Turkish Journal of Veterinary and Animal Sciences

http://journals.tubitak.gov.tr/veterinary/

Research Article

Turk J Vet Anim Sci
(2022) 46: 263-274
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doi:10.3906/vet-2110-15

Production efficiency, nutrient digestibility, and meat quality of broilers reared on different fat sources and emulsifiers

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Received: 06.10.2021 • **Accepted/Published Online:** 24.01.2022 • **Final Version:** 25.04.2022

Abstract: Two fat sources, soybean oil (SO) and refined poultry oil (RPO), and 4 emulsifiers (control, lysolecithin, lysophospholipid, and bile acids) were used in this experiment. Thirteen hundred and sixty (1360) birds (ROSS - 308) were divided into 8 groups having 5 replicates, 34 birds in each. Energy efficiency, feed conversion (FCR), and protein efficiency ratios were improved in birds receiving SO than RPO diets. Weight gain, FCR, feed intake, and dressing percentage were increased in broiler birds receiving bile acid than those given lyso-phospholipid and lysolecithin ($p < 0.05$). Cooking loss was greater ($p < 0.05$) in broiler birds given RPO than those fed SO. Birds receiving bile acid had greater ($p < 0.05$) water holding capacity of chest meat than other fat emulsifiers. Bile acids in broiler diet presented higher ($p < 0.05$) digestibility of crude protein and ether extract as compared to other treatments. Bile acid supplemented diets had a minimum ($p < 0.05$) cost of production per kg live weight than other fat emulsifiers. Therefore, the use of bile acids with RPO diets can increase nutrient digestibility, growth performance, meat quality, and economic efficiency in broiler production systems.

Key words: Emulsifiers, oil sources, growth performance, nutrient digestibility, meat quality, economics

1. Introduction

Commercial broiler production systems require energy-efficient diets due to their shortage of high production efficiency. As a result, the inclusion of energy-rich fat sources in broiler diets is essential to meet the consumer's required meat quality attributes. [1]. Energy-rich fat sources have an important role in protecting shocks, hormone production, maintaining body temperature, muscular metabolism, and normal functioning of the central nervous system [2] in broiler production. Water-insoluble fatty acids are produced from the enzymatic breakdown of lipids, but the environment in gastrointestinal tract (GIT) is aqueous under normal physiological conditions [3]. In this condition, insoluble fatty acids result in poor absorption in the body. Fatty acids aggregate to form micelles, which are soluble in an aqueous medium and help absorb fatty acids through the small intestine. This process is facilitated by bile acids, which act as natural emulsifiers. At an early age, the production of bile acid and lipase is insufficient to fully digest the dietary fats because the GIT tract is not mature enough [4]. Therefore, fat is unable to form mixed micelles in the lumen for digestion and absorption and it passes through the GIT undigested causing reduction in fat digestion and absorption. Hence, there is a need for additional addition of emulsifier or lipase to improve fat digestion and derive energy value from fat sources during early age of broiler chick.

Several emulsifiers are being used in the poultry industry. Some are natural like bile acids, while others are nutritional emulsifiers like lysolecithin and lecithin [5]. Lysolecithin is produced from the enzymatic degradation of lecithin, and this process includes the conversion of phospholipids into lyso-phospholipids [6]. While lecithin is obtained as a byproduct of the soybean oil (SO) industry and used as an energy source and a natural emulsifier [7], both lecithin and lysolecithin are being used as an emulsifier in broiler diet. Lysophospholipids are much more effective than lecithin in fat emulsifying characteristics. Lysophospholipids have greater hydrophilic-lipophilic balance than bile and lecithin and reduced critical micelle concentration [8]. This indicates that lysophospholipids had greater ability to form micelles in broiler GIT and provide a large surface area for lipase action than lysolecithin. Furthermore, dietary addition of bile acids enhanced emulsification, micelle development, and fat digestion [9]. Moreover, supplementation of exogenous desiccated bile in broiler's diet had better daily weight gain, fat digestibility, and FCR [10]. Therefore, this study was planned to investigate and compare different emulsifiers (lysolecithin, lysophospholipids, and bile

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acids) on growth performance and meat quality in broiler reared on soybean oil and refined poultry oil based diets.

2. Materials and methods

The present study was conducted at R&D house, Sharif Feed Mills, Okara, Punjab with prior approval from the animal care committee of University of Agriculture, Faisalabad via letter no. 15497-500.

2.1. House preparation

Before the arrival of chicks, the house was cleaned, washed, fumigated, and closed to minimize the microbial load. The experimental trial was conducted under all hygienic and standard conditions. Birds were vaccinated with ND + IB (day 1), IBD (day 8), IBD (day 18), and ND (day 25) vaccine.

2.2. Experimental birds and diet

The objective of this research study was to evaluate the interaction of different fat sources and emulsifiers on broiler production performance and meat quality. Two fat sources (refined poultry oil and soybean oil) and 4 emulsifiers (control, lysolecithin, lysophospholipid and bile acids) were used in this experiment. Thirteen hundred and sixty (1360) birds (ROSS - 308) were distributed into 8 treatments having 5 replicates, 34 birds in each. Eight diets, A (SO + No emulsifier), B (SO + lysophospholipid at 0.05%), C (SO + lysolecithin at 0.05%), D (SO + bile acids at 0.05%), E (RPO + No emulsifier), F (RPO + lysophospholipid at 0.05%), G (RPO + lysolecithin at 0.05%) and H (RPO + bile acids at 0.05%), were formulated (Table 1).

2.3. Data collection

2.3.1. Production performance

Data on the growth parameters were recorded weekly using formulas given by Kamran et al. [11] and Marcu et al. [12].

Feed intake = Feed offered – Feed refusal

FCR = Feed intake (g) / Weight gain (g)

Protein Efficiency ratio (PER) = Weight gain / Protein intake

Energy efficiency ratio (EER) = Weight gain / energy intake × 100

European production efficiency factors (EPEF) = Livability/FCR× live weight (kg)/age (days) × 100

2.3.2. Nutrient digestibility

A digestibility trial was conducted to study the digestibility of dietary nutrients through the indirect marker method [13]. Acid insoluble ash (AIA) was used as an external marker, and Celite was added to feed at 1.0% of feeds. Fecal samples (six after every four hours) at 21 and 35 days were taken and mixed to form a composite sample. Fecal samples were dried at 65 °C to preserve the samples, and then contents of feed and feces were analyzed for nutrient composition in duplicate [14].

Digestibility (%) = 100 – (100 × maker in feed (%) / marker in feces (%) × nutrient in feces (%) / nutrient in feed (%))

2.3.3. Slaughter parameters

On day 35, two birds from each pen were slaughtered to obtain meat samples.

2.3.4. Meat quality parameters

About 1 to 2 g breast meat (in ground form) was blended in 10 mL deionized water. pH meter was used to measure pH value [15]. The breast meat sample (15 gram in chopped form) was centrifuged (at 5000 rpm for 15 mints at 4 °C). After that, water was drained immediately. Water holding capacity was determined according to Pearson and Dutson [16]. A small portion of breast meat approximately 40 g or 2 × 5 cm was cooked in the water bath at 80 °C for half an hour. After cooling the meat, weight decrease from the meat represent cooking loss [17]. Meat samples from breast fillet were dried to measure dry matter, crude fat, crude protein, and crude ash according to the procedures described by AOAC [14]. The meat from breast and drumstick were cooked at 80 °C and presented with mineral water to 10 specialists. They tasted the samples and evaluated them on the hedonic scale bases (1 to 9 reading).

2.3.5. Economics

Expenditure incurred on chicks, feed, litter, and medication was used for the calculation of the cost of production. To calculate the net profit, total expenditure was subtracted from the sale price of the bird on per bird basis.

2.4. Statistical analysis

The obtained data were subjected to statistical analysis using analysis of variance technique (ANOVA) with the completely randomized design under the factorial arrangement, and treatment means were compared using Tukey's test in Minitab 17 (Steel et al., 1997).

3. Results

Effects of different emulsifiers on growth performance in broiler reared on SO and RPO during the overall period (1–35 days) are given in Table 2. RPO and SO in broiler diet had no influence ($p > 0.05$) on feed intake and weight gain, while FCR was improved ($p < 0.05$) in a group fed diet containing SO than those receiving RPO. Feed consumption was low ($p < 0.05$), body weight gain and FCR were higher ($p < 0.05$) in broiler birds given bile acids than in the ones given other emulsifiers. Interaction ($p < 0.05$) was recorded between oil sources and emulsifier type on broiler growth performance. Growth performance was improved ($p < 0.05$) in birds receiving bile acid in both soybean oil and poultry oil than those receiving poultry oil without an emulsifier-based diet.

Table 1. Composition of experimental diets.

Ingredients (%)	Starter Phase		Finisher Phase	
	Soybean oil (A-D)[1]	**Poultry Oil (E-H)**[2]	**Soybean oil (A-D)**[1]	**Poultry Oil (E-H)**[2]
Corn	52.50	52.41	55.69	55.54
Soybean Meal 45%	38.93	38.95	34.64	34.67
Soya oil	3.66	0	6.03	0
Refined Poultry Oil	0	3.73	0	6.15
Calcium Carbonate	0.90	0.90	0.72	0.72
DCP	2.17	2.17	1.76	1.76
Sodium Chloride	0.39	0.39	0.39	0.39
Sodium Bicarbonate	0.30	0.30	0.12	0.12
L-Lysine Sulphate	0.35	0.35	0.08	0.08
DL-Methionine	0.37	0.37	0.26	0.26
L-Threonine	0.11	0.11	0	0
Vit. premix*	0.15	0.15	0.15	0.15
Min. premix**	0.15	0.15	0.15	0.15
Extra Phy	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0
Nutrients (calculated)				
ME (Kcal/kg)	3000	3000	3200	3200
Crude Protein	22	22	20	20
Ether Extract	5.87	5.94	8.29	8.41
Crude Fiber	2.94	2.94	2.80	2.80
Ash	4.93	4.93	4.42	4.41
Calcium	0.96	0.96	0.79	0.79
Av. P	0.48	0.48	0.40	0.40
Sodium	0.25	0.25	0.20	0.20
Potassium	0.88	0.88	0.81	0.81
Chlorine	0.30	0.30	0.30	0.30
DEB	250	250	210	210
Dig. Lysine	1.28	1.28	1.03	1.03
Dig. Methionine	0.67	0.67	0.54	0.54
Dig. Met + Cys	0.95	0.95	0.80	0.80
Dig. Threonine	0.86	0.86	0.69	0.69
Dig. Tryptophan	0.25	0.25	0.23	0.23
Dig. Arginine	1.41	1.41	1.28	1.28
Dig. Leucine	1.70	1.70	1.59	1.59
Dig. Isoleucine	0.86	0.86	0.79	0.79
Dig. Valine	0.92	0.92	0.85	0.85
Dig. Histidine	0.53	0.53	0.49	0.49
Nutrients (Analyzed)				
Dry matter	88.82	89.42	90.38	90.69
Crude Protein	21.83	22.05	20.22	20.42
Ether Extract	5.45	5.48	7.26	7.80
Acid Insoluble Ash	1.24	1.41	1.42	1.56

*Vitamins premix provides 10000 IU Vitamin A, 5 mg Riboflavin, 12 mg Ca Pantothenate, 2.2 mg thiamin, 1.55 mg Folic acid, 44 mg nicotinic acid, 2.2 mg Vitamin B_6, 12.1 µg Vitamin B_{12}, 250 mg Choline chloride, 0.11 mg d-biotin, 1100 IU Vitamin D_3, 11.0 IU Vitamin E, 1.1 mg Vitamin K per kg of diet.

**Mineral premix provides 30 mg Fe, 50 mg Zn, 5 mg Cu, 60 mg Mn, 0.1 mg Co, 0.3mg I and 1 mg Se per kg of diet.

[1]A (SO + No emulsifier), B (SO + lysophospholipid at 0.05%), C (SO + lysolecithin at 0.05%), D (SO + bile acids at 0.05%).

[2]E (RPO + No emulsifier), F (RPO + lysophospholipid at 0.05%), G (RPO + lysolecithin at 0.05%) and H (RPO + bile acids at 0.05%).

Table 2. Different oil sources and emulsifiers on growth performance in broiler.

	Feed Intake (g)	Weight gain (g)	FCR	PER	EER	EPEF	Mortality (%)
Oil Sources							
Soybean Oil	3179	1981	1.61^{b}	3.0^{a}	2.0^{a}	340	5.44
Poultry Oil	3199	1945	1.65^{a}	2.9^{b}	1.9^{b}	329	4.85
SEM	***20.2***	***12.4***	***0.011***	***0.02***	***0.01***	***4.63***	***0.82***
p-Value	***0.481***	***0.51***	***0.013***	***0.001***	***0.016***	***0.090***	***0.614***
Emulsifiers type							
No Emulsifier	3147^{bc}	1900^{b}	1.66^{a}	2.9^{b}	1.9^{b}	310^{c}	7.06
Lysophosholipid	3116^{c}	1906^{b}	1.64^{ab}	2.9^{b}	1.9^{ab}	331^{bc}	2.94
Lysolecithin	3267^{a}	2004^{a}	1.63^{ab}	2.9^{ab}	1.9^{ab}	337^{ab}	6.18
Bile Acids	3227^{ab}	2042^{a}	1.58^{b}	3.0^{a}	2.0^{a}	360^{a}	4.41
SEM	***28.6***	***17.5***	***0.016***	***0.03***	***0.02***	***6.54***	***1.15***
p-Value	***0.002***	***0.0001***	***0.008***	***0.002***	***0.007***	***0.0001***	***0.074***
Oil Sources x Emulsifiers type							
SO + No Emulsifier	3327^{a}	2086^{a}	1.60^{b}	3.0^{a}	2.0^{ab}	341^{ab}	10.59^{a}
SO + Lysophosholipid	2964^{b}	1802^{b}	1.65^{ab}	2.9^{ab}	1.9^{ab}	311^{bc}	2.94^{b}
SO + Lysolecithin	3202^{a}	1982^{a}	1.62^{b}	3.0^{a}	2.0^{ab}	345^{ab}	3.53^{ab}
SO + Bile Acids	3223^{a}	2054^{a}	1.57^{b}	3.0^{a}	2.1^{a}	363^{a}	4.71^{ab}
RPO + No Emulsifier	2966^{b}	1713^{b}	1.73^{a}	2.7^{b}	1.9^{b}	279^{c}	3.53^{ab}
RPO + Lysophosholipid	3268^{a}	2011^{a}	1.63^{b}	2.9^{a}	2.0^{ab}	351^{ab}	2.94^{b}
RPO + Lysolecithin	3333^{a}	2027^{a}	1.65^{ab}	2.9^{ab}	2.0^{ab}	328^{ab}	8.82^{ab}
RPO + Bile Acids	3231^{a}	2031^{a}	1.59^{b}	3.0^{a}	2.0^{ab}	357^{a}	4.12^{ab}
SEM	***40.5***	***21.7***	***0.022***	***0.04***	***0.03***	***9.26***	***1.63***
p-Value	***0.0001***	***0.0001***	***0.010***	***0.005***	***0.014***	***0.0001***	***0.007***

SEM: Standard error of the mean, $p > 0.05$ (Nonsignificant), $p < 0.05$ (Significant),
a-c values of superscript different in column differ significantly.
PER: Protein efficiency ratio, EER Energy efficiency ratio, EPEF: European production efficiency factor, SO: Soybean oil, RPO: refined poultry oil.

Poultry and soybean oil did not influence dressing percentage, breast, and thigh meat yield in broiler birds ($p > 0.05$). Dressing percentage was improved ($p < 0.05$) in broiler birds receiving bile acids than those receiving other emulsifier types, whereas breast and thigh meat yield were remained unaffected ($p > 0.05$) by emulsifier type in broilers. Relative organs weights include the weight of heart, liver, gizzard, and abdominal fat pad. Different oil sources and types of emulsifiers had no influence ($p > 0.05$) on organ weight percentages. No interaction ($p > 0.05$) was noted between oil sources and type of emulsifier (Lysophosholipid, Lysolecithin and bile acids) on carcass characteristics and relative organs weight in broilers (Table 3).

Cooking loss was greater in birds receiving poultry oil than those receiving soybean oil ($p < 0.05$), while WHC and pH value were remained unaffected ($p > 0.05$) by oil sources (soybean and poultry oil). Bile acid supplemented group had higher ($p < 0.05$) WHC of breast meat than other emulsifier types; however, cooking loss and pH value were not influenced ($p > 0.05$) by emulsifier type. There was no interaction between the oil source and type of emulsifier ($p > 0.05$) on the meat quality parameter or broiler breast meat (Table 4).

The ether extract was greater ($p < 0.05$) in birds receiving poultry oil than those receiving soybean oil; however, moisture, ash, and crude protein (CP) remained unaffected ($p > 0.05$) by different oil sources. Ash was lower ($p < 0.05$), CP and ether extract (EE) content were greater ($p < 0.05$) in birds given bile acid as compared to other emulsifier types. There was an interaction ($p < 0.05$) between oil source and type of emulsifier on CP and EE of

Table 3. Different oil sources and emulsifiers on carcass yield in broiler.

(%)	Dressing percentage	Thigh weight*	Breast weight*	Liver weight**	Gizzard weight**	Heart weight**	Abdominal fat**
Oil Sources							
Soybean Oil	63.2	37.5	62.5	2.1	1.1	0.4	1.8
Poultry Oil	63.8	37.1	62.9	2.0	1.0	0.4	1.9
SEM	***0.45***	***0.35***	***0.35***	***0.05***	***0.02***	***0.009***	***0.05***
p-Value	***0.317***	***0.457***	***0.457***	***0.900***	***0.064***	***0.984***	***0.777***
Emulsifiers type							
No Emulsifier	63.4^{ab}	36.4	63.6	2.1	1.0	0.4	1.8
Lysophosholipid	63.7^{ab}	37.0	63.0	1.9	1.0	0.4	1.9
Lysolecithin	62.1^{b}	37.7	62.4	2.1	1.1	0.4	2.0
Bile Acids	64.7^{a}	38.2	61.8	2.1	1.0	0.4	1.8
SEM	***0.63***	***0.49***	***0.49***	***0.07***	***0.03***	***0.001***	***0.08***
p-Value	***0.045***	***0.072***	***0.072***	***0.322***	***0.605***	***0.733***	***0.324***
Oil Sources x Emulsifiers type							
SO + No Emulsifier	62.9	37.2	62.8	2.1	1.1	0.4	1.7
SO + Lysophosholipid	64.0	37.1	62.9	2.0	1.1	0.4	1.9
SO + Lysolecithin	62.2	37.5	62.5	2.1	1.2	0.4	1.9
SO + Bile Acids	63.5	38.1	61.9	2.0	1.0	0.4	1.9
RPO + No Emulsifier	63.9	35.6	64.4	2.0	1.0	0.4	1.8
RPO + Lysophosholipid	63.3	36.9	63.1	1.9	1.0	0.4	1.9
RPO + Lysolecithin	62.0	37.8	62.2	2.1	1.0	0.4	2.0
RPO + Bile Acids	65.9	38.3	61.7	2.1	1.1	0.4	1.8
SEM	***0.89***	***0.69***	***0.69***	***0.09***	***0.04***	***0.001***	***0.106***
p-Value	***0.343***	***0.472***	***0.476***	***0.723***	***0.094***	***0.364***	***0.721***

SEM: Standard error of the mean, p > 0.05 (nonsignificant), p < 0.05 (significant)
a-c values of superscript different in column differ significantly.
*Breast and thigh yield (% to carcass weight).
**Relative organ (liver, gizzard and heart) weight and abdominal fat (% to live weight)
SO: Soybean oil, RPO: refined poultry oil.

broiler breast meat. Bile acids supplemented in poultry oil-based diet had higher CP and EE content of broiler breast meat ($p < 0.05$) than soybean oil and without emulsifier-based diet (Table 4).

Sensory evaluation parameters include smell, juiciness, tenderness, taste, and overall quality of meat. Oil sources (poultry oil or soybean oil) had no effect ($p > 0.05$) on sensory evaluation parameters of broiler breast and drumstick meat. Similarly, smell, taste, juiciness, tenderness, and overall quality of meat remain unaffected ($p > 0.05$) by the type of emulsifier (Lysophosholipid, Lysolecithin, and bile acids). There was no interaction ($p > 0.05$) of oil sources and emulsifier types on sensory evaluation parameters of broiler meat (Table 5).

Soybean oil in the broiler diet had higher ($p < 0.05$) EE digestibility, while digestibility of dry matter (DM) and CP were not affected ($p > 0.05$) by oil sources at day 21. Digestibility of CP and EE was higher ($p < 0.05$) in birds receiving bile acid as compared to other treatments. Soybean oil supplemented with bile acid and Lysolecithin had higher ($p < 0.05$) EE digestibility, while lower ($p < 0.05$) EE digestibility was recorded in birds receiving refined poultry oil without an emulsifier based diet (Table 6).

Different oil sources (soybean oil and poultry oil) had no influence ($p > 0.05$) on the digestibility of CP, DM, and EE. Digestibility of DM and CP were greater ($p < 0.05$) in birds receiving bile acid than those given Lysophosholipid and Lysolecithin. Crude protein digestibility was greater (p

Table 4. Different oil sources and emulsifiers on meat quality parameters and proximate composition in broiler.

	Meat quality			**Proximate analysis (%)**			
Oil Sources	**WHC (%)**	**Cooking Loss (%)**	**pH**	**Moisture**	**Ash**	**Crude Protein**	**Ether Extract**
Soybean Oil	58.9	27.1^{b}	6.1	74.1	3.5	19.6	1.9^{b}
Poultry Oil	59.0	30.2^{a}	6.1	73.9	3.5	19.7	2.0^{a}
SEM	***1.05***	***1.00***	***0.02***	***0.30***	***0.09***	***0.18***	***0.03***
p-Value	***0.946***	***0.05***	***0.345***	***0.780***	***0.627***	***0.829***	***0.019***
Emulsifiers type							
No Emulsifier	56.8^{b}	29.7	6.2	73.8	3.8^{a}	18.8^{b}	1.7^{c}
Lysophosholipid	58.8^{ab}	28.4	6.2	74.1	3.5^{ab}	19.4^{b}	1.8^{bc}
Lysolecithin	57.1^{b}	27.3	6.1	74.2	3.4^{ab}	19.8^{ab}	2.0^{ab}
Bile Acids	63.1^{a}	29.2	6.1	73.9	3.3^{b}	20.6^{a}	2.1^{a}
SEM	***1.48***	***1.42***	***0.03***	***0.42***	***0.12***	***0.26***	***0.04***
p-Value	***0.031***	***0.667***	***0.487***	***0.869***	***0.042***	***0.0001***	***0.0001***
Oil Sources x Emulsifiers type							
SO + No Emulsifier	56.6	28.2	6.1	74.1	3.8	18.4^{b}	1.6^{c}
SO + Lysophosholipid	60.8	26.3	6.1	74.3	3.4	19.4^{ab}	1.8^{bc}
SO + Lysolecithin	55.3	26.5	6.2	74.1	3.4	20.0^{ab}	2.0^{ab}
SO + Bile Acids	63.0	27.6	6.1	73.8	3.3	20.7^{a}	2.0^{ab}
RPO + No Emulsifier	57.2	31.2	6.2	73.5	3.8	19.3^{ab}	1.9^{abc}
RPO + Lysophosholipid	56.8	30.6	6.2	73.9	3.6	19.3^{ab}	1.9^{abc}
RPO + Lysolecithin	58.9	28.1	6.1	74.4	3.5	19.6^{ab}	2.0^{ab}
RPO + Bile Acids	63.2	30.7	6.1	74.0	3.3	20.6^{a}	2.1^{a}
SEM	***2.09***	***2.00***	***0.04***	***0.59***	***0.17***	***0.37***	***0.06***
p-Value	***0.370***	***0.926***	***0.220***	***0.840***	***0.915***	***0.377***	***0.410***

SEM: Standard error of the mean, $p > 0.05$ (nonsignificant), $p < 0.05$ (significant)
a-b values of superscript different in column differ significantly.
SO: Soybean oil, RPO: refined poultry oil, WHC, water holding capacity.

< 0.05) in birds given bile acid in a soybean oil-based diet as compared to other treatments (Table 6).

Cost of production / kg broiler live weight was decreased in birds fed poultry oil than soybean oil-based diet. Bile acid supplemented diet had lesser ($p < 0.05$) cost production / kg live weight than other fat emulsifiers (Table 7 and 8).

4. Discussion

Poultry oil and soybean oil in the broiler diet had no effect ($p > 0.05$) on WG, EPEF and feed intake, while PER, FCR, and EER were improved in birds receiving soybean oil than those receiving poultry oil. This might be due to the fact that soybean oil (rich in unsaturated fatty acids) improves the digestion process by enhancing bile secretion for micelle formation, which consequently benefits bird performance [18]. Results are in line with the outcomes of Kamran et al. [9] who concluded that birds fed a diet containing soy oil had improved ($p < 0.05$) body weight gain (2157 g) and FCR (1.64) than those fed poultry oil (WG: 2076 g, FCR: 1.68) and oxidized soy oil (WG: 1944 g, FCR: 1.76). Zhang et al. [19] reported that broiler birds fed diet having soybean oil had greater ($p < 0.05$) weight gain (1746 vs 1717 and 1646 g) and better ($p < 0.05$) FCR (1.81 vs 1.85 and 1.94) than poultry and tallow oil. Results are contrary to Polycarpo et al. [2] who reported that feed intake and weight gain were not different ($p > 0.05$) in birds receiving chicken tallow and soybean oil.

The highest weight gain, lower feed intake and improved FCR were observed in the group having bile acids ($p < 0.05$). This is because endogenous bile acids are insufficient to emulsify whole fat present in the

Table 5. Effect of different emulsifiers on sensory evaluation of breast and drumstick meat in broiler reared on soybean and poultry oil.

	Breast Meat					Drumstick Meat				
Oil Sources	**Smell**	**Taste**	**Juiciness**	**Tenderness**	**Overall Quality**	**Smell**	**Taste**	**Juiciness**	**Tenderness**	**Overall Quality**
Soybean Oil	6.6	6.4	6.2	6.5	6.2	6.4	6.1	6.1	6.3	6.2
Poultry Oil	6.5	6.5	6.2	6.4	6.5	6.3	6.1	5.9	6.1	6.5
SEM	***0.19***	***0.19***	***0.19***	***0.155***	***0.19***	***0.18***	***0.21***	***0.18***	***0.17***	***0.16***
p-Value	***0.927***	***0.523***	***0.924***	***0.909***	***0.197***	***0.924***	***1.000***	***0.482***	***0.243***	***0.270***
Emulsifiers type										
No Emulsifier	6.1	6.3	6.0	6.2	5.9	6.4	6.0	6.0	6.0	6.4
Lysophosholipid	6.5	6.4	6.2	6.6	6.4	6.3	6.0	6.0	6.3	6.3
Lysolecithin	6.6	6.3	6.1	6.3	6.5	6.3	6.0	5.8	6.3	6.5
Bile Acids	7.0	6.8	6.4	6.7	6.6	6.4	6.3	6.2	6.3	6.2
SEM	***0.27***	***0.27***	***0.26***	***0.22***	***0.27***	***0.26***	***0.30***	***0.25***	***0.23***	***0.23***
p-Value	***0.145***	***0.477***	***0.672***	***0.358***	***0.237***	***0.969***	***0.892***	***0.799***	***0.835***	***0.745***
Oil Sources x Emulsifiers type										
SO + No Emulsifier	6.1	6.3	5.9	6.4	5.7	6.5	5.9	5.9	6.1	5.9
SO + Lysophosholipid	6.7	6.3	6.4	6.6	6.5	6.3	6.1	6.1	6.3	6.7
SO + Lysolecithin	6.5	6.2	6.3	6.1	6.3	6.3	6	6	6.3	6.6
SO + Bile Acids	6.9	6.6	6.1	6.7	6.1	6.3	6.2	6.3	6.6	5.6
RPO + No Emulsifier	6.1	6.3	6.0	6.0	6.0	6.3	6.1	6.1	5.9	6.8
RPO + Lysophosholipid	6.2	6.5	6.0	6.5	6.3	6.2	5.9	5.9	6.2	5.9
RPO + Lysolecithin	6.7	6.3	5.9	6.5	6.7	6.3	5.9	5.6	6.2	6.4
RPO + Bile Acids	7.1	7.0	6.7	6.7	7.0	6.5	6.3	6	5.9	6.7
SEM	***0.39***	***0.39***	***0.37***	***0.309***	***0.38***	***0.37***	***0.42***	***0.35***	***0.33***	***0.32***
p-Value	***0.779***	***0.961***	***0.481***	***0.636***	***0.552***	***0.955***	***0.963***	***0.838***	***0.769***	***0.100***

SEM: Standard error of the mean, $p > 0.05$ (nonsignificant), $p < 0.05$ (significant)
SO: Soybean oil, RPO: refined poultry oil.

diet. So, the addition of exogenous bile acids, which are composed of hyocholic acid, hyodeoxycholic acid and chenodeoxycholic, improved fat utilization and growth performance of birds. Also, dietary bile acid enhances the digestion of saturated fatty acids in GIT [20]. Similar results are recorded by Kamran et al. [9] who concluded that the use of polyglycerol polyricinoleate at 0.025, 0.035, and 0.045% in soy oil based diet had improved ($p < 0.05$) FCR (1.69, 1.69, 1.67 vs 1.76) in broilers. Chen et al. [21] concluded that the use of 0.05% lysophospholipid in broiler diet had improved ($p < 0.05$) feed intake (2838 vs 2926 g) and FCR (1.78 vs 1.85). Allahyari-Bake and Jahanian [22] observed that the addition of lysophospholipid in broilers diet containing soy free fatty acids had improved ($p < 0.05$) weight gain (2390 vs 2285 g) and FCR (1.77 vs. 1.88) than control. Liu et al. [23] reported that weight gain (1761 vs 1692 g) and FCR (1.56 vs 1.61) were improved ($p < 0.05$) in birds receiving 97% deoiled lecithin in the basal diet. Alzawqari et al. [24] showed that the addition of dissected bile acid at 0.05% in broiler diet had improved ($p < 0.05$) weight gain (1550 vs 1155 g) and FCR (2.15 vs 2.61) in birds than control group. Abbas et al. [25] reported that use of emulsifier (lecithin) at 0.035% in broiler diet had better ($p < 0.05$) FCR (2.24 vs 2.43) in birds fed different oil levels (1, 2 and 3%) during finisher phase than those who reared on lecithin free diet. This might be due to the higher emulsified property of lecithin.

Dressing percentage was greater ($p < 0.05$) in birds receiving bile acids, while breast, thigh meat yield, and relative organs weight were remained unaffected (p >

Table 6. Different oil sources and emulsifiers on nutrient digestibility in broiler.

	At day 21 (%)			**At day 35 (%)**		
	Dry matter	**Ether Extract**	**Crude Protein**	**Dry matter**	**Ether Extract**	**Crude Protein**
Oil Sources						
Soybean Oil	85.6	71.4	71.2^{a}	84.7	71.0	70.8
Poultry Oil	84.7	69.6	67.2^{b}	84.5	70.8	70.1
SEM	***0.48***	***0.87***	***0.85***	***0.42***	***0.79***	***0.67***
p-Value	***0.198***	***0.149***	***0.002***	***0.648***	***0.908***	***0.47***
Emulsifiers type						
No Emulsifier	84.1	69.0^{ab}	67.1^{b}	83.8^{ab}	69.5	69.3^{b}
Lysophosholipid	84.8	67.5^{b}	68.7^{ab}	83.5^{b}	70.3	69.1^{b}
Lysolecithin	85.7	72.3^{a}	69.0^{ab}	85.2^{ab}	71.1	70.0^{ab}
Bile Acids	85.8	73.3^{a}	72.0^{a}	86.0^{a}	72.8	73.4^{a}
SEM	***0.68***	***1.23***	***1.2***	***0.59***	***1.12***	***0.95***
p-Value	***0.287***	***0.006***	***0.048***	***0.015***	***0.210***	***0.01***
Oil Sources x Emulsifiers type						
SO + No Emulsifier	83.8	69.2	70.1^{ab}	84.8^{ab}	70.6	69.6^{b}
SO + Lysophosholipid	85.3	68.1	70.1^{ab}	84.2^{ab}	71.8	70.4^{ab}
SO + Lysolecithin	86.8	74.1	72.0^{a}	83.7^{ab}	69.0	67.1^{b}
SO + Bile Acids	86.3	74.4	72.8^{a}	86.4^{ab}	72.5	76.1^{a}
RPO + No Emulsifier	84.5	68.8	64.2^{b}	82.8^{b}	68.4	68.9^{b}
RPO + Lysophosholipid	84.3	66.9	67.3^{ab}	82.8^{b}	68.8	67.9^{b}
RPO + Lysolecithin	84.6	70.4	66.0^{ab}	86.7^{a}	73.2	72.9^{ab}
RPO + Bile Acids	85.2	72.3	71.2^{ab}	85.6^{ab}	73.0	70.7^{ab}
SEM	***0.97***	***1.74***	***1.69***	***0.83***	***1.58***	***1.34***
p-Value	***0.532***	***0.804***	***0.471***	***0.024***	***0.112***	***0.002***

SEM: Standard error of the mean, $p > 0.05$ (nonsignificant), $p < 0.05$ (significant)
a-b values of superscript different in column differ significantly.
SO: Soybean oil, RPO: refined poultry oil.

0.05). Bile acids increase the absorption of fat which is not stored in abdominal fat. The abdominal fat pad is linked directly to body fat content in birds [26]. Results are similar with Bontempo et al. [27] who observed that the addition of emulsifier (0.1%) had higher ($p < 0.05$) carcass and breast yield than control group. Contrary to the fact, Abbas et al. [25] reported that adding emulsifier at 0.035% in broiler fed diet containing different oil levels (1, 2, and 3%) had higher ($p < 0.05$) heart weight and reduced ($p < 0.05$) gizzard weight than the control group. Results are not in line with the outcome of Alzawqari et al. [24] who reported that carcass parameters were not affected ($p > 0.05$) by the addition of dissected bile acid in broiler diet. Similarly, Pantaya et al. [28] reported that dressing percentage, liver weight, gizzard weight and abdominal fat were not affected ($p > 0.05$) by the addition of different levels (0.005, 0.01, and 0.015%) of bile acid in broiler diet.

Water holding capacity of broiler breast meat was greater in birds receiving bile acids; however, cooking loss and pH were remained unaffected ($p > 0.05$) by emulsifier type. This is due to that fat bound with protein molecules reduces its water holding capacity. Bile acids emulsify the fat molecules resulting in increased water holding capacity. Results are similar with An et al. [29] who showed that addition of 0.2% exogenous emulsifier in broiler diet had higher ($p < 0.05$) WHC. Contrary results were recorded by Zhao and Kim [30] who reported that the use of emulsifier (lysophospholipids) in broiler diet had no effect ($p > 0.05$) on muscle pH, water holding capacity, drip loss, and meat color. Zosangpuii et al. [31] reported that supplementation

Table 7. Different oil sources and emulsifiers on economics efficiency in broiler (main effect).

	Oil sources				Emulsifier type					
Production Cost (Rs.)	Soybean Oil	Refined Poultry Oil	SEM	p-Value	No Emulsifier	Lyso-phosholipid	Lyso-lecithin	Bile Acids	SEM	p-Value
Bird cost	32	32	-	-	32	32	32	32	-	-
Feed cost / bird	210.3^{a}	202.4^{b}	1.30	0.0001	202.9^{bc}	201.6^{c}	211.6^{a}	209.2^{ab}	1.84	0.001
Miscellaneous[1]	25	25	-	-	25	25	25	25	-	-
Production cost / bird[2]	267.3^{a}	259.4^{b}	1.30	0.0001	259.9^{bc}	258.6^{c}	268.6^{a}	266.2^{ab}	1.84	0.001
Av. body weight (g)	2021.9	1986.5	12.4	0.053	1941.1^{b}	1947.1^{b}	2045.4^{a}	2083.0^{a}	17.6	0.0001
Production cost / kg	132.4	131.0	0.84	0.231	134.4^{a}	133.2^{a}	131.4^{ab}	127.8^{b}	1.18	0.003

Table 8. Different oil sources and emulsifiers on economics efficiency in broiler (simple effect).

	Soybean Oil				Refine Poultry Oil					
Production Cost (Rs.)	No Emulsifier	Lyso-phosholipid	Lyso-lecithin	Bile Acids	No Emulsifier	Lyso-phosholipid	Lyso-lecithin	Bile Acids	SEM	p-Value
Bird cost	32	32	32	32	32	32	32	32	-	-
Feed cost / bird	219.0^{a}	196.3^{cd}	212.2^{ab}	213.6^{ab}	186.7^{d}	206.9^{bc}	211.1^{ab}	204.8^{bc}	2.60	0.0001
Miscellaneous[1]	25	25	25	25	25	25	25	25	-	-
Production cost / bird[2]	276.0^{a}	253.3^{cd}	269.2^{ab}	270.6^{ab}	243.7^{d}	263.9^{bc}	268.1^{ab}	261.8^{bc}	2.60	0.0001
Av. body weight (g)	2127.9^{a}	1842.5^{b}	2022.7^{a}	2094.4^{a}	1754.4^{b}	2051.6^{a}	2068.1^{a}	2071.7^{a}	24.9	0.0001
Production cost / kg	129.7^{b}	137.7^{a}	133.1^{ab}	129.2^{b}	139.1^{a}	128.7^{b}	129.7^{b}	126.4^{b}	1.67	0.001

[1]Miscellaneous cost include vaccination cost, farm preparation and brooding expenditures.
[2]Production cost per bird = Bird cost + Feed cost per bird + Miscellaneous.
a-e values of superscript different in row differ significantly.

of emulsifier (0.1%) had no effect ($p > 0.05$) on lightness, redness, and yellowness in broiler fed corn soya diet.

Digestibility of DM and CP was higher in birds receiving bile acid than those given Lysophosholipid, Lysolecithin and control. This may be due to the addition of exogenous bile acid improved fat emulsification, digestion, and absorption in birds [20]. Results are similar to the outcomes of Liu et al. [23] who reported that fat digestibility (81.38 vs. 77.80%) was higher ($p < 0.05$) in birds receiving 97% deoiled lecithin in the basal diet. Dabbou et al. [32] found that globin, a natural emulsifier at 0.05% in broiler diet, had increased ($p < 0.05$) protein digestibility (67.8 vs. 63.9%) and energy efficiency (6.4 vs. 5.9 MJ/kg). Addition of 0.1% emulsifier in broiler diet had improved ($p < 0.05$) digestibility of gross energy (81.64 vs 80.72%) and nitrogen (67.38 vs 66.54) than control group [30]. Alzawqari et al. [24] observed that fat digestibility was improved ($p < 0.05$) by the addition of dissected bile acid (84.22 vs 59.26) than control group in the broiler diet. Abbas et al. [25] revealed that supplementation of emulsifier at 0.035% on different oil levels (1, 2, and 3%) in broiler birds had higher ($p < 0.05$) digestibility of DM (79.89 vs 75.78%) and EE (89.12 vs 86.41%) than control group (without emulsifier). Maisonnier et al. [20] concluded that supplementing 0.3% bile salts and 0.5% guar gum had a better ($p < 0.05$) effect on lipid digestibility (89.4% vs 81.4%) and reduced effect on lipid digestibility (71.2% vs. 81.4%) respectively.

Cost of production / kg live weight was lower in birds fed poultry oil than soybean oil-based diet. It is due to the cost of poultry oil is less as compared to soybean oil. Similar results were recorded by Rahman et al. [33] who concluded that use of palm oil in broiler diet had increased ($p < 0.05$) production cost per kg live weight (125 vs 115 TK). Sahito et al. [34] showed that increasing the level of fish oil (0.3 to 2.6%) in broiler diet increased the total cost of production (207 to 215) per live weight. Tabeidian et al. [35] reported that addition of tallow fat at 6% in poultry diet reduced ($p < 0.05$) feed cost (3850 to 3132 Rials) due to lower price of tallow fat. Results are not in line with Dada [36] who reported that use of 5% palm oil sludge in broiler diet reduces cost of production (8.55 vs. 11.28) per kg weight gain than control group. Likewise, Dorra et al. [37] observed that use of recovered frying oil had lower cost of production than control group (12.9 vs 13.69 LE).

Cost of production / kg live weight was lower ($p < 0.05$) in bile acid supplemented group than other fat emulsifiers and control. Results are consistent with Haetinger et al. [38] who reported that addition of emulsifiers containing lysophospholipids had reduced total cost of production (246.15 vs 247.73 $). Nagargoje et al. [39] showed that 50% replacement of crude soy lecithin with vegetable commercial oil had increased net profit than control group (10.63 vs 5.2). Abou-Elkhair et al. [40] observed that addition of emulsifiers and yeast in broiler diet had higher profit margin (35.36 vs 33.57 LE).

5. Conclusion

It can be concluded that soybean oil had improved growth performance than refined poultry oil. Further, addition of bile acids as an emulsifier can improve growth performance, nutrient digestibility, meat quality, and economic efficiency in broiler production systems.

Acknowledgments

The authors are very grateful to Dr. Babar Rashid, Business Head, Sharif Feed Mills (Renala Hujra Shah Muqeem Road, Sher Garh, Okara, Punjab) for providing their R&D facilities to conduct presented research work (https://sgroup.pk/). Also, the authors acknowledge the fellowship provided by the Higher Education Commission Pakistan (HEC) to Muhammad Shoaib under the framework of HEC Indigenous PhD Fellowship Program.

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Funding

The study was funded by Higher Education Commission Pakistan.

Conflict of interest

The authors declare no conflicts of interest.

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