Blood lipid metabolites and meat lipid peroxidation responses of broiler chickens to dietary lecithinized palm oil

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Abstract

This trial was conducted to investigate the effects of supplementing saturated and unsaturated fat sources on serum metabolites and meat physiochemical parameters in the diets of broiler chickens. A total of 360 day-old male broiler chicks (Ross 308) were used in a completely randomized design with five treatments and six replicates of 14 chicks. The assay diets were developed by applying a basal diet with no supplemented fat and the addition of soybean oil (SO), lecithinized palm oil (LPO), a 50 : 50 mix of SO and LPO (ESL), and 75 : 25 mix of SO and LPO (HSL) ratios to the basal diet. The inclusion levels of experimental fats were 2% and 4% in the starter and growing periods, respectively. Blood samples were collected from broilers to evaluate serum biochemical metabolites on day 41. Thigh meat samples were provided and analysed after 1, 5 and 10 days' storage to evaluate lipid peroxidation at the end of the experiment. Fat and protein contents of thigh muscle and abdominal fat weight were measured and reported. Chickens fed LPO had greater serum triacylglycerol and very low density lipoprotein concentrations compared with those that received other dietary treatments (P <0.05). The fat content of the meat was higher in birds supplemented with SO, LPO and ESL than control (P <0.05). After 5 and 10 days of storage, the values of thiobarbituric acid reactive substance were lower in meat of broilers receiving LPO than SO and HSL (P <0.05). In conclusion, LPO decreased lipid peroxidation during different storage periods compared with SO.

Keywords: Blood parameters, broilers, fat type, meat physiochemical parameters

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Introduction

Nowadays, there is an increasing trend to replace animal fat sources with vegetable oils in the diet of broiler chickens. Animal fats (e.g. tallow, poultry fat) are known to have high content of saturated fatty acids (SFA), while vegetable oil sources are rich in unsaturated fat types (Ravindran *et al*., 2016). Although poly-unsaturated fatty acids (PUFA) have greater digestibility than saturated ones, excessive consumption might favour lipid peroxidation, inhibit synthesis of higher homologous of essential fatty acids, alter membrane structures, and impair immune function (Martinez & Ballabriga, 1987; Kang *et al*., 2001; Trivedi & Singh, 2005). The effect of fat type in broiler diets on blood triacylglycerol and lipoprotein concentrations has been demonstrated by researchers (Crespo & Esteve-Garcia, 2003; Wongsuthavas *et al*., 2007; Viveros *et al*., 2009). However, various concentrations of blood metabolites have been observed in response to the consumption of different fat types. For example, fat sources containing SFA increased blood triacylglycerol concentration in broiler chickens (Velasco *et al*., 2010). The use of several types of palm oil products, such as crude palm oil, refined palm oil, palm olein and palm acid oils in poultry diet, has been reported in the literature (Tancharoenrat *et al*., 2013). In the current study, lecithinized palm oil (LPO) (Osmosis Nutrition Sdn. Bhd) was assayed. Lecithinized palm oil is a type of processed vegetable fat powder. Lecithin as an emulsifier might contribute to the intestinal fatty acid emulsification and consequently enhance fat digestion.

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To the authors' knowledge, the effect of LPO on blood metabolites of broiler chickens has not been investigated and further research in this field is therefore warranted.

In the poultry industry, maintaining meat quality is a challenge for producers. Safe, effective, and cost-efficient approaches should be established to increase the stability of broiler meat products during storage (Kang *et al*., 2001). Dietary administration of synthetic antioxidants and the inclusion of dietary tocopherol are well documented. Nevertheless, certain synthetic antioxidants have been associated with deleterious effects on poultry and consumers (Kang *et al*., 2001). Accordingly, more research is needed to study other methods for decreasing the peroxidation of lipids in meat products. Lecithinized palm oil has large amounts of SFA, which might be beneficial for meat oxidative stability. Additionally, palm oil contains antioxidants such as oleic and linoleic acids, and vitamin E tocotrienols, which inhibit cholesterol synthesis as well (Chong & Ng, 1991). Furthermore, the ratio of SFA : monounsaturated fatty acid (MUFA) : PUFA in diets rich in palm oil is close to 1 : 1 : 1, which is recommended by the World Health Organization (WHO) (Trivedi & Singh, 2005). The effective role of palm oil in reducing lipid peroxidation has been shown in the eggs of laying hens (Kang *et al*., 2001) and meat of broiler chickens (Ura *et al*., 2008). Jahja *et al.* (2011) remarked that fat sources consisting of SO, palm oil and linseed oil affect egg production rate, egg weight and yolk proportion. However, research in the field of LPO on the meat oxidative stability of broiler chickens is scarce. The hypothesis of this study was that LPO or its combination with other oils would affect the blood parameters and meat oxidative stability in broiler chickens.

Thus, the objective of the current study was to examine the effects of LPO and SO individually and in combination on serum lipid metabolites and lipid peroxidation in thigh meat of broilers during various storage times.

Material and Methods

Three hundred and sixty day-old male broiler chicks (Ross 308) were purchased from a commercial hatchery and used in this experiment. At arrival, chicks were weighed, wing banded, and assigned to treatment groups so that the initial weight was similar among treatments (45 ± 0.5 g). Six replicates comprising 30 cages of 12 chicks each were randomly allotted to five dietary treatments in a completely randomized design across starter (1–21) and growing-finishing (21–42) periods. Diets were in mash form, and the inclusion levels of experimental fats were 2% and 4% in the starter and growing periods, respectively. Dietary treatments included a basal diet with no supplemented fat and either soybean oil (SO), lecithinized palm oil (LPO), a 50 : 50 mix of SO and LPO (ESL) and a 75 : 25 mix of SO and LPO (HSL) ratios added to the basal diet. Experimental diets were formulated to meet or exceed NRC (1994) recommendations (Tables 1 and 2). Chicks were housed in 124 × 65 cm battery cages and had free access to feed and water throughout the trial. The ambient temperature was gradually decreased from 33 °C at first week to 25 °C on day 21 and was then kept constant. The lighting programme consisted of 23 hours light and 1 hour darkness. All the experimental procedures were evaluated and approved by the Institutional Animal Care and Ethics Committee from the Islamic Azad University, Isfahan (Khorasgan) Branch.

After 12 hours of fasting, blood samples were collected in non-heparinized tubes on day 41 of age from two birds per pen by puncturing the brachial vein. The blood was centrifuged at 2000×g for 15 min to obtain serum (SIGMA 4-15 lab centrifuge, Germany). Individual serum samples were analysed for total cholesterol, triacylglycerol, high-density lipoprotein (HDL), low-density lipoprotein (LDL) and very low density lipoprotein (VLDL) using the kit package (Pars Azmoon Co., Tehran, Iran).

On day 42 of the trial, three birds from each cage were selected according to the average bodyweight in the cage and were slaughtered. Their left thighs were removed, deboned, and ground, then a portion of 100 g minced thigh muscle was immediately stored in plastic bags at 4 °C in a refrigerator for 1, 5 and 10 days to measure lipid oxidation. The abdominal fat of carcasses was excised, weighed, and reported as live bodyweight basis.

Lipid oxidation was monitored by measuring thiobarbituric acid reactive substances (TBARS), using the method described by Strange *et al.* (1977). Briefly, 20 g minced muscle was blended with 50 mL cold 20% trichloroacetic acid (TCA) for 2 minutes. The blender contents were rinsed with 50 mL of water, mixed together, and filtered through a Whatman #1 filter, and TCA extract was prepared. Then 5 mL aliquot of the TCA extract was mixed with 5 mL of 0.01 M 2-thiobabituric acid and heated in a boiling water bath for 45 min. After cooling under running tap water for 10 min, colour development, measured as absorbance at 532 nm by spectrophotometer (model110 RS; Unico, Dayton, NJ), was identical when a colour development procedure was used with a standard solution of tetraethoxypropane or with TCA extracts of meat. Oxidation products were quantified as malondialdehyde equivalents (mg malondialdehyde kg−1 meat).

Table 1 Dietary composition and nutrients at 1 to 21 days old

Ingredients	Treatments [1]				
	Control	SO	LPO	ESL	HSL
Corn	583	539	544	542	540
Soybean meal	372	396	391	393	395
Soybean oil	0	20	0	10	15
Lecithinized palm oil	0	0	20	10	5
Monocalcium phosphate	16	16	16	16	16
Calcium carbonate	16	16	16	16	16
DL-Methionine	3	3.1	3.1	3.1	3.1
L-Lysine	1.8	1.7	1.7	1.7	1.7
L-Threonine	0.7	0.7	0.7	0.7	0.7
Choline	1	1	1	1	1
Vitamin premix [2]	1	1	1	1	1
Mineral premix [3]	1	1	1	1	1
Sodium chloride	2.7	2.7	2.7	2.7	2.7
NaHCO3	1.8	1.8	1.8	1.8	1.8
Total	1000	1000	1000	1000	1000
Calculated nutrient level					
ME (Mj/kg)	12.01	12.14	12.04	12.09	12.12
Crude protein (g/kg)	211.2	218.3	216.5	217.4	217.8
Lysine (g/kg)	12.6	13	12.9	13	13
Methionine + Cysteine (g/kg)	6.1	6.4	6.3	6.3	6.4
Calcium (g/kg)	10	10	10	10	10
Available phosphorous (g/kg)	5	5	5	5	5
Analysed values					
Dry matter (g/kg)	916.1	919.3	925.5	924.6	925.6
Crude protein (g/kg)	227.8	223.7	225.6	210.7	211.9
Ether extract (g/kg)	32	50.6	57.7	54.1	54.7
Ash (g/kg)	77.6	82.6	78.2	66.7	76.4

[1]SO: soybean oil, LPO: lecithinized palm oil, ESL: 50:50 mix of SO, LPO: 75:25 mix of SO and LPO
[2]Vitamin premix provided per kg of diet: vitamin A (retinol), 12000 IU; vitamin D3 (Cholecalciferol), 4500 IU; vitamin E (tocopheryl acetate), 70 IU; vitamin k3, 3.5 mg; thiamine 3 mg; riboflavin, 7.5 mg; pantothenic acid, 18 mg; pyridoxine, 4.3 mg; cyanocobalamin, 0.017 mg; niacin, 65 mg; biotin, 0.3 mg; folic acid, 2 mg; choline chloride, 600 mg; antioxidant 100 mg
[3]Mineral premix provided per kg of diet: Fe (FeSO4.7H2O, 20.09% Fe), 80 mg; Mn ($MnSO_4.H_2O$, 32.49% Mn), 120 mg; Zn (ZnO, 80.35% Zn), 110 mg; Cu ($CuSO_4.5H_2O$), 16 mg; I (KI, 58% I), 1.3 mg; Se ($NaSeO_3$, 45.56% Se), 0.3 mg

Representative samples of the diets were ground (1-mm) and analysed for chemical composition. The results are summarized in Tables 1 and 2, respectively. Dry matter and crude protein of diet samples were determined using methods 930.15 and 990.03, respectively (AOAC, 2000). Ether extract (EE) of diets was analysed by Soxhlet fat analysis after acid hydrolysis (method 954.02) as described by AOAC (2000). The ash contents were determined based on methods reported by Debon & Tester (2001). Fatty acid composition of fat sources was determined following the procedure reported by Sukhija & Palmquist (1988) and results are summarized in Table 3. Meat protein was determined with the standard Kjeldahl copper catalyst method (AOAC, 1990). Intramuscular fat content was determined with the Soxhlet procedure according to the AOAC (1990).

Table 2 Dietary composition and nutrients at 21 to 42 days old

Ingredients	Treatments [1]				
	Control	SO	LPO	ESL	HSL
Corn	652	569	578	573	571
Soybean meal	306	349	340	345	347
Soybean oil	0	40	0	20	30
Lecithinized palm oil	0	0	40	20	10
Monocalcium phosphate	14.3	14.4	14.4	14.4	14.4
Calcium carbonate	16	16	16	16	16
DL-Methionine	2.5	2.9	2.9	2.9	2.9
L-Lysine	1.2	0.9	0.9	0.9	0.9
L-Threonine	0.6	0.6	0.6	0.6	0.6
Choline	1	1	1	1	1
Vitamin premix [2]	1	1	1	1	1
Mineral premix [3]	1	1	1	1	1
Sodium chloride	1.1	2	2	2	2
NaHCO3	3.3	2.2	2.2	2.2	2.2
Total	1000	1000	1000	1000	1000
Calculated nutrient level					
ME (Mj/kg)	12.30	12.90	12.70	12.81	128.6
Crude protein (%)	186.3	199.1	196	197.6	198.5
Lysine (%)	10.5	11.2	11	11.1	11.2
Methionine + Cysteine (%)	8.5	9.1	8.9	9	9
Calcium (%)	9.5	9.5	9.5	9.5	9.5
Available phosphorous (%)	4.5	4.5	4.5	4.5	4.5
Analysed values					
Dry matter	908.8	917.4	902	916.3	915
Crude protein	196.3	209.1	201	192.2	195.8
Ether extract	30.1	73.9	71.9	63.5	72.9
Ash	90.2	70.1	71.9	63.5	72.9

[1]SO: soybean oil; LPO: lecithinized palm oil; ESL: 50 : 50 mix of SO; LPO: 75 : 25 mix of SO and LPO
[2]Vitamin premix provided per kg of diet: vitamin A (retinol), 12000 IU; vitamin D3 (Cholecalciferol), 4500 IU; vitamin E (tocopheryl acetate), 70 IU; vitamin k3, 3.5 mg; thiamine 3 mg; riboflavin, 7.5 mg; pantothenic acid, 18 mg; pyridoxine, 4.3 mg; cyanocobalamin, 0.017 mg; niacin, 65 mg; biotin, 0.3 mg; folic acid, 2 mg; choline chloride, 600 mg; antioxidant 100 m.
[3]Mineral premix provided per kg of diet: Fe (FeSO4.7H2O, 20.09% Fe), 80 mg; Mn ($MnSO_4$.H2O, 32.49% Mn), 120 mg; Zn (ZnO, 80.35% Zn), 110 mg; Cu ($CuSO4.5H_2O$), 16 mg; I (KI, 58% I), 1.3 mg; Se ($NaSeO_3$, 45.56% Se), 0.3 mg

Data were subjected to an analysis of variance appropriate to a completely randomized design using the general linear model (GLM) procedure of SAS 9.2 (SAS Institute Inc., Cary, NC). If a significant effect was detected, differences between treatments were separated with the LSD test. Statements of statistical significance are based on a probability of $P < 0.05$, unless otherwise stated.

Table 3 Fatty acid composition of lecithinized palm oil and soybean oil (g/kg)

	LPO [1]	SO [2]
Saturated fatty acids		
C12:0 Lauric	0.8	-
C14:0 Myristic	12.0	0.9
C16:0 Palmitic	751.6	108.9
C17:0 Margaric	1.5	1.0
C18:0 Stearic	52.9	44.6
C20:0 Arachidic	3.4	4.0
C21:0 Heneicosanoic	-	0.3
C22:0 Behenic	0.6	4.4
C23:0 Tricosanoic	0.1	0.5
C24:0 Lignoceric	0.6	1.5
Unsaturated fatty acids		
C16:1 Palmitoleic	0.5	0.9
C17:1 Heptadecenoic	0.1	0.6
C18:1 Elaidic	135.3	221.2
C18:2 Linoleic	38.3	537.6
C18:3 Linolenic	2.1	70.6
C20:1 Eicosenoic	0.4	2.0
C20:2 Eicosadienoic	-	0.4
C20:3 Eicosatrienoic	-	0.2
C20:4 Arachidonic	0.1	0.3
Total fatty acids	999.2	999.9
Saturated	823.5	166.1
Unsaturated	176.8	833.8
Unsaturated to saturated ratio	0.21	5.01

[1] Lecithinized palm oil; [2] soybean oil

Results

Results of serum biochemical parameters are summarized in Table 4. Dietary fat sources influenced serum lipids. Accordingly, chickens fed on LPO-added diets had substantially greater triacylglycerol and VLDL concentrations than those birds that received other dietary treatments (P <0.05). Otherwise, serum cholesterol, HDL and LDL concentrations were not affected by dietary treatments.

The least meat fat content was observed in broilers supplemented with control diets (without oil supplementation). This was considerably lower than the other experimental treatments (Table 5) (P <0.05). Otherwise, fat content of the meat in broilers of ESL group was greater than control, LPO, and HSL (Table 5) (P <0.05). Additionally, meat protein content in control birds was significantly higher than SO and ESL (Table 5) (P <0.05). Furthermore, birds fed on control diet had remarkably greater moisture content of the thigh meat than broilers in LPO, ESL and HSL groups (Table 5; P <0.05). Abdominal fat significantly increased in broilers received LPO compared with the birds in control and SO groups (Table 5) (P <0.05).

Table 4 Effect of dietary fat types on blood biochemical parameters in broiler chickens

Blood Parameters	Treatments [1]					
	Control	SO	LPO	ESL	HSL	SEM
Cholesterol (mg/dl)	121.18	113.13	121	123.83	112.08	1.906
Triacylglycerols (mg/dl)	45.64^{c}	50.63^{c}	85.55^{a}	67.79^{b}	60.02^{bc}	2.924
HDL[2] (mg/dl)	78.61	78.38	75.91	78.55	74.08	1.030
LDL[3] (mg/dl)	35.64	25.88	33.80	34.31	30.10	0.920
VLDL[4] (mg/dl)	9.13^{c}	10.13^{c}	17.10^{a}	13.54^{b}	12.22^{bc}	0.584

$^{a, b, c, d}$ Means in the same row with different superscript differ significantly (P <0.05)
[1] SO: soybean oil, LPO: lecithinized palm oil, ESL: 50:50 ratio of soybean oil and lecithinized palm oil, HSL: 75:25 ratio of soybean oil and lecithinized palm oil
[2] HDL: High density lipoproteins
[3] LDL: low density lipoproteins
[4] VLDL: very low density lipoproteins

On day 1 of meat storage, TBARS values were greater in birds fed on ESL and HSL than those fed on the control diet (Table 5) (P <0.05), whereas lower values were observed in meat of broilers supplemented with SO than the other groups (Table 5) (P <0.05). As storage time continued until day 5, TBARS increased in samples related to SO and HSL groups compared with control (Table 5) (P <0.05), while meat samples of LPO and ESL remained somewhat stable with no significant difference in comparison with control. After 10 days of storage, birds fed on SO and HSL-added diets had the greatest meat TBARS values compared with the other dietary treatments (Table 5) (P <0.05).

Table 5 Effect of dietary fat types on meat quality, abdominal fat and thiobarbituric acid reactive substances during different storage times

Parameters	Treatments [1]					
	Control	SO	LPO	ESL	HSL	SEM
Meat quality						
Protein (%)	19.18^{a}	18.37^{bc}	18.83^{ab}	18.00^{c}	18.70^{abc}	0.125
Fat (%)	4.58^{c}	6.03^{ab}	5.98^{b}	7.20^{a}	5.58^{bc}	1.267
Moisture (%)	73.71^{a}	72.79^{ab}	72.12^{b}	71.66^{b}	72.41^{b}	0.211
Abdominal fat (% BW)	0.57^{d}	0.79^{cd}	1.15^{ab}	1.46^{a}	0.95^{bc}	0.230
TBARS [2]						
Day 1(mg/kg meat)	0.1096^{c}	0.0825^{d}	0.1181^{bc}	0.1349^{a}	0.1260^{ab}	0.003
Day 5 (mg/kg meat)	0.2648^{b}	0.4299^{a}	0.3155^{b}	0.2843^{b}	0.4813^{a}	0.025
Day 10 (mg/kg meat)	0.9130^{d}	2.4564^{a}	1.1812^{c}	1.3645^{c}	2.7713^{a}	0.135

$^{a, b, c, d}$ Means in the same row with different superscript differ significantly (P<0.05)
[1] SO: soybean oil, LPO: lecithinized palm oil, ESL: 50 : 50 ratio of soybean oil and lecithinized palm oil, HSL: 75 : 25 ratio of soybean oil and lecithinized palm oil
[2] Thiobarbituric acid reactive substance

Discussion

In the current study, LPO contained 823.5 g/kg SFA versus 176.8 g/kg unsaturated fatty acids, while SO contained 833.8 g/kg unsaturated fat types (Table 3). The composition of fatty acids is known to have crucial importance in evaluating fat sources of poultry diets (Burlikowska *et al.,* 2010). Greater concentration

of serum triacylglycerol in broilers supplemented with LPO than SO might be the reason that LPO is rich in saturated versus unsaturated fatty acids, whereas SO is known to be high in unsaturated fat types. The modifying impact of dietary fat types on serum triacylglycerol and lipoproteins has been suggested (Velasco *et al*., 2010).Generally, fats containing high concentration of SFA increase blood triacylglycerol and reduce the PUFA to SFA ratio of deposited fat in broiler tissues (Velasco *et al*., 2010). Moreover, lecithin might increase the blood triacylglycerol, as observed in the work of Huang *et al.* (2008), who demonstrated that 2% lecithin supplementation increased serum triacylglycerol compared with broilers in control group. Therefore, it seems that dietary supplementation of SO modified the effect of LPO in ESL-fed broilers and resulted in lower concentrations of blood triacylglycerol and VLDL than the LPO group. Mechanisms involving the effect of dietary fat on serum lipid concentrations are not completely understood. However, lack of serum triacylglycerol variations of SO-fed birds compared with chickens in control group might in part be because of the reducing effect of PUFA on hepatic fatty acids and triacylglycerol synthesis. PUFAs have inhibitory effects on Δ9-desaturase, which might result in impaired secretion of VLDL-cholesterol and triacylglycerol from the liver to the blood (Legrand *et al*., 1987; Løchsen *et al*., 1997; Cerqueira *et al*., 2011). Additionally, consuming diets rich in unsaturated fat types may increase the rate of β-oxidation and elevate the rate of triacylglycerol uptake from blood to the tissues that decrease the blood triacylglycerol. Noted mechanisms show that there might be a link between VLDL and triacylglycerol concentrations in blood samples of the current trial following LPO consumption. In accordance with the current results, Velasco *et al.* (2010) reported that broilers received diets containing palm oil had greater serum triacylglycerol than those fed on sunflower oil-supplemented diets. Moreover, Sanz *et al.* (2000) observed lower blood triacylglycerol concentrations in broilers fed on SO compared with tallow as a saturated fat source. On the contrary, Baldizan *et al.* (2010) failed to indicate any difference between blood lipid concentrations in broilers receiving peach palm oil compared with crude palm oil, although peach palm oil had 43.5% less SFA. These discrepancies indicate the need for further research in this field.

Generally, nutrition is a factor that is known to affect the chemical composition of broiler meat. Accordingly, in the current study, birds supplemented with LPO and ESL had higher meat fat content than those in the control group. Nevertheless, the fat content of the meat in broilers receiving LPO and ESL was not different from SO-fed birds. Otherwise, chickens fed on LPO and ESL possessed greater abdominal fat than both control and SO. The concentration of blood VLDL could be an indicator of fat deposition in the abdominal area and meat of broilers (Whitehead & Griffin, 1984). The current results indicated that serum VLDL in chickens that received LPO and ESL was higher than the other groups. Thereby, lipids that are transferred from the liver via VLDL probably had more pronounced effects on lipid contents in adipose tissue compared with meat fat. This is consistent with the report of Crespo & Esteve-Garcia (2002). Meat protein content in control birds was the maximum value between groups. In this regard, protein deposition may be increased in response to lower fat content of the meat. It confirms the reduced dietary fat intake of control chickens and consequently lower fat deposition in their meat.

The development of malondialdehyde values in the muscle foods is an indicator of lipid oxidation that can be quantified by spectrophotometry. Malondialdehyde is a group of secondary by-products derived from the degradation of fatty acids. The reaction of aldehydes and ketones with TBA produces TBARS (Guillen-Sans & Guzman-Chozas, 1998). The lower TBARS values in the thigh meat of the chickens that received LPO and ESL compared with SO and HSL during storage may be because of greater ratios of SFA accumulation in their meat, since dietary fats influence the lipid composition of chicken muscle (Yau *et al*., 1991). This shows that palm oil is an appropriate source to use in poultry feeds to protect meat from peroxidation compared with unsaturated fats. Furthermore, the current results suggested that peroxidation of the meat fat during the storage time depends mostly on the fatty acid profile of the consumed fat source, although dietary fat resulted in higher fat deposition in adipose tissue than meat. Reports have indicated that saturated fat sources are more conserved toward lipid peroxidation than unsaturated fatty acids (Lopez-Bote, 2000; Kang *et al*., 2001). Also, research has demonstrated that lipid peroxidation in the meat could develop during storage time owing to the effect of enzymatic (Asghar *et al*., 1988) and inorganic iron activity (Kanner *et al.,* 1988). Accordingly, Smink *et al*. (2008) remarked that randomized palm oil increased saturated fat deposition in the meat of broilers compared with vegetable oils that are rich in unsaturated fatty acids and improved meat firmness. In line with the current results, a diet with high palm oil content reduced TBARS values in eggs of laying hens more than a diet that is low in palm oil (Kang *et al*., 2001). It has been also reported that graded levels of unsaturated fat sources such as sunflower oil increased lipid peroxidation in thigh and breast muscle in broiler chickens during various storage periods (Gheisari *et al*., 2004).

Conclusion

A conclusion that emerged from this study is that LPO and ESL increased serum triacylglycerol and VLDL compared with the other groups, while most of the lipids transferred through VLDL were deposited in

adipose tissue compared with meat. However, dietary inclusion of LPO as a saturated fat source caused lower lipid peroxidation during long-term storage in comparison with SO or HSL, suggesting that a higher ratio of unsaturated to saturated fat sources might increase lipid peroxidation. It shows the key role of choosing proper fat sources in diet formulation, considering the current production target.

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Authors' Contributions

AG contributed to the project idea, design and execution of the study. SSASF was in charge of project assistance, executing the study and writing the manuscript. SP and ENE participated in project implementation and MM was involved in statistical analysis of the study.

Conflict of Interest Declaration

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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