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Effects of dietary supplementation of soybean lecithin on growth performance, nutrients digestibility and serum profiles of broilers fed fried soybean oil

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ABSTRACT

The objective of this study was to evaluate the effects of soybean lecithin in broiler diets formulated with either fried or non-fried soybean oils (as an energy source), on growth performance, digestibility, and some serum parameters. A total of 600 broilers (50% male) were assigned to 4 experimental groups (with 10 replicates of 15 birds each): (i) group (S) fed with soybean oil only, (ii) group (SL) fed with soybean oil + lecithin (0.035% in feed), (iii) group (F) fed with fried soybean oil only, and iv) group (FL) fed with fried soybean oil + lecithin (0.035% in feed). Broilers that received lecithin with fried soybean oil (group FL) exhibited significantly higher body weights (1.228 vs. 1.210 kg, $p < 0.05$ and 1.935 vs. 1.917 kg, $p < 0.05$) than group F in the last two experimental periods (22–28 and 29–35 days), respectively. On the contrary, the addition of soybean lecithin to diets formulated with either fried or non-fried soybean oil resulted in a significant increase in weight of some carcase cuts (thigh, breast) and a significant decrease in some visceral organs (intestine, liver, viscera), without affecting the digestibility parameters here assessed. Our findings revealed that the addition of soybean lecithin to standard soybean oil (group SL) significantly decreased serum triglycerides (77.16 vs. 83.46 mg/dL, $p < 0.05$) compared to group S. In conclusion, it was possible to use recovered frying soybean oil in broiler diets without a negative impact on growth performance and serum triglyceride level, while these parameters were improved by the addition of soybean lecithin.

HIGHLIGHTS

- By-products obtained from oil/food processing represent an affordable and sustainable alternative to traditional fat sources for broiler feeding.
- Fried soybean oil used in broiler feed had the same effects on growth performance and nutrient digestibility as the non-fried oil.
- The use of soybean lecithin in broiler feed led to improved growth performance, cuts up yield and serum triglyceride level.

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Introduction

In the recent decades, there have been several attempts to reduce the cost of feed by using agro-industrial by-products, as well as nonconventional growth promotors (such as herbal extracts and essential oils) to improve growth performance and reduce the incidence of muscle abnormalities (Mudalal et al. 2021; Mudalal and Zaazaa 2022; Zaazaa, Sabbah, et al. 2022).

Fat incorporation in the feed of fast-growing animals is widely practiced worldwide to meet the energy requirements of these animals. Fat supplementation also aims to improve the content of essential fatty acids (EFA) and fat-soluble vitamins (Blanch et al. 1996; Tavárez et al. 2011; Zhang et al. 2011; Ravindran et al. 2016). In Palestine, as in many other regions of the world, there is an increasing trend in the inclusion of traditional fats (soap stocks) to broiler feed.

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However, traditional fats are relatively expensive, so finding affordable and cost effective substitutes is crucial. One of the alternative fats for livestock feed production is vegetable frying oils (Tres et al. 2013), which are widely available in the Middle East markets as they are often used to fry popular foods such as falafel. In Middle Easter countries (including Palestine), there are no regulations for the use of recycled oils in animal feed, so there are no requirements for the maximum permitted inclusion of recycled oils or for oil quality standards. However, frying at high temperatures in the presence of atmospheric oxygen and water from dehydrated food, results in oxidation, hydrolysis, cyclisation, and polymerisation of lipids (Zhang et al. 2012; Vieira et al. 2017). This array of chemical reactions gives rise to several degradation–derived molecules (such as alcohols, ketones, epoxides, hydroxy compounds, etc.) (Billek 2000; Choe and Min 2007), which affect the quality of oil (Bastida and Sanchez-Muniz 2001; Gupta and Gupta 2006). However, there are few studies on the impact of feeding frying oil on broiler's health and performance. Tres et al. (2013) demonstrated that feeding recovered frying oil to chickens had no effect on fatty acid (FA) composition and oxidative stability of chicken meat, plasma and liver; in contrast, the use of such oil source in feed decreased α-tocopherol content in tissues and had a negative impact on meat quality. Dorra et al. (2014) also reported that the use of recovered frying oil had no negative impact on carcase characteristics, blood parameters and meat quality.

In addition to the effect of the composition and quality of the fat on broiler growth performance, the extent of fat digestion and absorption also plays an important role. One possible strategy to improve fat digestion and metabolism is the addition of soybean lecithin to feeds, especially at early age when a low activity of bile salts and lipid digestive enzymes is observed (Noy and Sklan 1998; Upadhaya et al. 2017). In fact, soybean lecithin has good emulsification capacity (Hertrampf 2001; Roy et al. 2010; Abbas et al. 2016), as well as good cholesterol-lowering properties (Ipatova et al. 2003; Zhao et al. 2015). Moreover, soybean lecithin is a valuable source of gross energy, phosphorus, choline and EFA (linoleic and linolenic acids) (Viñado et al. 2019). However, there are conflicting opinions on the effects of soybean lecithin in livestock nutrition (Azman and Ciftci 2004), and there is insufficient information to recommend its use in broiler diets. Viñado et al. (2019) demonstrated that soybean lecithin with high free fatty acid content can be used as partial substitute for soybean oil or in combination with an acid oil in broilers diet, without any effects on broiler performance or FA digestibility. In addition, Viñado et al. (2020) reported that partial replacement of soybean oil with soybean lecithin (2% of total addition) had no effect on jejunal morphology or *trans* FA absorption in 46-day-old broiler chickens, but the total replacement had a great effect on polyunsaturated FA (PUFA) absorption at ileal level and increased *Lactobacillus* spp. counts at the jejunum. Nevertheless, these dietary changes did not influence broiler performance (Viñado et al. 2020).

Considering the need to further investigate the effect of using fried oil and soybean lecithin on growth performance and nutrient digestibility of broilers, the aim of this study was to evaluate the effects of adding soybean lecithin to broiler diets formulated with non-fried or fried soybean oil (as an energy source), on broiler's performance, digestibility, carcase cuts, and some serum parameters.

Materials and methods

Materials

Refined soybean oil was provided by Abu Al-Ragheb Ltd. (Hebron, Palestine), while soybean lecithin was from Girdharilal Sugar and Allied Industries Ltd. (Delhi, India). The fried soybean oil was collected from a local restaurant after frying falafel, a typical Middle Eastern street food, for 16 h (2 days of 8-h of deep-frying each). The frying temperature was 180 °C; the capacity of the fryer was 8 L, and 2 L of oil were replenished four times daily, for a total oil consumption of 16 L/day.

Animal experimental trial

The Animal Welfare Committee of the An-Najah National University approved the experimental protocol of this study (approval code: 11B 2021; approval date: 11 June 2021). A total of 600-day-old Ross broilers were used in a 42-day experiment. The broilers were divided into four experimental groups with 10 replicates (15 birds/replicate). The groups were designated as follow: Group S fed with feed containing only soybean oil; Group SL fed with feed containing soybean oil plus lecithin (0.035%); Group F fed diets containing only fried soybean oil; Group FL fed diets containing fried soybean oil plus lecithin (0.035%).

The basal diet (Table 1) was formulated to meet broiler NRC (1994) requirements. Each treatment group contained 50% male and 50% female and

Table 1. Composition of the basal diets fed to broilers in feeding trial as fed basis.

Ingredient	Starter (g/kg)	Grower (g/kg)
Yellow corn	418.1	410.1
Soybean meal	311.3	267.1
Wheat	150.0	165.1
Sunflower meal	40.1	60.0
Oil	38.1	59.1
DCP[a]	16.5	13.0
Limestone	13.0	15.0
NaCl	2.5	2.5
Premix[b]	4.0	4.0
DL-methionine	2.5	2.0
L-lysine	4.5	3.0
Threonine	1.0	1.0
Sodium bicarbonate	1.0	1.0
Chemical composition%		
Crude protein	21.50	20.01
Crude fat	3.80	5.90
Calcium	0.98	0.79
Available P	0.45	0.38
ME, Kcal/ kg ration	3000	3100

[a]Dicalcium phosphate. [b]Premix/kg diet: vitamin A, 12,000 IU; vitamin D3, 1500 IU; vitamin E, 50 mg; vitamin K3, 5 mg; vitamin B1, 3 mg; vitamin B2, 6 mg; vitamin B6, 5 mg; vitamin B12, 0.03 mg; niacin, 25 mg; Ca-D-pantothenate, 12 mg; folic acid, 1 mg; D-biotin, 0.05 mg; apo-carotenoic acid ester, 2.5 mg; choline chloride, 400 mg; manganese, 100 g; zinc, 100 g; iron, 40 g; copper, 15 g; iodine, 1 g; cobalt, 0.2 g; selenium, 0.35 g; wheat enzyme, 100 g; phytase, 750 FTU; Lasalocid, 100 g; Bacitracin Methylene Disalicylate (BMD), 55 g. ME: Metabolisable Energy.

similar distribution was considered in each replication. The chickens were given starter feed for the first 21 days and grower feed for the 22–35 days period. Both feed and water were accessible to the birds on an *ad libitum* basis. Open-sided house temperature was maintained according to the management guide of Ross broilers: 34-36 °C during the 1–14 days period and then taken to 26 °C till termination of the feeding trial. Lighting was continuous during the whole experiment.

Growth performance

At 7, 14, 21, 28 and 35 days of age, the body weight (BW) of birds and their feed intake (FI) were recorded to evaluate the feed conversion ratio (FCR) for all feeding phases.

Visceral organs

At the end of the 5th week of the feeding trial, the birds were restricted from feed for 12 h but had free access to water. One bird per replicate was randomly chosen, weighed, and sacrificed by bleeding of the jugular vein. Visceral organs (liver, thymus, bursa, pancreas, and spleen) were collected and weighed. The relative weights of these organs were calculated and expressed as relative to BW (g of organ/kg of BW) (Mudalal et al. 2021; Zaazaa, Mudalal, et al. 2022).

Serum profile

From each replicate, five blood samples were obtained from the brachial vein one day before slaughtering. The samples were centrifuged at 3000 g for 5 min, and the serum was transferred into a 2 mL Eppendorf tube and frozen at −20 °C until analysis (Zhao et al. 2017). The concentrations of serum triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C) were determined by enzymatic colorimetric methods, using diagnostic kits (Quimica Clinica Aplicada S. A., Amposta, Spain) and a spectrophotometer (SP-UV1100 Onilab, City of industry, CA) according to manufacturer's directions.

Digestibility

On day 35, 12 birds (both males and females) from each group were kept in individual cages, where faeces were daily collected in trays placed under each cage for three consecutive days. During the adaptation period before the collection, birds were restricted from feed for 12 h with free access to water and were fed with experimental diets *ad libitum* for 3 days.

The faecal samples were collected and stored at −20 °C each day. After 3-day excreta collection period, feed intakes were recorded, and excreta of each cage were mixed. The faecal sample mixtures were dried in an oven at 60 °C overnight and ground to pass through a 1 mm screen before being analysed.

Feed and excreta analysis

Samples of feed and excreta were analysed for dry matter (DM), crude protein (CP), and ether extract (EE), according to the standard methods of AOAC (1990).

Statistical analysis

Data are reported as mean value of each analytical determination ± standard error mean (SEM). Analysis of variance (ANOVA) was performed to test the significance of treatment. To separate means of statistically different parameters, Tukey's honest significance test was performed at a 95% confidence level ($p < 0.05$). The IBM SPSS Statistics 20 software (Chicago, USA) was used to elaborate the data.

A principal component analysis (PCA) with a varimax rotation, was carried out with the most significant data, using the XLSTAT software (7.5.2 version, Addinsoft, France).

Results

Growth performance

Table 2 shows the effects of different oil additions to the feed, with and without soybean lecithin (S, SL, F, and FL), on the performance indices of broilers at different ages. No significant differences in feed intake were observed among groups (S, SL, F, and FL) during the different experimental periods. Moreover, FCR was not affected by addition of soybean lecithin in both types of oils (non-fried and fried). However, when soybean lecithin was added to the standard soybean oil (group SL), the broilers BW significantly increased compared to the S group during the different experimental periods. A similar effect was observed in the fried oil trials; in fact, the addition of soybean lecithin to fried soybean oil (group FL) significantly incremented broilers' BW (1.228 *vs.* 1.210 kg, $p < 0.05$ and 1.935 *vs.* 1.917 kg, $p < 0.05$) compared to group F in the last two experimental periods (22–28 and 29–35 days), respectively. On other hand, a moderate improvement in BW was observed between group F and FL in the remaining periods (1–7, 8–14, and 15–21 days).

Nutrient digestibility

Table 3 shows the results of nutrient digestibility of the animal trials, where it can be noted that the incorporation of soybean lecithin in broilers diets did not affect ($p > 0.05$) the digestibility of feed nutrients.

Carcase cuts and visceral organs

As shown in Table 4, no significant differences in the weight of the drumstick, heart, spleen, and gizzard were found among groups. Group SL had a significantly higher weight of thigh and breast and lower weight of neck, viscera, intestine, and liver as compared to group S. On the other hand, group FL exhibited significantly higher breast and liver weights and lower thigh, viscera, intestine and crop weights as compared to group F. There were no significant differences in all cut weights between groups S and F, except for the thigh weight which was significantly higher in group F.

Serum profile

Table 5 reports the serum profile of broilers fed with soybean oil or fried oil alone or with soybean lecithin. Our results showed that the addition of soybean lecithin to standard soybean oil (group SL) significantly reduced serum TG (77.16 *vs.* 83.46 mg/dL, $p < 0.05$) compared to group S, while soybean lecithin moderately reduced serum TG in group FL compared to groups F and S, respectively. Regarding LDL-C, the addition of soybean lecithin to both soybean and fried oils resulted in a small decrease in LDL-C levels. In

Table 3. Effects of different oil additions to the feed (with and without soybean lecithin) on apparent nutrient digestibility of broiler (%).

Items	S	SL	F	FL	SEM	*p* Value
DM	68.13	68.87	67.97	68.50	0.353	0.354
Fibre	37.37	38.03	36.87	37.93	0.498	0.385
CP	83.74	84.43	83.36	84.23	0.318	0.071
EE	75.78	77.57	75.95	77.44	0.458	0.224

Data were reported as mean and standard error mean (SEM) of 12 replicates. Different letters in the same row indicate significant differences ($p < 0.05$). Treatments: S: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin. CP: crude protein; DM: dry matter; EE: ether extract.

Table 2. Effects of different oil additions to the feed (with and without soybean lecithin) on performance indices of broilers at different ages.

Items		S	SL	F	FL	SEM	*p* Value
Feed intake (kg)	1–7 day	0.126	0.129	0.127	0.128	0.002	0.636
	8–14 day	0.454	0.458	0.454	0.458	0.004	0.815
	15–21 day	1.081	1.088	1.080	1.089	0.008	0.761
	22–28 day	1.985	1.997	1.985	1.997	0.009	0.679
	29–35 day	3.066	3.083	3.065	3.079	0.012	0.622
Body weight (kg)	1–7 day	0.145^{b}	0.149^{a}	0.146^{b}	0.148^{ab}	0.001	0.008
	8–14 day	0.393^{c}	0.414^{a}	0.395^{bc}	0.411^{ab}	0.003	0.007
	15–21 day	0.813^{b}	0.832^{a}	0.811^{b}	0.827^{ab}	0.004	0.018
	22–28 day	1.217^{bc}	1.241^{a}	1.210^{c}	1.228^{ab}	0.004	0.000
	29–35 day	1.920^{bc}	1.947^{a}	1.917^{c}	1.935^{ab}	0.004	0.002
Feed conversion ratio (kg/kg gain)	1–7 day	0.867	0.865	0.868	0.867	0.010	0.998
	8–14 day	1.156	1.105	1.149	1.115	0.014	0.123
	15–21 day	1.331	1.307	1.331	1.317	0.010	0.380
	22–28 day	1.631	1.609	1.641	1.626	0.008	0.120
	29–35 day	1.597	1.584	1.599	1.591	0.005	0.170

Data were reported as mean and standard error mean (SEM) of 10 replicates. Different letters in the same row indicate significant differences ($p < 0.05$). Treatments: S: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin.

Table 4. Effects of different oil additions to the feed (with and without soybean lecithin) on relative weight of broiler carcase cuts and visceral organs (g/carcase weight).

Parameter	S	SL	F	FL	SEM	*p* Value
Thigh	13.04^{b}	13.31^{a}	13.41^{a}	12.66^{b}	0.143	0.006
Drumstick	25.12	24.72	25.01	25.22	0.185	0.315
Wings	9.22^{ab}	9.04^{b}	9.49^{a}	9.26^{ab}	0.085	0.010
Breast	39.21^{b}	40.18^{a}	38.48^{b}	40.32^{a}	0.175	0.000
Neck	5.35^{ab}	5.07^{bc}	5.42^{a}	5.06^{c}	0.073	0.002
Viscera	17.10^{a}	16.04^{b}	17.01^{a}	16.23^{b}	0.110	0.000
Intestine	7.45^{a}	7.02^{b}	7.54^{a}	7.13^{b}	0.065	0.000
Heart	0.74	0.70	0.76	0.69	0.020	0.133
Liver	3.35^{a}	3.13^{b}	3.27^{ab}	3.14^{b}	0.043	0.003
Spleen	0.15	0.13	0.14	0.15	0.010	0.518
Gizzard	2.11	2.00	2.05	2.00	0.030	0.075
Crop	0.66^{ab}	0.62^{b}	0.68^{a}	0.61^{b}	0.015	0.013
Proventriculus	0.69^{a}	0.62^{b}	0.67^{ab}	0.65^{ab}	0.018	0.050
Abdominal fat	1.05	1.00	1.03	1.00	0.015	0.081
Pancreas	0.15	0.13	0.14	0.14	0.010	0.499
Live weight/kg	2.11^{b}	2.23^{a}	2.100^{b}	2.21^{a}	0.014	0.000
Dressing %	77.91^{b}	79.20^{a}	77.79^{b}	78.69^{ab}	0.288	0.005

Data were reported as mean and standard error mean (SEM) of 10 replicates. Different letters in the same row indicate significant differences ($p < 0.05$). Treatments: S: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin.

Table 5. Effects of different oil additions to the feed (with and without soybean lecithin) on serum profiles of broilers.

Items	S	SL	F	FL	SEM	*p* value
Total cholesterol (mg/dL)	140.85	138.42	143.27	140.39	2.357	0.562
Triglycerides (mg/dL)	83.46^{a}	77.16^{b}	84.69^{a}	80.26^{ab}	1.487	0.005
HDL-C (mg/dL)	94.53	93.76	92.68	93.35	3.727	0.988
LDL-C (mg/dL)	45.54^{ab}	41.26^{b}	47.43^{a}	45.14^{ab}	1.42	0.029

Data were reported as mean and standard error mean (SEM) of 50 replicates. Different letters in the same row indicate significant differences ($p < 0.05$). Treatments: S: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin. HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol.

contrast, no significant differences were found among groups for TC and HDL-C.

PCA

To better understand correlation among all factors, two PCA were performed. The first one (Figure 1) considered parameters related to bird's growth performance and nutrient digestibility; in this case, the biplot represented 72.48% of the total variability (40.78% for PC1 and 31.70% for PC2). From the analysis of Figure 1, it can be observed that the samples from the 4 dietary groups are well separated and two clusters are formed. The first cluster consists of samples from birds fed with S and F diets, which seems to be related to the FCR variable. In quadrant 2, on the other hand, it is possible to find the second cluster, consisting of birds fed with SL and FL diets, which seem to be more closely related to BWG. As for the FI variable, this is positioned near the x axis, which confirms that this parameter was not affected by the tested diets.

The second PCA (Figure 2) was performed on bird's serum profile and selected carcase cuts, where the biplot represented 46.46% of the total variability (23.27% for PC1 and 23.19% for PC2). In the fourth quadrant, it is possible to note a cluster represented by the birds fed with SL and FL diets, which correlates more strongly with the breast and live weight variables. In the opposite quadrant (2), the relative weight of some organs (liver, legs, heart), the abdominal fat, LDL and TG are more related to F and S diets.

Discussion

Growth performance

Our findings showed that, regardless of the type of oil (non-fried or fried), the addition of soybean lecithin improved the broilers' BW; this effect was particularly evident in the SL group during the entire feeding period, whereas in the FL group it was observed only in the last two growing periods. On the other hand, soybean lecithin supplementation had no effect on FI and FCR. In this context, Roy et al. (2010) and Zosangpuii et al. (2011) reported that exogenous emulsifiers have positive effects on BW, FI and FCR in broilers. Viñado et al. (2020) also reported that the inclusion of lecithin in feed showed a significant effect on growth performance. The positive impact of lecithin as an emulsifier when added to broiler feeding might be due to its improved palatability, which leads to higher feed and energy intake (Cho et al. 2012). However, Azman and Ciftci (2004) noted that the BW was not affected at 21 and 35 days of age when soybean oil was completely replaced by soybean lecithin in the feed. On the other hand, the current study revealed that soybean lecithin had no influence on feed intake, which was consistent with previous work by Aguilar et al. (2013).

Dorra et al. (2014) showed that the addition of frying oil to broiler diet did not significantly affect the growth parameters of broilers. These results were also confirmed by the study of Tres et al. (2013), who used a mixture of recovered frying oils (sunflower oil/olive oil, 70:30, v/v) after commercial frying of potato chip (at 170 °C) with a final polymer value > 6%; under these conditions, the fried oil had no effect on the fat digestion process of broilers and consequently on FCR (Tres et al. 2013).

The inconsistent results regarding performance and digestibility among the different studies could be due to the diverse FA composition of the fat sources and

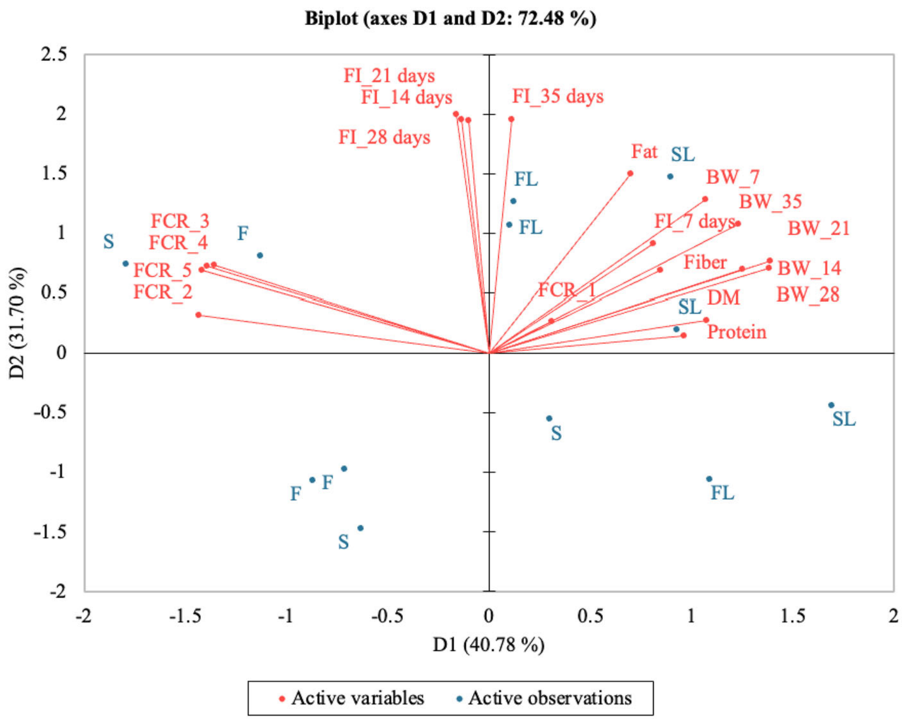

Figure 1. Biplot of bird's growth performance and nutrient digestibility. Treatments: S: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin. BW: Body Weight; CP: Crude Protein; DM: Dry Matter; FI: Feed Intake; FCR: Feed Conversion Ratio.

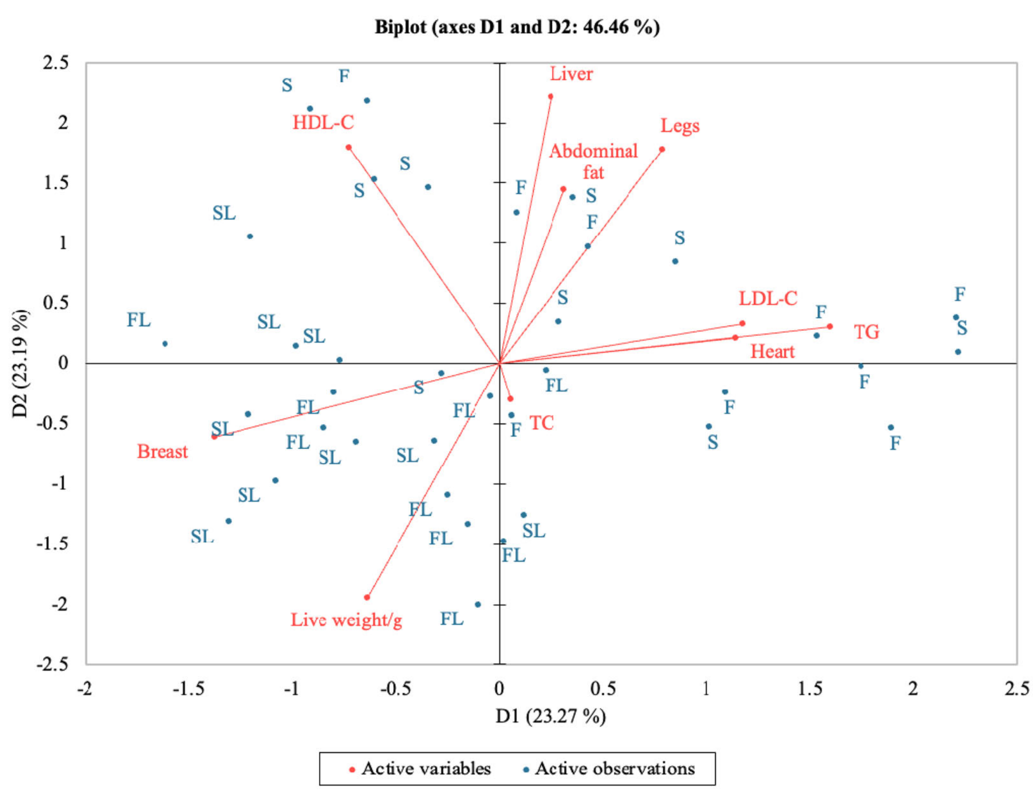

Figure 2. Biplot of bird's serum profile and selected carcase cuts. Treatments: SS: basal diet with soybean oil; SL: basal diet with soybean oil plus 0.035% soybean lecithin; F: basal diet with oxidised oil; FL: basal diet with oxidised oil plus 0.035% soybean lecithin. TC: total cholesterol; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol; TG: Triglycerides.

their effects on fat digestion and absorption. In general, long-chain saturated FA (SFA) have low digestibility, especially palmitic and stearic acids. In this context, Knarreborg et al. (2004) found that broiler chickens exhibited higher the digestibility of medium-chain SFA than long-chain ones. On the other hand, several authors have demonstrated that unsaturated fatty acids (UFA) exhibit higher absorption than SFA (Tancharoenrat et al. 2014; Rodriguez-Sanchez et al. 2019).

The liver is the major organ of lipid metabolism and is responsible for 95% of *de novo* FA synthesis (Theil and Lauridsen 2007). In the present study, the relative liver weight decreased significantly when soybean lecithin was added to the diet; our findings agree with the previous findings of Huang et al. (2007) and Nagargoje et al. (2016). It is possible that the emulsifying effect of lecithin resulted in less lipid accumulation in the liver (Huang et al. 2007). However, Siyal et al. (2017) found that the relative liver weight of broilers increased when they were fed 0.1% lecithin during the growing phase (21–42 days).

Digestibility

The digestibility of dry matter, crude protein, crude fibre, and ether extract was not affected by addition of soybean lecithin to the diet, regardless of the oil used as the energy source. Our results were in agreement with Huang et al. (2007), who did not find any effect on digestibility when adding different levels of lecithin (25, 50 and 100% of total fat). However, the study of Zampiga et al. (2016) showed an increase in the digestibility of these parameters after 21 days of age.

The lack of agreement between our results and some previous studies could be attributed to different sources of lipids and various levels of emulsifiers used in the diet (Dierick and Decuypere 2004; Aguilar et al. 2013). Furthermore, vegetable oils are easier to digest than animal fats, as documented by Li et al. (1990) and Tan et al. (2011). However, Zhao et al. (2015) reported that emulsifiers enhanced digestibility of nutrients in animals fed a low-energy diet with beef tallow as a fat source. Regarding the use of fried oils in animal feeding, Tres et al. (2013) reported that a fried vegetable oil blend made of sunflower oil/olive oil (70:30, v/v) with a polymer content of 6%, did not impact on broilers' digestibility parameters.

Finally, the results of PCA performed on bird's growth performance and nutrient digestibility (Figure 1) agree with those of Tres et al. (2013) and Dorra et al. (2014), which report how the addition of fried oil to broilers feed does not impact FI.

Serum profile

The levels of the serum parameters are related to broilers' health status, and they are good indicators of their nutritional conditions. In general, frying did not impact the serum lipids profile. These results agree with the study by Dorra et al. (2014), who observed that the TG content of broilers' serum was not affected when fried sunflower oil was utilised for broilers feed. Blas et al. (2010) stated that the fried oil should have a polar compound content higher than 10% to have a significant effect on serum parameters of broilers. In fact, Tres et al. (2013) found that, using a PUFA-rich fried oil with a medium content of polymers (~6%), did not influence the serum FA profile.

On the other hand, our findings show that the addition of soybean lecithin lowered the serum TG level, especially in the SL group. Similar data were reported by Huang et al. (2007) for different levels of lecithin addition, as well as by Siyal et al. (2017) when 0.1% soybean lecithin was added to the feed. However, Guerreiro Neto et al. (2011) did not detect any significant effect of the emulsifier addition on serum TG level.

Regarding the serum TC and HDL-C levels, they were not affected by soybean lecithin addition, independently of the oil used; in this case, our results are consistent with those of Guerreiro Neto et al. (2011), who found no significant effects of the added emulsifier on serum TC and HDL-C. On the other hand, Huang et al. (2007) and Siyal et al. (2017) found that using lecithin powder in feed reduced the levels of serum TC and HDL-C in broilers. Concerning the LDL-C level, a non-significant, decreasing trend was noted when soybean lecithin was added; our results were similar to those of Guerreiro Neto et al. (2011), while Siyal et al. (2017) found that the use of soybean lecithin at 0.1% in feed lowered serum LDL-C. It has been reported that soybean lecithin reduces the absorption of cholesterol and increases the sterol excretion in broilers' faeces (Ramesh et al. 2013).

The differences among studies about the effects of soybean lecithin on the profile of serum lipids could be attributed due to different experimental conditions concerning the dose and form of lecithin that were used. In this case, the PCA results (Figure 2) also confirmed what was reported in previous studies. In particular, Tres et al. (2013) demonstrated that the inclusion of recovery frying oil in chicken feed did not impact serum FA profile and liver weight, while Viñado et al. (2020) found that the use of soybean lecithin did not influence broiler performance and fat deposition/absorption.

Conclusions

Addition of recovered frying soybean oil in broiler diet showed similar effects on broiler growth, nutrients digestibility and serum profiles, as the non-fried oil did. Using soybean lecithin in broiler diet had significant positive impact on body weight, some carcase cuts and visceral organs. Minor improvements in serum profile (especially TG) were observed when broiler was fed with soybean lecithin. Further investigations are needed to find the optimum level of emulsifier and the type of oil to be used in broiler diets as energy source.

Disclosure statement

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

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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