.46	53.74	24.95
C 18:3 n-3	3.25	1.03	0.86	1.32	5.98	42.82
C 20:0	0.37	0.18	0.36	0.49	0.39	0.24
C 20:1 n-9	0.43	0.16	0.20	0.36	0.27	0.23
C 20:4 n-6	0.00	0.00	0.10	0.00	0.09	0.00
SFA[2]	21.38	72.06	44.41	17.73	16.42	12.25
MUFA[3]	20.83	11.20	34.74	59.35	23.77	19.98
PUFA[4]	57.79	16.74	20.85	22.92	59.80	67.77
SFA:UFA	0.27	2.58	0.80	0.22	0.20	0.14
n-9	19.91	10.84	33.82	56.09	22.20	19.10
n-6	54.53	15.72	19.63	21.46	53.83	24.95
n-3	3.25	1.03	0.86	1.32	5.98	42.82
n-6:n-3	16.78	15.26	22.83	16.25	9.00	0.58

[1] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [2] SFA: saturated fatty acids. [3] MUFA: monounsaturated fatty acids. [4] PUFA: polyunsaturated fatty acids.

feed and water were provided *ad libitum*. Controls of feed intake and weight of the animals were made on days 30, 37, 44 and 50 in order to determine the average daily intake, average daily gain and feed to gain ratio. At the end of the experiment (50 days) all the animals were sacrificed with CO_2.

Sample collection

Throughout all the experimental period (30-50 days), the excreta were weighed and representative samples were taken from each chicken three times per week. The samples from each bird were mixed, homogenized and a sample of 100 g was taken. The excreta samples were freeze-dried, reground and kept at –20°C until their analysis.

All the chickens were cut with a blade cutter and homogenized during 4 min. A representative sample of each animal was freeze-dried, reground and kept to –20°C until its analysis.

Analytical determinations

The routine determinations of quality were carried out (AOAC, 1995) in the fats and oils used in the study. The moisture, crude protein, crude fat and ashes content of the whole body and excreta samples was determined following the methodologies described in the AOAC (1995). Gross energy (GE) of whole body and excreta was determined using an adiabatic calorimetric bomb (IKA C-4000, JankeKunkel, Staufen, Germany).

Individual fatty acids were quantified by gas chromatography in the feeds and in the excreta as described by Sukhija and Palmquist (1988), whereas in the experimental oils and in whole body the technique described by Carrapiso *et al.* (2000) was followed. Briefly, these techniques consist in a direct transesterification: the sample is incubated at 70°C with methanol chloride, and, after that, the organic layer is extracted with toluene. Nonadecanoic acid (C19)6 (Sigma) was added at the beginning of the procedure as an internal standard.

The heptane extracts were injected in a Gas-Chromatograph HP6890 (Agilent, Waldbronn, Germany). The method conditions were the following: capillary column, Hewlett Packard HP-23 (cis/trans FAME column) 60 m × 0.25 mm internal diameter with a thickness of stationary phase film of 0.25 μm; carrier gas, helium; flow, 1.3 mL min^{-1}; detector, flame ionization detector (FID); temperature program of the

oven, 1.5°C min^{-1} from 140 to 160°C, 0.5°C min^{-1} from 160 to 180°C; 2.5°C min^{-1} from 180 to 230°C; injector and detector temperature, 280°C; injection volume, 1 μL.

Calculations

Balance of energy and body components (protein, fat, and fatty acids) were analyzed as follows:

$$DN = IN - EN$$

$$GN = FBC - IBC$$

$$NL = DN - GN$$

where: DN = digested nutrients or energy. IN = ingested nutrients or energy, EN = excreted nutrients or energy, GN = gained nutrients or energy, FBC = final body composition, IBC = initial body composition, NL = nutrient or energy losses

The apparent metabolizable energy (AME) of the experimental diets was calculated using the following formula from gross energy (GE):

$$\% \text{ AME} = [(\text{GE ingested} - \text{GE excreted}) / \text{GE ingested}] \times 100$$

Finally the efficiency of deposition of energy and nitrogen was calculated as follows:

$$\% \text{ Efficiency energy deposition} = (\text{GE gained} / \text{AME}) * 100$$

$$\% \text{ Efficiency nitrogen deposition} = (\text{N gained} / \text{N ingested}) * 100$$

Statistical analysis

Data were subjected to one-way ANOVA by using the General Linear Model (GLM) procedure of SAS (v.9.1., SAS Inst., Inc., Cary, NC). Initial and final weights were included as a covariate when needed. Missing values were registered in some treatments and final n for the different treatments was CO = 7, PO = 7, OO = 8, SO = 8, and LO = 7. Means presented in tables were calculated as LSmeans. The alpha level used for determination of significance for all analyses was set at 0.05. All mean separations were done using Tukey's correction.

Results

The productive performance data registered throughout the experimental period (30-50 days) presented no significant differences among the different experimental treatments. Mean values for average daily intake, average daily gain and feed conversion rate were 108.3 ± 13.53 g, 50.7 ± 6.40 g and 2.08 ± 0.204, respectively.

Body chemical composition of the animals is presented in Table 3 expressed in absolute values (g) and also compared to fresh matter. There were no statistically significant differences among treatments regarding energy, protein, ashes and water content. However, body fat content of the animals consuming the more unsaturated diet (linseed oil) was lower (+16 to +20%; $P < 0.001$) than the body fat of the animals fed the mono-unsaturated and saturated diets (coconut, palm and olive oil).

Table 3. Final weight and body composition of chickens at the end of the experiment (day 50 of age) depending on the diet[1]

Treatment[2]	Final BW[3] (g)	GE[4] (cal g^{-1})	Body fat		Crude protein		Ash		Moisture	
			%[5]	g	%[5]	g	%[5]	g	%[5]	g
CO	1,781	2,882	19.9^{a}	367^{a}	17.0	313	2.43	44.8	60.5	1,113
PO	1,893	3,001	19.8^{a}	366^{a}	17.3	318	2.66	48.9	60.3	1,110
OO	1,768	2,804	19.7^{a}	362^{a}	16.9	312	2.47	45.3	60.9	1,121
SO	1,883	2,973	18.7^{ab}	346^{a}	16.6	306	2.49	45.7	60.2	1,107
LO	1,887	2,821	15.8^{b}	290^{b}	16.7	307	2.58	47.5	60.0	1,103
P value	0.168	0.187	< 0.001	< 0.001	0.287	0.257	0.178	0.158	0.748	0.707
RSD	128.0	186.7	1.80	33.2	0.62	11.2	0.194	3.45	1.28	23.5

[1] Values corresponding to LSmeans and residual standard deviation (RSD), obtained by ANOVA (n = 8). [2] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [3] BW: Body weight. [4] GE: Gross energy. [5] % = g/100 g final BW. [a-b] Values in the same column with different superscript are statistically different ($p < 0.05$).

Table 4. Fat balance of chickens depending on the diet (days 30 to 50 of age) expressed in g per 100 g of weight gain[1]

Treatments[2]	Fat intake	Excreted fat	Digested fat[3]	Digestibility[4] (%)	Fat gain[5]	Fat losses[6]
CO	20.9	3.21^{b}	17.7^{ab}	84.8^{a}	25.7^{a}	–8.31^{bc}
PO	21.6	6.65^{a}	15.0^{b}	69.8^{b}	26.9^{a}	–11.24^{c}
OO	22.9	4.71^{ab}	18.2^{a}	79.3^{ab}	24.8^{a}	–7.12^{bc}
SO	22.6	3.87^{ab}	18.8^{a}	83.1^{a}	23.5^{ab}	–4.99^{b}
LO	21.8	3.16^{b}	18.6^{a}	85.7^{a}	18.9^{b}	0.24^{a}
P value	0.447	0.009	0.018	0.005	0.006	0.001
RSD	2.28	1.891	2.21	8.06	3.12	3.012

[1] Values corresponding to LSmeans and residual standard deviation (RSD), obtained by ANOVA (n = 8). [2] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [3] Digested fat = Fat intake – Excreted fat. [4] % digestibility = (digested fat / fat intake) * 100. [5] Fat gain = Final fat content – Initial fat content. Final fat content: individual fat content of the chickens at the end of the experiment; Initial fat content: average fat content of the 6 control chickens at the beginning of the experiment. [6] Fat losses = digested fat – gained fat. [a,b,c] Values in the same column with different superscript are statistically different ($p < 0.05$).

The fat balance is presented in Table 4, where ingested, excreted, digested and gained fat is expressed as g per 100 g of weight gain. The animals fed the palm oil-rich diet consumed the same amount of fat as the rest of the chickens, but excreted higher amounts of fat, resulting in a lower fat digestibility (–19 to –23%; $P < 0.01$) compared to diets CO, SO and LO. Animals fed the less unsaturated diets (CO, PO, OO) showed a higher value of gained fat (+24 to +30%; $P < 0.05$) than the animals fed the LO diet. As a consequence, these animals gained more fat than they digested. On the other hand, the animals fed the LO diet gained less fat than they have digested. This can be observed in the lost fat column of Table 4, where negative values show more gain than digestion, and positive values show less gain than digestion.

Results regarding the nitrogen balance are presented in Table 5. There were no statistically significant differences among treatments, suggesting that the inclusion of the different fat sources in this experiment did not affect the intake, excretion and gain of nitrogen.

Concerning the energy balance, presented in Table 6, there were no differences among treatments in the measured and calculated parameters excepting the % of AME. The chicks from treatment LO had higher %AME value compared to the chicks from treatment PO (+13%, $P < 0.05$). There were no differences, however, in the gained energy, in spite of the differences found in fat metabolized.

In the SFA, MUFA and PUFA balances (Table 7) it can be seen that, in all cases, the chickens that have consumed the diets rich in specific fatty acids have a higher intake of these fatty acids. In particular, regarding the SFA balance, the chickens from treatment PO have excreted the higher amount of SFA, resulting in the lowest digestibility of these fatty acids. The best SFA digestibility is presented in the chickens from treatment CO, followed by treatments OO, SO and LO. In all diets the amount of SFA gained was higher than the amount digested (+8 to +129% higher) and in diets PO, OO, SO and LO the percentage of SFA gained was higher than the percentage gained in diet CO (+80 to +122% higher; $P < 0.001$).

Focusing on MUFA, the animals from treatment OO consumed and digested the highest amount of

Table 5. Nitrogen balance of chickens depending on the diet (days 30 to 50 of age), expressed as g per 100 g of weight gain[1]

Treatments[2]	N Intake	Excreted N	N gain[3]	N efficiency (%)[4]
CO	7.58	3.34	2.74	36.2
PO	7.57	3.39	2.79	36.9
OO	8.07	3.71	2.74	34.2
SO	7.37	3.58	2.61	35.9
LO	7.54	3.48	2.61	34.7
P value	0.434	0.883	0.249	0.223
RSD	0.726	0.765	0.184	2.54

[1] Values corresponding to LSmeans and residual standard deviation (RSD), obtained by ANOVA (n = 8). [2] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [3] N gain= Final N content – Initial N content. Final N content: individual N content of the chickens at the end of the experiment; Initial N content: average N content of the 6 control chickens at the beginning of the experiment. [4] % N efficiency = (N gain/ingested N) * 100.

Table 6. Energy balance of chickens depending on the diet (days 30 to 50 of age), expressed in kcal per 100 g of weight gain[1]

Treatment[2]	GE[3] intake	GE[3] excreted	AME[3]	AME (%)[4]	Energy gain[5]	Energy efficiency (%)[6]	Energy losses[7]
CO	1,017	187	830	81.9^{ab}	341	41.1	489
PO	1,074	281	793	74.0^{b}	340	42.8	453
OO	1,104	235	868	78.8^{ab}	328	38.0	541
SO	1,087	233	854	78.8^{ab}	355	42.4	499
LO	994	165	828	83.3^{a}	337	40.6	491
P value	0.280	0.060	0.600	0.050	0.690	0.290	0.380
RSD	108.9	73.5	89.6	5.6	34.8	4.58	82.0

[1] Values corresponding to LSmeans and residual standard deviation (RSD), obtained by ANOVA (n = 8). [2] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [3] GE: Gross energy; AME: apparent metabolizable energy; AME = GE ingested – GE excreted. [4] % AME = (AME/GE ingested)*100. [5] Energy gain = Final body energy – Initial body energy. Initial body energy = average energy content of the 6 control chickens killed at the start of the experiment. Final body energy = individual energy content of the chickens at the end of the experiment. [6] Energy efficiency % = (Energy gained / AME) * 100. [7] Energy losses = AME – gained energy. [a,b] Values in the same column with different superscript are statistically different ($p < 0.05$).

Table 7. Fatty acids (FA) balance of chickens depending on the diet (days 30 to 50 of age)[1]

	CO[2]	PO	OO	SO	LO	RSD	P value
Saturated FA							
Ingested, g	146.8^{a}	105.4^{b}	38.2^{c}	36.1^{c}	27.7^{c}	10.79	0.001
Excreted, g	19.60^{b}	55.58^{a}	9.26^{c}	9.15^{c}	7.19^{c}	5.965	0.001
Digested, g[3]	127.2^{a}	49.8^{b}	28.9^{c}	27.0^{c}	20.5^{c}	8.96	0.001
Digestibility, %[4]	86.8^{a}	47.3^{c}	76.7^{b}	74.9^{b}	74.3^{b}	6.13	0.001
Gained, g[5]	141.4^{a}	95.0^{b}	57.9^{c}	59.5^{c}	44.4^{c}	11.29	0.001
Gained, %[6]	107.6^{b}	187.1^{a}	196.7^{a}	211.6^{a}	229.3^{a}	34.69	0.001
Monounsaturated FA							
Ingested, g	22.8^{d}	82.5^{b}	127.7^{a}	52.3^{c}	45.2^{c}	9.58	0.001
Excreted, g	3.41^{c}	12.91^{ab}	17.00^{a}	8.00^{bc}	6.16^{bc}	5.36	0.004
Digested, g[3]	19.4^{d}	69.5^{b}	110.7^{a}	44.2^{c}	39.1^{c}	5.59	0.001
Digestibility, %[4]	85.1	84.3	87.3	84.9	86.5	4.25	0.674
Gained, g[5]	92.3^{b}	142.3^{a}	153.5^{a}	88.8^{b}	62.5^{c}	15.82	0.001
Gained, %[6]	445.7^{a}	213.8^{b}	139.0^{c}	193.0^{bc}	172.3^{bc}	47.40	0.001
Polyunsaturated FA							
Ingested, g	34.1^{c}	49.5^{c}	49.3^{c}	131.4^{b}	153.4^{a}	13.16	0.001
Excreted, g	8.30^{c}	12.47^{bc}	13.00^{bc}	20.42^{a}	16.00^{ab}	4.58	0.006
Digested, g[3]	25.8^{c}	36.9^{c}	36.3^{c}	111.1^{b}	137.4^{a}	10.95	0.001
Digestibility, %[4]	75.9^{b}	74.8^{b}	74.5^{b}	84.7^{a}	89.5^{a}	4.82	0.001
Gained, g[5]	29.2^{b}	36.5^{b}	38.2^{b}	91.7^{a}	78.3^{a}	10.51	0.001
Gained, %[6]	111.1^{a}	105.7^{a}	100.1^{a}	81.8^{b}	58.8^{c}	11.26	0.001

[1] Values corresponding to LSmeans and residual standard deviation (RSD), obtained by ANOVA (n = 8). [2] CO: 10% coconut oil; PO: 10% palm oil; OO: 10% olive oil; SO: 10% soybean oil; LO: 10% linseed oil. [3] Digested = ingested – excreted. [4] % Digestibility = (digested / ingested)*100. [5] Gained = final FA – initial FA; final FA = individual FA content of the chickens at the end of the experiment; initial FA = average FA content of the 6 control chickens at the beginning of the experiment. [6] % gained = (gained/digested) * 100. [a,b,c,d] Values in the same row with different superscript are statistically different ($p < 0.05$).

these fatty acids. There were no differences of digestibility among treatments and the animals that consumed the highest amount of MUFA (treatments PO and OO) were also those with the higher gain of these fatty acids.

Finally, the PUFA balance showed that the animals from treatments SO and LO had consumed and digested the higher amount of these fatty acids. Consequently, these treatments result in the highest PUFA digestibility values. Regarding gained PUFA, the animals eating the more saturated diets (CO, PO and OO) gained barely the same amount of PUFA that they had digested. However, the animals fed the PUFA-rich diets (SO and LO) the amount of PUFA gained was lower than the amount digested (–18 to –41% lower).

Discussion

The performance data presented is in concordance with other authors who studied high inclusion levels of different fat sources. In particular, Crespo and Esteve-Garcia (2002a) using 10% of added tallow, soybean oil and linseed oil and Sanz *et al.* (1999) using 8% of tallow, lard and sunflower oil did not find any differences in the productive performance of broiler chickens. However, Newman *et al.* (2002) found a better food conversion ratio in broilers fed sunflower oil compared to those fed tallow, even though statistical differences in food intake and weight gain were not detected. Similarly, different authors (Sibbald *et al.*, 1962; Fuller and Rendon, 1977; Pinchasov and Nir, 1992) have shown that dietary fat has no effect upon performance in broilers when the energy to protein ratio and the rest of nutrients are maintained.

Abdominal fat is representative of the total fat deposition of the broiler chicken (Crespo and Esteve-García, 2002a). Similarly to our results, other authors have found a reduction in abdominal fat deposition in the broilers fed sunflower and linseed oil compared to the animals fed tallow (Sanz *et al.*, 1999; Crespo and Esteve-García, 2001; Villaverde *et al.*, 2005). Moreover, Newman *et al.* (2002) showed that the animals fed unsaturated fats (8% fish oil and sunflower oil) had lower abdominal fat content compared to the animals consuming saturated fat (8% tallow). Thus, fatty acid composition of dietary fat modifies body fat deposition, not only in profile but in quantity; the amount of fat deposited is lower in animals fed highly unsaturated diets compared to animals fed saturated ones.

In this experiment, no effect of unsaturation was found on the nitrogen balance as in previous experiments from our lab (Villaverde *et al.*, 2005). However these results are not in agreement with other published works. Crespo and Esteve-García (2002b) found that the animals fed the more saturated diet had a higher intake and excretion of nitrogen than the animals fed unsaturated oils, which resulted in lower nitrogen efficiency. On the other hand, Sanz *et al.* (2000a) observed that the source of the dietary fat affected total protein gain in broilers. They found no differences in protein intake and in final weight, but the birds consuming the more saturated fat had a higher fat deposition and a lower protein deposition compared to animals fed unsaturated diets. These results suggest that there are differences in fat utilization or distribution depending on the added fat source. Thus, calories from unsaturated fats would be destined to metabolic functions whereas calories from saturated fat would be deposited in adipocytes. Moreover, there are studies (Watkins *et al.*, 1982; Leyton *et al.*, 1987) showing that dietary PUFA are oxidized faster than long chain SFA in the production of metabolic energy.

Similarly to the results here presented, Crespo and Esteve-García (2002b), using different fat sources, did not found differences among treatments regarding AME, % of AME, energy gain, energy losses and energy efficiency in broilers. What they did find was a higher energy intake and excretion in the animals fed the diet rich in tallow. However, Sanz *et al.* (2000a), using two sources of fat (one saturated and the other unsaturated) found higher energy gain in the animals fed the saturated fat. The results from the present study do not show that the saturation degree of dietary fat modify energy gain in broilers, even though there is a higher fat gain and a lower % of AME in the birds fed the more saturated fat. Once again, these results lead one to think that the energy derived from fatty acids has a different metabolic fate depending on their physicochemical traits.

Calculating the SFA, MUFA and PUFA gain as the difference between gained and digested fatty acids (Table 7) in all treatments, as the saturation of dietary fat increases, fatty acids gain is higher. In fact, the amount of fat gained is higher than the amount digested except for the LO treatment. The amount of SFA and MUFA gained is always higher than the amount available, which indicates a net endogenous synthesis of these fatty acids, more pronounced in the CO and PO treatments. Regarding PUFA, the gain is more or less equal to the digestion in the more saturated treatments,

whereas there is a loss of this type of fatty acids in SO and LO treatments. The fatty acids balances in this study are in agreement with the results found with Crespo and Esteve-García (2002b). The important question is why there are differences in the use of fatty acids depending on their chemical structure. Some authors have studied the metabolic processes that can help to explain this finding. Many authors say that PUFA a) cause a reduction of hepatic lipogenesis and b) contribute to a higher lipid oxidation to obtain energy. Chicken studies that investigate enzymes involved in β-oxidation and in fatty acid synthesis, use either direct techniques or gene expression measurements as an indicator of the final protein product (Leyton *et al.*, 1987; Shimomura *et al.*, 1990; Takeuchi *et al.,* 1995; Power and Newsholme, 1997; Sanz *et al.*, 2000b). From mammals, it is known that PUFAs intracellular concentrations modulate the action of different nuclear receptors and transcription factors controlling the lipogenesis and lipid oxidation. In particular, fatty acid oxidation is promoted in the liver by dietary PUFA, mainly thorough activation of the nuclear receptor ppar-α. On the other hand, fatty acid synthesis is decreased by dietary PUFA thorough degradation of the transcription factor SREBP-1 (Jump *et al.*, 2006).

As mentioned above, PUFA provide more metabolizable energy than SFA to the animal organism, due to their better digestibility. However, this plus of energy is not being deposited in form of triglycerides, because fat deposition is not increased and the amount of fat gained is even lower than the amount consumed. To explain this finding, some authors suggest that part of the metabolizable energy of PUFA is lost in other metabolic processes, such as thermogenesis (Takeuchi *et al.*, 1995; Baillie *et al.*, 1999; Raimbault *et al.*, 2001; Toyomizu *et al.*, 2002). However the biological sense of this apparent energy inefficiency is still not understood.

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