ITALIAN JOURNAL OF ANIMAL SCIENCE
2021, VOL. 20, NO. 1, 1612–1619
https://doi.org/10.1080/1828051X.2021.1973599

Taylor & Francis
Taylor & Francis Group

PAPER

Efficacy of lysophospholipids on growth performance, carcase, intestinal morphology, microbial population and nutrient digestibility in broiler chickens fed different dietary oil sources

Ali Solbi, Vahid Rezaeipour, Rohullah Abdullahpour and Shahabodin Gharahveysi

Department of Animal Science, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran

ABSTRACT

An experiment was conducted to investigate the growth performance, microbial population, intestinal morphology and nutrient digestibility of broiler chickens fed diets supplemented with lysophospholipids (LPL) in combination with soybean (SO), flaxseed (FSO) or sesame seed (SSO) oil sources. A completely randomised design with a 2 × 3 factorial arrangement including two levels of LPL (0 or 0.1% Lipidol) and three different oil sources was used. A total of three hundred one-day-old broiler chicks were randomly allocated into six treatments of five pens with ten birds per pen. The results showed that body weight gain (BWG) and feed conversion ratio (FCR) significantly increased in broilers fed dietary LPL and SSO ($p < .05$). There was a significant interaction between the oil sources and LPL supplementation on 10 days of age ($p < .05$). Inclusion of SSO to the diets increased villus width and villus surface area compared with SO diet ($p < .05$). Broilers fed LPL supplemented diets had lower crypt depth, while villus length to crypt depth ratio was greater in broilers fed LPL supplementation ($p < .05$). *Lactobacillus* population increased in broilers fed LPL supplemented diet compared to those without dietary LPL ($p < .05$). Inclusion of LPL increased ileal digestibility of dry matter, crude protein and ether extract ($p < .05$). Broiler fed SSO diets had greater digestibility coefficient for ether extract compared with SO group ($p < .05$). In conclusion, dietary LPL supplementation and SSO increased growth performance, intestinal morphology, microbiota activity and nutrient digestibility in broiler chickens.

HIGHLIGHTS

- Lysophospholipids (LPL) supplementation increased growth performance, intestinal morphology, and microbiota activity in broiler chickens.
- Supplemental LPL enhanced ileal nutrient digestibility coefficients in broiler chickens.
- Dietary sesame seed oil (SSO) increased growth performance, ether extract digestibility and intestinal morphometric variables in broiler chickens compared with soybean oil (SO).

ARTICLE HISTORY
Received 22 July 2021
Revised 21 August 2021
Accepted 24 August 2021

KEYWORDS
Lysophospholipids; broilers; oil; microbiota; nutrient digestibility

Introduction

Lipids (oils and fats) are widely added into poultry diets to enhance the dietary energy concentration, increase the bioavailability of fat-soluble vitamins, and increase feed palatability. Lysophospholipids (LPL) are different mixtures of biosurfactants (emulsifiers) that derive from an enzymatic hydrolysis (phospholipase A1 or A2) of phospholipids and aid in the digestion and absorption of lipids (Haetinger et al. 2021). The mechanism of action of LPL has been well documented as hydrophilic compounds properties and thus a better oil–water emulsification capacity (Zampiga et al. 2016). Dietary LPL increase monoglycerides and diglycerides release by emulsion of dietary fat and promote incorporation of fatty acids into micelles and increase fat digestibility (Zhao and Kim 2017). It has been observed that LPL supplemented diets enhanced energy retention and intestinal morphometric indices including villus length or absorption area in broiler chickens (Brautigan et al. 2017). In addition, it has been documented that LPL increases gut permeability to bimolecular compounds such as proteins, enzyme activity, impact on the formation of protein channels and cause duodenal epithelial cells hypertrophy in broiler chickens (Zampiga et al. 2016).

CONTACT Dr. Vahid Rezaeipour Vrezaeipour@gmail.com, Vrezaeipour@qaemiau.ac.ir Department of Animal Science, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran.

Therefore, it is assumed that enhancing lipid digestibility as a result of using LPL supplementation may increase growth performance and gut health of broiler chickens.

Various sources of lipids such as animal fats and vegetable oils are used in the broiler rations. Several factors may influence dietary lipids digestion and absorption in broiler chickens such as lipid source, fatty acid composition, the saturation degree of lipid and the chain length of fatty acids (Tancharoenrat et al. 2013). The use of vegetable oils is more important than animal fats in poultry nutrition due to their lower content of saturated fatty acids and long chain fatty acids. It is well documented that polyunsaturated fatty acids (PUFAs) are the components that have major roles in several biological activities such as metabolism and endocrine events (Zanussi et al. 2019). However, de novo synthesis of omega 3 PUFAs does not occur in birds species due to the lack of fatty acid desaturase enzymes activity in their body (Cerolini et al. 2005). Therefore, it is necessary to make the diets supplemented with omega 3 sources in the poultry species. Flaxseed oil (FO) may be a suitable source of linolenic acid (ALA) in the broiler chicken diets may lead to the incorporation of polyunsaturated fatty acids into the bird's tissues (Lopez-Ferrer et al. 2001). There are several reports on the beneficial effects of dietary flaxseed oil on the growth performance and gut health of broilers and quails (Abbasi et al. 2019; Nasir et al. 2020; Mirshekar et al. 2021). These effects may be explained by the increased digestibility of flaxseed oil that occurs with enhancing in the unsaturated grade of fatty acids. Also, a few experiments have evaluated the substitution of soybean oil by flaxseed oil on the microbiota activity and intestinal morphometric indices of broilers. Sesame (*Sesamum indicum*) is an important tropical or subtropical plant which is cultivated in much tropical area of the world as well as in the northeast of Iran. Sesame seed is composed of 45–50% lipids that a large portion of these seeds are used for oil production (Rezaeipour et al. 2016). Sesame oil consist of a variety of main fatty acids including oleic acid (35–50%), linoleic acid (35–50%), stearic acid (3.5–6%) and palmitic acid (7–12%) based on the species of sesame seeds (Mohammed et al. 2018). Despite the presence of about 85% unsaturated fatty acids in the sesame oil, oxidative stability of sesame oil is superior to that of other vegetable oils (Abou-Gharbia et al. 2000). A group of phytoestrogen (phenolic) compounds known as lignans in the sesame oil including sesamol and sesamolinol formed from sesamolin are the major antioxidants responsible for the reduction of sesame oil rancidity (Mohamed and Wakwak 2014). Sufficient information on the growth performance of broiler chickens with dietary sesame oil is not available. It was hypothesised that, dietary LPL in combination with different oil sources may enhance growth performance of broiler chickens through increase the gut morphology and nutrient digestibility. On the other hand, it was assumed that inclusion of LPL supplementation may have different effects for oil sources such as sesame seed oil, flaxseed oil and soybean oil in terms of nutrient digestibility coefficient, intestinal morphology and subsequently growth performance of broiler chickens.

Therefore, this experiment was aimed to evaluate the effect of LPL supplementation on growth performance, carcase traits, intestinal morphology, microbial population and nutrient digestibility in broiler chickens fed different oil sources.

Materials and methods

All experimental protocols in this study were approved and conducted under the guidelines of the Animal Care and Use Committee of Qaemshahr Branch, Islamic Azad University.

Experimental diets and birds

A total of three hundred Ross 308 broiler chickens (one d old) with an average weight of 44 ± 2 g were used in a 35-day experiment. Broilers were distributed into six experimental groups with five replicate pens of ten birds per pen with a 2 × 3 factorial arrangement design. Factors were 2 levels of LPL (0 or 0.1% Lipidol) and 3 oil sources including soybean oil (SO), flaxseed oil (FSO) or sesame seed oil (SSO). The LPL supplementation (Lipidol, Easybio Company, Seoul, South Korea), derived from soy lecithin, was provided from a company (Gorgan, Iran). Corn-soybean meal based diets (1–10, 11–24, and 25–35 days) containing SO (Table 1) were formulated according to the nutrient recommendations for Ross 308 broiler chicken. To prepare experimental diets based on different oils, SSO and FSO were substituted for SO in the basal diets. All broilers were allowed to consume feed and water *ad libitum*.

Growth performance and carcase characteristics

To determine the body weight gain (BWG), all broiler chickens were weighed by pen on d 1, 10, 24 and 35. Feed intake (FI) was recorded on the same days and

Table 1. Composition of basal diets (as-fed basis).

Item	Starter d 1–10	Grower d 11–24	Finisher d 25–35
Ingredient (g/kg unless stated otherwise)			
Corn grain	543.9	575.3	620.8
Soybean meal (450 g CP/kg)	389.5	353.1	300.3
Soybean oil	20.0	30.0	40.0
Oyster shell	11.9	11.1	10.3
Dicalcium phosphate	17.7	15.3	14.2
Common salt	3.0	3.0	3.0
Sodium bicarbonate	2.2	2.0	1.5
Vitamin premix[a]	2.5	2.5	2.5
Mineral premix[b]	2.5	2.5	2.5
DL-Methionine	2.7	2.3	2.1
L-Lysine-HCl	3.7	2.9	2.8
L-Threonine	0.4	0.08	0.02
Calculated nutrient content			
Metabolizable energy (MJ/kg)	12.46	12.88	13.30
Crude protein	227.0	214.0	194.0
Calcium	9.5	8.6	7.0
Available Phosphorous	4.8	4.3	4.0
Sodium	2.3	2.2	2.0
Lysine	14.3	12.8	11.5
Methionine	5.6	5.1	4.7
Methionine + Cysteine	0.97	0.85	0.80
Threonine	9.6	8.7	7.8
Dry matter	897.5	893.2	889.7

[a]Provides per kilogram of diet: 9000 IU vitamin A; 2000 IU vitamin D_3; 18 IU vitamin E; 2 mg menadion; 1.8 mg thiamine; 6.6 mg riboflavin; 30 mg niacin; 3 mg pyridoxine; 15 µg vitamin B_{12}; 100 mg D-pantothenic acid; 1 mg folic acid; 0.1 mg biotin; 500 mg choline chloride; and 100 mg antioxidant.
[b]Provides per kilogram of diet: 100 mg Mn; 84.7 mg Zn; 50 mg Fe; 10 mg Cu; 1 mg I; and 0.2 mg Se.
CP: crude protein.

obtained data was then used to calculate feed conversion ratio (FCR).

At the end of the experiment (35 days of age), five broiler chickens per treatment (with a weight close to the pen average) were selected and sacrificed by cervical dislocation method. The digestive tract of each bird was gently removed and the weight of thigh, breast, liver, pancreas, heart, gizzard, and proventriculus was measured. Data were presented based on g/100 g body weight of bird. In addition, the length of duodenum, jejunum, ileum and caecum as different parts of intestinal tract was recorded.

Intestinal morphology and microbial population

In order to determine the intestinal morphometric indices and caecal microbiota activity, one bird per pen (five birds per treatment) was randomly chosen from each pen and euthanized by cervical dislocation on day 35. Small intestine of each bird was gently removed and a 3 cm fragment of jejunum (middle of the jejunum) was excised for morphological measurements. Jejunum was fragmented from the distal portion of duodenal loop to the Meckel's diverticulum. Taken samples were flushed with physiological saline, and then fixed in 10% buffered formalin solution (10%). tissue sample was processed was paraffin embedding technique after dehydration and then, a 5-mm section was stained with haematoxylin and eosin. The jejunal morphometric variables including villus length (VL) and width (VW), crypt depth (CD), and VL/CD ratio were recorded by a light microscope system with LED Illumination. The villus surface area (VSA) was calculated using the following formula (Sakamoto et al. 2000):

$$\mathrm{VSR} = (2\pi) \times (\mathrm{VW}/2) \times (\mathrm{VL}).$$

The same euthanized birds were also used for microbial population study. Caecal content (3 g) from each selected bird was separately collected in a sterile tube for the enumeration of microbial population. Briefly, One gram per each sample was transferred into 9 mL sterile physiological saline solution (NaCl 85%) and was serially diluted from 10^{-1} to 10^{-7}. Subsequently, 0.1 ml of each dilution suspension was plated onto appropriate media. Eosin methylene blue agar (Merck, Darmstadt, Germany) was used for *E. coli* enumeration after incubation at 37 °C for 24 h. *Lactobacilli* bacteria was cultured on de Man, Rogosa, Sharpe agar (Merck, Darmstadt, Germany) after incubation for 48–72 h at 37 °C. Bacteria were counted using a colony counter and the results expressed as the logarithm of the number of bacteria per gram of the sample.

Nutrient digestibility

In order to determine apparent ileal digestibility (AID), chromium oxide (3 g/kg of diet) as an indigestible marker was added to each experimental treatment on 28–35 days of age. At the end of the bioassay, five broiler chickens per each experimental group were selected and euthanized by cervical dislocation. Ileum segment (Meckel's diverticulum to 1 cm proximal to the ileo-caecal junction) was chosen for each bird after the removing of the digestive tract. Samples of fresh digesta from the end half of this section were collected and dried at 55 °C for 72 h, and then ground to pass through a one-mm screen. All feed and ileal digesta samples were analysed for dry matter (method 934.01), crude protein (method 988.05) and ether extract (920.39) according to AOAC (1990) procedures. Chromium oxide was determined using Fenton and Fenton (1979) procedure. AID coefficients were calculated using the following equation:

$$\mathrm{D}\ (\%) = 100 - (100 \times (\mathrm{A}/\mathrm{B}) \times (\mathrm{C}/\mathrm{E}))$$

where D = Digestibility, A = chromium oxide in feed (%), B = chromium oxide in ileal digesta (%),

Table 2. Effects of treatments on feed intake, live weight gain, and feed conversion ratio (FCR) of broiler chickens.

		Live weight gain (g/d)				Feed intake (g/d)				FCR (g/g)			
Oil source (%)	LPL (%)	1–10	11–24	25–35	1–35	1–10	11–24	25–35	1–35	1–10	11–24	25–35	1–35
Soybean	0	25.77	42.44	58.34	42.19	35.53	70.05	128.41	78.00	1.37^{ab}	1.66	2.20	1.84
Soybean	0.1	26.03	46.51	63.85	45.46	38.17	77.23	127.29	80.88	1.47^{a}	1.67	1.99	1.78
Flaxseed	0	23.93	44.86	63.51	44.10	35.03	70.28	131.72	79.01	1.46^{a}	1.59	2.08	1.79
Flaxseed	0.1	26.39	47.46	61.74	45.20	32.92	74.35	127.30	78.20	1.24^{c}	1.57	2.08	1.73
Sesame	0	27.84	42.34	66.68	45.62	33.72	76.64	130.14	80.17	1.21^{c}	1.81	1.96	1.76
Sesame	0.1	28.54	48.97	70.21	49.24	36.50	74.91	125.62	79.01	1.28^{bc}	1.53	1.79	1.60
SEM		0.75	2.41	2.52	1.12	1.51	3.42	3.98	2.16	0.05	0.06	0.07	0.05
Main effects													
Soybean		25.90^{b}	44.47	61.10^{b}	43.82^{b}	36.85	73.64	127.84	79.45	1.42	1.66	2.10^{a}	1.81^{a}
Flaxseed		25.16^{b}	46.16	62.63^{ab}	44.65^{ab}	33.97	72.32	129.52	78.60	1.35	1.58	2.08^{a}	1.76^{ab}
Sesame		28.19^{a}	45.65	68.45^{a}	47.43^{a}	35.16	75.78	127.88	79.59	1.25	1.67	1.88^{b}	1.68^{b}
SEM		0.53	1.70	1.78	0.79	1.06	2.41	2.80	1.52	0.04	0.04	0.05	0.03
	0	25.85	43.21	62.84	43.97	34.76	72.32	130.09	79.06	1.35	1.69	2.08	1.79
	0.1	26.98	47.64	65.27	46.63	35.86	75.50	126.73	79.37	1.33	1.59	1.94	1.70
SEM		0.43	1.39	1.45	0.64	0.87	1.97	2.28	1.24	0.03	0.03	0.04	0.02
P-value													
Oil source		0.001	0.773	0.010	0.009	0.185	0.574	0.891	0.887	0.012	0.421	0.010	0.034
LPL		0.072	0.032	0.254	0.007	0.386	0.248	0.312	0.872	0.725	0.096	0.053	0.031
Oil source × LPL		0.320	0.709	0.342	0.480	0.203	0.390	0.886	0.561	0.022	0.074	0.363	0.534

Means within the same column with no common superscripts differ significantly ($p < .05$).
LPL: Lysophospholipids (0 or 0.1% Lipidol); SEM: standard error of the means

C = nutrient concentration in ileal digesta (%), E = nutrient concentration in feed (%).

Statistical analysis

Data obtained from this study were analysed as a 2 × 3 factorial experiment using the general linear model of SAS (2001). The means comparisons were analysed by Tukey test and differences between treatments were deemed to be significant if the probability value (*p*-value) was <.05.

Results

The influence of dietary LPL supplementation and oil sources on the growth performance of broiler chickens are presented in Table 2. The interactions between dietary oil sources and LPL on growth performance parameters were not significant, except for feed conversion ratio (FCR) on 10 days of age ($p < .05$). Inclusion of SSO to the diets increased body weight gain (BWG) during the starter, finisher, or overall phases in broiler chickens, but did not differ from FSO treatment (during finisher, or the entire trial period) that was intermediate ($p < .05$). BWG was significantly ($p < .05$) enhanced by the addition of LPL to the experimental diets. No significant differences were observed for feed intake (FI) in broiler chickens. Dietary LPL supplementation improved FCR during the entire experimental period ($p < .05$). In addition, FCR variable during the starter, finisher, or overall phases tended to increase as SSO added to the experimental diets ($p < .05$) but did not differ from FSO treatment (during starter, or the entire experimental period) that was intermediate.

Table 3. Effects of treatments on carcase characteristics and internal organs of broiler chickens (g/100g body weight of bird).

		Item					
Oil source (%)	LPL	Carcase	Breast	Thigh	Liver	Pancreas	Heart
Soybean	0	58.22	20.48	17.73	2.62	0.29	0.57
Soybean	0.1	59.03	20.75	18.27	2.36	0.28	0.52
Flaxseed	0	58.35	20.67	17.67	2.54	0.30	0.53
Flaxseed	0.1	58.55	20.25	18.30	2.50	0.30	0.50
Sesame	0	56.43	18.98	17.45	2.34	0.34	0.51
Sesame	0.1	58.66	20.36	18.29	2.32	0.27	0.51
SEM		1.25	0.70	0.71	0.18	0.035	0.03
Main effects							
Soybean		58.62	20.62	18.00	2.49	0.28	0.54
Flaxseed		58.45	20.46	17.98	2.53	0.30	0.51
Sesame		57.55	19.67	17.87	2.33	0.30	0.51
SEM		0.88	0.49	0.50	0.12	0.024	0.02
	0	57.67	20.04	17.62	2.51	0.31	0.53
	0.1	58.75	20.45	18.29	2.40	0.28	0.51
SEM		0.72	0.40	0.41	0.10	0.020	0.01
P-value							
Oil source		0.66	0.46	0.97	0.45	0.84	0.43
LPL		0.30	0.47	0.21	0.44	0.32	0.27
Oil source × LPL		0.71	0.44	0.96	0.73	0.51	0.72

LPL: Lysophospholipids (0 or 0.1% Lipidol); SEM: standard error of the means.

No significant differences were found for carcase variables and internal organs for the broiler chickens given the different dietary oil sources or LPL supplementation (Table 3). Dietary treatments had no significant effects on the length of the different parts of small intestine of broiler chickens (Table 4).

The interactions between dietary oil sources and LPL on the intestinal morphometric variables were not significant (Table 5). Villus width (VW) and villus surface

Table 4. Effects of the dietary treatments on proventriculus and gizzard weights (g/100 g body weight of bird) and the length (cm) of different parts of intestine in broiler chickens.

		Item					
Oil source (%)	LPL	Proventriculus	Gizzard	Duodenum	Jejunum	Ileum	Ceca
Soybean	0	0.43	2.00	28.59	72.60	75.01	16.21
Soybean	0.1	0.41	2.07	30.00	71.79	76.19	15.02
Flaxseed	0	0.41	2.17	31.01	76.00	78.40	17.60
Flaxseed	0.1	0.40	2.03	30.81	80.41	76.60	18.19
Sesame	0	0.38	2.21	31.00	74.01	73.42	17.22
Sesame	0.1	0.36	2.16	31.79	76.80	69.58	17.00
SEM		0.038	0.16	1.75	3.18	4.61	1.10
Main effects							
Soybean		0.42	2.03	29.30	72.20	75.60	15.60
Flaxseed		0.40	2.10	30.90	78.20	77.50	17.90
Sesame		0.37	2.18	31.40	75.40	71.50	17.10
SEM		0.026	0.11	1.23	2.25	3.25	0.77
	0	0.41	2.13	30.20	74.20	75.60	17.00
	0.1	0.39	2.08	30.86	76.33	74.13	16.73
SEM		0.021	0.09	1.01	1.84	2.66	0.63
p-Value							
Oil source		0.34	0.58	0.39	0.13	0.34	0.07
LPL		0.58	0.72	0.60	0.36	0.66	0.74
Oil source × LPL		0.97	0.75	0.87	0.65	0.83	0.66

Means within the same column with no common superscripts differ significantly ($p < .05$).
LPL: Lysophospholipids (0 or 0.1% Lipidol); SEM: standard error of the means.

Table 5. Effects of treatments on jejunum morphology and viable cell counts of microflora in ileo-caecal of broiler chickens.

		Jejunum morphology (μm)					Microbial population (log_{10} cfu/g)	
Oil source (%)	LPL	VL	VW	CD	VL/CD	VSA (mm^2)	*Lactobacillus*	*E. coli*
Soybean	0	1120.9	155.67	208.03	5.39	0.54	6.93	5.26
Soybean	0.1	1111.0	168.09	197.15	5.64	0.58	7.29	5.05
Flaxseed	0	1111.3	173.60	228.43	4.90	0.60	6.82	5.21
Flaxseed	0.1	1254.8	207.89	196.08	6.39	0.81	7.59	5.09
Sesame	0	1197.6	201.53	210.06	5.73	0.76	7.11	5.41
Sesame	0.1	1244.7	215.77	194.38	6.42	0.84	7.87	5.01
SEM		49.47	14.46	6.52	0.29	0.06	0.17	0.19
Main effects								
Soybean		1115.9	161.89^{b}	202.59	5.25	0.56^{b}	7.11	5.15
Flaxseed		1183.0	190.75^{ab}	212.26	5.65	0.71^{ab}	7.20	5.15
Sesame		1221.2	208.66^{a}	202.22	6.07	0.79^{a}	7.49	5.21
SEM		34.96	10.21	4.60	0.20	0.04	0.12	0.13
	0	1143.3	176.94	215.51	5.34	0.64	6.95	5.29
	0.1	1203.5	197.26	195.87	6.15	0.75	7.58	5.05
SEM		28.59	8.35	3.76	0.17	0.03	0.10	0.11
P-value								
Oil source		0.123	0.015	0.244	0.161	0.007	0.109	0.944
LPL		0.152	0.107	0.001	0.003	0.066	0.004	0.129
Oil source × LPL		0.317	0.708	0.259	0.120	0.418	0.442	0.781

Means within the same column with no common superscripts differ significantly ($p < .05$).
LPL: Lysophospholipids (0 or 0.1% Lipidol); VL, villus length: VW, villus width; CD, crypt depth; VSA: villus surface area; SEM: standard error of the means.

area (VSA) tended to increase with inclusion of SSO to the dietary treatments compared to SO diet ($p < .05$) but did not differ from FSO treatment that was intermediate. Decreased crypt depth (CD) and increased villus length (VL) to CD ratio was observed in broiler chickens fed with LPL supplemented diet ($p < .05$).

Efficacy of dietary treatments on the caecal *lactobacillus* and *E. coli* population are shown in Table 5. No significant influence of oil sources or dietary supplemental LPL was found on viable count of *E. coli* in broiler chickens. Supplementation of the diet with LPL resulted in greater caecal *Lactobacillus* population of broilers ($p < .05$).

In ileal nutrient digestibility (Table 6), the LPL supplement main effect showed that LPL supplement had beneficial impacts on the ileal digestibility coefficients of dry matter (DM), crude protein (CP) and ether extract (EE) in broilers ($p < .05$). Dietary SSO increased ileal digestibility of EE in broiler chickens compared SO diet ($p < .05$) but did not differ from FSO treatment that was intermediate.

Discussion

In the present experiment, BWG and FCR were improved by dietary LPL supplementation. There are

Table 6. Effects of dietary treatments on the nutrient digestibility in broiler chickens.

		Item		
Oil source (%)	LPL	Dry matter	Crude protein	Ether extract
Soybean	0	72.49	70.25	77.51
Soybean	0.1	74.50	73.03	79.98
Flaxseed	0	71.24	70.77	76.50
Flaxseed	0.1	72.76	73.99	85.23
Sesame	0	70.75	71.23	80.48
Sesame	0.1	72.25	73.98	85.24
SEM		0.95	1.17	1.49
Main effects				
Soybean		73.49	71.62	78.75[b]
Flaxseed		72.00	72.37	80.86[ab]
Sesame		71.48	72.62	82.87[a]
SEM		0.67	0.83	1.05
	0	71.51	70.75	78.15
	0.1	73.16	73.67	83.48
SEM		0.55	0.68	0.86
p-Value				
Oil source		0.113	0.680	0.041
LPL		0.044	0.007	0.003
Oil source × LPL		0.956	0.972	0.134

Means within the same column with no common superscripts differ significantly ($p < .05$).
LPL: Lysophospholipids (0 or 0.1% Lipidol); SEM: standard error of the means.

several studies available on the positive influence of LPL on the growth performance of broiler chickens (Zampiga et al. 2016; An et al. 2020; Zangeneh et al. 2020). In accordance with these results, it has been reported that the synthetic LPL product improved body weight gain and FCR of broiler chickens (Haetinger et al. 2021). In contrast with the present findings, supplementation of lysolecithin as LPL additive in broiler diets had no significant influence on the growth performance during 1–21 days of age (Gheisar et al. 2015). On the other hand, several reports indicated that supplementation of the diets with LPL increased growth performance of broiler chickens mainly during the early feeding phase (Chen et al. 2019; Zhao and Kim 2017). This effect may due to the insufficient production of bile salts and lipase in young broilers, which results in a low capacity of fat digestion and absorption (Chen et al. 2019). Therefore, increase in the BWG and FCR in broiler chickens in response to LPL supplementation may be the result of enhanced fatty acid and nutrient digestibility.

In the present experiment, the LPL supplementation increased intestinal morphometric variables including crypt depth and villus length to crypt depth ratio. Increasing the villus length to crypt depth ratio is a main factor to evaluate the nutrient absorption ability in broiler chickens (Roofchaei et al. 2019). Besides, it is well documented that the status of intestinal mucosa is an important indicator for determining gastrointestinal health and function (Kolbadinejad and Rezaeipour 2020). Therefore, an increase in these morphological indices may enhance the absorption capacity and digestive enzyme activity in broilers. In consistent with our results, it was observed that addition of LPL to broilers diet not only decreased crypt depth in the jejunum but also increased jejunal villus length to crypt depth ratio (Boontiam et al. 2017).

In the present study, broiler chickens fed diets containing LPL supplementation presented a greater viable count of *Lactobacillus* in the caecal region. The mode of action of LPL on the proliferation of positive bacteria such as Lactobacilli has been demonstrated (Huyghebaert et al. 2011). According to these authors, the LPL additives could contribute to the decline of the growth depressing substances that secreted by positive bacteria. On the other hand, it is reported that LPL supplementation may alter the bacteria membrane permeability, subsequently to disrupt the bacteria integrity due to ionic imbalance (Polycarpo et al. 2016). A dearth of information exists in term of intestinal microbial population in response to LPL supplemented diets. Therefore, further studies are needed to better understand of the effects of LPL supplementation on the microbiota activity in broiler chickens.

The effect of the LPL supplemented diets on the ileal nutrient digestibility was significant.

In consistent with the present results, several studies demonstrated the beneficial effect of LPL feed additive on the nutrient digestibility in broiler chickens (Schwarzer and Adams 1996; Boontiam et al. 2017; Zhao and Kim 2017). The positive impacts of LPL supplemented diets on the ileal digestibility coefficients may be attributed to the emulsification property of these molecules. LPL compounds have a suitable hydrophilic-to-lipophilic balance value than lecithin, which increases water in oil emulsion (Shumilina et al. 2006). LPL substances are magnificent surfactants and can increase the mixing of intestinal digesta, decline the particle size of the emulsified droplets and subsequently increase the enzyme availability to lipids (Jansen 2015).

Inclusion of SSO into the diet increased growth performance of broiler chickens compared with dietary SO. Although several studies have been conducted on the beneficial effects of plant oils such as SO or FSO compared with animal fats in growth performance of broilers (Lai et al. 2018; Olomu and Baracos 1991; Tancharoenrat et al. 2013), limited data are available on the SO efficacy compared with other vegetable oils in broiler diets. Furthermore, Most of these researches have been on the effectiveness of sesame seeds or cakes, but not SSO (Jacob et al. 1996; Onainor et al.

2018). In contrast with our results, no significant influence of sesame seed or SSO was observed on the productive performance of laying quails (Al-Daraji et al. 2012). In parallel with the present results, it has been reported that SSO or sesame seed supplemented diets had positive effect on the body weight gain in broiler chickens (Agah et al. 2016; Onainor et al. 2018).

Dietary SSO increased morphological variables including villus width and villus surface area in the Jejunum region of broiler chickens. This result supported the study of (Agah et al. 2016) who observed that dietary SSO could increase intestinal morphometric indices such as villus absorption surface, villus length and villus width in broiler chickens. Besides, an increase in the intestinal villus height and surface area for absorption was observed in broiler chickens fed with diets supplemented by sesame seed (Adebiyi et al. 2015). The exact mechanism by which using SSO in the diet increases gut health and morphology is not well understood. However, there is evidence that SSO may increase intestinal health and function due to its antioxidant properties of lignans (Ahmad et al. 2006). In line with this mechanism, it has been documented that increased intestinal villi length and surface area in broiler chickens may be due to the antioxidant efficacy of some of dietary ingredients (Hassanpour et al. 2010).

Inclusion of SSO into the broiler diets increased lipid digestibility. In a study on the common carp (*Cyprinus carpio*), it has been observed that addition of SSO increased fat digestibility (Albassam and Al-Habeeb 2019). In the literature review, no information has been reported about the effect of SSO on the nutrient digestibility in poultry. Therefore, more research is needed in this field.

Conclusions

It is concluded that LPL supplementation can be used to increase growth performance, gut morphology and microbial population in broiler chickens. In view of nutrient digestibility, it is observed that the LPL additive extensively increased ileal digestibility coefficients. Furthermore, it was observed that SSO increased productive performance, intestinal morphometric variables and ether extract digestibility of broiler chickens. However, further research is needed to elucidate the mechanism of action of sesame SSO on the nutrient digestibility in broilers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data statement availability

All data generated and analysed during this study are included in this published article.

Animal welfare statement

All animal protocols for this study were approved by the Animal Care and Use Committee at the Qaemshahr Branch, Islamic Azad University (Qaemshahr, Iran).

ORCID

Vahid Rezaeipour http://orcid.org/0000-0003-3651-2852
Shahabodin Gharahveysi http://orcid.org/0000-0002-1069-0215

References

Abbasi F, Samadi F, Jafari SM, Ramezanpour S, Shams-Shargh M. 2019. Production of omega-3 fatty acid-enriched broiler chicken meat by the application of nanoencapsultsed flaxseed oil prepared via ultrasonication. J Funct Foods. 57:373–381.

Abou-Gharbia HA, Shehata AAY, Shahidi F. 2000. Effect of processing on oxidative stability and lipid classes of sesame oil. Food Res Int. 33(5):331–340.

Adebiyi O, Famakinwa A, Adeniji O, Omojola A. 2015. Effect of dietary replacement of soyabean meal with toasted sesame seed on performance, tibia bone mineralisation and gut morphology of broilers chicken. AJEA. 5(2): 156–163.

Agah MJ, Golian A, Nassiri-Moghaddam H, Raji AR, Zarban A, Farhosh R. 2016. Effect of dietary supplementation of sesame (*Sesamum indicum* L.) oil and/or A-tocopheryl acetate on performance, intestinal morphology and blood metabolites in male broiler chickens. Res Anim Prod Sci Res. 6: 30–41.

Ahmad S, Yousuf S, Ishrat T, Khan MB, Bhatia K, Fazli IS, Khan JS, Ansari NH, Islam F. 2006. Effect of dietary sesame oil as antioxidant on brain hippocampus of rat in focal cerebral ischemia. Life Sci. 79(20):1921–1928.

Albassam NHS, Al-Habeeb FM. 2019. A study of total, protein and lipid digestibility coefficient of common carp *Cyprinus carpio* L. diet supplemented with different percentages of sesame seeds oil *Sesamum indicum*. Tikrit J Agric Sci. 18: 215–222.

Al-Daraji H, Al-Mashadani H, Al-Hayani W, Al-Hassani A. 2012. Effect of the supplementation of the laying quails ration with sesame (*Sesamum indicum*) seeds and oil on egg quality traits. Int J Appl Biol Pharm Technol. 3:54–63.

An JS, Yun W, Lee JH, Oh HJ, Kim TH, Cho EA, Kim GM, Kim KH, Lee SD, Cho JH. 2020. Effects of exogenous emulsifier supplementation on growth performance, energy digestibility, and meat quality in broilers. J Anim Sci Technol. 62(1):43–51.

Boontiam W, Jung B, Kim Y. 2017. Effects of lysophospholipid supplementation to lower nutrient diets on growth performance, intestinal morphology, and blood metabolites in broiler chickens. Poult Sci. 96(3):593–601.

Brautigan D, Li R, Kubicka E, Turner S, Garcia J, Weintraut M, Wong E. 2017. Lysolecithin as feed additive enhances collagen expression and villus length in the jejunum of broiler chickens. Poult Sci. 96(8):2889–2898.

Cerolini S, Surai P, Speake B, Sparks N. 2005. Dietary fish and evening primrose oil with vitamin E effects on semen variables in cockerels. Br Poult Sci. 46(2):214–222.

Chen C, Jung B, Kim W. 2019. Effects of lysophospholipid on growth performance, carcass yield, intestinal development, and bone quality in broilers. Poultr Sci. 98(9):3902–3913.

Fenton T, Fenton M. 1979. An important procedure for the determination of chromic oxid in feed and feces. Can J Anim Sci. 59:631–634.

Gheisar MM, Hosseindoust A, Kim HB, Kim IH. 2015. Effects of lysolecithin and sodium stearoyl-2-lactylate on growth performance and nutrient digestibility in broilers. Korean J Poult Sci. 42(2):133–137.

Haetinger V, Dalmoro Y, Godoy G, Lang M, de Souza O, Aristimunha P, Stefanello C. 2021. Optimizing cost, growth performance, and nutrient absorption with a bio-emulsifier based on lysophospholipids for broiler chickens. Poultr Sci. 100(4):101025.

Hassanpour H, Moghaddam AZ, Yazdani A, Bashi MC. 2010. Evaluation of intestinal morphology and nitric oxide metabolites in broiler chickens supplemented by green tea. Comp Clin Pathol. 19(1):43–47.

Huyghebaert G, Ducatelle R, Van Immerseel F. 2011. An update on alternatives to antimicrobial growth promoters for broilers. Vet J. 187(2):182–188.

Jacob J, Mitaru B, Mbugua P, Blair R. 1996. The feeding value of Kenyan sorghum, sunflower seed cake and sesame seed cake for broilers and layers. Anim Feed Sci Technol. 61(1–4):41–56.

Jansen M. 2015. Modes of action of lysophospholipids as feed additives on fat digestion in broilers.

Kolbadinejad A, Rezaeipour V. 2020. Efficacy of ajwain (*Trachyspermum ammi* L.) seed at graded levels of dietary threonine on growth performance, serum metabolites, intestinal morphology and microbial population in broiler chickens. J Anim Physiol Anim Nutr. 104(5):1333–1342.

Lai W, Huang W, Dong B, Cao A, Zhang W, Li J, Wu H, Zhang L. 2018. Effects of dietary supplemental bile acids on performance, carcass characteristics, serum lipid metabolites and intestinal enzyme activities of broiler chickens. Poultr Sci. 97(1):196–202.

Lopez-Ferrer S, Baucells M, Barroeta A, Galobart J, Grashorn M. 2001. n-3 enrichment of chicken meat. 2. Use of precursors of long-chain polyunsaturated fatty acids: linseed oil. Poult Sci. 80(6):753–761.

Mirshekar R, Dastar B, Shargh MS. 2021. Supplementing flaxseed oil for long periods improved carcass quality and breast fatty acid profile in Japanese quail. Animal. 15(2):100104.

Mohamed NE, Wakwak MM. 2014. Effect of sesame seeds or oil supplementation to the feed on some physiological parameters in Japanese Quail. J Radiat Res Appl Sci. 7(1): 101–109.

Mohammed F, Abdulwali N, Guillaume D, Tenyang N, Ponka R, Al-Gadabi K, Bchitou R, Abdullah AH, Naji KM. 2018. Chemical composition and mineralogical residence of sesame oil from plants grown in different Yemeni environments. Microchem J. 140:269–277.

Nasir J, Chand N, Khan S, Abudabos A, Khan R. 2020. Consumption of flaxseed enhances poly unsaturated fatty acids in broiler meat. J Anim Physiol Nutr. 1:1–6.

Olomu J, Baracos V. 1991. Influence of dietary flaxseed oil on the performance, muscle protein deposition, and fatty acid composition of broiler chicks. Poult Sci. 70(6):1403–1411.

Onainor E, Sorhue G, Uguru J. 2018. Effect of processing method of sesame (*Sesamum indicum* Linn.) seeds on the growth performance and nutrient utilization of broiler chicks. Int J Agric Forest. 8:10–15.

Polycarpo G, Burbarelli M, Carao A, Merseguel C, Dadalt J, Maganha S, Sousa R, Cruz-Polycarpo V, Albuquerque R. 2016. Effects of lipid sources, lysophospholipids and organic acids in maize-based broiler diets on nutrient balance, liver concentration of fat-soluble vitamins, jejunal microbiota and performance. Br Poult Sci. 57(6):788–798.

Rezaeipour V, Barsalani A, Abdullahpour R. 2016. Effects of phytase supplementation on growth performance, jejunum morphology, liver health, and serum metabolites of Japanese quails fed sesame (*Sesamum indicum*) meal-based diets containing graded levels of protein. Trop Anim Health Prod. 48(6):1141–1146.

Roofchaei A, Rezaeipour V, Vatandour S, Zaefarian F. 2019. Influence of dietary carbohydrases, individually or in combination with phytase or an acidifier, on performance, gut morphology and microbial population in broiler chickens fed a wheat-based diet. Anim Nutr. 5(1):63–67.

Schwarzer K, Adams CA. 1996. The influence of specific phospholipids as absorption enhancer in animal nutrition. Fett/Lipid. 98(9):304–308.

Sakamoto K, Hirose H, Onizuka A. 2000. Quantitative study of changes in intestinal morphology and mucus gel on total parenteral nutrition in rats. J Surg Res. 94:99–106.

Shumilina E, Khromova YL, Shchipunov YA. 2006. The effect of lysophosphatidylcholine and phosphatidylglycerol on lecithin polymer-like micelles. Colloid J. 68(2):241–247.

Tancharoenrat P, Ravindran V, Zaefarian F, Ravindran G. 2013. Influence of age on the apparent metabolisable energy and total tract apparent fat digestibility of different fat sources for broiler chickens. Anim Feed Sci Technol. 186(3–4):186–192.

Zampiga M, Meluzzi A, Sirri F. 2016. Effect of dietary supplementation of lysophospholipids on productive performance, nutrient digestibility and carcass quality traits of broiler chickens. Ital J Anim Sci. 15(3):521–528.

Zangeneh S, Torki M, Abdolmohammadi A, Saki A. 2020. Dietary addition of lysophospholipids and vitamin C affects growth performance, serum metabolites, antioxidant capacity and carcass characteristics of broiler chickens reared under low ambient temperature. Anim Prod Sci. 60(12):1557–1566.

Zanussi HP, Shariatmadari F, Sharafi M, Ahmadi H. 2019. Dietary supplementation with flaxseed oil as source of omega-3 fatty acids improves seminal quality and reproductive performance in aged broiler breeder roosters. Theriogenology. 130:41–48.

Zhao P, Kim I. 2017. Effect of diets with different energy and lysophospholipids levels on performance, nutrient metabolism, and body composition in broilers. Poultr Sci. 96(5): 1341–1347.