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The Effect of Replacing Different Levels of Soybean Oil with Soybean Acid Oil and Adding Lipidol on Production and Economic Performance, Carcass Characteristics, and Meat Quality of Broiler Chickens

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Abstract

The aim of this study was to evaluate the effects of replacing different levels of soybean oil with soybean acid oil, along with supplementation of Lipidol, on performance, carcass characteristics, meat quality, and economic indices of as-hatched broiler chickens. A total of 360 day-old Arian broiler chicks were allocated in a 3×2 factorial arrangement (three levels of soybean oil replaced with soybean acid oil: 0%, 33%, and 66%, × two levels of Lipidol supplementation: 0 and 0.1%) in a completely randomized design, comprising six treatments with four replicates of 15 chicks each, for a 35-day rearing period. The results showed that the replacement of soybean oil with soybean acid oil and Lipidol supplementation had no significant effects on final body weight and feed intake of broilers ($P> 0.05$). However, feed conversion ratio (FCR) was significantly influenced by the replacement levels of acid oil, where 33% replacement in the starter phase and 66% in the grower phase led to a significant increase in FCR ($P< 0.05$). Supplementation of Lipidol resulted in an increased FCR during starter and grower phases ($P< 0.05$). The interaction between soybean acid oil replacement and Lipidol supplementation was significant for abdominal fat percentage ($P< 0.05$), as in diets without acid oil replacement, Lipidol supplementation increased abdominal fat, while this effect was not observed in diets containing 33% and 66% acid oil replacements. Meat quality parameters were not significantly affected by any of the treatments ($P> 0.05$). In conclusion, the results indicated that replacing soybean oil with soybean acid oil, albeit it may increase FCR at younger ages (1-14 and 1-24 days), had no significant effect on broiler live performance, economic traits and meat quality considering the 1-35 days growth period. Lipidol supplementation resulted to increase feed cost and feed cost to gain, and poorer FCR at younger ages and increased abdominal fat percentage of carcass, thus suggesting a lack of economic benefit for broiler producers.

Introduction

In the poultry industry, feed cost constitutes the major portion of total production expenses, and the metabolizable energy (ME/AMEn) content of the diet plays a pivotal role in determining growth rate and feed conversion efficiency in broiler chickens. Fats and oils are widely used as concentrated sources of dietary energy, and soybean oil is one of the most common lipid ingredients due to its favorable fatty acid profile and high digestibility. However, fluctuations in oil prices and the competition between feed and food industries have prompted nutritionists to explore alternative and low-cost energy sources. One such alternative is a by-product of the soybean oil refining process, generally known as soybean acid oil (SAO) or acidulated soapstock. Owing to its high content of free fatty acids (FFA) and MIU impurities (moisture, insoluble matter, and unsaponifiable materials), its energy value and digestibility differ from those of refined soybean oil (Peña *et al*., 2014;

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Borsatti *et al*., 2018). Several studies have demonstrated that the apparent metabolizable energy (AMEn) value of soybean acid oil falls within a range that makes it a potentially economical energy source in broiler diets (Viera *et al*., 2002; Freitas *et al*., 2005; Borsatti *et al*., 2018). Reported AMEn values for acidulated soapstock are typically lower than those of refined soybean oil, yet they remain acceptable when cost efficiency is taken into consideration (Peña *et al*., 2014; Borsatti *et al*., 2018). In a comprehensive study, Borsatti *et al*. (2018) evaluated the AMEn of several by-products derived from the soybean oil industry and indicated that their energy values vary depending on composition (i.e., Triacylglycerol (TAG)/Diacylglycerol (DAG)/ Free Fatty acids (FFA) ratio, moisture, and impurities) as well as bird age. Moreover, subsequent research has shown that partial or total replacement of saturated fats, such as palm oil, with soybean acid oil—or the use of their blends—can enhance fatty acid absorption and maintain comparable lipid utilization efficiency to soybean oil, particularly in the grower–finisher period, provided that the unsaturated fatty acids: saturated fatty acids (UFA: SFA) ratio and FFA percentage are within optimal ranges (Jiménez-Moya *et al*., 2021). Earlier findings have also indicated that at moderate inclusion levels and under proper blending ratios with unsaturated fat sources, the adverse effects of high FFA on lipid absorption can be mitigated (Peña *et al*., 2014). To overcome the limited digestibility of high-FFA fats or other lipid sources with lower utilization efficiency, the application of nutritional emulsifiers and surfactants has gained increasing attention. Lysophospholipids (LPLs)—commercially available in additives such as Lipidol—have been shown to improve lipid emulsification, enhance lipase accessibility, and promote intestinal morphology, thereby increasing the absorption of lipids and other nutrients (Zhao and Kim, 2017). Experimental studies have reported that supplementation of LPLs in energy- or protein-reduced diets can restore or even enhance growth performance and feed conversion ratio (Zhao and Kim, 2017). Furthermore, recent studies and meta-analyses have confirmed the beneficial impacts of LPLs on nutrient digestibility, carcass composition, and serum biochemical indices. Under certain conditions—such as heat stress or high dietary fat inclusion—LPL supplementation has also been associated with improved economic returns and production efficiency (Zhang *et al*., 2022). Based on the available evidence, it can be hypothesized that soybean acid oil, when included at different dietary levels as a partial or total replacement for refined soybean oil, may serve as a cost-effective energy source in broiler nutrition. However, its effectiveness depends largely on the fatty acid composition, FFA content, and the age or growth phase of the bird. Concurrently, the inclusion of a commercial lysophospholipids additive such as Lipidol may alleviate the potential negative effects of elevated FFA levels and improve the energy utilization efficiency of this by-product. Therefore, the present study was designed to evaluate the effects of different inclusion levels of soybean acid oil—with or without Lipidol supplementation—on productive performance, carcass and meat quality traits, and the economic efficiency of broiler chickens. The findings of this research are expected to provide practical insights into the feasibility of using this by-product in commercial poultry diets and to establish applicable recommendations for the industry.

Materials and Methods

This research was conducted in the summer at the Poultry Research Unit of Gonbad Kavous University, and the related analyses were also performed in the Animal Science Laboratory of the university. The desired soybean fatty acid was obtained from the Alteen Daneh Company's oil extraction plant located in Gonbad Kavus Industrial Estate. The lysophospholipids supplement with the trade name Lipidol was prepared from the official representative of Pathway Intermediates, South Korea, in Iran. The commercial supplement Lipidol consisted of lysophosphatidylinositol, lysophosphatidylcholine, lysophosphatidyl ethanolamine, and lysophosphatidic acid. In addition, hydrolyzed soybean lecithin and calcium silicate were also used as carriers in its composition. 360 one-day-old Arian strain broiler chicks were used in a completely randomized 2×3 factorial design (two levels of lysophospholipid supplementation: 0 and 0.1% × three levels of acid oil replacement for soybean oil: 0%, 33%, and 66%) with 6 treatments and 4 replications, with 15 broiler chicks hatched in each. Diets were formulated with UFFDA software based on the Arian broiler breeding manual (2020), and the nutrient composition matrix of feed ingredients was based on National Research Council (NRC, 1994) tables (Table 1). Growth period was 35 days, and all chicks received starter (1-14 d), grower (15-24 d) and finisher diets (25-35 d). The chicks were transferred to a 24-pen house during the experiment and had free access to water and the relevant feed treatment. Chicken rearing management programs, including temperature, light, vaccination, floor density and bedding, were carried out uniformly and in accordance with the recommended standard conditions. Feed consumption was measured periodically in each experimental unit. The number of mortalities and their weights were recorded during the experiment to be included in the calculation of weight gain and feed consumption of the chickens that died during the experiment. At the beginning and end of the experiment, the chickens in each replication were weighed cumulatively, and the

weight gain during the entire period was calculated. Before weighing the chickens, they were deprived of water and feed for 4 hours to ensure that their digestive tract contents were empty. FCR was calculated by dividing the average feed consumption of each pen in each period by the average weight gain of that pen at the same period. After the end of the 35-day rearing period, a chicken with a weight close to the average of the pen was selected from each replication, weighed and slaughtered. After dressing, the carcass was eviscerated, and thighs and breast (without skin) were separated. Then, using scales with an accuracy of 1 and 0.01 grams, the weights of the eviscerated carcass, liver, heart, gizzard, abdominal fat, breast, and thighs were measured, and their relative weights were calculated as a percentage of the live weight before slaughtering. In order to evaluate the quality of poultry meat, the right thigh of each chicken was carefully separated and stored in a freezer for 30 days at -21°C. At the end of the storage period in the freezer, thigh samples were placed at room temperature for one hour, and then the meat part was separated from the thigh bone. Then, the obtained samples were completely homogenized with a meat grinder, and 50 grams of each sample was used for meat quality tests. To examine the degree of lipid oxidation in thigh meat, the thio-barbituric acid (TBA) test was used, in which milligrams of malondialdehyde (MDA) per kilogram of sample was calculated and considered as the basis for meat oxidative spoilage (Tarladgis *et al*., 1960) To determine the pH of meat, the electrode of the pH meter (model 691, Metrohm) was placed in the homogenized meat sample and the acidity of the sample was reported at ambient temperature (Hazrati *et al*., 2020). The percentage of dry matter was determined by the approximate analysis method (AOAC, 1990). Also, to determine the water holding capacity, one gram of boneless and skinless meat sample was used and placed in filter paper (No. 4, Whatman). Then, the filter paper was rolled up and centrifuged at 6000 rpm for 10 minutes. Finally, the water holding capacity of the samples was calculated and reported as a percentage (Mehri *et al*., 2015).

Table 1: Feed ingredients and chemical composition of the basal diet used in different phases (%, as is)

	Starter (1-14 d)	**Grower (15-25 d)**	**Finisher (26-35 d)**
Corn (CP=8.5%)	57.90	61.68	65.82
Soybean meal (CP=44%)	36.45	32.50	28.33
Soy Oil	**1.08**	**1.61**	**1.97**
Di-calcium phosphate	1.79	1.61	1.39
Oyster shell	1.18	1.07	0.99
Salt	0.39	0.41	0.41
DL-methionine	0.34	0.30	0.26
L-lysine	0.22	0.18	0.19
L-threonine	0.10	0.09	0.09
Vitamin Premix[1]	0.25	0.25	0.25
Mineral Premix[2]	0.25	0.25	0.25
Anticoccidiosis	0.05	0.05	0.05
Calculated chemical composition of basal diets (%)			
AMEn (Kcal/Kg)	2870	2950	3025
Crude protein	21.5	20	18.5
Linoleic acid	1.42	1.49	1.56
Arginine	1.31	1.21	1.10
Lysine	1.33	1.20	1.10
Methionine	0.66	0.59	0.54
Methionine+ Cysteine	1.00	0.92	0.85
Tryptophan	0.30	0.28	0.25
Threonine	0.89	0.82	0.76
Calcium	0.96	0.84	0.78
Available Phosphorus	0.48	0.44	0.39

1. Vitamin supplement provided the following amounts per kg of diet: 12,800 IU vitamin A, 4,000 IU vitamin D3, 48 IU vitamin E, 4.4 mg vitamin K, 22.5 mg pantothenic acid, 65 mg niacin, 6.4 mg pyridoxine, 0.016 mg Cyanocobalamin, 1.6 mg folic acid, 400 mg choline chloride.

2. Mineral supplement provided the following amounts per kg of diet: 120 mg manganese (manganese sulfate), 110 mg zinc (zinc oxide), 20 mg iron (ferrous sulfate), 1.25 mg iodine (calcium iodate), 0.3 mg selenium (sodium selenite).

The calculated economic traits were European Production Efficiency Factor (Kryeziu *et al*., 2018), feed cost per chicken (Rials /bird), feed cost: gain (Rials/kg) (Moradi *et al*., 2013) and monetary returns (Rials/bird) (McCoy *et al*., 1994), which is the price of feed ingredients at the start of the experiment and the selling price of chickens (Rials/Kg) at marketing were used. In brief, relationships for calculating feed

cost per chicken (Rials/b), feed cost: gain (Rials/kg) and monetary returns per chicken (Rials/b) are summarized below:

Feed cost (Rials/b) = [∑ (feed price (Rials/Kg) in the same period × feed intake (Kg) of each period)]

Feed cost: gain (Rials/Kg) = Feed cost (Rials/b)/ Weight gain (Kg)

Monetary Returns (Rials/b) = [Live weight (Kg) × 610000 - feed cost (Rials/b)], where 610000 was the Rials Live weight price of chickens at the time of marketing.

$$\text{European Performance} = \frac{\text{body weight (kg)} \times \text{Viability (\%)} \times 100}{\text{FCR} \times \text{Growth period (days)}}$$

Efficiency Factor (EPEF)

Viability (%) = 100- mortality (%)

Data were analyzed in a completely randomized design (CRD) by the ANOVA procedure of SAS software (SAS Institute, 2003). When the effects of dietary treatments were significant ($P< 0.05$), means were compared using the Tukey test comparison procedure of SAS software (SAS Institute, 2003).

In this study, the statistical model of the design is shown in Equation 1, where μ = population mean, A_i = effect of level of soy oil replaced with soybean acid oil, B_j = effect of adding Lipidol, AB_{ij} = interaction effect of level of soybean oil replaced with soybean acid oil × Lipidol, and ε_{ijk} = experimental error.

$$Yijk = \mu + A_i + B_j + AB_{ij} + \varepsilon_{ijk} \quad \text{(Equation 1)}$$

Results

Production traits

The effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol on body weight and weight gain has been shown in Table 2, and these effects on feed intake and feed conversion ratio (FCR) of broiler chickens have been shown in Table 3. In the present study, neither the main effects nor the interaction effect between the replacement of soybean oil with soybean acid oil and dietary supplementation with Lipidol showed significant differences in final body weight or daily weight gain of broiler chickens. Feed intake was not significantly affected by either the replacement of soybean oil with soybean acid oil or supplementation with Lipidol. Regarding feed conversion ratio (FCR), the interaction between soybean acid oil and Lipidol supplementation was not significant. However, partial replacement of soybean oil with soybean acid oil increased FCR in some feeding phases, particularly at 33% replacement in the starter period and 66% in the 1-24 days (starter + grower). Interestingly, Lipidol supplementation in the current study resulted in a significant increase in FCR, indicating poorer feed efficiency in the supplemented groups compared to the control.

Table 2: Effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol supplement on body weight and weight gain of broiler chickens at different ages (days)

DAYS	Body weight and Weight Gain (g)				
	14	24	35	14-24	24-35
Main effect of soybean and acid oil substitution					
R0	431.8	1094.9	1948.5	662.3	853.6
R1	426.3	1084.1	1968.5	657.7	883.9
R2	429.6	1073.3	1939.3	643.8	865.5
SEM	3.41	12.57	21.83	10.71	17.45
P-value	0.528	0.492	0.634	0.460	0.479
Main effect of Lipidol Supplement					
L0	430.3	1090.8	1956.6	660.7	865.8
L1	428.9	1077.4	1947.5	649.0	869.5
SEM	2.79	10.26	17.83	8.15	14.25
P-value	0.58	0.368	0.721	0.384	0.857
Interaction effect of soybean and acid oil substitution × Lipidol Supplement					
R0×L0	430.0	1095.7	1968.2	664.8	872.5
R0×L1	433.6	1094.2	1928.8	659.8	834.6
R1×L0	430.4	1090.8	1956.7	660.7	865.8
R1×L1	422.2	1077.4	1980.3	655.2	902.0
R2×L0	430.7	1086.0	1945.1	655.4	859.1
R2×L1	428.5	1060.7	1933.4	632.2	871.9
SEM	4.83	17.78	30.87	15.15	24.68
P-value	0.49	0.800	0.601	0.788	0.321

[a.b] Means within the same column with different superscripts differ ($P< 0.05$).

R: levels of soybean oil substitution with soybean acid oil in the diet: R_0: 0%, R_1: 33% and R_2: 66%.

L: amount of Lipidol use: L_0: no Lipidol use in the diet, L_1: Lipidol use at a rate of 1 g/kg diet.

SEM: standard error of the mean, P-value: Probability level.

Table 3: Effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol supplement on feed intake and feed conversion ratio (FCR) of broiler chickens at different ages (days)

	Feed intake					FCR				
days	**1-14**	**1-24**	**1-35**	**14-24**	**24-35**	**1-14**	**1-24**	**1-35**	**14-24**	**24-35**
Main effect of soybean and acid oil substitution										
R0	525.9	1593.5	3166.7	1067.7	1573.1	1.359^{b}	1.519^{b}	1.664	1.614	1.845
R1	531.3	1603.8	3200.8	1072.4	1597.0	1.395^{a}	1.544^{ab}	1.665	1.632	1.810
R2	532.5	1596.0	3173.5	1063.6	1577.5	1.385^{ab}	1.553^{a}	1.676	1.654	1.835
SEM	4.50	16.24	31.25	12.79	20.88	0.008	0.009	0.010	0.016	0.024
P-value	0.553	0.898	0.720	0.509	0.695	0.015	0.036	0.685	0.217	0.570
Main effect of Lipidol Supplement										
L0	527.7	1594.2	3175.4	1066.5	1581.1	1.369^{b}	1.525^{b}	1.662	1.617	1.828
L1	532.1	1601.3	3185.3	1069.3	1584.0	1.390^{a}	1.552^{a}	1.675	1.649	1.825
SEM	3.67	13.26	25.52	10.44	17.05	0.006	0.007	0.008	0.013	0.019
P-value	0.418	0.710	0.786	0.853	0.906	0.040	0.016	0.286	0.094	0.908
Interaction effect of soybean and acid oil substitution × Lipidol Supplement										
R0×L0	519.8	1580.9	3166.5	1061.1	1585.6	1.348	1.505	1.647	1.598	1.819
R0×L1	531.9	1606.1	3166.8	1074.2	1560.7	1.369	1.532	1.682	1.629	1.872
R1×L0	527.7	1594.2	3175.4	1066.5	1581.1	1.369	1.525	1.662	1.617	1.828
R1×L1	535.0	1613.3	3226.8	1078.3	1612.9	1.420	1.563	1.668	1.645	1.791
R2×L0	535.7	1607.5	3184.2	1071.9	1576.7	1.390	1.545	1.677	1.636	1.837
R2×L1	529.3	1584.5	3162.9	1055.3	1578.4	1.380	1.561	1.676	1.671	1.812
SEM	6.36	22.97	44.19	18.08	29.53	0.011	0.013	0.015	0.022	0.033
P-value	0.344	0.532	0.708	0.656	0.637	0.053	0.671	0.478	0.989	0.366

[a.b] Means within the same column with different superscripts differ ($P< 0.05$).
R: levels of soybean oil substitution with soybean acid oil in the diet: R0: 0%, R1: 33% and R2: 66%.
L: amount of Lipidol use: L0: no Lipidol use in the diet, L1: Lipidol use at a rate of 1 g/kg diet.
SEM: standard error of the mean, P-value: Probability level.

Table 4: Effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol supplement on carcass characters and edible viscera of broiler chickens at 35 d of age

Treatments	**Relative weight of carcass parts (%)**				**Relative weights of edible viscera (%)**		
	Edible carcass	**Thighs**	**Breast**	**Abdominal fat**	**Liver**	**Heart**	**Gizzard**
Main effect of soybean and acid oil substitution							
R_0	65.27	19.33	25.60	1.83	1.92	0.43	1.35
R_1	65.03	18.78	25.39	1.65	1.87	0.44	1.19
R_2	65.45	18.96	26.18	1.86	1.89	0.42	1.20
SEM	0.56	0.30	0.61	0.13	0.06	0.02	0.06
P-value	0.870	0.437	0.644	0.467	0.857	0.764	0.154
Main effect of Lipidol Supplement							
L_0	65.36	18.88	25.82	1.78	1.90	0.43	1.22
L_1	65.14	19.17	25.63	1.77	1.89	0.42	1.27
SEM	0.46	0.25	0.50	0.10	0.05	0.02	0.05
P-value	0.739	0.418	0.792	0.987	0.962	0.658	0.504
Interaction effect of soybean and acid oil substitution × Lipidol Supplement							
$R_0×L_0$	64.87	19.04	26.10	1.52^{c}	1.90	0.46	1.39
$R_0×L_1$	65.67	19.63	25.12	2.14 ^{a}	1.94	0.41	1.31
$R_1×L_0$	65.03	18.82	24.63	1.74^{abc}	1.91	0.43	1.17
$R_1×L_1$	65.04	18.75	26.15	1.56^{c}	1.83	0.45	1.21
$R_2×L_0$	66.19	18.78	26.73	2.08^{ab}	1.88	0.42	1.10
$R_2×L_1$	64.72	19.13	25.63	1.64^{bc}	1.91	0.41	1.30
SEM	0.79	0.43	0.86	0.18	0.09	0.03	0.09
P-value	0.369	0.732	0.253	0.026	0.734	0.478	0.295

[a.b] Means within the same column with different superscripts differ ($P< 0.05$).
R: levels of soybean oil substitution with soybean acid oil in the diet: R_0: 0%, R_1: 33% and R_2: 66%.
L: amount of Lipidol use: L_0: no Lipidol use in the diet, L_1: Lipidol use at a rate of 1 g/kg diet.
SEM: standard error of the mean, P-value: Probability level.

Carcass characteristics

The effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol on carcass characteristics of broiler chickens is shown in Table 4. The results of the present study indicated a significant interaction between soybean acid oil replacement and dietary supplementation with Lipidol on abdominal fat percentage of broiler chickens. Specifically, in diets without soybean acid oil, the inclusion of Lipidol led to a marked increase

in abdominal fat percentage, whereas in diets containing 33% and 66% soybean acid oil, no significant effect was observed. However, the main effects of acid oil replacement or Lipidol addition on other carcass traits—including eviscerated carcass yield, breast and thigh percentages, and edible viscera organ weights—were not significant.

Table 5: Effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol supplement on meat quality characteristics of broiler chickens

Treatments	Meat quality parameters			
	Dry matter (%)	Lipid oxidation (mg MDA/1000g meat)	Water holding capacity (%)	pH
Main effect of soybean and acid oil substitution				
R_0	24.15	0.64	63.07	6.31
R_1	24.14	0.53	61.34	6.35
R_2	23.85	0.47	60.60	6.37
SEM	0.48	0.09	1.35	0.03
P-value	0.881	0.440	0.432	0.392
Main effect of Lipidol Supplement				
L_0	24.07	0.51	61.95	6.35
L_1	24.03	0.58	61.38	6.34
SEM	0.39	0.08	1.10	0.02
P-value	0.948	0.579	0.719	0.945
Interaction effect of soybean and acid oil substitution × Lipidol Supplement				
$R_0 \times L_0$	23.96	0.71	61.90	6.34
$R_0 \times L_1$	24.33	0.56	59.30	6.28
$R_1 \times L_0$	23.77	0.48	61.31	6.37
$R_1 \times L_1$	24.51	0.58	61.37	6.34
$R_2 \times L_0$	24.46	0.34	62.65	6.33
$R_2 \times L_1$	23.24	0.59	63.48	6.41
SEM	0.68	0.13	1.91	0.04
P-value	0.330	0.351	0.647	0.267

[a.b] Means within the same column with different superscripts differ ($P < 0.05$).
R: levels of soybean oil substitution with soybean acid oil in the diet: R_0: 0%, R_1: 33% and R_2: 66%.
L: amount of Lipidol use: L_0: no Lipidol use in the diet, L_1: Lipidol use at a rate of 1 g/kg diet.
SEM: standard error of the mean, P-value: Probability level.

Table 6: Effect of replacing different levels of acid oil with soybean oil and adding Lipidol supplement on production index and economic traits of broiler chickens

Treatments	Feed cost (Rials/bird)	Feed cost: gain (Rials/kg)	Monetary returns (Rials/bird)	Production index
Main effect of soybean and acid oil substitution				
R_0	543630	285790	544950	334.7
R_1	545850	283960	554910	337.9
R_2	537650	284020	565290	330.7
SEM	5319	1875	9497	5.1
P-value	0.541	0.739	0.706	0.617
Main effect of Lipidol Supplement				
L_0	535920[b]	280460[b]	557630	336.5
L_1	548830[a]	288710[a]	539140	332.3
SEM	4343	1531	7754	4.2
P-value	0.049	0.001	0.109	0.482
Interaction effect of soybean and acid oil substitution × Lipidol Supplement				
$R_0 \times L_0$	537876	279762	562707	341.5
$R_0 \times L_1$	549377	291812	527185	327.8
$R_1 \times L_0$	535942	280455	557610	336.4
$R_1 \times L_1$	555761	287455	552212	339.3
$R_2 \times L_0$	533947	281165	552567	331.6
$R_2 \times L_1$	541358	286875	538020	329.6
SEM	7522	2651	13431	7.2
P-value	0.707	0.465	0.528	0.518

[a.b] Means within the same column with different superscripts differ ($P < 0.05$).
R: levels of soybean oil substitution with soybean acid oil in the diet: R_0: 0%, R_1: 33% and R_2: 66%.
L: amount of Lipidol use: L_0: no Lipidol use in the diet, L_1: Lipidol use at a rate of 1 g/kg diet.
SEM: standard error of the mean, P-value: Probability level.

Meat quality

The effect of replacing different levels of soybean oilwith soybean acid oil and adding Lipidol on the meat quality of broiler chickens is shown in Table 5. The results of the present study showed that the interactive effect between different levels of soybean acid oil replacement and Lipidol supplementation on meat quality parameters of broiler chickens was not significant. Likewise, neither the main effect of soybean acid oil substitution nor Lipidol addition alone produced significant differences in carcass or meat quality indices.

Economic traits

The effect of replacing different levels of soybean oil with soybean acid oil and adding Lipidol on the economic performance of broilers is shown in Table 6. In this study, the interaction effect between replacing different levels of soybean acid oil with soybean oil and the supplementation of a commercial lysophospholipid (Lipidol) on the economic traits of broiler chickens was not significant. Similarly, the main effect of replacing soybean oil with soybean acid oil on economic indicators, including feed cost, feed cost to weight gain, and monetary returns, was not significant. However, the main effect of Lipidol supplementation was significant for some economic traits ($P< 0.05$), indicating that the inclusion of this additive increased feed cost and feed cost to weight gain.

Discussion

The present study evaluated the effects of replacing soybean oil with soybean acid oil and supplementing with Lipidol on performance, carcass characteristics, meat quality, and economic indices of broiler chickens. The findings indicate that under the experimental conditions of this study, altering the lipid source or including an emulsifier had no marked effect on the growth performance of birds.

These results are consistent with the findings of Salari *et al*. (2023), who also reported that dietary lysophospholipid supplementation did not significantly affect body weight in broilers. Similarly, Gheisar *et al.* (2015) observed no significant differences in early growth performance with lysophospholipid inclusion, and Al-Marzooqi and Leeson (1999) found no clear improvement in body weight gain when using dietary emulsifiers. Conversely, several other studies have reported positive effects of emulsifiers on broiler growth performance. For example, Upadhaya *et al.* (2017) observed significant increases in body weight gain following supplementation with lysophospholipids or similar emulsifiers. More recent research by Basareh *et al.* (2023) also demonstrated improvements in growth rate and FCR when lysophospholipids were combined with specific oil sources such as sesame oil. The inconsistency among studies may be attributed to several factors, including the type and dosage of emulsifier, lipid source, ingredient quality, rearing conditions (temperature, humidity, and hygiene), and bird age. In particular, Oketch *et al*. (2023) reported that the beneficial effects of emulsifiers are more pronounced in younger chicks due to their limited bile salt secretion and immature digestive enzyme activity (especially lipase). As birds mature, their natural capacity for fat emulsification and digestion improves, reducing the need for exogenous emulsifiers.

Feed intake was not significantly affected by either the replacement of soybean oil with soybean acid oil or supplementation with Lipidol. This observation agrees with Gheisar *et al*. (2015) and Al-Marzooqi and Leeson (1999). However, some studies have reported increased feed intake with lysophospholipid or emulsifier supplementation (Salari *et al*., 2023; Pashaei Jalal *et al*., 2022), which contrasts with the present findings. Such variation may stem from differences in the type of emulsifier, dietary energy level, and the physiological stage of the birds (Oketch *et al*., 2022; Tenorio *et al*., 2022).

Regarding feed conversion ratio (FCR), the interaction between soybean acid oil and Lipidol supplementation was not significant. However, partial replacement of soybean oil with soybean acid oil increased FCR in some feeding phases, particularly at 33% replacement in the starter period and 66% in the 1-24 days (starter + grower), indicating reduced feed efficiency. This result aligns with the findings of Jiménez-Moya *et al*. (2021), who reported that diets containing fats with higher levels of FFA or saturated fatty acids may reduce feed efficiency. In contrast, some reports have shown improved FCR with soybean acid oil supplementation (Shahryari *et al*., 2021). These discrepancies may relate to variations in the fatty acid profile, FFA percentage, or processing quality of the lipid sources used.

Interestingly, Lipidol supplementation in the current study resulted in a significant increase in FCR, indicating poorer feed efficiency in the supplemented groups compared to the control. In the present study, the main drawback of lysophospholipid on FCR was seen in the initial ages (1-14 and 1-24 days) when the chicks are not complete for lipid digestion and absorption (shortage of bile salt and low pancreatic lipase and colipase secretion and their activities, short small intestine and rapid transit time of digesta, low activity of Fatty Acids Binding Protein for transport of long chain fatty acids (Noy and Sklan, 1995; Sklan, 1979; Uni *et al*., 1995; Katongole and March, 1980). In this situation, adding emulsifiers may cause lipids to be emulsified too rapidly or too finely; they may pass through the small intestine before sufficient pancreatic lipase, colipase, and bile salts can act, leading to malabsorbed fatty acids that are excreted

rather than utilized (Smink *et al*., 2012). Another reason for this result may be found in high levels of calcium in starter rations, which emulsifiers can interact with calcium or mineral soaps in the gut, reducing both fat and mineral bioavailability (Sizova and Ryazantseva, 2022). This finding contradicts many previous studies reporting improved feed efficiency with lysophospholipid addition (Dierick *et al*., 2021; Basareh *et al*., 2023). Such differences could be due to the experimental design, quality or concentration of the emulsifier used, dietary energy level, or interactions between the emulsifier and lipid composition. In agreement with Pashaei Jalal *et al*. (2022), emulsifier supplementation has sometimes increased feed intake while simultaneously impairing feed conversion efficiency — a pattern consistent with the current observations.

Previous studies have reported inconsistent findings regarding the influence of emulsifiers on carcass composition and lipid deposition. Several researchers have observed a significant reduction in abdominal fat content following emulsifier supplementation (Hu *et al*., 2019), which may be attributed to improved lipid emulsification, enhanced absorption of essential fatty acids, and a decrease in hepatic lipogenesis. Conversely, other studies have reported no significant effect (Guerreiro Neto *et al*., 2011) or even an increase in fat deposition (Wang *et al*., 2016), likely depending on factors such as emulsifier type and dosage, dietary fat source, bird age, and rearing conditions (Cheah *et al*., 2017; Liu *et al*., 2026).

The observed increase in abdominal fat in broilers fed diets devoid of soybean acid oil but supplemented with Lipidol might be associated with altered metabolic partitioning of energy and enhanced lipid storage. In contrast, higher inclusion levels of acid oil may have attenuated this response by modifying the balance between lipid oxidation and deposition, as dietary fatty acid profile has been shown to influence both abdominal fat accumulation and β-oxidation activity in broilers (Sanz *et al*., 2000; Crespo and Esteve-Garcia, 2001, 2002). Hence, further research under diverse nutritional settings is warranted to clarify the interactive effects of lipid sources and emulsifiers on carcass quality and energy metabolism in broilers.

It should be noted that soybean acid oil, unlike refined soybean oil, contains a high proportion of FFAs, which exhibit a lower tendency to form micelles in the intestinal lumen. This property reduces emulsification efficiency and consequently decreases lipid digestibility (Tancharoenrat *et al*., 2014). Under such circumstances, the inclusion of biosurfactants or emulsifiers such as lysophospholipids can enhance micelle formation and facilitate the absorption of FFAs (Upadhaya *et al*., 2017). Therefore, it was hypothesized that supplementation with lysophospholipids in diets containing soybean acid oil would improve fat utilization and consequently meat quality through better oxidative stability.

Previous research has demonstrated that lysophospholipids, as biological emulsifiers, can improve lipid digestion and absorption, reduce lipid oxidation, and enhance meat oxidative stability (Kang *et al*., 2020). Similarly, Shahmoradi *et al*. (2022) reported that dietary supplementation with lysophospholipid-based additives such as Lipidol decreased malondialdehyde (MDA) concentrations in broiler muscle tissues after slaughter. However, in the present study, such improvements were not observed. This lack of response may be attributed to several factors. Previous research has shown that lysophospholipids, as biological emulsifiers, can improve fat digestion and absorption, reduce fat oxidation, and increase the oxidative stability of meat (Kang *et al*., 2020). Similarly, Shahmoradi *et al*. (2022) reported that dietary supplementation with lysophospholipid-based additives such as Lipidol reduced the concentration of malondialdehyde in muscle tissues of broiler chickens after slaughter. However, in the present study, no such improvement was observed. This result may be due to the low levels of fat or acid oil in the low-energy diet of the Arian strain, as well as the sufficient amount of endogenous bile salts secreted by the liver of broilers, or the presence of other emulsifiers found in soybeans (lecithin, saponins, phospholipids, etc.) in the basal diet, which resulted in little or no benefit for supplemented Lipidol (Cho *et al*., 2020).

Overall, the results of this study are consistent with previous findings by Crespo and Esteve-Garcia (2001) and suggest that the effects of dietary fat sources and emulsifiers on meat quality depend on the fatty acid composition, FFA content, and rearing conditions. Further investigations are warranted to clarify the interaction between FFA levels and emulsifier types in relation to meat quality in broilers.

Information regarding the combined effects of acid oil and lysophospholipids on economic parameters in broilers is limited. In the present experiment, replacing soybean oil with soybean acid oil reduced the cost per kilogram of feed. Nevertheless, since this substitution slightly decreased body weight gain, the feed cost per weight gain was not significantly affected. Furthermore, the monetary returns were not influenced by the dietary treatments. It should be noted that the gross monetary returns do not directly reflect the profitability of a production unit but are highly correlated with the profit index (Park *et al*., 2024). On the other hand, supplementation of Lipidol increased the feed cost and consequently the total production cost. Because this additive is relatively expensive and showed only limited effects on feed intake and weight gain in this study, it is reasonable that economic indicators such as feed cost to weight

gain were negatively affected. Similar results were reported by Maghsoudlou *et al*. (2024), who found that adding Lipidol to broiler diets had no significant effect on production index or gross monetary returns per bird. Likewise, Parak *et al*. (2024) observed that replacing soybean oil with soybean fatty acids had no significant effect on feed cost, feed cost per weight gain, production index (PI), or gross economic efficiency, which is consistent with the findings of the present study. Moreover, several international studies have indicated that the use of lower-quality fat sources may reduce feed cost, but without improving growth performance, the overall economic impact remains minimal (Vieira and Angel, 2014; Borsatti *et al*., 2018; Jiménez-Moya *et al*., 2021). Therefore, it can be concluded that although partial replacement of soybean oil with soybean acid oil can be cost-effective in reducing feed expenses, maintaining or improving growth performance is essential to achieve real economic benefits. Conversely, the use of high-priced additives such as Lipidol can only be economically justified if they result in a significant improvement in feed conversion ratio or body weight gain.

Conclusion

Overall, partial substitution of soybean oil with soybean acid oil may be economically feasible, yet it does not enhance growth or meat quality. Not only did the use of lysophospholipids not show any significant effect on production performance, but it also resulted in a higher feed cost and feed cost to gain of the broilers. The use of emulsifiers such as Lipidol appears to be justified only when they provide measurable improvements in feed efficiency or carcass composition. Therefore, their application should be carefully considered according to the dietary fat content and its profile, the level of FFAs, and the economic context of the production system.

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