

Does the use of different oil sources in quail diets impact their productive and reproductive performance, egg quality, and blood constituents?

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ABSTRACT The present study investigated the impact of dietary oil sources (soybean, corn, peanut, flaxseed, olive, and sunflower oils as sources of omega 3, 6, and 9 fatty acids) on productive and reproductive traits, egg quality, hematological and biochemical blood parameters of laying Japanese quail. A total of 360 eight-week mature Japanese quail were randomly divided into 6 groups fed for 8 wk on a basal diet included with 1.5% of different oil sources. Results showed that the highest egg weights and the best feed conversion ratio ($P < 0.01$) were recorded for quail fed diets supplemented with 1.5% soybean and peanut oil. The highest hatchability percentages ($P < 0.05$) were recorded for quail fed diets supplemented with corn oil as compared to the other oils. Furthermore, diets enriched with corn, olive, or sunflower oils had higher values of blood lymphocytes (%)

compared to the other treated groups. Blood total cholesterol significantly decreased in quail fed on corn, peanut, flaxseed, or olive oil sources as compared to soybean or sunflower oil groups. Immunologically, the highest levels ($P < 0.001$) of immunoglobulins (G and M) were recorded for quail fed on corn or olive oil sources compared to other oil sources. Quail consuming olive oil-included diets showed a significant increase in superoxide dismutase and glutathione S-transferase activities and a significant decrease on malondialdehyde level compared with those consumed the other oil sources. It could be concluded that varying the oil source can affect productive, reproductive, and health aspects of Japanese quail. Soybean oil showed good results regarding production aspects; however, olive oil was the best regarding health aspects.

Key words: different oils, production, reproduction, quail, antioxidant status

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INTRODUCTION

Oils are usually added to the diet of poultry to enhance the density of energy as economic tool to produce formulations rich in energy. It was showed that there were various constitutions regarding structure of fatty acids; fatty acid contains oxygen, hydrogen, and carbon and known as saturated fatty acids, polyunsaturated fatty acids, or monounsaturated fatty acids as theorized by Al-Daraji et al. (2010), Reda et al. (2019),

and Mohamed et al. (2019). Vegetable oils have several quantities of long-chain unsaturated fatty acids. Chow (1992) revealed that the content of fat and fatty acids composition in egg lipids have been included in human health. Norum (1992) found direct relationship between intake of saturated fatty acids and incidence of cardiovascular diseases. Aydin et al. (2006) reported that increasing dietary ratio of polyunsaturated fatty acids to saturated fatty acid declined cholesterol content in blood plasma. Meanwhile, Pappas et al. (2005) indicated that there were positive effects from the intake of mono-unsaturated fatty acids, like oleic acid (C18:1 n-9) and n-3 fatty acids on animal health, with declined blood triglycerides. Most efforts were initially focused on minimizing the content of cholesterol in the final products and gave different results (Basmacoglu et al., 2003). But research studies have recently concerned on modifying the composition of fatty acids in food

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(Alagawany et al., 2018, 2019; Abd El-Hack et al., 2019). Modifications in egg yolk fatty acids content can enhance the eggs' health image and could improve their supplementation value. Grobas et al. (2001) showed that dietary lipids types in layer feed could change lipid profile of the egg yolk. Omega-3 fatty acids are important for the normal growth and development and share in the treatment and the prevention of inflammatory, hypertension, autoimmune disorders, as well as cancer (El-Yamany et al., 2008; Yang et al., 2018; Zhang et al., 2018).

The vegetable oil sources like flaxseed oil may increase the content of n-3 fatty acid (in the form of linolenic acid) and the precursor of the whole n-3 family. Sunflower and corn oil are the most unsaturated oil among the widely consumed oils. Sunflower and corn oil are rich in omega-6 fatty acids, especially linoleic acid (Baucells et al., 2000). It is hypothesized that the dietary inclusion of different oils (1.5%) is expected to exert beneficial impacts on the laying quail. The present research, therefore, was designed to determine the influence of varying oil sources on the productive and reproductive performance, egg quality, hematological parameters, liver and kidney functions, antioxidant indices, lipid profile, and immunity of the laying quail.

MATERIALS AND METHODS

This experiment was conducted at Quail Unit, the Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, Egypt. All of the experimental procedures were carried out according to the Local Experimental Animal Care Committee and approved by the ethics of the institutional committee of the Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, Egypt.

Animals, Design, and Diets

A total number of 360 8-wk-old Japanese quail (*Coturnix coturnix japonica*) were randomly divided into 6 groups (45 females and 15 males each) with 5 replicates per group each of 9 females and 3 males and fed for 8 wk on a basal diet included with 1.5% of soybean oil or corn oil or peanut oil or flaxseed oil or olive oil or sunflower oil. The different oils were purchased from Elhawag company for Natural Oils (Cairo, Egypt). The basal diet (Table 1) was formulated to meet the quail requirements according to NRC (1994).

All birds were housed in conventional type cages with dimensions of 60 × 50 × 30 cm³ and kept under the same hygienic, environmental, and managerial conditions. Quail were exposed to 16 h light/day during the experiment. Feed in mash form and fresh water were ad libitum supplied all time.

Collection of Data and Calculations

Productive Performance Feed intake was weekly recorded and calculated as grams of feed consumed

over 7 D divided by the number of birds in each replicate. Feed conversion ratio (g feed/g egg) was calculated as the amount of feed consumed divided by the egg mass value. Egg number and egg weight were daily recorded to get the egg mass (egg weight × egg number).

Egg Quality Traits Egg quality criteria were weekly measured using 4 randomly selected eggs from each replicate. Using a sensitive electronic balance, eggs were weighed. Egg length and width were recorded using caliper for calculation of shape index (egg shape index = egg width/egg length × 100). To determine the internal egg quality criteria, eggs were broken in glass Petri dish. Shells were separated carefully. Eggshell weight was recorded. Egg yolks were separated from the albumen. By subtracting the weight of yolk and shell from the whole egg weight, the albumen weight was calculated. The yolk index was calculated according to the equation of Funk et al. (1958), as yolk index = yolk height/yolk diameter (mm). Unit surface shell weight (USSW) was also calculated as egg weight (mg)/egg surface area (cm²), where egg surface area (S) in cm² = 3.9782W^{0.75056}, and W = egg weight (mg). Haugh units (HU) were calculated using the formula of Eisen et al. (1962), as HU = 100 log (H + 7.57 - 1.7 W^{0.37}), where H = height of the albumen (mm) and W = egg weight (g). Finally, eggshell thickness (μm) was measured using a micrometer.

Reproductive Performance At the fourth week of each month, eggs from each replicate were collected over 2 D and incubated. After hatching, chicks were counted. To determine the percentages of fertility and hatchability, non-hatched eggs were broken. The hatchability was calculated as the hatched chicks from fertile eggs and as the hatched chicks from the total eggs set. Percentage of fertility was expressed as follows: fertility % = the number of hatched eggs + eggs containing embryos/the total eggs set (Abd El-Hack et al., 2017).

Hematological and Biochemical Parameters After slaughter, blood samples were randomly collected from 5 birds per treatment into sterilized tubes that were closed with rubber stoppers. Blood samples were centrifuged (G force rate = 2146.56 × g) and serum samples were detached and stored at -20°C until analysis. Hematological parameters [hemoglobin (Hb), hematocrit (HCT), red blood cells (RBC), platelet (PLT), mean cell volume (MCV), and white blood cells (WBC)] were determined. Total protein (g/dl), albumin (g/dl), alanine transaminase (ALT; U/L), aspartate transaminase (AST; U/L), triglyceride (TG; mmol/L), total cholesterol (TCh; mmol/L), high-density lipoprotein (HDL) cholesterol (mmol/L), low-density lipoprotein (LDL) cholesterol (mmol/L) levels were determined spectrophotometrically using commercial kits from Biodiagnostic Company (Giza, Egypt). Immunoglobulin G (IgG; mg/dL) and IgM (mg/dL) levels were determined according to the study by Akiba et al. (1982). The activity of superoxide dismutase (SOD) and glutathione S-transferase (GST) and the level of malondialdehyde (MDA) were determined in serum using commercial kits and a spectrophotometer (Shimadzu, Japan).

Table 1. Ingredient and nutrient contents of basal diet of laying Japanese quail.

Items	%
Ingredient (%)	
Yellow corn	59.00
Soybean meal 44%	27.50
Corn gluten meal 62%	4.60
Soybean oil	1.5
Limestone	5.54
Di-calcium phosphate	1.20
Salt	0.30
Premix ¹	0.30
L-Lysine%	0.06
Calculated composition (%) ²	
Metabolizable energy, Kcal/Kg	2,900
Crude protein	20.00
Calcium	2.50
Nonphytate phosphorous	0.35
Lysine	1.00
Total sulfur amino acids	0.70

¹Layer Vitamin-mineral Premix each 1 Kg consists of vit. A, 8,000 IU; vit. D3, 1,300 ICU, vit. E 5 mg; vit. K, 2 mg; vit B1,0.7 mg; vit. B2, 3 mg; vit. B6, 1.5 mg; vit. B12, 7 mg; biotin 0.1 mg; pantothenic acid, 6 g; niacine, 20 g; folic acid, 1 mg, manganese, 60 mg; zinc, 50 mg, copper, 6 mg; iodine, 1 mg, selenium, 0.5 mg; cobalt, 1 mg.

²Calculated according to NRC (1994).

Statistics

All of the statistical analyses were performed using the SPSS (2008) (version 17.0). The production and reproduction parameters, egg quality, hematological parameters, serum constituents, immunity, and oxidative status were assessed with a one-way ANOVA (with the diet as the fixed factor) using the post-hoc Tukey's range test ($P < 0.05$).

RESULTS

Productive Performance

Data concerned effects of feeding laying Japanese quail with different sources of oils on their laying performances are listed in Table 2. It was clear that the egg number/bird decreased significantly ($P < 0.001$) in Japanese quail fed diets with 1.5% flaxseed oil in their diets compared to the other treated and soybean oils supplemented diets throughout the experimental period from 8 to 16 wk of age. Concerning egg weight, the highest egg weights ($P < 0.01$) were recorded for quail fed diets supplemented with 1.5% soybean and peanut oil (13.91 and 14.06 g, respectively). Meanwhile, groups that received 1.5% corn oil, flaxseed oil, olive oil, and sunflower oil had the lowest values of egg weights during 8–16 wk of age. Regarding egg mass, quail fed flaxseed or sunflower oil showed a significant decrease in egg mass as compared to the other treated group, but no significant differences were reported for egg mass among laying quail consumed diets supplemented with soybean, corn, peanut, and olive oils. Clear significant differences in feed intake were reported as a result of differences in the type of oil used; quail fed on diets that contained peanut oil consumed higher amount of feed ($P < 0.0001$), compared with other groups, whereas

quail fed soybean oil diet consumed the least amount of feed compared to other treated groups. The best significant values ($P < 0.0001$) for FCR (g feed/g egg) were reported for quail that consumed diets supplemented with soybean oil followed by corn oil and peanut oil groups, while the worst FCR was recorded for the flaxseed oil group.

Reproductive Performance

The differences in fertility and hatchability % as a result of using diets with different sources of oil as a feed for laying Japanese quail are presented in Table 3. Results revealed that quail fed diets supplemented with sunflower oil had significant decrease ($P < 0.05$) in fertility and hatchability percentages overall throughout the experimental period (8–16 wk of age) as compared to the other treated groups. On the other hand, the highest hatchability percentages ($P < 0.05$) were recorded for quail fed on diets supplemented with corn oil (84.56%) as compared to soybean, peanut, flaxseed, and olive oils (74.89, 72.08, 72.22, and 74.77%, respectively).

Egg Quality Parameters

Data of egg quality of Japanese quail fed diets with different types of oil sources are listed in Table 4. Results revealed that egg quality parameters of Japanese quail that fed different sources of oil in their diets were not affected significantly. These parameters include shell %, shell thickness (mm), egg shape index, yolk %, USSW (g/cm²), albumin % (mm), albumin height, and HU. On the other hand, quail fed diets supplemented with peanut oil had the highest significant value of yolk index ($P < 0.005$) compared to diets containing soybean oil and flaxseed oil.

Hematological Parameters

The effects of oil sources included in laying Japanese quail diets on some hematological parameters are listed in Table 5. It was clear that diets enriched with corn, olive, or sunflower oils had the lowest ($P < 0.0001$) values for WBCs (10³/mm³), MID%, GRA%, RBCs (10⁶/mm³), and HCT% as compared to other treated diets with different oil sources. On the other hand, the same oils had higher values of LYM (%) compared to the other treated groups. The olive oil group recorded higher Hb (g/dl), while the corn oil group recorded the lowest ($P < 0.001$) values for Hb (g/dl). Flaxseed oil-supplemented quail diet showed significant decrease in RBC (10⁶/mm³) and MCV (μm³). Finally, MCH (pg) and PLT (103/μL) were increased significantly ($P < 0.0001$) in quail that received diets supplemented with olive or sunflower oil sources.

Serum Parameters

The effects of feeding different oil sources on serum parameters protein and lipid as well as antioxidant status

Table 2. Productive performance of Japanese quail as affected by dietary treatments during the experiment.

Items	Soybean oil	Corn oil	Peanut oil	Flaxseed oil	Olive oil	Sunflower oil	<i>P</i> -value
Egg number/bird							
8–12 wk	23.39 ± 0.46 ^a	22.78 ± 0.24 ^a	23.33 ± 0.40 ^a	21.50 ± 0.28 ^b	23.83 ± 0.27 ^a	23.00 ± 0.21 ^a	0.004
12–16 wk	22.78 ± 0.53 ^{b,c}	24.13 ± 0.36 ^a	21.98 ± 0.06 ^{c,d}	21.62 ± 0.23 ^d	23.08 ± 0.05 ^b	22.22 ± 0.30 ^{b,c,d}	0.001
8–16 wk	23.09 ± 0.41 ^{a,b}	23.46 ± 0.13 ^a	22.66 ± 0.23 ^b	21.56 ± 0.10 ^c	23.46 ± 0.12 ^a	22.61 ± 0.16 ^b	<0.001
Egg weight (g)							
8–12 wk	14.02 ± 0.09 ^a	13.42 ± 0.12 ^b	14.06 ± 0.14 ^a	13.51 ± 0.12 ^b	13.29 ± 0.23 ^b	13.37 ± 0.03 ^b	0.0043
12–16 wk	13.79 ± 0.26 ^{a,b}	13.43 ± 0.09 ^{b,c}	14.07 ± 0.09 ^a	13.53 ± 0.16 ^{b,c}	13.30 ± 0.08 ^{b,c}	13.18 ± 0.18 ^c	0.0156
8–16 wk	13.91 ± 0.17 ^a	13.42 ± 0.05 ^b	14.06 ± 0.12 ^a	13.52 ± 0.02 ^b	13.29 ± 0.15 ^b	13.28 ± 0.10 ^b	0.0014
Egg mass (g/bird)							
8–12 wk	327.89 ± 6.75 ^a	305.69 ± 2.28 ^{b,c}	328.04 ± 8.96 ^a	290.44 ± 3.84 ^c	316.63 ± 4.00 ^{a,b}	307.58 ± 2.50 ^b	0.0021
12–16 wk	313.85 ± 1.58 ^b	324.06 ± 4.24 ^a	309.24 ± 2.75 ^b	292.36 ± 1.06 ^c	306.88 ± 2.42 ^b	292.85 ± 1.50 ^c	<0.0001
8–16 wk	320.87 ± 3.86 ^a	314.91 ± 2.14 ^a	318.63 ± 5.81 ^a	291.44 ± 1.43 ^b	311.78 ± 3.10 ^a	300.20 ± 0.63 ^b	0.0002
Feed intake (g/bird)							
8–12 wk	858.52 ± 4.35 ^d	862.96 ± 5.63 ^d	891.48 ± 6.80 ^c	938.89 ± 2.63 ^b	956.85 ± 5.43 ^a	870.74 ± 3.03 ^d	<0.0001
12–16 wk	854.44 ± 3.40 ^d	918.89 ± 4.25 ^b	946.67 ± 2.25 ^a	874.44 ± 4.67 ^c	852.55 ± 4.05 ^d	919.26 ± 3.03 ^b	<0.0001
8–16 wk	856.48 ± 2.15 ^d	890.93 ± 0.89 ^c	919.07 ± 2.29 ^a	906.67 ± 1.06 ^b	904.70 ± 1.38 ^b	895.00 ± 1.29 ^c	<0.0001
Feed conversion ratio (g feed/g egg)							
8–12 wk	2.62 ± 0.07 ^d	2.82 ± 0.02 ^c	2.72 ± 0.05 ^{c,d}	3.24 ± 0.04 ^a	3.02 ± 0.05 ^b	2.83 ± 0.02 ^c	<0.0001
12–16 wk	2.72 ± 0.00 ^d	2.84 ± 0.05 ^c	3.06 ± 0.03 ^{a,b}	2.99 ± 0.01 ^b	2.78 ± 0.01 ^{c,d}	3.14 ± 0.02 ^a	<0.0001
8–16 wk	2.67 ± 0.03 ^d	2.83 ± 0.02 ^c	2.88 ± 0.05 ^c	3.11 ± 0.02 ^a	2.90 ± 0.03 ^{b,c}	2.98 ± 0.01 ^b	<0.0001

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different ($P < 0.05$).

of laying Japanese quail are presented in [Table 6](#). Quail fed on soybean oil diets had increased values of serum TP (g/dl) as compared to other treatment groups but the lowest TP values were recorded for quail fed on peanut oil diets. Concerning ALB (g/dl), flaxseed oil-supplemented quail had higher values of ALB ($P < 0.05$) than other treatment groups while olive or sunflower oil groups had decreased values ($P < 0.05$) of ALB. Collectively, the level of A/G (%) was increased ($P < 0.01$) in peanut oil-supplemented quail when compared to the other treated groups. Regarding liver enzyme activities, quail fed on peanut or corn oil had increased AST level ($P < 0.01$) than other groups. Meanwhile, ALT level was increased in sunflower oil-supplemented group ($P < 0.0001$) as compared to the other oil source groups. The TC (mg/dl) level decreased significantly in quail fed on corn, peanut, flaxseed, or olive oil sources ($P < 0.0001$) as compared to soybean or sunflower oil groups. Moreover, all oil sources-supplemented quail had decreased ($P < 0.0001$) TG level as compared to the soybean oil group. Other lipid profiles such as HDL and LDL were found to be significantly increased ($P < 0.0001$) in quail fed diets included with 1.5% of olive or sunflower oils as compared to other oil sources groups. The highest levels ($P < 0.001$) of IgG and IgM were recorded for quail fed on corn or olive oil

sources when compared to other oil sources. The increased levels ($P < 0.0001$) of serum complement C3 were reported for quail fed on diets included with 1.5% olive oil compared to other oil sources. Quail consumed olive oil-included diets showed significant increase in SOD and GST and significant decrease in MDA activities compared with those consumed diets included with other sources of oil. On the contrary, the soybean oil group had lower SOD and GST activities and higher values of MDA.

DISCUSSION

Fat and oils are usually added to the poultry diets (meat or egg production) to enhance the energy density as economic tools of producing energy-rich formulations. In this study, the highest egg production was achieved by hens that received diets included with corn or olive oil, while flaxseed oil reduced egg number significantly. And these results did not agree with those obtained by [Al-Daraji et al. \(2010\)](#), who reported that flax oil-supplemented quail hens produce higher number of eggs than those supplemented with corn oil. This study confirmed that the differences in oil sources in quail hens' diets affect egg number, where the flaxseed oil group had the lowest egg number compared to other

Table 3. Reproductive performance of Japanese quail as affected by dietary treatments during the experiment.

Items	Soybean oil	Corn oil	Peanut oil	Flaxseed oil	Olive oil	Sunflower oil	<i>P</i> -value
Fertility %							
8–12 wk	91.55 ± 1.13	95.24 ± 4.76	78.73 ± 4.70	88.43 ± 6.43	91.54 ± 4.81	86.25 ± 7.02	0.3523
12–16 wk	83.33 ± 4.17 ^{a,b}	95.83 ± 4.17 ^a	96.88 ± 1.80 ^a	91.67 ± 5.51 ^a	93.75 ± 0.00 ^a	75.00 ± 7.22 ^b	0.0309
8–16 wk	87.44 ± 2.51 ^{a,b}	95.54 ± 4.46 ^a	87.80 ± 1.47 ^{a,b}	90.05 ± 2.32 ^a	92.65 ± 2.41 ^a	80.62 ± 2.53 ^b	0.0374
Hatchability %							
8–12 wk	76.86 ± 4.09 ^a	79.52 ± 0.48 ^a	69.16 ± 3.13 ^b	65.28 ± 1.39 ^b	65.18 ± 0.87 ^b	65.06 ± 2.54 ^b	0.0029
12–16 wk	72.92 ± 4.17 ^b	89.58 ± 4.17 ^a	75.00 ± 3.61 ^b	79.17 ± 5.51 ^{a,b}	84.38 ± 5.41 ^{a,b}	58.33 ± 2.08 ^c	0.0044
8–16 wk	74.89 ± 0.27 ^b	84.56 ± 2.32 ^a	72.08 ± 0.36 ^b	72.22 ± 2.71 ^b	74.77 ± 2.27 ^b	61.69 ± 2.30 ^c	0.0001

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different ($P < 0.05$).

Table 4. Egg quality of Japanese quail as affected by dietary treatments during the experiment.

Items	Soybean oil	Corn oil	Peanut oil	Flaxseed oil	Olive oil	Sunflower oil	<i>P</i> -value
External traits							
Shell %	15.92 ± 0.36	16.19 ± 0.26	14.37 ± 0.36	14.81 ± 0.32	14.98 ± 0.87	14.42 ± 0.48	0.088
Shell thickness (mm)	0.20 ± 0.005	0.21 ± 0.006	0.20 ± 0.001	0.20 ± 0.017	0.19 ± 0.012	0.19 ± 0.008	0.6933
Egg shape index	82.79 ± 2.39	81.02 ± 3.47	79.47 ± 1.97	80.62 ± 2.38	76.65 ± 3.19	80.51 ± 4.22	0.8044
USSW (g/cm ²)	47.09 ± 0.22	46.92 ± 0.28	47.38 ± 0.19	47.12 ± 0.03	47.42 ± 0.04	47.29 ± 0.14	0.3584
Internal traits							
Yolk %	31.00 ± 0.77	30.11 ± 0.18	30.06 ± 0.21	30.31 ± 1.12	30.97 ± 0.20	30.29 ± 0.86	0.846
Albumin % (mm)	53.08 ± 1.11	53.70 ± 0.23	55.57 ± 0.16	54.88 ± 1.35	54.06 ± 1.07	55.30 ± 1.07	0.433
Albumin height	5.01 ± 0.32	5.03 ± 0.37	5.39 ± 0.14	5.74 ± 0.54	4.67 ± 0.21	5.12 ± 0.39	0.4158
Yolk index	49.31 ± 1.62 ^{b,c}	50.43 ± 0.67 ^{a,b,c}	53.24 ± 1.06 ^a	48.43 ± 1.30 ^c	52.59 ± 0.88 ^{a,b}	50.35 ± 0.23 ^{a,b,c}	0.0511
Haugh unit	90.44 ± 1.69	90.99 ± 2.17	92.11 ± 0.95	94.70 ± 2.72	88.85 ± 1.48	92.14 ± 2.10	0.4411

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different ($P < 0.05$).

oil sources. The differences in egg production may be attributed to multiple components of the different oil sources and their utilization in layers (Ding et al., 2017). These results disagreed with those obtained by Güçlü et al. (2008), who found that using of 4% different oil sources in laying quail diets for 10 wk had no effects on egg numbers. The higher egg weights in this study were recorded for quail hens receiving the diets containing soybean or peanut oil compared to the other diets. These results in contrast to those obtained by Güçlü et al. (2008), who reported that quail hens fed the olive oil-containing or sunflower-containing diets produced the heaviest eggs. The differences in egg weight and egg production could be attributed to the differences of oil sources (Grobas et al., 2001) and subsequently the differences in fatty acid contents of the diet (Vilchez et al., 1991) which influences the digestibility and absorption rate of nutrients. Quail fed with peanut oil consumed higher amount of feed while the lowest feed intake was recorded for the soybean oil group. Meanwhile, soybean oil had the best FCR followed by corn oil and peanut oil groups, while the worst FCR was recorded for the flaxseed oil group. The improvement in FCR may be attributed to the added fat to diets which had more energy than other diets. Also, the improvement in feed conversion in response to fat feeding is due to decrease in feed intake and increased egg production and egg weight (Celebi and Macit, 2009). Our results did not agree to those reported by Güçlü et al. (2008), who used soybean, sesame, sunflower, olive,

cottonseed, hazelnut, maize, or fish oil for laying quail and reported non-significant differences in feed intake and FCR. Furthermore, Balevi and Coskun (2000) used 9 sources of oils at level 2.5% (soybean, cotton, flax, corn, sunflower, olive, tallow, fish, and rendering oils) in diets of Hysex brown layers and reported non-significant effects on egg yield, egg size, and feed intake and FCR. Moreover, Kehui et al. (2004) confirmed that different oils had no influence on FCR but affect the egg mass when compared between fish, palm, or soybean oil sources in Hexices hen's diet. In contrast to our results, Costa et al. (2008) evaluated linseed oil content replacing soybean oil in different levels of the laying hens diet and observed no effects on egg number, egg weight and mass, feed intake, and feed conversion ratio. Collectively, the egg size and egg production were inversely related to ratio of omega-6 to omega-3 fatty acids in oil-containing quail diets (Dalton, 2000; Alagawany et al., 2019).

Concerning reproductive parameters, sunflower oil group had significant decrease ($P < 0.05$) in fertility and hatchability percentages, while the highest fertility and hatchability percentages ($P < 0.05$) were recorded for quail fed on diets supplemented with corn oil. Dalton (2000) attributed the differences in fertility and hatchability to the inverse relationship with ratio of omega-6 to omega-3 fatty acids in oil-containing quail diets. These results were partially similar to those reported by Al-Daraji et al. (2010), who concluded that quail fed on diets with corn oil had increased percentages for

Table 5. Hematological parameters of Japanese quail as affected by dietary treatments during the experiment.

Items	Soybean oil	Corn oil	Peanut oil	Flaxseed oil	Olive oil	Sunflower oil	<i>P</i> -value
WBCs (10 ³ /mm ³)	275.23 ± 10.97 ^{a,b}	199.23 ± 4.41 ^d	282.43 ± 7.90 ^a	250.53 ± 12.46 ^{b,c}	227.60 ± 8.86 ^c	188.24 ± 5.36 ^d	<0.0001
LYM (%)	88.55 ± 1.23 ^b	92.73 ± 0.07 ^a	87.27 ± 0.86 ^b	86.81 ± 0.93 ^b	93.20 ± 0.43 ^a	93.36 ± 0.19 ^a	<0.0001
MID (%)	10.01 ± 0.98 ^a	6.63 ± 0.05 ^b	10.78 ± 0.63 ^a	11.13 ± 0.75 ^a	6.36 ± 0.37 ^b	6.21 ± 0.17 ^b	<0.0001
GRA (%)	1.43 ± 0.31 ^b	0.63 ± 0.02 ^c	1.95 ± 0.22 ^{a,b}	2.06 ± 0.18 ^a	0.44 ± 0.07 ^c	0.43 ± 0.02 ^c	<0.0001
RBCs (10 ⁶ /mm ³)	2.41 ± 0.06 ^a	1.86 ± 0.06 ^c	2.38 ± 0.01 ^a	2.10 ± 0.10 ^b	2.13 ± 0.04 ^b	1.77 ± 0.10 ^c	0.0001
Hb (g/dl)	13.50 ± 0.55 ^{b,c}	11.73 ± 0.18 ^d	12.87 ± 0.07 ^{c,d}	13.40 ± 0.61 ^{b,c}	16.23 ± 0.23 ^a	14.55 ± 0.45 ^b	<0.0001
HCT (%)	22.60 ± 0.60 ^a	17.67 ± 0.52 ^{c,d}	22.20 ± 0.06 ^a	18.68 ± 0.82 ^{b,c}	19.77 ± 0.37 ^b	16.10 ± 0.17 ^d	<0.0001
MCV (μm ³)	94.00 ± 0.15 ^a	94.60 ± 0.26 ^a	93.33 ± 0.24 ^a	88.97 ± 0.33 ^b	92.90 ± 0.20 ^a	91.33 ± 2.45 ^{a,b}	0.0217
MCH (pg)	56.13 ± 2.12 ^d	62.93 ± 1.63 ^c	54.13 ± 0.38 ^d	63.82 ± 0.26 ^c	76.32 ± 1.00 ^b	82.57 ± 2.82 ^a	<0.0001
PLT (10 ³ /μL)	37.33 ± 3.84 ^c	27.07 ± 0.61 ^c	30.00 ± 3.21 ^c	47.50 ± 4.25 ^{b,c}	128.67 ± 3.84 ^a	64.33 ± 17.46 ^b	<0.0001

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different ($P < 0.05$).

Abbreviations: GRA, granulocytes; HCT, hematocrit; HGB, hemoglobin; LYM, lymphocytes; MCH, mean corpuscular hemoglobin; MCV, mean corpuscular volume; MID, mid-range; PLT, platelet count; RBC, red blood cell; WBC, white blood cell.

Table 6. Serum parameters of Japanese quail as affected by dietary treatments during the experiment.

Items	Soybean oil	Corn oil	Peanut oil	Flaxseed oil	Olive oil	Sunflower oil	<i>P</i> -value
TP (g/dL)	4.04 ± 0.25 ^a	3.36 ± 0.76 ^{a,b}	2.70 ± 0.31 ^b	3.94 ± 0.01 ^{a,b}	3.04 ± 0.21 ^{a,b}	3.46 ± 0.23 ^{a,b}	0.1663
ALB (g/dL)	1.39 ± 0.13 ^{a,b}	1.25 ± 0.16 ^b	1.45 ± 0.04 ^{a,b}	1.63 ± 0.02 ^a	1.16 ± 0.08 ^b	1.20 ± 0.07 ^b	0.0406
GLOB (g/dL)	2.65 ± 0.38	2.12 ± 0.59	1.26 ± 0.26	2.30 ± 0.01	1.88 ± 0.13	2.26 ± 0.16	0.1208
A/G (%)	0.59 ± 0.136 ^b	0.69 ± 0.113 ^b	1.30 ± 0.237 ^a	0.71 ± 0.009 ^b	0.62 ± 0.001 ^b	0.54 ± 0.007 ^b	0.0075
AST (IU/L)	13.37 ± 0.44 ^{b,c}	15.66 ± 0.33 ^a	15.93 ± 0.73 ^a	12.69 ± 0.67 ^c	13.32 ± 0.19 ^{b,c}	14.67 ± 0.43 ^{a,b}	0.0026
ALT (IU/L)	67.15 ± 9.15 ^d	218.80 ± 0.69 ^b	184.20 ± 1.50 ^c	238.38 ± 5.82 ^b	214.30 ± 4.27 ^b	337.83 ± 18.92 ^a	<0.0001
TC (mg/dL)	314.20 ± 14.32 ^a	202.10 ± 1.21 ^c	262.40 ± 11.89 ^b	184.20 ± 8.20 ^c	188.20 ± 4.04 ^c	300.70 ± 9.30 ^a	<0.0001
TG (mg/dL)	1239.00 ± 21.36 ^a	466.10 ± 22.81 ^e	1141.95 ± 9.84 ^b	610.00 ± 17.32 ^d	319.45 ± 16.66 ^f	800.80 ± 20.44 ^c	<0.0001
HDL (mg/dL)	18.80 ± 0.70 ^c	32.51 ± 2.98 ^b	7.10 ± 1.10 ^d	22.51 ± 0.95 ^c	45.29 ± 3.88 ^a	38.76 ± 1.38 ^{a,b}	<0.0001
LDL (mg/dL)	47.41 ± 3.69 ^c	76.38 ± 4.52 ^b	27.41 ± 1.50 ^d	39.70 ± 3.55 ^c	90.02 ± 4.07 ^a	101.78 ± 4.96 ^a	<0.0001
IgG (mg/dL)	0.53 ± 0.07 ^c	1.01 ± 0.02 ^a	0.57 ± 0.09 ^{b,c}	0.76 ± 0.03 ^{b,c}	1.06 ± 0.08 ^a	0.77 ± 0.09 ^b	0.0007
IgM (mg/dL)	0.53 ± 0.06 ^c	0.95 ± 0.04 ^a	0.56 ± 0.09 ^{b,c}	0.75 ± 0.02 ^b	1.06 ± 0.09 ^a	0.74 ± 0.03 ^b	0.0002
C3 (mg/dL)	30.13 ± 0.07 ^c	30.65 ± 1.01 ^c	19.51 ± 0.75 ^d	29.79 ± 0.92 ^c	51.83 ± 0.71 ^a	45.92 ± 1.11 ^b	<0.0001
SOD (U/mL)	0.16 ± 0.025 ^c	0.24 ± 0.035 ^{a,b}	0.18 ± 0.023 ^{b,c}	0.18 ± 0.002 ^{b,c}	0.27 ± 0.017 ^a	0.21 ± 0.022 ^{a,b,c}	0.0483
MDA (nmol/mL)	0.56 ± 0.06 ^a	0.36 ± 0.10 ^{b,c}	0.52 ± 0.06 ^{a,b}	0.47 ± 0.02 ^{a,b}	0.25 ± 0.05 ^c	0.46 ± 0.05 ^{a,b}	0.0281
GST (µmol Cdnb/min/mL)	0.15 ± 0.027 ^c	0.23 ± 0.031 ^{a,b}	0.16 ± 0.017 ^{a,b,c}	0.16 ± 0.003 ^{b,c}	0.23 ± 0.015 ^a	0.19 ± 0.021 ^{a,b,c}	0.0647

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different ($P < 0.05$).

Abbreviations: A/G, albumin/globulin ratio; Alb, albumin; ALT, alanine aminotransferase; AST, aspartate aminotransferase; C3, complement 3; GLOB, globulin; GST, glutathione S-transferase; HDL, high-density lipoprotein; IgG, immunoglobulin G; LDL, low-density lipoprotein; MDA, malonaldehyde; SOD, superoxide dismutase; TC, total cholesterol; TG, triglycerides; TP, total protein.

fertility and hatchability than those fed on sunflower oil but not compatible with flax oil results. The enhancement in the reproductive traits of quail hens when flax oil was supplemented to their diet in comparison with sunflower oil group may be attributed to hormone metabolism regulation by dietary phytoestrogens, mainly estrogen (Aydin et al., 2006).

Oil sources do not affect most egg quality parameters except quail fed diets supplemented with peanut oil had the highest significant value for yolk index ($P < 0.005$) compared to diets containing soybean oil and flaxseed oil and this indicating freshness and good quality yolk of peanut oil group. These results partially agreed with those obtained by Güçlü et al. (2008), who found that different oil sources significantly altered yolk index and HU but not affect egg albumen index and eggshell thickness. Moreover, Bertipaglia et al. (2016) reported no effects of different oil sources in quail diets such as soybean, poultry slaughterhouse, fish, and grape seed oils on egg quality parameters including yolk index. In addition, the results agreed with those recorded by Grobas et al. (2001), who found that HU not differed in the eggs of quail received diets included with olive and soybean oil. Moreover, Bozkurt et al. (2012) indicated that HU, albumen height, yolk weight not significantly affected by supplementation of oils into the laying hen diet, but relative albumen weight significantly decreased.

The soybean oil group had higher values of serum TP as compared to other groups but the lowest TP values were recorded for quail fed on peanut oil diets, flaxseed oil increased the level of ALB, while A/G ratio was increased in the peanut oil-supplemented group. According to Sanz et al. (2000), the unsaturated lipids source utilization increases protein and reduces fat in the broilers. The difference in protein accretion was attributed to the level of saturation of the fat because the energy derived from unsaturated fat may be used for other metabolic purposes, whereas the energy derived from saturated sources is less promptly utilized and

accumulates as body fat. Moreover, the improvement in protein values may be attributed to the inclusion of these oils on fatty acids which may affect the synthesis and deposition of muscle protein through a prostaglandin-dependent mechanism (Palmer, 1993). Peanut or corn oil increased AST level ($P < 0.01$), while sunflower oil increased ALT level than other groups. The differences in liver enzyme activity by the different oil sources were also reported by Ahmed et al. (2013), who reported that both canola and olive oils increased the activity of ALT and AST enzymes in serum of birds fed high caloric diet. The increased levels of ALT and AST are indication of the loss of the function of the liver cell membrane (Drotman and Lawhan, 1978).

Corn, peanut, flaxseed, or olive oil sources decreased TC and all oil sources decreased TG levels compared to soybean oil. These results partially agreed with those by Güçlü et al. (2008), who reported that serum TG was lower in the birds that received sunflower-containing diets and hazelnut oil than in the other treatments (cottonseed, fish oil, soyabean, olive, sesame or maize) and serum TC level was higher in cottonseed and hazelnut oil groups than the other oil groups. The same author reported that serum LDL level was decreased in soybean- and olive-fed groups than the other oil sources. On the contrary, Fernandez et al. (1996) reported decreased serum TC levels in soybean oil-fed than olive oil-fed rats. Crespo and Esteve-Garcia (2003) compared sunflower and olive oils in broiler diets and found that the total cholesterol level was lower in the sunflower oil-fed group. Online, El-Yamany et al. (2008) compared between corn-, linseed-, sunflower-, and olive oil-containing diets on broiler performance and reported that different oils included in the diet did not affect the TG and HDL but decreased TC concentration. The differences in lipid profile due to fat sources also confirmed by Ozdogan and Aksit (2003), who compared corn, sunflower, soybean, and tallow fat in broiler diets and reported that HDL, LDL, and cholesterol values in

broiler serum were significantly different, whereas triglyceride values were not. Our results may suggest that using corn, peanut, flaxseed, or olive oil might have an inhibitory effect of these oils on lipogenesis or repartitioning the lipids in the body. Our reports matched with other studies have reported that diets containing plant oils lower the serum LDL-cholesterol and triglycerides levels but do not decrease the HDL-cholesterol levels (Lindsey et al., 1990; Osim et al., 1996). A class form of lipoproteins (HDL) has somewhat varied size (8–11 nm in diameter). These lipoproteins carry cholesterol and fatty acids from the different body's tissue to the liver. In this study, the cholesterol and triglyceride levels in blood decreased in response to treatment with corn, peanut, flaxseed, or olive oil sources, which was consistent with Bölükbaşı and Erhan (2007), who reported that inclusion of olive oil at level 3% caused a reduction in triglyceride and did not decrease the HDL level. Triglycerides are secreted from the liver into the blood by triglyceride-rich lipoproteins; therefore, the impaired hepatic lipogenesis results in reduced plasma concentrations of the triglyceride (Zhou et al., 2009; Mahgoub et al., 2019). The result was also confirmed by Schuman et al. (2000), who reported that feeding of laying hens with flaxseed, flax oil, or n-3-fatty acid had a reduction in liver lipid content.

Immunologically, the highest levels of immunoglobulins (G and M) were recorded for quail fed on corn or olive oil. The supplementation of fatty acid affects both oxidative status and immunity in quail. The improved immunity may be attributed to modulation through both humoral and cellular immune responses (Alagawany et al., 2019). Function, maturation, proliferation, and production of lymphocytic cytokines, splenocytes, and heterophils are influenced by fatty acids, besides production of antibody like IgG and IgM (Alagawany et al., 2019). Furthermore, olive contains flavonoids that are able to improve immune status and increase IgM and IgG (Christake et al., 2004; Geetha and Chakravarthula, 2018; Kishawy et al., 2019). These results did not agree with those by Parsaei et al. (2014), who fed different levels of olive oil (0, 0.25, 0.5, 0.75, and 1%) for broilers from 14 to 42 D of age and reported non-significant levels on IgM and IgG between different groups. Moreover, Yang et al. (2006) reported that corn oil enhanced IgA levels in the cecum lumen, but serum IgG levels tended to decrease by oil supplementation. Olive oil has a powerful antioxidant effect, and it showed a significant increase in SOD and GST and significant decrease in MDA activities compared with those consumed diets included with other sources of oil. These antioxidant effects may be due to the high levels of monounsaturated fatty acids in olive oil (Tufarelli et al., 2016; Velmurugan et al., 2018). These results supported by Oliveras-López et al. (2008) showed that dietary supplementation with extra-virgin olive oil protected pancreatic and liver islets incubated with 10 $\mu\text{mol/L}$ H₂O₂ against lipid peroxidation in cell membrane compared to control and sunflower oil-fed rats. Our results were

parallel to those reported by Papadopoulou et al. (2017), who found that supplementation of chicken and drinking water with polyphenols from olive mill waste waters reduced oxidative stress-induced damage and improved their antioxidant mechanisms.

CONCLUSIONS

From the aforementioned results and discussion, conclusion could be drawn that varying the oil source can affect productive, reproductive, and health aspects of Japanese quail. Soybean oil showed good results regarding production aspects; however, olive oil was the best regarding health aspects.

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REFERENCES

- Abd El-Hack, M. E., M. Alagawany, S. A. A. El-Sayed, and J. Fowler. 2017. Influence of dietary inclusion of untreated or heat-treated *Jatropha* meal on productive and reproductive performances and biochemical blood parameters of laying Japanese quail. *Poult. Sci.* 96:2761–2767.
- Abd El-Hack, M. E., M. Alagawany, and S. Abdelnour. 2019. Responses of growing rabbits to supplementing diet with a mixture of black and red pepper oils as a natural growth promoter. *J. Anim. Physiol. Anim. Nutr.* 103:509–517.
- Ahmed, A. S., S. M. El-Bahr, and A. A. Al-Azraqi. 2013. Effect of canola and olive oils on productive, immunological and some biochemical parameters of broiler chickens fed iso caloric and high caloric diets. *Inter. J. Poult. Sci.* 12:726–734.
- Akiba, Y., L. S. Jensen, C. R. Bart, and R. R. Kraeling. 1982. Plasma estradiol, thyroid hormones and liver lipids determination in birds. *J. Nut.* 112:299–308.
- Alagawany, M., M. E. Abd El-Hack, A. A. Al-Sagheer, M. A. Naiel, I. M. Saadeldin, and A. A. Swelum. 2018. Dietary cold pressed watercress and coconut oil mixture enhances growth performance, intestinal microbiota, antioxidant status, and immunity of growing rabbits. *Animals* 8:212.
- Alagawany, M., S. S. Elnesr, M. R. Farag, M. E. Abd El-Hack, A. F. Khafaga, A. E. Taha, and K. Dhama. 2019. Omega-3 and Omega-6 fatty acids in poultry nutrition: effect on production performance and health. *Animals* 9:573.
- Al-Daraji, H. J., H. A. Al-Mashadani, W. K. Al-Hayani, H. A. Mirza, and Al-Hassani. 2010. Effect of dietary supplementation with different oils on productive and reproductive performance of quail. *Int. J. Poult. Sci.* 9:429–435.
- Aydin, R., M. Karaman, H. H. C. Torak, A. K. Ozugur, D. Aydin, and T. Ciek. 2006. The effect of long-term feeding of conjugated linoleic acid on fertility of Japanese quail. *S. Afr. J. Anim. Sci.* 36:99–104.
- Balevi, T., and B. Coskun. 2000. Effects of some dietary oils on performance and fatty acid composition of eggs in layers. *Revue Méd. Vét.* 151:847–854.
- Basmacoglu, H., M. Cabuk, K. Unal, K. Ozkan, S. Akkan, and H. Yalcin. 2003. Effects of dietary fish oil and flax seed on cholesterol and fatty acid composition of egg yolk and blood parameters of laying hens. *S. Afr. J. Anim. Sci.* 33:266–273.
- Baucells, M. D., N. Crespo, A. C. Barroeta, S. Lopez-Ferrer, and M. A. Grashorn. 2000. Incorporation of different polyunsaturated fatty acids into eggs. *Poult. Sci.* 79:51–59.

- Bertipaglia, L. A., M. I. Sakamoto, L. M. A. Bertipaglia, and G. M. P. D. Melo. 2016. Lipid sources in diets for egg-laying Japanese quail: performance and egg quality. *Acta Sci. Anim. Sci.* 38:281–284.
- Bölikbaşı, S. C., and M. K. Erhan. 2007. Effects of semi replacement of dietary olive oil and corn oil with conjugated linoleic acid (CLA) on broiler performance, serum lipoprotein levels, fatty acid composition in muscles and meat quality during refrigerated storage. *J. Anim. Vet. Adv.* 6:262–266.
- Bozkurt, M., K. Küçükyılmaz, A. U. Çatli, M. Çınar, E. Bintaş, and F. Çöven. 2012. Performance, egg quality, and immune response of laying hens fed diets supplemented with mannan-ligosaccharide or an essential oil mixture under moderate and hot environmental conditions. *Poult. Sci.* 91:1379–1386.
- Celebi, S., and M. Macit. 2009. Effects of feeding tallow and plant fat to laying hens on performance, egg quality and fatty acid composition of egg yolk. *J. Appl. Anim. Res.* 36:49–52.
- Chow, K. C. 1992. *Fatty Acids in Foods and Their Health Implications*. Marcel Dekker, New York.
- Christake, E. P., I. Paneri, M. Giannenas, N. Papazahariadou, A. Botsoglou, and A. B. Spais. 2004. Effect of mixture of herbal extract on broiler chicken infected with *eimeria tenella*. *Anim. Res.* 53:137–144.
- Costa, F. G. P., J. G. Souza, J. H. V. Silva, C. B. V. Rabello, C. C. Goulart, and R. C. Lima Neto. 2008. Influência do óleo de linhaça sobre o desempenho e a qualidade dos ovos de poedeiras semipesadas. *Revist. Bras. Zootec.* 37:861–868.
- Crespo, N., and E. Esteve-Garcia. 2003. Polyunsaturated fatty acids reduce insulin and very low density lipoprotein levels in broiler chickens. *Poult. Sci.* 82:1134–1139.
- Dalton, M. N. 2000. Effects of Dietary Fats on Reproductive Performance, Egg Quality, Fatty Acid Composition of Tissues in Japanese Quail (*Coturnix Coturnix Japonica*). M.Sc. Thesis. Faculty of the Virginia Polytechnic Institute and State University, USA.
- Ding, X., Y. Yu, Z. Su, and K. Zhang. 2017. Effects of essential oils on performance, egg quality, nutrient digestibility and yolk fatty acid profile in laying hens. *Anim. Nutr.* 3:127–131.
- Drotman, R., and G. Lawhan. 1978. Serum enzymes are indications of chemical induced liver damage. *Drug Chem. Toxicol.* 1:163–171.
- Eisen, E. J., B. B. Bohren, and H. E. Mckean. 1962. The Haugh unit as a measure of egg albumen quality. *Poult. Sci.* 41:1461–1468.
- El-Yamany, A. T., H. M. H. El-Allawy, L. D. Abd El-Samee, and A. A. El-Ghamry. 2008. Evaluation of using different levels and sources of oil in growing Japanese quail diets. *Amer. Euras. J. Agric. Envir. Sci.* 3:577–582.
- Fernandez, S., C. Gonzales, F. Diaz, A. M. Fueyo, J. M. Gutierrez, and A. M. Patterson. 1996. Long-term effects in two generations of enriched soybean and olive oil diets on some cardiovascular and biochemical parameters in male rats. *Int. J. Vit. Nutr. Res.* 66:393–399.
- Funk, E. M., G. Froning, G. Grottes, R. Forward, and J. Kinder. 1958. Quality of eggs laid by caged layers. *World's Poult. Sci. J.* 15:207.
- Geetha, V., and S. N. Chakravarthula. 2018. Chemical composition and anti-inflammatory activity of *Boswellia ovalifoliolata* essential oils from leaf and bark. *J. For. Res.* 29:373–381.
- Grobias, S., J. Mendez, R. Lazaro, C. De Blas, and G. G. Mateos. 2001. Influence of source and percentage of fat added to diet on performance and fatty acids composition of egg yolks of two strains of laying hens. *Poult. Sci.* 80:1171–1179.
- Güçlü, B. K., F. Uyanık, and K. M. İşcan. 2008. Effects of dietary oil sources on egg quality, fatty acid composition of eggs and blood lipids in laying quail. *South Afr. J. Anim. Sci.* 38:91–100.
- Kehui, O., W. Wenjun, X. Mingshen, J. Yan, and S. Kinchen. 2004. Effects of different oils on the production performances and polyunsaturated fatty acids and cholesterol level of yolk in hens. *Asian-Australas. J. Anim. Sci.* 17:843–847.
- Kishawy, A. T., S. A. Amer, M. E. Abd El-Hack, I. M. Saadeldin, and A. A. Swelum. 2019. The impact of dietary linseed oil and pomegranate peel extract on broiler growth, carcass traits, serum lipid profile, and meat fatty acid, phenol, and flavonoid contents. *Asian-Australas. J. Anim. Sci.* 32:1161–1171.
- Lindsey, S., J. Benattar, A. Pronczuk, and K. C. Hayes. 1990. Dietary palmitic acid enhances HDL-cholesterol and LDL receptor mRNA abundance in hamsters. *Proc. Exp. Biol. Med.* 195:261–269.
- Mahgoub, S. A. M., M. E. Abd El-Hack, I. M. Saadeldin, M. A. Hussein, A. A. Swelum, and M. Alagawany. 2019. Impact of *Rosmarinus officinalis* cold-pressed oil on health, growth performance, intestinal bacterial populations, and immunocompetence of Japanese quail. *Poult. Sci.* 98:2139–2149.
- Mohamed, L. A., M. M. El-Hindawy, M. Alagawany, A. S. Salah, and S. A. El-Sayed. 2019. Effect of low- or high-CP diet with cold-pressed oil supplementation on growth, immunity and antioxidant indices of growing quail. *J. Anim. Physiol. Anim. Nutr.* 103:1380–1387.
- Norum, K. R. 1992. Dietary fat and blood lipids. *Nutr. Rev.* 50:30–37.
- NRC 1994. *Nutrient Requirements of Poultry*, 9th rev. ed. Natl. Acad. Press, Washington, DC.
- Oliveras-López, M. J., G. Berná, E. M. Carneiro, H. L. G. de la Serana, F. Martín, and M. C. López. 2008. An extra-virgin olive oil rich in polyphenolic compounds has antioxidant effects in OF1 mice. *J. Nutr.* 138:1074–1078.
- Osim, E. E., D. U. Owu, and K. M. Etta. 1996. Mean arterial pressure and lipid profile in rats following chronic ingestion of palm oil diets. *Afr. J. Med. Med. Sci.* 25:335–340.
- Ozdogan, M., and M. Aksit. 2003. Effects of feeds containing different fats on carcass and blood parameters of broilers. *J. Appl. Poult. Res.* 12:251–256.
- Palmer, R. J. 1993. Prostaglandins and the control of muscle protein synthesis and degradations leukotrienes essent, fatty acids. *Poult. Sci.* 72:95.
- Papadopoulou, A., K. Petrotos, and D. Stagos. 2017. Enhancement of antioxidant mechanisms and reduction of oxidative stress in chickens after the administration of drinking water enriched with polyphenolic powder from olive mill waste waters. *Oxid. Med. Cell. Longev.* 2017:10:8273160.
- Pappas, A. C., T. A. Camovic, N. H. C. Sparks, P. F. Surai, and R. M. McDevitt. 2005. Effects of supplementing broiler breeder diets with organic selenium and polyunsaturated fatty acids on egg quality during storage. *Poult. Sci.* 84:865–874.
- Parsaei, S., Z. Amimi, and M. Houshmand. 2014. Effects of olive leaf on blood metabolites and humoral immunity response of broiler chickens. *Int. J. Adv. Biol. Biomed. Res.* 2:741–751.
- Reda, F. M., M. Alagawany, H. K. Mahmoud, S. A. Mahgoub, and S. S. Elnesr. 2019. Use of red pepper oil in quail diets and its effect on performance, carcass measurements, intestinal microbiota, antioxidant indices, immunity and blood constituents. *Animal* 14:1025–1033.
- Sanz, M., A. Flores, and C. J. Lopez-Bote. 2000. The metabolic use of energy from dietary fat in broilers is affected by fatty acid saturation. *Br. Poult. Sci.* 41:61–68.
- Schuman, B. E., E. J. Squires, and S. Leeson. 2000. Effect of dietary flax seed, flax oil and n-3 fatty acid supplement on hepatic and plasma characteristics relevant to fatty liver haemorrhagic syndrome in laying hens. *Br. Poult. Sci.* 41:465–472.
- SPSS 2008. *Statistical Package for the Social Sciences*, Ver. 17.0. SPSS Inc., Chicago, IL, USA.
- Tufarelli, V., V. Laudadio, and E. Casalino. 2016. An extra-virgin olive oil rich in polyphenolic compounds has antioxidant effects in meat-type broiler chickens. *Environ. Sci. Poll. Res. Int.* 23:6197–6204.
- Velmurugan, N., D. Kalpana, J. Y. Cho, and Y. S. Lee. 2018. Chemical composition and antioxidant capacity of the aqueous extract of *Phellodendron amurense*. *J. For. Res.* 29:1041–1048.
- Vilchez, C., S. P. Touchburn, E. R. Chavez, and C. W. Chan. 1991. Effect of feeding palmitic, oleic, and linoleic acids to Japanese quail hens (*Coturnix coturnix japonica*). 1. Reproductive performance and tissue fatty acids. *Poult. Sci.* 70:2484–2493.
- Yang, X., Y. Guo, Z. Wang, and W. Nie. 2006. Fatty acids and coccidiosis: effects of dietary supplementation with different oils on coccidiosis in chickens. *Avian Pathol.* 35:373–378.
- Yang, H., X. Li, and D. Huan. 2018. Effects of three positively buoyant dietary supplements on the buoyancy of feces, growth and intestinal health of Tilapia, *Oreochromis Niloticus* × *O. Aureus*. *Aquac. Fish.* 3:72–78.
- Zhang, N., W. Lan, and Q. Wang. 2018. Antibacterial mechanism of *Ginkgo biloba* leaf extract when applied to *Shewanella putrefaciens* and *Saprophytic staphylococcus*. *Aquac. Fish.* 3:163–169.
- Zhou, T. X., Y. J. Chen, J. S. Yoo, Y. Huang, J. H. Jee, H. D. Jang, S. O. Shin, H. J. Kim, J. H. Cho, and I. H. Kim. 2009. Effects of chitooligosaccharide supplementation on performance, blood characteristics, relative organ weight, and meat quality in broiler chickens. *Poult. Sci.* 88:593–600.