Effects of dietary oil sources on egg quality, fatty acid composition of eggs and blood lipids in laying quail

B.K. Güçlü[1#], F. Uyanık[2] and K.M. İşcan[3]
[1] Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, University of Erciyes, 38090, Kayseri-Turkey
[2] Department of Biochemistry, Faculty of Veterinary Medicine, University of Erciyes, 38090, Kayseri-Turkey
[3] Department of Zootechnics, Faculty of Veterinary Medicine, University of Erciyes, 38090, Kayseri-Turkey

Abstract

This study was performed to investigate the effects of different oils in the diets of laying quail on their performance, egg quality, serum lipids and fatty acid composition of egg yolk. One hundred and ninety two 12-wk old Japanese quail were allocated to eight groups with two replicates containing 12 quail each. They were fed for 10 weeks on diets containing 4% oil from different sources, *viz.* either sunflower, sesame, cottonseed, olive, hazelnut, maize, soyabean or fish oil. The dietary oils affected egg weight and its specific gravity, the egg yolk index and the Haugh unit but had no effect on live weight of the birds, eggshell thickness and albumen index. The highest egg weights were recorded in the groups fed olive and sunflower oil. Eggs from the soyabean oil group had the highest specific gravity. Serum triglyceride concentrations were lower in the birds receiving diets containing sunflower and hazelnut oil than in the other treatments. Serum total cholesterol levels were higher in the groups fed hazelnut and cottonseed oil than in those receiving the other oils. Serum low density lipoprotein (LDL) levels were lower in the groups fed soyabean and olive oil than the other oil sources. The results of this study demonstrated that olive oil improved egg weight and egg shell quality compared to the other oils tested; fish and soyabean oil increased the omega-3 fatty acid level of egg yolk, and soyabean oil had positive effects on serum lipid concentrations. Incorporation of these oils into the diets of Japanese quail may have practical value in manipulating egg yolk quality.

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[#] Corresponding author. E-mail: berrinkg@hotmail.com

Introduction

Animal products such as meat, milk and egg play an important role in human nutrition. In recent years people have become increasingly aware of the quality of their food. Due to increasing public demand for animal products low in fat and cholesterol, studies have been focusing on improving the quality of foods from animal origin (Hargis & Van Elswyk, 1993; Newman *et al*., 2002; Basmacıoğlu *et al*., 2003).

Cholesterol and fatty acid concentrations of egg yolk vary depending on dietary manipulation and pharmacological agents as well as genetics, age and production level of the bird. Concerning nutrition, one of the methods developed to change the lipid profile of eggs has been the use of different oil sources that are commonly used as energy sources in the diets of laying hens (Baucells *et al*., 2000; Grobas *et al*., 2001; Shafey *et al*., 2003; Cabrera *et al*., 2005). Some of the oil sources are rich in long chain polyunsaturated fatty acids (PUFA) that can change the proportion of the constituents of egg yolk (Hargis & Van Elswyk, 1993; Eseceli & Kahraman, 2004). Although some plant oils used in animal diets contain the same or similar concentrations of fatty acids, they may differ significantly from each other in respect of their physical properties due to the ratio of fatty acids and triglycerides in their structures. These differences may be caused by many factors such as climate, soil type, vegetative stage and the genetics of the plant (Şenköylü, 2001). Investigations have been conducted on the effects of some plant oils and fat on certain production criteria in poultry (Vilchez *et al.*, 1990; Sadi *et al*., 1996; Balevi & Coşkun, 2000; Grobas *et al*., 2001; Shafey *et al*., 2003; Basmacıoğlu *et al*., 2003; Guo *et al*., 2004), though results for some parameters investigated, have been inconsistent (Grobas *et al*., 2001; Shafey *et al*., 2003; Murata *et al*., 2003; Cabrera *et al*., 2005). Furthermore, a comprehensive investigation of the effects of different plant oils on the performance, interior and exterior egg quality, egg yolk fatty acid composition as well as serum lipid profile of laying quail has not been conducted. Therefore, this study was performed to investigate the effects of different sources of dietary oils on the performance of laying Japanese quail and the concentration of their serum lipids, the quality of their eggs and fatty acid composition of the egg yolk.

Materials and Methods

One hundred and ninety two 12 wk old Japanese quail (*Coturnix coturnix japonica*) hens were used in this study. Following one wk of adaptation period the quail were weighed to provide an equal live weight in all groups at the beginning of the study. They were evenly distributed in eight groups with two replicates per group containing 12 quail each. For 10 weeks the quail were fed diets containing 4% oil from the following plant sources: sunflower, sesame, cottonseed, olive, hazelnut, maize and soyabean as well as fish oil (Table 1). The quail hens were allowed free access to food and water. The birds were housed in stainless-steel wire cages in an experimental house on a 17–h lighting schedule. Ingredients and chemical composition of diet are shown in Table 1. The chemical composition of the diet was analyzed using the AOAC methods. Dry matter (DM) and crude ash were determined with electric and muffle furnaces set at 105 °C and 550 °C, respectively (AOAC, 1984, method 14.081 for DM and AOAC 1990, 942.05 for crude ash). Crude cellulose level was calculated from the loss on ignition of the residue remaining after digestion of samples with acid and alkaline solutions under specific conditions (AOAC 1984, methods 7.066-7.070). The crude fat was ether-extracted using a Soxhlet apparatus, and quantity of fat was determined gravimetrically (AOAC 1990, method 920.39). Total nitrogen (N) was determined by the Kjeldahl method (AOAC 1990, method 954.01) and the factor, N x 6.25, was used to convert N into crude protein (CP). The calculated values were obtained from the sum of the values of each ingredient obtained by the following formula: assumed value of the ingredient x the percentage of the ingredient in the diet.

Table 1 Ingredients and chemical composition of the diet fed to quail hens

	Composition
Ingredients (kg/1000 kg)	
Maize	380.0
Soyabean meal	250.0
Sunflower meal	100.0
Barley	127.0
Meat–bone meal	20.0
Oil	40.0
Limestone	73.0
Dicalcium phosphate	4.0
Sodium chloride	3.0
Vitamin premix*	1.5
Mineral premix**	1.5
Composition (g/kg, analysed)	
Dry matter	909.0
Crude protein	203.3
Ether extract	39.6
Crude cellulose	48.2
Crude ash	121.4
Calculated values, g/kg	
Total calcium	32.9
Total phosphorus	7.2
Metabolisable energy (MJ/kg)	11.7

*Vitamin premix provided per kg of premix: 6 000 000 IU vitamin A; 6 000 IU vitamin D_3; 20 000 IU vitamin E; 2 g vitamin K2; 1.2 g vitamin B_1; 2.4 g vitamin B_2; 2 g vitamin B_6; 12 mg vitamin B_{12}; 10 g niacin; 300 mg folic acid; 4 g calcium pantothenate; 50 mg D-Biotin.
** Mineral premix provided per kg of premix: 80 g Mn; 30 g Fe; 60 g Zn; 5 g Cu; 0.5 g Co; 2 g I; 236 g Ca.

The live weights of birds were recorded in the beginning and end of the study. Egg production was recorded daily and food consumption and egg weight were recorded at two weekly intervals. Feed efficiency was calculated by determining the amount of food consumed per one kg of egg. Ten eggs from each group were collected at monthly intervals to determine interior and exterior egg quality. Specific gravity of a whole egg (g/cm^3) was measured by the Archimedes's method with an instrument designed for the measurement of egg weight in air (Wa) and weight in water (Ww) at 15.6 °C, and specific gravity was calculated with the formula [Specific gravity = Wa/ (Wa-Ww)] at the same day of egg collection (Thompson & Hamilton, 1982; Hempe *et al*., 1988). The other egg quality parameters were measured 24 h later. Eggshell thickness was determined by the mean of three measurements taken from three different sides of the shell. Albumen height (H_A), length (L_A) and width (W_A) were measured, and then albumen index was calculated using the following formula [Albumen index = $H_A/\{(L+W_A)/2\}$x100]. Yolk height (H_Y) and diameter (D) were measured and yolk index was calculated with the following formula [Yolk index = (H_Y/D) x100]. Haugh unit was calculated with the following formula where H_A is albumen height and W_E is egg weight: [Haugh unit = 100 log ($H_A + 7.57 - 1.7\ W_E^{\ 0.37}$)] (Wells, 1968).

At the end of the experiment 14 blood samples were collected from each group and serum was separated by centrifugation at 1300 g after one hour incubation at room temperature, and stored at –20 °C pending analysis. Serum was analysed with a Shimadzu UV Model 1208 spectrophotometer using commercial kits (Biosystem, Spain) for triglycerides, total cholesterol, high density lipoprotein (HDL) and low density lipoprotein (LDL) concentrations.

Ten eggs from each group were collected to determine their fatty acid profiles. Lipids were extracted from eggs by the method of the AOAC (1990, method 920.39). The fatty acid methyl esters were prepared from oil samples according to IUPAC (1976) and from subsequent fatty acid profiles determined by gas chromatography. Fatty acids were separated and identified using a Thermoguest Trace gas chromatograph equipped with a SP-2330 (30 mm x 0.25 mm inside diameter) capillary column of silica. The apparatus was programmed with an initial temperature of 120 °C for 2 min, allowing increases of 5 °C until a final temperature of 220 °C was reached. The temperatures of the injector and detector (flame ionization detector) were 240 °C and 250 °C, respectively. Helium was used as the carrier gas with an injection split ratio of 150:1. Gas flows used, were adjusted to H_2:35 mL/min and dry air to 350 mL/min. Peaks separated, were identified by comparison with standard samples of known composition. Internal standard (Sigma cat no: 189-19) was used for fatty acid quantification.

Statistical analyses of data were performed by SPSS 9.0 version for Windows (Özdamar, 2002). One-way analysis of variance (ANOVA) was used for the differences between groups. When the F values were significant, the Duncan's Multiple Range Test was performed. Since group feeding was performed no statistical analysis was done for food consumption, egg production and feed efficiency.

Results and Discussion

In this study, fish oil represented oil from animal origin and the sunflower, maize, soyabean, sesame, olive, cottonseed and hazelnut oil, the plant oils. The fatty acid composition of the oils is presented in Table 2. The fatty acid composition of the fish oil used in the present study differed from that reported by Balevi & Çoşkun (2000). Fish oil also contained higher levels of docosahexaenoic acid (C22:6n3) (10.2%), eicosenoic acid (C20:1n9) (11.3%), eicosapentaenoic acid (C20:5n3) (9.4%), erucic acid (C22:1n9) (7.7%) and palmitoleic acid (C16:1) (8.3%) than the plant oils while its linoleic acid level (1.0%) was lower. The highest linoleic acid (C18:2n6) concentrations were recorded in sunflower, maize, sesame, cottonseed and soyabean oil. The linoleic acid levels of these oils ranged from 53% to 60% (Table 2). Olive and hazelnut oil were rich in oleic acid (C18:1n9), at levels of 70.9% and 73.2%, respectively. The highest level of linolenic acid (7.16% α-linolenic acid and 0.38% γ-linolenic acid) was recorded in soyabean oil. The highest levels of palmitic acid (C16:0) and total saturated fatty acids were measured in cottonseed, sesame and fish oil while hazelnut oil contained the lowest level. These findings were similar to the results of previous studies using the same oils (Balevi & Coşkun, 2000; Grobas *et al*., 2001; Milin *et al*., 2001; Şenköylü, 2001; Eseceli & Kahraman, 2004; Guo *et al*., 2004; Cabrera *et al*., 2005). However, the slight differences obtained in the fatty acid composition of the oil sources used in this study compared to published values might be due to many factors such as production of the crops in different climates and differences on the vegetation stage of the plants, that could have affected the fatty acid composition of oils (Şenköylü, 2001).

Table 2 Fatty acid composition (%) of oils included in the diets of laying quail

Fatty acids	Sunflower oil	Maize oil	Fish oil	Soyabean oil	Sesame oil	Olive oil	Cottonseed oil	Hazelnut oil
C12:0	-	-	0.084	-	0.016	-	0.018	-
C14:0	0.07	0.04	5.30	0.10	0.64	0.02	0.80	0.04
C14:1	-	-	0.15	-	-	-	-	-
C15:0	0.02	0.02	0.49	0.04	0.04	0.02	0.03	0.02
C15:1	0.01	-	0.24	0.02	-	-	-	-
C16:0	6.16	10.98	13.80	11.33	18.72	13.05	22.01	5.25
C16:1	0.09	0.12	8.34	0.11	0.49	0.87	0.60	0.17
C17:0	0.04	0.07	1.73	0.16	0.14	0.15	0.17	0.05
C17:1	0.03	0.04	0.39	0.07	0.09	0.24	0.11	0.11
C18:0	3.56	1.82	2.88	4.08	2.69	3.11	2.16	3.53
C18:1n9	28.37	28.26	21.94	22.20	20.34	70.92	17.99	73.20
C18:2n6	60.03	56.03	1.04	53.03	55.03	10.09	55.03	17.16
C18:3n6	0.015	0.05	0.12	0.38	0.05	0.05	-	0.02
C18:3n3	0.109	0.90	0.50	7.06	0.72	0.52	0.17	0.15
C20:0	0.238	0.36	0.15	0.32	0.24	0.41	0.22	0.13
C20:1n9	0.253	0.35	11.25	0.39	0.26	0.33	0.27	0.22
C20:2n6	0.038	0.05	0.63	0.13	0.06	0.04	0.09	0.02
C20:3n3	0.025	0.02	0.06	0.03	0.01	-	0.01	-
C21:0	0.008	0.01	0.03	0.03	0.01	0.01	0.01	0.01
C20:5n3	0.126	0.10	9.36	0.08	0.20	0.16	0.07	0.09
C22:0	0.587	0.14	0.04	0.35	0.22	0.11	0.11	-
C22:2n6	0.007	-	0.41	-	0.00	-	0.01	-
C22:1n9	0.007	0.01	7.72	0.01	0.00	-	0	-
C22:6n3	0.014	0.03	10.20	0.26	0.06	0.09	0.11	-
C23:0	0.026	0.01	0.07	0.04	0.02	0.02	0.02	0.01
C24:0	0.206	0.15	0.20	0.11	0.11	0.05	0.08	0.07
C24: 1n9	0.006	0.10	2.36	0.04	0.06	-	0.12	-
Σ SFA	10.92	13.60	24.68	16.56	22.84	16.97	25.62	9.10
Σ MUFA	28.77	28.89	52.23	22.89	21.23	72.36	19.08	73.70
Σ PUFA	60.32	57.51	22.80	60.60	55.91	10.61	55.22	17.12
Σ Omega-3	0.299	1.059	20.193	7.464	0.984	0.774	0.369	0.239
Σ Omega-6	60.04	56.47	2.67	53.17	54.94	9.84	54.86	16.88

SFA - Saturated fatty acids; MUFA - Monounsaturated fatty acids; PUFA - Polyunsaturated fatty acids.

The absence of a response to the dietary inclusion of oils, both of plant and animal origin, on the live weight of quail (P >0.05) in the present study (Table 3) confirmed the findings of studies conducted on laying hens (Baucells *et al*., 2000; Shafey *et al*., 2003) and broilers (Newman *et al*., 2002).

In the present study egg production was recorded as 90.6%, 84.3%, 83.2% in the groups fed the diets containing the olive, cottonseed and hazelnut oil, respectively. The food consumption and the feed efficiency ranged from 32.3 to 35.3 g/day and from 2.6 to 2.9, respectively (Table 4). Because group feeding was performed, statistical analysis could not be done. Therefore, it is not possible to discuss the performance parameters.

The quail fed the sunflower and olive oil containing diets produced the heaviest eggs (P <0.01). In contrast to the findings of some previous studies (Baucells *et al*., 2000; Basmacıoğlu *et al*., 2003; Shafey *et al*., 2003; Guo *et al*., 2004; Cabrera *et al*., 2005), in this study higher egg weights were obtained from hens receiving the diets containing sunflower and olive oil compared to the other diets. This suggests that different oil sources (Grobas *et al*., 2001) and thus the fatty acid content of the diet (Vilchez *et al*., 1990, 1991) could affect egg weight.

In the present study slight improvements in eggshell thickness were measured in all diets except those containing the maize, sesame and fish oil (P >0.05). Specific gravity was the highest (P <0.001) in the eggs

Table 3 Effects of different oil sources on body weight and egg weight (g) of laying quail (means ± s.e.)

Oil sources	Initial body weight	Final body weight
Sunflower	216.1 ± 4.13	250.3 ± 6.28
Maize	215.6 ± 5.30	240.9 ± 7.34
Fish	215.7 ± 5.14	230.5 ± 4.95
Soyabean	216.7 ± 5.63	241.1 ± 8.59
Sesame	215.8 ± 4.67	236.4 ± 6.22
Olive	216.0 ± 3.84	251.2 ± 5.95
Cottonseed	216.6 ± 5.09	234.8 ± 8.28
Hazelnut	216.0 ± 4.25	229.4 ± 5.08
P	NS	NS

NS - not significant; P >0.05

Table 4 Effects of different oil sources on egg production (%), daily food consumption (g/quail, day) and feed efficiency (kg feed/kg egg) of laying quail

Oil source	Egg production	Feed consumption	Feed efficiency
Sunflower	81.0	34.1	2.6
Maize	81.4	35.3	2.9
Fish	80.4	32.3	2.7
Soyabean	80.2	33.1	2.6
Sesame	80.2	34.9	2.8
Olive	90.6	34.9	2.7
Cottonseed	84.3	32.5	2.6
Hazelnut	83.2	33.4	2.7

from the treatments containing hazelnut, cottonseed, soyabean and olive oil. Similar improvements in the specific gravity of eggs (Table 5) indicate an improvement in eggshell quality. The highest specific gravity value (1.0725), thus the best improvement, was recorded in the hazelnut oil group. Çetingül & İnal (2003) reported similar improvements when feeding hazelnut oil, and Vilchez *et al*. (1992) found that oleic acid improved the specific gravity of eggs. In the present study hazelnut oil contained the highest level (73.3%) of oleic acid. Therefore, it can be speculated that this improvement in specific gravity probably resulted from the high oleic acid concentration of hazelnuts.

The albumen index of the eggs was not affected by the oils used in this study, while the egg yolk index ($P < 0.001$) and Haugh unit ($P < 0.05$) were higher in the fish oil group than in the remaining groups (Table 5). Grobas *et al*. (2001) reported no difference in the Haugh unit of eggs when olive and soyabean oil were compared, substantiating the observation in the present study.

The serum lipid profile of the quail is presented in Table 6. In laying fowls, olive oil (Shafey *et al*., 2003), fish oil (Beynen & Katan, 1985; Murata *et al*., 2003) and soyabean oil (Murata *et al*., 2003) had no effect on serum triglyceride concentrations. Radcliffe *et al*. (2001) compared cottonseed and maize oil in rats and found no effects of these oils on their serum triglyceride concentrations. On the other hand, in other studies where various oil sources were compared, serum triglyceride concentrations were decreased when fish oil was included in the diets of broilers (Newman *et al*., 2002), quail (Hood, 1991) and rats (Ruiz-Gutierrez *et al*., 1999). In the present study the lowest serum triglyceride concentrations were recorded in the diet containing sunflower oil, and this is comparable to the results of the broiler study by Newman *et al*. (2002). Since the highest concentration of saturated fatty acids was measured in cottonseed oil, the highest serum triglyceride levels could be expected in the cottonseed oil fed group.

Table 5 Effects of different oil sources on egg weight (g), specific gravity (g/cm^3), eggshell thickness (mmx10^{-2}), Haugh unit, egg albumen index and egg yolk index of laying quail (means ± s.e.)

Oil source	Egg weight g	Specific gravity g/cm^3	Eggshell thickness mmx10^{-2}	Haugh unit	Egg albumen index	Egg yolk index
Sunflower	12.0^a±0.06	1.0686^{ab}±0.001	20.1±0.40	87.7^{bc}±0.67	10.7±0.32	48.3^{ab}±0.66
Maize	11.5^b±0.20	1.0655^b±0.001	19.6±0.34	88.4^{abc}±0.71	11.0±0.40	48.5^{ab}±0.75
Fish	11.3^b±0.10	1.0653^b±0.001	19.3±0.27	90.1^a±0.69	11.7±0.41	49.5^a±0.70
Soyabean	11.7^{ab}±0.12	1.0706^a±0.001	19.9±0.36	87.1^c±0.62	10.1±0.20	47.0^{bc}±0.57
Sesame	11.4^b±0.08	1.0687^{ab}±0.001	19.5±0.43	89.2^{ab}±0.61	11.1±0.31	48.7^{ab}±0.40
Olive	2.0^a±0.13	1.0703^a±0.0008	20.2±0.18	88.4^{abc}±0.37	10.8±0.30	45.5^c±0.29
Cottonseed	11.7^{ab}±0.15	1.0722^a±0.0007	20.1±0.41	87.5^{bc}±0.60	10.6±0.34	47.9^{ab}±0.42
Hazelnut	11.5^b±0.16	1.0725^a±0.0008	19.9±0.16	87.5^{bc}±0.67	10.5±0.22	47.8^{ab}±0.45

$^{a-c}$ Means within columns with different superscripts a-d differ significantly at $P < 0.05$.

In the present study the lowest serum total cholesterol concentrations were found in quail fed the diets containing the soyabean, sunflower and sesame oil while the highest concentrations were in the birds receiving the hazelnut and cottonseed oil treatments. In a rat study, Fernandez *et al*. (1996) also found a lower serum cholesterol concentration in soyabean oil than olive oil fed rats. The birds receiving soyabean oil, which contains the highest linolenic acid, had the lowest serum total cholesterol concentration. This is consistent with the results of Sadi *et al*. (1996). The low cholesterol levels of the sesame oil group supports the finding of Satchithanandam *et al*. (1993) who suggested that sesame oil may prevent hypercholesterolemia. Crespo & Esteve-Garcia (2003) compared sunflower oil and olive oil in broiler diets, and found the lowest serum total cholesterol level in the sunflower oil fed group. The result of these studies is consistent with that of the present study.

Serum HDL concentrations were not affected by any of the oil sources in the present study. Similar results were reported by Radcliffe *et al*. (2001) who compared cottonseed and maize oils in rats, and Murata *et al*. (2003) who compared soyabean, fish, canola and poultry by-product oils in laying hens. The LDL levels were lower in the serum of birds consuming soyabean and olive oil containing diets than in the birds on the cottonseed and hazelnut oil diets, but no differences were found compared to other groups. Crespo & Esteve-Garcia (2003) investigated the effects of diets with tallow, olive, sunflower and linseed oils on

Table 6 Effects of different oil sources on serum triglycerides, total cholesterol, high density lipoprotein (HDL) and low density lipoprotein (LDL) concentrations (mg/dL) of laying quail (means ± s.e.)

Oil source	Triglycerides	Total cholesterol	HDL	LDL
Sunflower	797.7^c ± 57.53	202.2^{cd} ± 15.10	32.7 ± 3.41	155.0^{ab} ± 14.44
Maize	1017.0^b ± 67.11	225.4^{cd} ± 21.15	27.1 ± 2.54	164.5^{ab}± 21.52
Fish	1017.5^b ± 60.75	240.5^{bc} ± 31.82	30.6 ± 4.45	176.8^{ab} ± 16.51
Soyabean	1085.7^{ab} ± 28.67	173.0^d ± 10.96	28.7 ± 1.69	135.6^b ± 9.55
Sesame	1097.6^{ab} ± 54.46	202.5^{cd} ± 19.58	26.3 ± 3.20	146.4^{ab} ± 15.70
Olive	1159.7^{ab} ± 58.85	245.7^{bc} ± 19.74	20.8 ± 1.44	141.8^b ± 17.49
Cottonseed	1186.3^a ± 28.70	295.6^{ab} ± 11.02	23.0 ± 1.25	193.5^a ± 13.20
Hazelnut	840.3^c ± 31.93	311.5^a ± 20.74	25.7 ± 2.45	197.3^a ± 18.68

$^{a-c}$ Means within columns with different superscripts a-d differ significantly at $P < 0.05$.

Table 7 Fatty acid composition (%) of the egg yolk of quail fed different sources of oil, constituting 4% of the diet (means ± s.e.)

Fatty acids	Sunflower oil	Maize oil	Fish oil	Soyabean oil	Sesame oil	Olive oil	Cottonseed oil	Hazelnut oil
C12:0	0.050^{a}±0.003	0.058^{a}±0.004	0.059^{a}±0.004	0.034^{a}±0.004	0.039^{a}±0.006	0.042^{a}±0.02	0.008^{b}±0.000	0.033^{a}±0.004
C13:0	-	-	0.002±0.002	0.02±0.004	0.02±0.005	0.006±0.002	0.002±0.001	0.03±0.004
C14:0	0.61^{bc}±0.02	0.64^{b}±0.03	0.86^{a}±0.03	0.53^{cd}±0.02	0.56^{cd}±0.04	0.47^{d}±0.03	0.53^{d}±0.02	0.54^{cd}±0.0
C14:1	0.12^{a}±0.01	0.13^{a}±0.009	0.14^{a}±0.01	0.07^{b}±0.004	0.08^{b}±0.01	0.08^{b}±0.006	0.09^{b}±0.01	0.08^{b}±0.006
C15:0	0.09^{b}±0.01	0.09^{b}±0.008	0.15^{a}±0.006	0.14^{a}±0.007	0.12^{ab}±0.006	0.10^{b}±0.009	0.09^{b}±0.006	0.13^{a}±0.01
C15:1	0.019^{b}±0.001	0.016^{b}±0.001	0.034^{a}±0.003	0.020^{b}±0.001	0.016^{b}±0.002	0.015^{b}±0.001	0.033^{a}±0.008	0.018^{b}±0.001
C16:0	26.34^{abc}±0.401	27.03^{ab}±0.43	27.23^{a}±0.53	25.86^{bc}±0.19	26.49^{ab}±0.43	24.13^{d}±0.42	26.13^{abc}±0.41	25.22^{ac}±0.27
C16:1	3.49^{c}±0.23	4.74^{ab}±0.18	5.19^{a}±0.26	3.40^{c}±0.14	3.53^{c}±0.33	4.00^{bc}±0.26	3.95^{bc}±0.33	3.72^{c}±0.32
C17:0	0.35^{a}±0.04	0.27^{ab}±0.03	0.35^{a}±0.02	0.34^{a}±0.03	0.25^{b}±0.02	0.21^{b}±0.01	0.24^{b}±0.02	0.22^{b}±0.01
C17:1	0.23^{c}±0.03	0.22^{c}±0.03	0.41^{a}±0.02	0.24^{c}±0.04	0.25^{bc}±0.01	0.34^{ab}±0.06	0.28^{bc}±0.01	0.31^{bc}±0.02
C18:0	8.40^{ab}±0.40	7.37^{bc}±0.15	8.25^{ab}±0.31	9.00^{a}±0.24	8.72^{ab}±0.33	6.72^{c}±0.36	7.89^{abc}±0.95	7.37^{bc}±0.27
C18:1n9	43.31^{c}±0.61	42.94^{cd}±0.75	46.35^{b}±0.74	38.31^{e}±0.70	40.77^{cde}±0.86	49.51^{a}±2.18	41.20^{de}±0.85	49.22^{a}±0.48
C18:2n6	13.11^{bc}±0.61	12.71^{c}±0.98	6.56^{e}±0.16	17.10^{a}±0.54	14.50^{bc}±1.07	9.92^{d}±1.40	15.20^{ab}±0.37	9.23^{d}±0.53
C18:3n6	0.23^{b}±0.01	0.19^{bc}±0.02	0.12^{d}±0.004	0.29^{a}±0.005	0.20^{bc}±0.02	0.16^{cd}±0.02	0.20^{b}±0.01	0.15^{d}±0.005
C18:3n3	0.14^{de}±0.009	0.25^{b}±0.01	0.13^{e}±0.004	0.72^{a}±0.04	0.21^{bc}±0.02	0.18^{cde}±0.008	0.19^{cd}±0.01	0.17^{cde}±0.01
C20:0	0.025^{bc}±0.001	0.018^{d}±0.001	0.035^{a}±0.002	0.026^{b}±0.002	0.024^{bc}±0.001	0.022^{cd}±0.001	0.019^{d}±0.000	0.020^{d}±0.001
C20:1n9	0.27^{bc}±0.02	0.25^{c}±0.02	0.97^{a}±0.09	0.28^{bc}±0.02	0.29^{bc}±0.02	0.38^{b}±0.02	0.28^{bc}±0.02	0.30^{bc}±0.02
C20:2n6	0.21^{bc}±0.01	0.17^{c}±0.01	0.27^{abc}±0.01	0.23^{bc}±0.06	0.38^{a}±0.07	0.34^{ab}±0.05	0.21^{bc}±0.02	0.23^{bc}±0.02
C20:3n3	0.13±0.003	0.093±0.008	0.12±0.01	0.11±0.009	0.11±0.01	0.12±0.01	0.099±0.008	0.11±0.01
C20:5n3	0.049^{c}±0.005	0.053^{bc}±0.007	0.11^{a}±0.007	0.078^{abc}±0.008	0.080^{abc}±0.02	0.069^{bc}±0.01	0.084^{ab}±0.01	0.081^{abc}±0.005
C22:2n6	1.71^{ab}±0.06	1.65^{ab}±0.07	0.99^{c}±0.11	1.58^{ab}±0.16	1.84^{a}±0.05	1.47^{b}±0.18	1.82^{a}±0.07	1.62^{ab}±0.05
C21:0	0.098^{a}±0.04	0.022^{b}±0.001	0.042^{b}±0.003	0.018^{b}±0.001	0.024^{b}±0.003	0.041^{b}±0.004	0.020^{b}±0.002	0.035^{b}±0.004
C22:1n9	0.028^{c}±0.007	0.025^{c}±0.005	0.17^{a}±0.02	0.089^{b}±0.03	0.10^{b}±0.03	-	0.047^{bc}±0.009	0.058^{bc}±0.01
C22:0	0.011±0.006	0.005±0.000	0.004±0.000	0.006±0.000	0.005±0.000	0.014±0.007	0.003±0.000	0.005±0.000
C22:6 n3	0.35^{e}±0.02	0.49^{d}±0.02	0.98^{a}±0.01	0.95^{a}±0.04	0.58^{c}±0.02	0.74^{b}±0.03	0.57^{c}±0.02	0.53^{cd}±0.01
C23:0	0.004±0.002	0.005±0.000	0.007±0.001	0.006±0.001	0.015±0.01	0.007±0.001	0.004±0.001	0.006±0.002
C24:0	0.16^{a}±0.02	0.096^{bc}±0.008	0.072^{bc}±0.02	0.60^{c}±0.01	0.13^{ab}±0.02	0.076^{bc}±0.02	0.086^{bc}±0.01	0.79^{bc}±0.01
C24:1n9	0.69^{a}±0.05	0.35^{cd}±0.06	0.25^{d}±0.04	0.35^{cd}±0.02	0.68^{a}±0.05	0.52^{b}±0.06	0.66^{a}±0.04	0.43^{bc}±0.01
Σ SFA	36.15^{ab}±0.58	35.57^{ab}±0.40	37.07^{a}±0.61	36.05^{ab}±0.39	36.39^{ab}±0.59	31.43^{d}±0.60	35.06^{bc}±1.01	33.69^{c}±0.45
Σ MUFA	48.15^{b}±0.75	48.67^{b}±0.87	53.53^{a}±0.50	42.76^{c}±0.75	45.73^{b}±0.95	54.86^{a}±2.23	46.56^{b}±1.05	54.14^{a}±0.70
Σ PUFA	15.94^{bc}±0.62	15.60^{c}±1.06	9.28^{e}±0.15	21.05^{a}±0.59	17.88^{bc}±1.03	12.99^{d}±1.58	18.37^{b}±0.37	12.13^{d}±0.57
Σ Omega-3	0.68^{e}±0.02	0.88^{d}±0.03	1.33^{b}±0.01	1.85^{a}±0.07	0.97^{d}±0.02	1.11^{c}±0.04	0.94^{d}±0.02	0.89^{d}±0.02
Σ Omega-6	13.69^{bc}±0.62	13.39^{c}±0.99	7.66^{e}±0.16	18.33^{a}±0.56	15.27^{bc}±1.07	10.82^{d}±1.44	15.97^{b}±0.37	9.91^{de}±0.54

Means within rows with different superscripts a-e differed significantly as $P < 0.05$.
SF - Saturated fatty acids; MUFA - Monounsaturated fatty acids; PUFA - Polyunsaturated fatty acids.

plasma cholesterol and very low density lipoprotein (VLDL) concentrations, and found lower VLDL levels in broilers fed sunflower and linseed oil than the broilers fed the tallow, olive oil or the basal diets. Although, in the present study, serum VLDL levels were not determined, the low LDL levels found in soyabean and olive oils may be due to the lower VLDL concentrations in plasma and alterations in conversion of VLDL to LDL (Beynen & Katan, 1985).

Differences were observed between groups with regard to fatty acid composition of egg yolk (Table 7). The highest oleic acid concentrations were determined in the eggs of the quail in the groups fed olive and hazelnut oil, which are rich in oleic acid. Similarly, the linoleic acid concentration of egg yolk was high in the groups fed sunflower, maize, sesame, soyabean and cottonseed oil, which are rich in linoleic acid. The highest linolenic acid concentration of egg yolk was found in the group fed soyabean oil, which is also rich in linolenic acid. Laying hens can convert linolenic acid to its n-3 products, eicosapentaenoic acid (C20:5 n-3) and docosahexaenoic acid (C22:6 n-3) by desaturation and elongation in the liver, and these elongated metabolites are deposited in egg yolk (Collins *et al*., 1997; Ayerza & Coates, 2000). The eicosapentaenoic and docosahexaenoic acid levels in the eggs collected from the group fed fish oil, which is rich in eicosapentaenoic acid and docosahexaenoic acid, were higher than in the other groups. Because soyabean oil had a high linolenic acid level, the high level of docosahexaenoic acid found in the yolk of the soyabean oil fed group, which is very similar to the docosahexaenoic acid level of the fish oil group probably arose from the elongation of linolenic acid. On the other hand, the lowest docosahexaenoic acid level found in egg yolk in the group fed sunflower oil is consistent with the lowest linolenic acid level of the sunflower oil added diet. The docosahexaenoic acid in the egg yolk might have resulted from either the direct deposit of docosahexaenoic acid from the diet or *de novo* synthesis of it from its precursor given in the diet (Baucells *et al*., 2000). The egg yolk's lipid profile for saturated fatty acid also reflected the fatty acid profiles of hazelnut oil in this oil added group. In parallel with the fatty acid composition of the oil added to the diets in the eggs of the quail fed olive, hazelnut and fish oil, monounsaturated fatty acid (MUFA) contents were higher while PUFA were lower than in the other groups.

Among the groups fed the plant oils, the lowest total omega-3 fatty acid level was recorded in the egg yolk of the sunflower oil fed group while the highest ($P < 0.001$) level was found in the soyabean oil group, as shown in Table 7. The high level of omega-3 fatty acid in the yolk was in parallel with the omega-3 concentration of soyabean oil. In other studies the omega-3 concentrations of egg yolk of groups fed diets containing fish (Baucells *et al*., 2000; Basmacıoğlu *et al*., 2003; Eseceli & Kahraman, 2004) and soyabean oil (Grobas *et al*., 2001) reflected the omega-3 concentration of these diet. In the present study the omega-3 level in egg yolk in the group receiving the diet containing fish oil was higher whereas the omega-6 level was lower than in the other oil added groups. This finding suggested that the long-chain n-3 PUFAs present in fish oil are effective in lowering total n-6 PUFAs in egg yolk (Watkins, 1991). In the present study, although the higher total PUFA levels were found in soyabean and sunflower oil, PUFA were deposited more efficiently in the yolk of the soyabean oil than in the sunflower oil group. This finding shows that the changes of fatty acids induced by dietary treatment were not uniformly distributed among all lipid classes of egg yolk, in agreement with results reported by Jiang *et al*. (1991). Desaturase activities regulate the tissue concentrations of fatty acids, especially for PUFA. However, dietary lipids can alter the fatty acid composition of yolk in poultry, and the type and amount of dietary unsaturated fatty acid modified the fatty acid composition of lipids in egg yolk (Watkins, 1991). The sunflower, maize, olive and hazelnut oil contained similar fatty acid compositions, consistent with the total MUFA, PUFA and omega-6 composition of the eggs of the quail fed the diets containing these oils ($P > 0.05$). However, the omega-3 fatty acid level of egg yolk from the birds receiving the diets containing the maize and olive oil was higher than in the yolk from the groups fed the diets containing sunflower and hazelnut oil ($P < 0.001$).These differences found in the omega-3 fatty acid levels of egg yolk may have resulted from small differences recorded in the omega-3 fatty acid levels of the above-mentioned oils. This suggested that even slight differences in the omega-3 fatty acid composition between oils should be taken into account in attempts to enrich the omega-3 fatty acid concentration of egg yolk.

Conclusion

The results of the present study demonstrated that different oil sources had varying effects on egg weight, egg quality, and serum lipids of the birds, as well as on the fatty acid composition of egg yolk. This is reflected by the fatty acid composition of the oils added to the diet. Since the olive oil improved eggshell quality, soyabean oil had positive effects on feed efficiency and serum lipid profile, fish and soyabean oils enriched the omega-3 fatty acid level of egg yolk, incorporation of these oils, especially soyabean oil, in the diets of quail may have practical value in the manipulations of egg yolk content.

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