Crude soybean lecithin as alternative energy source for broiler chicken diets

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ABSTRACT Two experiments were conducted to evaluate the use of crude soybean lecithin (L) as an alternative energy source in broiler feeding and to study its influence on performance, fatty acid (FA) digestibility between 9 to 11 D and 36 to 37 D, feed AME content, and the FA profile of the abdominal fat pad (AFP). A basal diet was supplemented at 3% with soybean oil (S; experiment 1) or a monounsaturated vegetable acid oil (A; experiment 2) and increasing amounts of L (1, 2, and 3%) were included in replacement. The inclusion of L did not modify performance results ($P > 0.05$). In starter diets, the replacement of S by L reduced feed AME content ($P < 0.001$) and lowered PUFA digestibility ($P = 0.028$), whereas in the grower-finisher phase, a blend of 2% of S and 1% of L did not modify feed AME content or FA digestibility. When L was included instead of A, no effects on feed AME value and total FA digestibility ($P > 0.05$) were shown in the starter phase, whereas in grower-finisher diets, a blending of 2% of A and 1% of L enhanced feed AME content ($P < 0.001$) and total FA digestibility ($P = 0.001$). The FA profile of the AFP reflected the FA composition of the diets. Crude soybean lecithin represents an alternative energy source for broiler chickens, and it can be used in growing-finishing diets in replacement of 1% S. The best option to include both alternative fats (L and A) was 2% of L with 1% of A in starter diets and 1% of L with 2% of A in grower-finisher diets because they showed positive synergic effects. The results suggest that dietary FA profile have a bigger impact on the AFP saturation degree than the different dietary lipid molecular structures.

Key words: crude soybean lecithin, acid oil, fatty acid digestibility, alternative energy source

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INTRODUCTION

Fat inclusion in broiler feeding is a widespread activity in aviculture which allows the reaching of the high energetic requirements of fast-growing birds. Fat inclusion also presents other positive features, such as essential fatty acids and vitamins supply, slowing the passage rate, and lubricating the feed milling equipment, among others (Ravindran et al., 2016). The price of conventional added fat sources in broiler feeding has been increasing in the last few years, in part by the rising demand of vegetable fats for biodiesel production and, according to soybean oil current forecasts, this trend is going to be maintained in the following years (Statista, 2018). This context explains why there is an increasing interest in the search and the use of alternative energy sources in broiler feeding in order to reduce production costs. Co-products derived from the vegetable oil refining process represent an attractive alternative to conventional energetic sources due to their competitive price and the possibility to recycle products in order to avoid environmental contamination.

A great variety of lecithin sources (vegetable and animal) exist, but those obtained from soybean seeds are the most relevant in terms of applications and worldwide production (Cui and Decker, 2016). Crude soybean lecithin is obtained prior to the refining process during the degumming step and consists of a lipid mixture mainly composed of polar lipids (>60%), in particular phospholipids (**PL**), and, to a lesser extent, of neutral lipids such as triacylglycerols (**TAG**; Van Nieuwenhuyzen and Tomás, 2008). The chemical structure of PL consists of a sn-1,2-diacylglycerol backbone with 2 fatty acid (**FA**) chains and a phosphate head group bound to a functional moiety (choline, ethanolamine, and inositol, among others) at the sn-3 position (Bueschelberguer et al., 2015). The presence of both hydrophilic (FA chains) and lipophilic (glycerol, phosphorus, and the functional moiety) components confers to lecithin emulsifying properties, giving many applications to these kinds of co-products. Although crude soybean lecithin represents an economic alternative and an important source of gross energy (**GE**), phosphorus, choline, linoleic and linolenic acid, there is not enough information available to recommend its use in broiler chickens.

On the other hand, vegetable acid oils are co-products derived from the crude vegetable oil refining

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process. These co-products are normally obtained by treating crude oil through an alkali reaction (chemical refining) with the aim to reduce free fatty acid (**FFA**) content and other impurities (Baião and Lara, 2005). In other words, acid oils are characterized by a high content in FFA (40 to 60%), a variable proportion of TAG, diacylglycerols, and monoacylglycerols, and a similar FA profile to their corresponding crude oils (Roll et al., 2018). In addition, their high content in GE gives an interesting and economic relevance to acid oils for all kinds of poultry species (Mateos et al., 2012).

The present study has been carried out in order to determine the potential use of crude soybean lecithin as an energy source in broiler feeding. The aim of the current work is to evaluate the impact of crude soybean lecithin dietary supplementation and its combination with other fats (soybean oil as a conventional source or monounsaturated vegetable acid oil as an alternative source) on performance parameters, feed AME content, FA digestibility, and the FA profile of the abdominal fat pad (**AFP**).

MATERIALS AND METHODS

The experiments were performed at *Servei de Granges i Camps Experimentals* (Universitat Autònoma de Barcelona, Bellaterra, Spain). These experimental procedures were approved by the Animal Ethics Committee of the Universitat Autònoma de Barcelona (CEEAH) and were in accordance with the European Union guidelines for the care and use of animals in research (European Parliament, 2010).

Experimental Design and Diets

Two trials of 38 D were performed with a feeding program in 2 phases: starter (from 0 to 21 D) and grower-finisher (from 22 to 38 D). Diets were presented in mash form, and the wheat- and soybean-meal-based diets were formulated to meet or exceed FEDNA (2008) requirements, as shown in Tables 1 and 2. In addition, titanium dioxide ($\mathbf{TiO_2}$) was added as an indigestible marker at 0.5%.

Experiment 1 A total of 96 Ross 308 newly hatched female broiler chickens were randomly allocated in metabolic cages (4 birds per cage) and assigned to 1 of 4 experimental treatments (6 replicates per treatment). The experimental diets (Table 1) were the result of a basal diet supplemented at 3% with different proportions of soybean oil (**S**) and crude soybean lecithin (**L**). The S3 treatment included S at 3% and was gradually replaced by L: S2-L1 (2% of S and 1% of L), S1-L2 (1% of S and 2% of L), and L3 (L at 3%).

Experiment 2 A total of 120 Ross 308 newly hatched female broiler chickens were allocated in metabolic cages (4 birds per cage) and assigned to 1 of 5 experimental treatments (6 replicates per treatment). The experimental diets consisted of a basal diet supplemented with 3% of different fat sources (Table 2). A monounsaturated vegetable acid oil (**A**; a blending 50:50 of olive pomace acid oil and sunflower acid oil) was included at 3% in treatment A3, and increasing amounts of L were added in replacement of A: A2-L1 (2% of A and 1% of L), A1-L2 (1% of A and 2% of L), and L3 (L at 3%). The S3 diet was included as a reference treatment.

Table 1. Ingredient composition of the starter and grower-finisher diets, as-fed basis (experiment 1).

Ingredients (%)	Starter diet (from to 0 to 21 D)	Grower-finisher diet (from to 22 to 38 D)
Wheat	36.55	46.84
Soybean meal 47%	29.43	21.09
Corn	9.71	–
Barley	9.71	15.58
Extruded full-fat soybean	4.76	–
Added fat[1]	3.00	3.00
Rapeseed meal 00	–	3.42
Sunflower meal 28%	–	2.44
Sepiolite	1.93	1.90
Palm oil	–	1.50
Calcium carbonate	1.19	1.08
Monocalcium phosphate	0.97	0.57
Trace mineral-vitamin premix[2]	1.15	1.01
Titanium dioxide	0.50	0.50
Salt	0.30	0.23
L-lysine	0.30	0.35
DL-methionine	0.28	0.21
L-threonine	0.08	0.09
Sodic bicarbonate	0.07	0.12
Clorure choline 75%	0.07	0.07

[1]Soybean oil (S) and crude soybean lecithin (L) in different blending proportions.

[2]Provides per kg feed: vitamin A (from retinol), 13,500 IU; vitamin D3 (from cholecalciferol), 4,800 IU; vitamin E (from alfa-tocopherol), 49.5 IU; vitamin B1, 3 mg; vitamin B2, 9 mg; vitamin B6, 4.5 mg; vitamin B12, 16.5 μg; vitamin K3, 3 mg; calcium pantothenate, 16.5 mg; nicotinic acid, 51 mg; folic acid, 1.8 mg; biotin, 30 μg; Fe (from $FeSO_4 \cdot 7H_2O$), 54 mg; I [from $Ca(I_2O_3)_2$], 1.2 mg; Co (from $2CoCO_3 \cdot 3Co(OH)_2 \cdot H_2O$),0.6 mg; Cu (from $CuSO_4 \cdot 5H_2O$), 12 mg; Mn (from MnO), 90 mg; Zn (from ZnO), 66 mg; Se (from Na_2SeO_3), 0.18 mg; Mo [from $(NH_4)_6Mo_7O_{24}$], 1.2 mg; organic acids (starter diets at 4 g/kg; grower-finisher diets at 3 g/kg); β-glucanase 350 IU; xylanase 1,125 IU.

Animal Husbandry and Controls

The animals were obtained from a local hatchery (Pondex S.A.U.; Juneda, Spain), weighed, wing-tagged, and randomly allocated in metabolic cages with a grid floor and a tray for excreta collection. Birds were allowed to consume both feed and water ad libitum in an environmentally controlled room. The temperature and light program used was consistent with the specifications in the Ross 308 lineage management handbook (Aviagen, 2014). Twice daily, animals and housing facilities were inspected for the general health status, constant feed and water supply, as well as temperature and ventilation.

Broiler BW was recorded individually at the day of hatching and day 21 and 38 post-hatch, whereas feed

Table 2. Ingredient composition of the starter and the grower-finisher diets, as-fed basis (experiment 2).

Ingredients (%)	Starter diet (from to 0 to 21 D)	Grower-finisher diet (from to 22 to 38 D)
Wheat	36.64	45.92
Soybean meal 47%	30.46	24.25
Corn	9.71	–
Barley	8.33	15.76
Extruded full-fat soybean	4.73	–
Added fat[1]	3.00	3.00
Rapeseed meal 00	–	3.41
Palm oil	–	1.51
Sepiolite	2.03	2.03
Calcium carbonate	1.16	1.00
Monocalcium phosphate	0.93	0.48
Trace mineral-vitamin premix[2]	1.44	1.17
Titanium dioxide	0.50	0.50
Salt	0.30	0.23
L-lysine	0.28	0.28
DL-methionine	0.28	0.22
L-threonine	0.07	0.07
Sodic bicarbonate	0.07	0.11
Clorure choline 75%	0.07	0.06

[1]Soybean oil (S), crude soybean lecithin (L), and acid oil (A) in different blending proportions.

[2]Provides per kg feed: vitamin A (from retinol), 13,500 IU; vitamin D3 (from cholecalciferol), 4,800 IU; vitamin E (from alfa-tocopherol), 49.5 IU; vitamin B1, 3 mg; vitamin B2, 9 mg; vitamin B6, 4.5 mg; vitamin B12, 16.5 μg; vitamin K3, 3 mg; calcium pantothenate, 16.5 mg; nicotinic acid, 51 mg; folic acid, 1.8 mg; biotin, 30 μg; Fe (from $FeSO_4 \cdot 7H_2O$), 54 mg; I [from $Ca(I_2O_3)_2$], 1.2 mg; Co (from $2CoCO_3 \cdot 3Co(OH)_2 \cdot H_2O$),0.6 mg; Cu (from $CuSO_4 \cdot 5H_2O$), 12 mg; Mn (from MnO), 90 mg; Zn (from ZnO), 66 mg; Se (from Na_2SeO_3), 0.18 mg; Mo [from $(NH_4)_6Mo_7O_{24}$], 1.2 mg; organic acids (starter diets at 5 g/kg; grower-finisher diets at 2.5 g/kg); β-glucanase 350 IU; xylanase 1,125 IU.

intake was measured by replicate (cage) on days 21 and 38 post-hatch. The data were used to measure BW and calculate the ADG, ADFI, the feed conversion ratio (**FCR**) of each period, and the global results of the experiments. Mortality was recorded daily to adjust ADFI and ADG. Two nutritional balances were performed for each experiment between day 9 to 11 (starter period) and day 36 to 37 (grower-finisher period), and excreta samples (free of contaminants such as feed, scales, and feathers) were taken each day of the digestibility balance. The excreta samples were homogenized, freeze-dried, ground, and kept at 4°C until further analysis. On day 21, 1 bird per replicate was euthanized by cervical dislocation due to stocking density reasons. At the end of the experiment, broiler chickens were fasted for 3 h, stunned, slaughtered, bled, plucked, and chilled at 4°C for 12 h in a commercial slaughterhouse (GIMAVE S.A.; Ripollet, Spain), and carcasses were recovered for further study. Carcasses (total BW excluding blood and feathers) were weighed, and AFP (from the proventriculus surrounding the gizzard down to the cloaca) of each bird was removed and weighed in order to calculate carcass yield and the AFP carcass percentage. Finally, a representative sample of AFP of each bird was taken, pooled by replicate, frozen at –20°C, and analyzed to determine the FA profile.

Laboratory Analyses

Experimental feed samples were taken at the beginning and end of each experimental period and were ground and kept at 4°C until further analysis. Diet proximate analyses were performed according to the methods of AOAC International (2005): ether extract (**EE**) by the Soxhlet analysis (Method 920.39), crude protein (Method 968.06), and crude fiber (Method 962.09). In addition, analyses of feed and excreta samples included ash determination (Method 942.05), dry matter (Method 934.01), and GE content by adiabatic bomb calorimeter (IKA-Kalorimeter system C4000; Staufen, Germany).

The inert marker was determined in feed and excreta by different ways in each experiment: in experiment 1, TiO_2 was determined by spectrophotometry ICP-OES (Optima 3200 RL, Perkin Elmer, Waltham, MA), whereas in experiment 2, TiO_2 was determined by using the method described by Short et al. (1996).

Oil samples (soybean oil, monounsaturated acid oil, and crude soybean lecithin) were analyzed in duplicate for FA composition by gas chromatography according to the method described by Guardiola et al. (1994). In addition, the acid value was determined according to ISO 660 (2009) method, and the acidity was expressed as the FFA percentage of oleic acid. Regarding PL content of the 2 batches of crude soybean lecithin used, acetone insoluble determination was performed following the Ja 4–46 analytical method from AOCS (2017) and the PL composition was determined by HPLC (D450 MT1, Kontron, Eching, Germany) following the method described by Helmerich and Koehler (2003).

In the case of feed and excreta, FA content was analyzed by adding nonadecanoic acid (Sigma-Aldrich Chemical Co., St. Louis, MO) as an internal standard and following the method described by Sukhija and Palmquist (1988), whereas in the case of AFP, the method described by Carrapiso et al. (2000) was used. The final extract obtained was injected in a gas chromatograph (HP6890, Agilent Technologies, Waldbronn, Germany) following the method conditions previously described by Cortinas et al. (2004). The FA were identified by matching their retention times with those of their relative standards (Supelco 37 component FAME Mix; Sigma-Aldrich Co.) and quantified by internal normalization. Nonadecanoic acid was used for the calibration curves and quantification of FA.

Calculations and Statistical Analysis

Apparent digestibility of FA (%) in excreta was calculated by the index method using the following equation:

$$\text{Apparent digestibility of nutrient} = 1 - \{(TiO_2/N)_d/(TiO_2/N)_e\}$$

Table 3. Chemical analysis of the fat sources[1] included in the experimental diets of experiments 1 and 2.

	Experimental fat				
	Experiment 1		Experiment 2		
Item	S	L	S	A	L
Fatty acid composition (%)[2]					
C16:0	11.65	14.21	10.63	9.97	17.84
C18:0	3.55	3.79	4.26	3.84	4.06
C18:1 ω-9	22.29	29.70	21.81	51.25	22.69
C18:2 ω-6	53.43	46.52	52.78	29.18	50.95
C18:3 ω-3	5.76	5.78	7.67	1.55	4.46
Minor FA	3.32	N.D.	2.85	4.21	N.D.
SFA	16.56	18.00	16.04	15.05	21.90
MUFA	24.25	29.70	23.51	54.22	22.69
PUFA	59.19	52.30	60.45	30.73	55.41
UFA:SFA	5.04	4.55	5.23	5.60	3.56
PUFA:SFA	3.57	2.91	3.77	2.04	2.53
Acidity (%)[2]					
FFA	2.41	13.22	1.49	52.92	14.48
Phospholipids (%)[2]					
Acetone insoluble	–	62.70	–	–	60.10
PC	–	15.88	–	–	12.54
PI	–	10.57	–	–	10.28
PE	–	7.79	–	–	6.14
AP	–	3.52	–	–	4.83
LPC	–	1.23	–	–	1.08
Gross energy (kcal/kg)					
GE	9,396	7,952	9,621	9,429	8,105

[1]S = soybean oil; L = crude soybean lecithin; A = acid oil.
[2]Percentage in total product.
SFA = saturated fatty acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; UFA: SFA = unsaturated-to-saturated fatty acid ratio; PUFA:SFA = polyunsaturated-to-saturated fatty acid ratio; PC = phosphatidylcholine; PI = phosphatidylinositol; PE = phosphatidylethanolamine; AP = phosphatidic acid; LPC = lysophosphatidylcholine; FFA = free fatty acid; GE = gross energy; ND = not determined; "–"= not analyzed.

where $(TiO_2/N)_d$ is the concentration of the inert marker and the nutrient in the diet, and $(TiO_2/N)_e$ is the concentration of the inert marker and the nutrient in the excreta. The AME of the diets was calculated by the following equation:

$$\text{AME (kcal/kg)} = \text{Apparent digestibility of GE (\%)} * \text{GE of the diet.}$$

Cage means were used as the experimental unit (6 replicates/treatment) in performance parameters (except BW), FA digestibility, and FA profile of the AFP and AME values of the diets. Data were analyzed by 1-way ANOVA using R Statistics (version 3.3.1), with treatment as the main factor. Tukey's multiple range test was performed to determine whether means were significantly different ($P \leq 0.05$). In experiment 2, soybean oil treatment (S3) was compared against A3 treatment separately with 1-way ANOVA.

RESULTS AND DISCUSSION

Characterization of Experimental Fats and Diets

The chemical analyses of the fat sources included in the diets of both experiments are presented in Table 3.

Regarding average FA profile, S and L were characterized by a high content in linoleic (S = 53.11%; L = 48.74%) and oleic acid (S = 22.05%; L = 26.20%). In general, L showed a higher palmitic acid concentration (16.02%) in comparison with S (11.14%). The composition results agreed with data reported in the literature for both fat sources (Soares and Lopez-Bote, 2002; FEDNA, 2015). On the other hand, A (experiment 2) was mainly composed of MUFA, in particular oleic acid (51.25%), but also contained linoleic (29.18%) and palmitic acids (9.97%). The average unsaturated-to-saturated FA ratio (**UFA:SFA**) was lower for L (4.06) than for S and A (S = 5.14; A = 5.60), whereas the average polyunsaturated-to-saturated FA ratio (**PUFA:SFA**) was higher for S (3.67) than for L and A (L = 2.72; A = 2.04).

Regarding added fats acidity (Table 3), S presented a lower content average of FFA (1.95%) than L (13.85%), whereas A was mainly composed of FFA (52.91%). In addition, L presented higher levels of PL (>38%), where phoshatidylcholine, phosphatidylinositol, and phosphatidylethanolamine were the most abundant. The L composition is according to results provided by Van Nieuwenhuyzen and Tomás (2008). However, it is important to highlight that the lecithin FA profile and PL content are highly dependent on the raw materials they are derived from (vegetable or animal source) and, even within crude soybean lecithin,

Table 4. Analyzed[1] gross energy, macronutrient content, and fatty acid composition for starter and grower-finisher diets[2] (experiment 1).

Item	Starter diet (from 0 to 21 D)				Grower-finisher (from 22 to 38 D)			
	S3	S2-L1	S1-L2	L3	S3	S2-L1	S1-L2	L3
Gross energy (kcal/kg)	4,159	4,121	4,111	4,059	4,165	4,135	4,121	4,125
Macronutrient content (%)								
Dry matter	91.79	91.24	91.22	91.14	90.85	90.62	90.62	91.15
Crude protein	23.66	22.99	22.95	23.54	21.77	20.62	22.25	21.21
Ash	8.43	8.98	8.86	9.47	8.89	8.25	9.43	8.83
Crude fat	5.42	5.49	5.45	5.18	6.33	5.95	5.98	6.08
Crude fiber	3.83	4.43	4.28	3.91	4.90	5.14	4.84	4.26
Fatty acid composition (%)								
C16:0	13.91	14.24	14.75	15.10	20.67	20.17	22.49	24.18
C18:0	3.53	3.85	3.85	3.77	3.43	3.35	3.44	3.46
C18:1 ω-9	19.43	19.35	19.47	19.47	24.49	23.47	25.05	25.68
C18:2 ω-6	54.65	54.08	53.42	53.00	44.14	45.49	41.90	39.74
C18:3 ω-3	6.09	6.11	6.14	6.31	4.72	4.98	4.61	4.41
Minor fatty acids	2.39	2.37	2.37	2.35	2.55	2.54	2.51	2.53
SFA	18.18	18.83	18.98	19.25	25.02	24.44	26.85	28.60
MUFA	21.08	20.98	21.12	21.11	26.37	25.25	26.88	27.50
PUFA	60.74	60.19	59.90	59.64	48.61	50.31	46.27	43.90
UFA:SFA	4.50	4.31	4.27	4.20	3.00	3.09	2.72	2.50
PUFA:SFA	3.34	3.20	3.16	3.10	1.94	2.06	1.72	1.53

[1]All samples were analyzed twice.

[2]S3 = soybean oil at 3.00%; S2-L1 = soybean oil at 2.00% and crude soybean lecithin at 1.00%; S1-L2 = soybean oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA: SFA = unsaturated-to-saturated fatty acid ratio; PUFA:SFA = polyunsaturated-to-saturated fatty acid ratio.

the soy variety, geographic region, weather, storage, and processing conditions have an important influence on the various composition aspects of lecithin (Nguyen et al., 2014). In addition, the GE content was markedly different among the 3 fat sources included in the diets, S and A presented higher GE values (S: 9,396 to 9,621 kcal/kg; A: 9,429 kcal/kg) than L (7,952 to 8,105 kcal/kg), justified by the lower heat combustion provided by PL in comparison with TAG and FFA.

Chemical analysis of diets from experiment 1 (Table 4) showed that as S was replaced by L, dietary SFA increased, in particular palmitic acid, whereas PUFA concentration decreased and, consequently, the UFA:SFA ratio decreased. Similar modifications on the FA profile were observed in piglet diets by Soares and Lopez-Bote (2002). They reported that a partial replacement of soybean oil by crude soybean lecithin (5% of S inclusion vs. 4% of S plus 1% of L) decreased the UFA:SFA ratio from 4.93 to 4.31. On the other hand, in experiment 2 (Table 5), an increasing incorporation of L in replacement of A led to a reduction in dietary MUFA concentration and increased dietary SFA and PUFA content, and, consequently, the dietary UFA:SFA ratio decreased and the PUFA:SFA ratio increased slightly. The addition of L at the expense of A modified the FA diet profile to similar contents of MUFA and PUFA present in diet S3. Regarding S3 treatment, results obtained showed a similar FA profile in both experiments.

Growth Performance and Abdominal Fat Deposition

The trial was successfully carried out, and animals showed good health throughout the entire study. The effect of the different dietary fat sources on growth performance in the starter (from day 0 to 21), the grower-finisher (from day 22 to 38), and the global (from day 0 to 38) periods, and abdominal fat deposition are presented in Tables 6 (experiment 1) and 7 (experiment 2).

The incorporation of L in replacement of S, in experiment 1, did not modify any performance parameter in any phase nor in the global period ($P > 0.05$). In the case of experiment 2, no differences were observed on growth performance among those experimental treatments with co-products as energy sources (A and L) in any feeding phase or the global period of the experiment ($P > 0.05$). Moreover, animals fed S3 obtained better FCR in the grower-finisher phase and the global period of the experiment when compared to those fed A3 ($P \leq 0.05$). Regarding the effect of L supplementation on growth performance, as an alternative to S, our findings agree with the results of Azman and Ciftci (2004). They observed that the partial replacement (50:50) of soybean oil by soybean lecithin (total added fat inclusion, 4% for starter and 6% for grower-finisher diets) did not modify BW (35 D) and global FCR. In contrast with our results, Huang et al. (2007) reported that a 75:25 soybean oil-soybean lecithin blending proportion (2% of total added fat in both starter and grower-finisher diets) improved the global ADG and FCR, whereas the total replacement of soybean oil by soybean lecithin negatively affected final BW, global ADG, ADFI, and FCR, justified by a suppression of food intake and a delay in gastric emptying (Nishimukai et al., 2003). However, in the present experiment, no effect of S total replacement by L on broiler feed intake was observed ($P > 0.05$).

Table 5. Analyzed[1] gross energy, macronutrient content, and fatty acid composition of the starter diet and the grower-finisher diet[2] (experiment 2).

	Starter diet (from 0 to 21 D)					Grower-finisher (from 22 to 38 D)				
Item	S3	A3	A2-L1	A1-L2	L3	S3	A3	A2-L1	A1-L2	L3
Gross energy (kcal/kg)	4,124	4,122	4,083	4,063	3,996	4,198	4,194	4,195	4,172	4,119
Macronutrient content (%)										
Dry matter	91.78	91.78	91.24	91.44	91.14	90.86	90.89	91.26	91.18	90.75
Crude protein	22.32	22.23	21.98	22.33	22.87	22.09	21.25	20.67	21.17	20.38
Ash	8.50	8.36	8.27	8.60	9.24	9.86	9.21	10.31	10.48	10.13
Crude fat	5.46	5.33	5.03	5.30	5.10	6.60	6.60	6.33	6.66	5.87
Crude fiber	4.38	3.84	3.83	4.67	3.48	4.62	4.17	4.09	3.34	4.57
Fatty acid composition (%)										
C16:0	13.51	14.28	14.97	15.68	16.47	19.44	20.48	21.31	22.33	23.75
C18:0	3.70	3.66	3.68	3.47	3.35	3.96	3.95	3.85	3.82	3.74
C18:1 ω-9	20.72	33.51	29.14	24.74	19.68	25.55	38.27	34.22	30.13	25.81
C18:2 ω-6	54.13	43.36	46.57	49.98	53.77	43.72	32.46	35.50	38.28	40.84
C18:3 ω-3	6.55	3.74	4.20	4.69	5.31	5.56	2.73	3.14	3.61	4.04
Minor fatty acids	1.39	1.45	1.44	1.44	1.42	1.77	2.11	1.98	1.83	1.82
SFA	17.21	17.94	18.65	19.15	19.81	23.66	24.71	25.44	26.44	27.80
MUFA	22.11	34.96	30.58	26.18	21.11	27.06	40.10	35.92	31.66	27.32
PUFA	60.68	47.10	50.77	54.67	59.08	49.28	35.19	38.64	41.90	44.88
UFA:SFA	4.81	4.58	4.36	4.22	4.05	3.23	3.05	2.93	2.78	2.60
PUFA:SFA	3.53	2.63	2.72	2.85	2.98	2.08	1.42	1.52	1.58	1.61

[1]All samples were analyzed twice.

[2]S3 = soybean oil at 3.00%; A3 = acid oil at 3.00%; A2-L1 = acid oil at 2.00% and crude soybean lecithin at 1.00%; A1-L2 = acid oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA: SFA = unsaturated-to-saturated fatty acid ratio; PUFA:SFA = polyunsaturated-to-saturated fatty acid ratio.

Table 6. Growth performance and carcass fat depot of broiler chickens according to different fat sources in the diet[1] (experiment 1).

	Dietary treatments[2]					
Item	S3	S2-L1	S1-L2	L3	RSE	*P*-value
From 0 to 21 D						
BW at 0 D (g)	43.9	42.9	43.0	43.0	2.67	0.996
BW at 21 D (g)	834	827	850	818	81.6	0.580
ADFI (g/d/bird)	54.5	55.1	54.6	53.0	2.74	0.585
ADG (g/d/bird)	37.8	37.6	37.5	37.2	2.02	0.956
FCR (g/g)	1.42	1.46	1.42	1.43	0.045	0.286
From 22 to 38 D						
BW at 38 D (g)	2,432	2,442	2,420	2,342	178.2	0.333
ADFI (g/d/bird)	165.4	169.1	166.2	159.3	10.77	0.473
ADG (g/d/bird)	92.7	93.4	90.8	88.6	5.47	0.448
FCR (g/g)	1.78	1.81	1.80	1.80	0.078	0.940
From 0 to 38 D						
ADFI (g/d/bird)	103.6	106.1	104.5	100.6	5.84	0.436
ADG (g/d/bird)	62.4	63.8	60.6	60.0	3.16	0.185
FCR (g/g)	1.66	1.66	1.69	1.68	0.045	0.666
Carcass weight (g)	2,169	2,184	2,175	2,100	81.7	0.309
Abdominal fat depot						
g	45.4	37.3	38.7	37.4	6.46	0.143
(%)	2.07	1.65	1.79	1.77	0.274	0.083

[1]S3 = soybean oil at 3.00%; S2-L1 = soybean oil at 2.00% and crude soybean lecithin at 1.00%; S1-L2 = soybean oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

[2]Values are means of 6 replicates with 4 chickens/replicate from 0 to 21 D and 3 chickens/replicate from 22 to 38 D. In the case of BW, values are means of 24 chickens for each treatment from 0 to 21 D and 18 chickens each treatment from 22 to 38 D.

BW = body weight; ADFI = average daily feed intake; ADG = average daily gain; FCR = feed conversion ratio; RSE = residual standard error.

Previous data regarding A replacement by L and its influence on performance parameters are scarce. Results of experiment 2 (Table 7) show that the replacement of A by L of up to 3% of inclusion does not negatively affect broiler chicken performance ($P > 0.05$). Nevertheless, several studies showed controversial results concerning the inclusion of acid oils instead of conventional added fats in broiler feeding and their influence on performance parameters. Some authors reported a negative influence on growth efficiency

Table 7. Growth performance and fat deposition of broiler chickens according to different fat sources included in the diet[1] (experiment 2).

	Dietary treatments[2]						
Item	S3[3]	A3	A2-L1	A1-L2	L3	RSE	*P*-value
From 0 to 21 D							
BW at 0 D (g)	45.1	45.2	45.1	45.1	45.10	2.47	0.999
BW at 21 D (g)	876	878	871	863	834	104.0	0.602
ADFI (g/d/bird)	56.2	57.1	54.8	57.0	56.9	3.79	0.677
ADG (g/d/bird)	39.6	39.7	39.3	39.0	37.4	3.29	0.649
FCR (g/g)	1.40	1.44	1.40	1.47	1.53	0.084	0.127
From 22 to 38 D							
BW at 38 D (g)	2,469	2,395	2,487	2,405	2,367	253.6	0.576
ADFI (g/d/bird)	163.5	160.9	164.4	163.4	164.0	8.49	0.896
ADG (g/d/bird)	91.7	87.8	93.4	89.3	88.8	7.26	0.563
FCR (g/g)	1.78^{x}	1.86^{y}	1.77	1.83	1.81	0.099	0.600
From 0 to 38 D							
ADFI (g/d/bird)	104.2	103.5	103.8	104.6	104.8	5.12	0.968
ADG (g/d/bird)	62.7	61.2	63.5	61.3	61.5	4.52	0.788
FCR (g/g)	1.66^{x}	1.71^{y}	1.64	1.71	1.68	0.078	0.401
Carcass weight (g)	2,229	2,183	2,247	2,194	2,133	151.8	0.641
Abdominal fat depot							
g	43.86	40.61	44.19	41.55	40.14	3.998	0.379
(%)	1.97	1.88	1.99	2.04	1.89	0.214	0.554

^{x,y}ANOVA A3 vs. S3: values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

[1]S3 = soybean oil at 3.00%; A3 = acid oil at 3.00%; A2-L1 = acid oil at 2.00% and crude soybean lecithin at 1.00%; A1-L2 = acid oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

[2]Values are means of 6 replicates with 4 chickens/replicate from 0 to 21 D and 3 chickens/replicate from 22 to 38 D. In the case of BW, values are means of 24 chickens for each treatment from 0 to 21 D and 18 chickens each treatment from 22 to 38 D.

[3]S3 was not included in the statistical analysis against diets containing co-products.

BW = body weight; ADFI = average daily feed intake; ADG = average daily gain; FCR = feed conversion ratio; RSE = residual standard error.

due to its high FFA content and, thus, a lower FA digestibility (Sklan, 1979; Blanch et al., 1996). This is consistent with the differences observed in the FCR results between S3 and A3 treatments. On the contrary, Vieira et al. (2006) concluded that the inclusion of soybean acid oil as an added fat source allowed the animals to obtain similar BW and FCR to broiler chickens fed soybean oil as energy source.

Regarding the effect of the dietary fat source on fat deposition, it is widely recognized that the dietary FA profile modifies abdominal fat deposition. Many authors have reported that animals fed diets with a lower UFA:SFA ratio presented higher levels of abdominal fat deposition, as compared to animals fed diets with a higher UFA:SFA ratio (Ferrini et al., 2008; González-Ortiz et al., 2013). It has been demonstrated that dietary PUFA inhibits lipid synthesis and increases FA oxidation, causing a reduction in abdominal and total body fat deposition (Sanz et al., 2000; Crespo and Esteve-García, 2001). However, no differences were observed between diets in either experiment ($P > 0.05$). This situation may be explained by the average narrow range of the UFA:SFA ratio presented in the grower-finisher experimental diets (experiment 1: S3 = 3.00 and L3 = 2.50; experiment 2: S3 = 3.23, A3 = 3.05 and L3 = 2.60).

Digestibility Balances

The feed AME value and the apparent digestibility of individual FA of the experimental diets in both periods (starter and grower-finisher periods) are given in Tables 8 (experiment 1) and 9 (experiment 2).

In both experiments, FA digestibility increased, numerically, from the starter to the grower-finisher period. It has been largely demonstrated that FA digestibility is lower in young broilers, as compared to adult broilers, and especially in the case of SFA (Baião and Lara, 2005; Tancharoenrat et al., 2013; Vilarrasa et al., 2015; Ravindran et al., 2016). Furthermore, in the present study, the apparent digestibility of unsaturated FA was higher, when compared to SFA, especially in young chicks. Young birds present a limited capacity to digest and absorb fat; nevertheless, this capacity improves with age. This fact is due to many reasons, but especially by a limited bile secretion, an inefficient enterohepatic bile recycling process, and the difficulty to digest and absorb long-chain FA and SFA due to their physicochemical behavior (Krogdahl, 1985; Tancharoenrat et al., 2013).

The starter digestibility balance in experiment 1 (Table 8) showed that L added diets presented a lower AME content as compared to the S3 diet ($P < 0.001$). This fact may be explained because, as S is replaced

Table 8. Apparent fatty acid digestibility (%) and feed AME value (kcal/kg) of starter diet and grower-finisher diet according to different fat sources included in the diet[1] (experiment 1).

	Dietary treatments[2]					
Item	S3	S2-L1	S1-L2	L3	RSE	*P*-value
From 9 to 11 D						
AME	3,050[a]	2,709[b,c]	2,848[b]	2,621[c]	109.7	<0.001
Total FA	79.59	74.48	71.82	70.76	6.298	0.088
SFA	59.46	52.58	51.53	51.57	9.577	0.372
C16:0	66.59	61.53	60.40	61.42	8.246	0.488
C18:0	50.99	45.13	41.65	46.32	12.680	0.531
MUFA	76.71	72.37	69.10	71.57	7.382	0.295
C18:1 ω-9	77.55	73.69	70.30	72.54	7.208	0.311
PUFA	86.61[a]	81.73[a,b]	78.48[b]	77.41[b]	5.372	0.028
C18:2 ω-6	86.29[a]	81.63[a,b]	78.58[b]	75.85[b]	5.412	0.019
C18:3 ω-3	89.53[a]	86.26[a,b]	83.60[b]	82.19[b]	4.039	0.023
From 36 to 37 D						
AME	3,092[a,b]	3,141[a]	2,944[b]	2,966[b]	96.7	0.007
Total FA	83.56	83.72	82.04	82.42	2.620	0.222
SFA	78.71	82.56	80.75	81.63	2.644	0.447
C16:0	81.12	84.04	83.01	84.07	2.167	0.583
C18:0	78.48	83.87	80.43	81.14	3.423	0.210
MUFA	86.05	86.08	85.22	85.81	1.798	0.295
C18:1 ω-9	87.59	87.13	86.76	87.48	1.751	0.315
PUFA	84.71[a]	83.88[a,b]	80.93[b]	80.80[b]	3.323	0.037
C18:2 ω-6	84.57[a]	83.83[a,b]	80.87[a,b]	80.59[b]	3.357	0.038
C18:3 ω-3	86.04[a]	85.35[a,b]	82.67[b]	82.64[b]	2.982	0.037

[a–c]Values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

[1]S3 = soybean oil at 3.00%; S2-L1 = soybean oil at 2.00% and crude soybean lecithin at 1.00%; S1-L2 = soybean oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

[2]Values are pooled means of 6 replicates.

AME = apparent metabolizable energy; FA = fatty acid; SFA = saturated fatty acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; RSE = residual standard error.

by L, animals showed lower apparent PUFA absorption ($P = 0.028$) and, in addition, total FA absorption tended to be worse ($P = 0.088$). These results are in line with data reported by Huang et al. (2007), who observed a lowering effect on the dietary AME value as soybean lecithin was added in substitution of soybean oil (replacement of 50 and 100% of a 2% dietary fat supplementation) in starter diets (excreta collected from broilers of 19 to 21 D of life). In contrast with our results, they also reported that the EE utilization was not modified by total replacement of soybean oil by soybean lecithin, and its utilization was enhanced with a 75:25 blending of soybean oil-soybean lecithin. It is important to highlight that our results did not show any emulsifying effect from lecithin inclusion, as was expected, especially in the case of young chicks and SFA digestibility. Phosholipids, as the main component of L, are amphiphilic substances with surface-active activity, which is the key origin of its application as commercial emulsifiers (Bueschelberguer et al., 2015). Some researchers have suggested that dietary exogenous emulsifiers may enhance the endogenous bile emulsification process during animal fat digestion and absorption, especially in the case of SFA (Jansen et al., 2015; Siyal et al., 2017). However, the crude soybean lecithin emulsifying effect on animal digestion and absorption has been controversial in the literature, due to some authors having proven it (Polin, 1980; Jones et al., 1992), but other authors not (Øverland et al., 1994; Blanch et al., 1996). The effectiveness in emulsifying activity is highly dependent on the saturation degree of the added fat source incorporated in the feed (Jones et al., 1992). The lack of an emulsifier effect on FA digestibility and AME value in experiment 1 could be attributable to using a highly digestible lipid source such as S in the starter diets, instead of a saturated lipid source such as tallow or palm oil.

In the grower-finisher digestibility balance (Table 8), no differences were found in AME between S3 and any of the L supplemented treatments; moreover, S2-L1 treatment showed a higher AME value than S1-L2 and L3 ($P < 0.007$). Total replacement of S by L (L3) caused a decrease in PUFA digestibility ($P = 0.037$), in particular linoleic and linolenic acid, but no differences were observed in total FA digestibility ($P = 0.222$). The results on the grower-finisher dietary AME value were according to those obtained by Huang et al. (2007), who did not observe, in adult broilers (excreta collected from 40 to 42 D of life), any modification in dietary AME content and EE utilization induced by the total replacement of soybean oil by soybean lecithin as the energy source (2% of added fats). The inclusion of L as a substitute of S in starter diets caused a reduction in AME content and FA digestibility; however, a 1% replacement in grower-finisher diets caused no adverse effects on feed AME content and FA digestibility.

Table 9. Apparent fatty acid digestibility (%) and feed AME (kcal/kg) value of starter diet and grower-finisher diet according to different fat sources included in the diet[1] (experiment 2).

	Dietary treatments[2]						
Item	S3[3]	A3	A2-L1	A1-L2	L3	RSE	*P*-value
From 9 to 11 D							
AME	2,977^{x}	2,873^{y}	2,877	2,876	2,786	90.02	0.254
Total FA	79.59^{x}	65.90^{y}	71.65	74.07	69.10	5.011	0.062
SFA	68.10^{x}	51.74^{y,b}	59.55^{a,b}	63.83^{a}	51.97^{b}	6.819	0.018
C16:0	73.10^{x}	61.47^{y}	67.68	70.37	65.28	5.786	0.088
C18:0	70.26^{x}	47.57^{y}	59.71	63.86	53.28	10.130	0.058
MUFA	80.33^{x}	70.53^{y}	76.05	77.48	71.12	5.223	0.081
C18:1 ω-9	80.75	71.89	76.80	79.02	71.12	5.248	0.094
PUFA	82.60^{x}	67.85^{y,b}	73.45^{a,b}	76.02^{a}	73.35^{a,b}	4.298	0.027
C18:2 ω-6	82.08^{x}	67.60^{y,b}	73.22^{a,b}	75.81^{a}	72.99^{a,b}	4.395	0.030
C18:3 ω-3	86.70^{x}	70.76^{y,b}	75.96^{a,b}	78.25^{a}	76.94^{a}	3.287	0.005
From 36 to 37 D							
AME	3,026^{x}	2,940^{y,b}	3,098^{a}	2,851^{b}	2,916^{b}	66.86	<0.001
Total FA	87.01^{x}	84.25^{y,a,b}	85.79^{a}	82.83^{b,c}	81.39^{c}	1.658	0.001
SFA	83.30	81.05^{b}	84.30^{a}	82.11^{a,b}	81.51^{a,b}	1.744	0.021
C16:0	86.13	84.08^{b}	86.80^{a}	84.73^{a,b}	84.22^{b}	1.414	0.036
C18:0	88.14^{x}	84.43^{y,b}	87.33^{a}	85.53^{a,b}	84.05^{b}	1.640	0.011
MUFA	88.23	88.63^{a,b}	89.40^{a}	86.75^{b}	84.57^{c}	1.170	<0.001
C18:1 ω-9	90.05	90.01^{a,b}	90.88^{a}	88.54^{b}	86.64^{c}	1.075	<0.001
PUFA	87.85^{x}	81.52^{y,a,b}	83.40^{a}	80.31^{a,b}	79.38^{b}	2.413	0.050
C18:2 ω-6	87.51^{x}	81.64^{y,a,b}	83.47^{a}	80.30^{a,b}	79.30^{b}	2.403	0.039
C18:3 ω-3	90.45^{x}	80.05^{y}	82.61	80.42	81.06	0.176	0.287

^{x,y}ANOVA S3 vs. A3: values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

$^{a-c}$ANOVA diets with coproducts: values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

[1]S3 = soybean oil at 3.00%; A3 = acid oil at 3.00%; A2-L1 = acid oil at 2.00% and crude soybean lecithin at 1.00%; A1-L2 = acid oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

[2]Values are pooled means of 6 replicates.

[3]S3 was not included in the statistical analysis against diets containing co-products.

AME = apparent metabolizable energy; FA = fatty acid; SFA = saturated fatty acid; MUFA = mono-unsaturated fatty acid; PUFA = polyunsaturated fatty acid; RSE = residual standard error.

Results extracted from the starter balance of experiment 2 (Table 9) showed that the inclusion of A3 at the expense of S3 presented a lower feed AME value ($P \leq 0.05$) and the animals showed lower FA digestibility ($P \leq 0.05$). Similar effects were observed on the grower-finisher balance, where S3 showed a higher AME content ($P \leq 0.05$) and animals absorbed total FA and PUFA better in comparison with animals fed A3 ($P \leq 0.05$). The depressing effect of acid oils on AME content and FA digestibility has been reported by many authors, especially in the case of fat sources with a high saturated FFA content (Sklan, 1979; Wiseman and Salvador, 1991; Roll et al., 2018). Wiseman and Salvador (1991) reported that the feed AME value linearly decreased with increasing FFA content when the combination or replacement of soybean oil (FFA content: 1.44%) by a soybean acid oil (FFA content: 68.34%) was performed. This effect was more pronounced in the case of young broilers and using saturated added fat sources (experiments comparing tallow and palm acid oil with their respective native oils). It has been demonstrated that FFA are more poorly absorbed than TAG because the presence of monoacylglycerol molecules is essential to the mixed micelle formation and, in addition, FFA tend to form insoluble soaps with cations, such as magnesium or calcium (Small, 1991; Ravindran et al., 2016). This fact explains why a high content in FFA (>50%) is directly related to a reduction in FA digestibility and feed AME value, especially in the starter period, as we have seen in experiment 2 (S3 vs. A3; Table 9).

Regarding the substitution of A by L (Table 9), the feed AME value resulted unaffected ($P = 0.254$) during the starter period. Nevertheless, SFA and PUFA absorption was influenced by the added fat source ($P \leq 0.05$), and a tendency in total FA and MUFA apparent absorption was shown ($P < 0.10$). Young broiler chickens fed A1-L2 digested and absorbed dietary SFA and PUFA better, when compared to those animals fed A3. On the other hand, in the grower-finisher period, treatment A2-L1 obtained the highest feed AME content value ($P < 0.001$), a higher TFA, MUFA, and PUFA digestibility, when compared to L3 treatment ($P \leq 0.05$), and a higher SFA digestibility, as compared to A3 treatment ($P = 0.021$). It has been widely demonstrated that blending fats with variated physicochemical properties enhance, by an interaction, the energetic value of fats in comparison with the sum of the energetic values of each individual fat (Peña et al., 2014; Borsatti et al., 2018). The establishment of a synergism between different fat sources could be related to the combination of complementary FA profiles or lipid molecular structures (TAG, FFA, PL, among others). For example, this effect is particularly marked in mixtures of saturated fat sources with unsaturated fat sources, due to the digestibility of SFA and non-polar molecules being

Table 10. Fatty acid composition (%) of abdominal adipose tissue according to different fat sources[1] in diet (experiments 1 and 2).

	Dietary treatments[2]					
	Experiment 1					
Item (%)	S3	S2-L1	S1-L2	L3	RSE	*P*-value
SFA	30.88	29.94	31.50	31.56	1.104	0.087
C16:0	24.57^{a,b}	23.62^{b}	25.10^{a}	25.10^{a}	0.802	0.019
C18:0	5.44	5.44	5.51	5.52	0.523	0.961
MUFA	45.41	46.20	46.88	46.54	1.797	0.645
C18:1 ω-9	37.54	38.30	39.48	38.97	1.295	0.182
PUFA	23.71	23.86	21.84	21.90	1.826	0.226
C18:2 ω-6	21.09	21.06	19.25	19.39	1.621	0.206
C18:3 ω-3	2.03	2.10	1.93	1.93	0.164	0.375
UFA:SFA	2.24	2.34	2.20	2.17	0.118	0.157
	Dietary treatments					
	Experiment 2					
Item (%)	S3[3]	A3	A2-L1	A1-L2	L3	RSE	*P*-value
SFA	29.19	29.81	30.16	30.95	31.62	1.423	0.154
C16:0	23.13	23.61	24.38	25.06	25.18	1.170	0.112
C18:0	5.37	5.34	5.21	5.03	5.56	0.429	0.217
MUFA	46.79^{y}	53.64^{x,a}	51.72^{a}	50.25^{a,b}	46.69^{b}	2.422	0.001
C18:1 ω-9	38.96^{y}	45.41^{x,a}	43.27^{b}	41.40^{b}	38.78^{c}	1.278	<0.001
PUFA	24.45^{x}	16.55^{y}	18.46	18.80	21.69	3.103	0.068
C18:2 ω-6	21.27^{x}	14.94^{y}	16.33	16.82	19.37	2.711	0.066
C18:3 ω-3	2.47^{x}	1.06^{y,b}	1.32^{a,b}	1.44^{a,b}	1.71^{a}	0.253	0.004
UFA:SFA	2.43	2.36	2.32	2.24	2.17	0.151	0.168

$^{x-y}$ANOVA S3 vs. A3: values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

$^{a-c}$ANOVA diets with coproducts: values within the same row with no common superscripts are significantly different, $P \leq 0.05$.

[1]S3 = soybean oil at 3.00%; S2-L1 = soybean oil at 2.00% and crude soybean lecithin at 1.00%; S1-L2 = soybean oil at 1.00% and crude soybean lecithin at 2.00%; A3 = acid oil at 3.00%; A2-L1 = acid oil at 2.00% and crude soybean lecithin at 1.00%; A1-L2 = acid oil at 1.00% and crude soybean lecithin at 2.00%; L3 = crude soybean lecithin at 3.00%.

[2]Values are pooled means of 6 replicates.

[3]S3 was not included in the statistical analysis against diets containing coproducts.

SFA = saturated fatty acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; UFA:SFA = unsaturated-to-saturated fatty acid ratio; RSE = residual standard error.

improved by the emulsifying properties of unsaturated FA (Sibbald, 1978; Borsatti et al., 2018). The emulsifying effect of crude soybean lecithin with a saturated native oil is another example of synergism. Results from a digestibility balance in laying hens conducted by Mandalawi et al. (2015) confirmed that the combination of a saturated animal fat with soybean lecithin in a blend of 50:50 (4% of added fat inclusion) improved total tract apparent retention of EE and GE. Another experiment in broiler chickens (Polin, 1980) combined tallow at 4% with different inclusion rates of soybean lecithin (0.02, 0.2, and 2%) and stated that 2% of soybean lecithin supplementation significantly improved tallow absorption in comparison with those diets containing 0.02 and 0.2% of soybean lecithin. Similar results were obtained in piglet diets (Jones et al., 1992). In this study, the combination of L and A, with a similar UFA:SFA ratio, but with a different (and complementary) FA profile and lipid molecular structures (FFA from A combined with surface-active PL from L; Table 3), obtained the best results. Dietary and endogenous PL play an important role in mixed micelle formation displacing monoacylglycerol and FFA molecules from the interface to the hydrophobic core of the mixed micelle and, due to this, they are capable of improving the absorption of lipids (Krogdahl, 1985). In experiment 2, the addition of L at 2% in starter diets and at 1% in grower-finisher diets in replacement of A resulted the best option in terms of FA digestibility and feed AME content.

Fatty Acid Composition of Abdominal Fat Adipose Tissue

The effect of dietary fat sources on the FA composition of AFP is presented in Table 10.

In experiment 1, S replacement by L produced changes between treatments for palmitic acid concentration ($P = 0.019$), and also a tendency ($P = 0.087$) for SFA was observed; however, in general, the use of one added fat source instead of the other did not modify the FA profile of the AFP.

In the case of experiment 2, the AFP of animals fed S3 presented a higher percentage of PUFA ($P \leq 0.05$) and a lower percentage of MUFA ($P \leq 0.05$) than animals fed A3. Regarding the replacement of A by L, the total replacement of A by L in the diet (L3) caused a significant increase in linolenic acid concentration ($P = 0.004$) and also tended to increase linoleic acid ($P = 0.066$), whereas a decrease ($P < 0.001$) in oleic acid concentration was observed.

As other authors reported before, the FA composition found in abdominal fat tissue reflected the FA profile of the experimental diets (Ferrini et al., 2008; Smink et al., 2010; Vilarrasa et al., 2015). In experiment

1, both fat sources presented a similar FA profile, UFA:SFA and PUFA:SFA ratios (Table 3); for this reason, few differences were observed between treatments in most FA. On the other hand, in experiment 2, both fat sources influenced and changed FA composition of AFP, and these changes were according to the main differences shown between A and L diets (Table 5), especially in the case of MUFA and PUFA concentration. Results show that dietary FA composition has a greater impact on the saturation degree of AFP than the lipid molecular structures have.

In conclusion, crude soybean lecithin is a suitable energy source for broiler chickens in the grower-finisher period. The inclusion of 1% of L in replacement of S in the grower-finisher phase did not affect feed AME content, FA digestibility, and, in turn, preserved productive performance and the FA profile of the AFP. On the other hand, the combination of L and A (2% of L and 1% of A in the starter and 1% of L and 2% of A in the grower-finisher) is the best strategy to include both alternative fats as energy source in broiler chicken diets, probably related to the positive synergism between FFA and PL. It was observed that the dietary FA profile has a greater impact on AFP saturation degree in comparison to the lipid molecular structures (TAG, PL, and FFA). Further studies might bring a better understanding of the mechanisms underlying these effects.

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