Effect of Dietary Supplementation of Full-Fat Canola Seeds on Productive Performance, Blood Metabolites and Antioxidant Status of Laying Japanese Quails

ABSTRACT

The present study was carried out to evaluate the effects of dietary supplementation of different levels of full-fat canola seeds (FFCS) on productive performance, blood metabolites and antioxidant status of laying Japanese quails. A total of 360, 8-week-old quails were divided into a completely randomize design with 4 dietary experimental groups and three pens each, each pen containing 30 hens. The experimental groups were fed iso-caloric and iso-nitrogenous diets supplemented with FFCS at levels 0, 50, 100 and 150 g/kg diet. The experiment lasted 16 weeks. All supplemented groups showed significant effects in the final body weight (g), hen feed consumption (g/hen/day), egg mass (g egg/hen/day) and hen-day egg production (%). However, egg weight (g) at 8-12 weeks of age reduced significantly. Moreover, feed conversion ratio (g feed/g egg), did not alter among groups. Egg quality criteria were not affected by FFCS supplementation except for the egg shape index which decreased significantly at 10 and 15% FFCS groups. Serum total protein, albumen, uric acid, creatinine, hepatic enzyme activities, triiodothyronine, total cholesterol and HDL-cholesterol concentrations were not altered. However, serum triglycerides and LDL-cholesterol showed significant reduction in all treated groups. Furthermore, serum glutathione peroxidase level was greatly influenced in supplemented groups, while malondialdehyde level reduced significantly. In conclusion, FFCS inclusion in Laying Japanese quail diets up to 15% enhanced the laying performance, blood lipids profile and anti-oxidative status. Thus, it can be regarded as alternative sources of energy and protein in poultry rations.

INTRODUCTION

Nutrition is one of the major factors impacting the expansion of animal and poultry production, basically due to the constant elevation in prices of conventional dietary ingredients (yellow corn and soybean), which leads poultry nutritionists to search for appropriate, cheap and high-quality alternative feedstuffs (Farahat et al., 2013; Abd El-Moneim & Sabic, 2019; Abd El-Moneim et al., 2019). Canola seeds (CS), considered one of the locally and available crops in Egypt, have been tested as a good alternative to partly substitute yellow corn and soybean in poultry diets (Najib & Al-Khateeb, 2004) without causing loss in productive performance. However, its usage is still restricted due to the low available energy and the presence of detrimental components, just as (glucosinolates, erucic acid , phenols, sinapine, phytic acid, tannins and fiber), which influence its nutritional value and reduced the digestibility of proteins and bioavailability of minerals in the intestine (Mailer et al., 2008; Khajali & Slominski, 2012; Jasinski et al., 2018). For these reasons, Egyptian scientists in crop plant breeders, have successfully employed mutagenesis techniques, using gamma...
radiation in CS and could establish a promising mutant line of canola seeds (MCS), which showed significant impact on seed yields, 40-45% oil in seeds and at least 28% protein, 3.5% fat and 0.35% phosphorus than their parents (Amer et al., 2017; Farrag, 2019). The fatty acid composition of MCS showed also a high level of unsaturated fatty acids (61%), low level of saturated fatty acids (7%), oleic acid (51.26%), linoleic acid (17.32%) and linolenic acid (9.38%). In addition, they markedly minimized its anti-nutritional substances, including, glucosinolate and erucic acid to a negligible degree (Anwar et al., 2015; Amer et al., 2017). To our knowledge, no studies were conducted concerning this innovation of MCS and its use as a local dietary alternative ingredient in laying quail diets. Therefore, this study aims to evaluate the effects of incorporating increasing levels of FFCS as an alternative feed supplement on productive performance, blood metabolites and antioxidant status of laying Japanese quails.

MATERIALS AND METHODS

Birds’ ethics and husbandry

The feeding experiment was conducted with 8 week old laying Japanese quail birds which were maintained at the Poultry experimental farm of the biological application department, Nuclear Research Center, Egypt. All procedures were carried out according to the guidelines of the Institutional Animal Care and Use Committee for animal research, which is a member of the Egyptian Network of Research Ethics Committee. The scientific and ethics committee of the Biological Application Department, Nuclear Research Center, Egypt approved all procedures used in this experiment (protocol number 186; date of approval: 14-7-2019).

Chemical analysis and Anti-nutritional compounds of CS

Proximate analysis of moisture, protein, fat, crude fiber, total carbohydrates and ash content were determined according to A.O.A.C (2010). Phytic acid content was determined using chromogenic reagent according to the method described by (Mohamed et al., 1986). The glucosinolate content of the samples was determined according to (Gardrat & Prevot, 1987). In-vitro protein digestibility (IVPD) was estimated according to the method of (Akesonand Stahman, 1984) using the following the equation:

\[
IVPD = \frac{\text{Nitrogen in supernatant}}{\text{Total nitrogen in the samples}} \times 100
\]

The chemical analysis, anti-nutritional compounds and in-vitro protein digestibility of CS were shown in Table 1.

Table 1 – Chemical composition of canola seeds on dry weight basis.

| Items                      | Traditional canola seeds | Mutant canola seeds |
|----------------------------|--------------------------|---------------------|
| Moisture %                 | 5.8                      | 4.82                |
| Crude protein %            | 22.3                     | 23.2                |
| Crude oil %                | 47.58                    | 48.9                |
| Crude fiber %              | 11.0                     | 9.8                 |
| Ash %                      | 2.95                     | 2.83                |
| Total carbohydrates %      | 10.10                    | 10.45               |
| Antinutritional factors    |                          |                     |
| Phytic acid g/kg           | 26.2                     | 12.2                |
| Total glycosinolate μmol/g | 22.7                     | 7.4                 |
| In-vitro protein digestibility g/100 g | 57                      | 62.1                |

Birds and Management

A total of 360, 8-week-old Japanese quail hens with average 242.1±1.54 g, initial body weight per female were divided into a completely randomized design with 4 dietary experimental groups and three pens each, each pen containing 30 hens. The experimental birds equal in body weight were housed in steel wire battery cages of (100 × 60 × 50 cm; length × width × height) in size, in an experimental house under the same management, hygienic and environmental conditions; a 16–hour’s lighting schedule and ambient temperature ranged from 20–25 °C during eight weeks experiment period. Cages were equipped with a stainless-steel nipple drinker.

Experimental diets and Canola seed source

The experimental diets were conducted on mutant line of full fat Canola seed (Brassica napus L.), which had been genetically improved and produced in previous studies conducted by (Amer et al., 2017) in plant breeding techniques process, through exposing the traditional canola seed to gamma radiation applications then growing the irradiated seed for several generations in the experimental fields of the plant research department, Nuclear Research Center, Egypt. The full-fat canola seed was dried and finely grinded using a grinder before supplementations to laying Japanese quail diets. For 16 weeks, the experimental groups as shown in Table 2, fed iso-caloric and iso-nitrogenous diets supplemented with FFCS at different levels of 0, 50, 100 and 150 g/kg diet, respectively. The first group (C0) received a basal diet based on yellow corn–soybean meal with no FFCS and served as control. The other treatments (C5, C10 and C15) were fed the basal diet supplemented with FFCS at different
levels 50, 100 and 150 g/kg diet, respectively. Diets were formulated according to NRC (1994) to cover the nutrient requirements of laying quails. Mash diets and drinking water were available *ad libitum* for each cage during the whole study. The diets composition and the calculated analysis are presented in Table 2.

| Item                     | Canola seeds concentrations |
|--------------------------|----------------------------|
| Ingredients, %           | CS (0%) | CS (5%) | CS (10%) | CS (15%) |
| yellow maize             | 53.88    | 52.67   | 51.72    | 49.24    |
| soybean meal (44%)       | 34.50    | 32.48   | 30.43    | 28.70    |
| dicalcium phosphate      | 1.20     | 0.90    | 0.60     | 0.30     |
| limestone                | 5.70     | 5.85    | 5.95     | 6.10     |
| sodium chloride          | 0.30     | 0.30    | 0.30     | 0.30     |
| vitamin-mineral premix   | 0.30     | 0.30    | 0.30     | 0.30     |
| dl-methionine            | 0.12     | 0.10    | 0.10     | 0.06     |
| soybean oil              | 4.00     | 2.40    | 0.60     | 0.00     |
| full fat canola seeds    | 0.00     | 5.00    | 10.0     | 15.0     |
| Calculated values, %     |          |          |          |
| crude protein            | 20.04    | 20.02   | 20.04    | 20.02    |
| metabolizable energy (ME)MJ/kg | 12.20 | 12.22   | 12.20    | 12.41    |
| crude fibre              | 3.60     | 4.03    | 4.47     | 4.89     |
| lysine                   | 1.14     | 1.18    | 1.21     | 1.25     |
| methionine               | 0.45     | 0.45    | 0.47     | 0.49     |
| methionine + cysteine    | 0.80     | 0.78    | 0.75     | 0.71     |
| calcium                  | 2.51     | 2.52    | 2.51     | 2.52     |
| available phosphorus     | 0.36     | 0.36    | 0.36     | 0.36     |

1 vitamin-mineral premix provided per kg diet: IU: vit. A 12,000, vit. D 5,000; g: vit. E 16.7, vit. K 0.67, vit. B 6, 0.67, vit. B 2, 0.25, vit. B 6, 0.004, nicotinic acid 16.7, pantothenic acid 6.7, biotin 0.07, folic acid 1.67, choline chloride 400, Zn 23.3, Mn 10, Fe 25, Cu 1.67, I 0.25, Se 0.033, Mg 133.4; 2 calculated according to National Research Council (NRC, 1994).

**Productive performance and egg parameters measured**

The individual live body weight of quail hen per replicate was recorded at the beginning and at the end of the experiment however feed consumption (FC) g feed/bird/day was registered per week. Feed conversion ratio (FCR) was estimated as: g feed /g egg. Egg number (EN) and egg weight (EW) were monitored daily to calculate %Hen-day egg production and the egg mass (EM) g/hen/day as: EM = EN x EW.

**Egg quality criteria**

Egg and eggshell quality examinations (eggshell thickness, shell, yolk and albumen weights (%), yolk index, yolk: albumen ratio, egg shape index and Haugh Unite (HU) score) were conducted according to (William, 1992) by using an average of 10 eggs laid between 12:00 and 15:00 from each treatment replicate which were randomly collected at the ends of 8, 12, and 16 weeks of age. To measure external and internal egg quality criteria, after the eggs were weighed and measured in their length and width, egg shape index was calculated as the ratio of egg width to length, the eggs were carefully opened on a glass plate, then both yolk and albumen were separated and weighed, while eggshells were cleaned, dried at room temperature and weighed. Yolk, albumen and shell weights were expressed as a percentage of egg weight. Mean eggshell thickness (with shell membrane) at three areas of the egg (air cell, equator and sharp end) was determined using a 0.01-mm micrometer. Yolk diameter was estimated by a vernier caliper to the nearest 0.05 mm, however yolk height was measured to the nearest 0.01 mm by means of tripod micrometer reading. The yolk index was calculated by dividing the yolk height on yolk diameter. HU score was computed according the following equation:

\[ HU(\%) = 100 \times \log (T + 7.57 - 1.7 \times M^{0.37}) \]

where: T and M refer to albumen height and egg weight g, respectively.

**Blood sampling and biochemical analysis**

At the termination of the experiment, 9 quail hens from each group (3 hens / pen) were randomly selected, slaughtered and blood samples were collected in a tube without anticoagulant for separate serum; then the samples were immediately centrifuged at 4500 rpm for 15 min and the obtained sera was frozen at -20 °C until further analysis. Serum total protein, albumin, total cholesterol (TC), triglycerides (TG), low-
density lipoprotein (LDL) and high-density lipoprotein (HDL) cholesterol, uric acid, creatinine concentrations, alkaline phosphatase (ALP) aspartate aminotransferase (AST), alanine aminotransferase (ALT) activities were analyzed using spectrophotometer (Spectronic 1201, Milton Roy, Ivyland, PA, USA) using commercial kits (Spinreact Co., Girona, Spain). Glutathione (GSH) and malondialdehyde (MDA) contents, and glutathione peroxidase (GPx) activity in the serum were analyzed using commercial kits (Cell Bio-labs Inc., San Diego, CA, USA). Serum concentration of triiodothyronine (T3) was measured in all blood samples using radioimmunoassay (RIA) kits.

**Statistical analysis**

The experimental results were analyzed with the general linear model and analysis of variance procedure using the statistical software SPSS (ver. 18.0; IBM Corp., Armonk, NY, USA). Tukey’s procedure for multiple comparison tests was used to identify the statistical significant effects at a significance level of $p<0.05$. Linear and quadratic effects of dietary FFCS supplement level were studied using polynomial contrasts.

**RESULTS AND DISCUSSIONS**

**Laying quail performance**

Laying performance of laying quails as influenced by increasing dietary supplementation of FFCS is presented in Table 3. The obtained results show that, at the end of the experimental period (8wks) the final body weight (g), hen feed consumption (g/hen/day), overall egg mass (g egg/hen/day) and hen-day egg production (%) of supplemented groups recorded significant effects in groups supplemented with increasing FFCS up to 15 % in the diet compared to the control group. On the other hand, increasing the inclusion levels of FFCS from 10 to 15% in laying quail diets reduced significantly egg weight (g) at 8-12 weeks of age, except, at 12-16 weeks of age in the group supplemented with 15% FFCS. Moreover, feed conversion ratio, g feed/g egg was not significantly altered among groups.

The enhancing effects of FFCS on aforementioned laying performance may be due to the genetic improvement in traditional CS, which was developed by scientists in crop plant breeders (Amer et al.,

| Indices | Dietary treatments$^1$ | SEM$^2$ | $p$-value |
|---------|----------------------|---------|-----------|
|         | CS (0%) | CS (5%) | CS (10%) | CS (15%) | Linear | Quadratic |
| Body weight, g | | | | |
| initial | 243.28 | 240.85 | 242.75 | 242.15 | 1.541 | 0.981 | 0.697 |
| final | 266.26$^a$ | 286.96$^a$ | 285.24$^a$ | 296.25$^a$ | 3.517 | 0.002 | 0.457 |
| Feed consumption, g/bird/day | | | | |
| weeks 8-12 | 21.49$^a$ | 24.94$^a$ | 26.27$^a$ | 25.13$^a$ | 0.630 | 0.007 | 0.017 |
| weeks 12-16 | 24.85$^a$ | 27.35$^a$ | 28.81$^a$ | 30.17$^a$ | 0.637 | <0.001 | 0.324 |
| overall | 23.17$^a$ | 26.14$^a$ | 27.54$^a$ | 27.64$^a$ | 0.582 | <0.001 | 0.017 |
| Feed conversion ratio, g feed/g egg | | | | |
| weeks 8-12 | 2.45 | 2.61 | 2.78 | 2.56 | 0.079 | 0.499 | 0.267 |
| weeks 12-16 | 2.60 | 2.56 | 2.48 | 2.43 | 0.036 | 0.076 | 0.960 |
| overall | 2.53 | 2.59 | 2.61 | 2.49 | 0.045 | 0.869 | 0.400 |
| Egg weight, g | | | | |
| weeks 8-12 | 13.16$^a$ | 12.91$^a$ | 12.83$^a$ | 12.55$^a$ | 0.075 | 0.001 | 0.863 |
| weeks 12-16 | 13.33$^a$ | 13.13$^a$ | 12.98$^a$ | 13.45$^a$ | 0.061 | 0.514 | 0.001 |
| overall | 13.25$^a$ | 13.02$^a$ | 12.91$^a$ | 13.00$^a$ | 0.042 | 0.002 | 0.006 |
| Hen-day egg production, % | | | | |
| weeks 8-12 | 66.52$^a$ | 73.81$^a$ | 73.62$^a$ | 77.86$^a$ | 1.121 | <0.001 | 0.378 |
| weeks 12-16 | 71.43$^a$ | 80.95$^a$ | 89.00$^a$ | 92.06$^a$ | 1.640 | <0.001 | 0.013 |
| overall | 68.98$^a$ | 77.38$^a$ | 81.31$^a$ | 84.96$^a$ | 1.282 | <0.001 | 0.065 |
| Egg mass, g egg/hen/day | | | | |
| weeks 8-12 | 8.83 | 9.56 | 9.54 | 9.83 | 0.204 | 0.135 | 0.592 |
| weeks 12-16 | 9.56$^a$ | 10.70$^a$ | 11.65$^a$ | 12.46$^a$ | 0.350 | <0.001 | 0.581 |
| overall | 9.19$^a$ | 10.13$^a$ | 10.59$^a$ | 11.11$^a$ | 0.248 | 0.002 | 0.509 |

$^1$ treatment groups: CS0 – corn-based diet, CS5 – 50 g canola seed/kg, CS10 – 100 g canola seed/kg, CS15 – 150 g canola seed/kg; $^2$SEM – standard error of means; $^a–c$ – means with different superscripts are significantly different.
2017; Farrag, 2019). This enhanced seed as shown in Table 1 of this study are characterized with low concentration of total glucosinolate 7.4 µmol/g seed, Phytic acid 12.2 g /kg seed and high level of in-vitro protein digestibility 62.1 g/100 g in comparison with the traditional CS. Although, Niemann et al. (2018) documented no deleterious effects in performance of broilers fed diet with 15.8 µmol glucosinolate /g diet. As a result, this improvement in FFCS characterizations, allowed for high level incorporation of canola seeds up to 15% into laying quail diets without causing any negative effects on the laying performance. Furthermore, a possible explanation for improving laying quail performance in the present study may be the high nutritive value of FFCS with high quality and content of oil percent,48.9% in CS, high level of essential minerals and a better quality of proteins 23.2% in terms of balanced essential amino acid composition and digestibility 62.1 g /100g. Besides, CS contain high percentage of unsaturated fatty acids 93.44%, mainly 61.69% oleic acid, 22.12% linoleic and 6.32% linolenic acid (Farrag, 2019), these essential fatty acids of canola oil are involved in its utilization mode, taste and suitable odor, lead to increasing hen feed consumption (g/ hen/day), which in turn correlate with the significant increase in hen-day egg production (%), egg mass (g egg/hen/day) and improving the final body weight of supplemented groups. Moreover, feeding birds on diets containing unsaturated fatty acids has improved their lipid metabolism and productive performance (Keum et al., 2018). In accordance with obtaining results, (Przybylski et al., 2013; Sharafi et al., 2015) reported 7% saturated acids, including palmitic and stearic acid, and high levels of unsaturated fatty acids 93%, including 61% oleic acid, 11% linolenic acid, and 21% linoleic acid in CS, this unique composition may provide the laying quail with essential fatty acids, energy and bioactive materials during the bird’s life production resulted in a positive impact on egg production and egg weight (Sharafi et al., 2015; Ibrahim et al., 2018). The results are in line with the findings of Zanini et al. (2006) who reported a significant increase in body weight gain in broilers fed a diet containing canola seed oil. Najib & Al-Khateeb (2004) also reported no negative impact in productive performance and egg quality traits in laying fed canola meal up to 10% in the diet. In addition, Naseem et al., 2006 showed better body weight gain and feed utilization efficiency in chickens fed diet containing 25% canola meal.

### Egg quality

The data of egg quality evaluated in response to the dietary supplementation of FFCS are presented in Table 4. There were no significant effects in (albumen, yolk and shell) percentages, yolk index, yolk: albumen ratio, Shell thickness, mm and haugh unit score among treatments, except for egg shape index which decreased significantly at10 and 15% FFCS.

The non-significant changes in aforementioned egg quality characters in all supplemented groups agree with previous findings (Kucukersan et al., 2010; Agah et al., 2010; Ismail et al., 2013), which showed insignificant difference of egg quality traits in laying hens fed diet supplemented with canola oil over 10%. A similar study by Najib & Al-Khateeb (2004) reported no negative impact in egg quality criteria in laying fed canola meal up to 10% in the diet. Moreover, the significant decrease in egg shape index by raising the inclusion levels of FFCS in laying quail diets may be attributed to the significant elevation in hen-day egg production (%) and egg weight of supplemented groups with FFCS. This finding agrees with Iqbal et al. (2017) who reported a correlation between egg weight and the egg shape index.

The data of egg quality evaluated in response to the dietary supplementation of FFCS are presented in Table 4. There were no significant effects in (albumen, yolk and shell) percentages, yolk index, yolk: albumen ratio, Shell thickness, mm and haugh unit score among treatments, except for egg shape index which decreased significantly at 10 and 15% FFCS.

### Table 4 – Effect of dietary supplementation of canola seeds on egg quality of laying Japanese quails at the end of the experimental period.

| Indices          | Dietary treatments1 | SEM2 | p-value |
|------------------|---------------------|------|---------|
|                  | CS (0%)             | CS (5%) | CS (10%) | CS (15%) | Linear Quadratic |
| Albumen, %       | 55.39               | 54.73  | 55.74   | 54.27   | 0.349 | 0.459 | 0.572 |
| Yolk, %          | 30.02               | 30.50  | 30.52   | 30.98   | 0.257 | 0.225 | 0.986 |
| Shell, %         | 14.59               | 14.78  | 13.74   | 14.75   | 0.258 | 0.818 | 0.435 |
| Egg shape index  | 81.283              | 79.303 | 77.863  | 76.593  | 0.584 | 0.003 | 0.743 |
| Yolk index       | 40.12               | 39.39  | 39.49   | 40.78   | 0.439 | 0.612 | 0.270 |
| Shell thickness, mm | 0.335             | 0.321  | 0.348   | 0.346   | 0.007 | 0.337 | 0.711 |
| Yolk: albumen ratio | 0.543             | 0.561  | 0.549   | 0.572   | 0.008 | 0.294 | 0.880 |
| Haugh unit score | 85.53               | 86.03  | 85.53   | 85.98   | 0.269 | 0.738 | 0.959 |

1treatment groups: CS0 – corn-based diet, CS5 – 50 g canola seed/kg, CS10 – 100 g canola seed /kg, CS15 – 150 g canola seed/kg; SEM – standard error of means; a–b– means with different superscripts are significantly different.
**Serum biochemical components**

Mean values for serum biochemical components in layers fed diets with 0, 5, 10 and 15% FFCS are presented in Table 5. The results showed insignificant (P>0.05) difference in terms of serum protein fractions (total protein and albumen), renal function biomarkers (uric acid and creatinine), lipid profile (total cholesterol, LDL-cholesterol and HDL-cholesterol) values and liver enzymes activity (ALP, ALT and AST). On the other hand, serum triglycerides showed significant decrease in supplemented groups with FFCS up to 15% in laying diets compared to the control.

The results showed insignificant differences in serum levels of protein fractions, liver enzymes activity, renal function biomarkers in response to the increasing levels of FFCS in laying quail diets. Similar results were reported in other studies conducted by (Szymeczko et al., 2011; Ahmed et al., 2015), in broilers fed rape seeds. Additionally, the insignificant effect in serum ALP activity as influenced by FFCS supplementation compared to the control may be reflex to physiological stressful condition introduced in supplemented groups. In general, the results of serum biochemical components in this study indicated that, the supplemented FFCS up to 15% in laying diets did not precipitate any significant harmful effect on the health status of the laying quails, also, this is a good indication that dietary CS was well utilized by quails.

The present study did not show significant differences among experimental groups in serum total cholesterol, LDL-cholesterol and HDL-cholesterol levels, while, there was a linear and quadratic lower level of serum triglycerides compared to the control. This finding indicating feeding diets containing canola oil may have a potential role in regulating blood lipid profiles; this effect might be attributed to the high content of unsaturated fat content in canola oil. As mentioned previously, canola oil is characterized by low level, 7% of saturated fatty acids, high levels of unsaturated fatty acids, including 61% oleic acid, 21% linoleic acid, and 11% alpha-linolenic acid and tocopherols 700 – 1,200 ppm (Lin et al., 2013). In line with previous studies by Gillingham et al. (2012), significant reductions in triglycerides levels were observed after canola oil-based diets were consumed compared with a baseline high saturated fatty acids diet. In addition, Lin et al. (2013) reported the ability of canola oil to suppress TC and LDL-C levels compared with saturated fatty acids.

**Thyroid activity and antioxidant status**

Serum triiodothyronine (T₃) concentrations of laying quails fed diets with varying FFCS levels are illustrated in (Fig. 1, A). The results revealed insignificant effect in all treatments, except in 5% FFCS group which showed a numerical elevation in serum triiodothyronine concentrations compared with other treatments. Furthermore, antioxidant status of laying quails treated with FFCS was greatly affected. Serum glutathione peroxidase activity in the present findings (Fig. 1, D)
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significantly increased by increasing the inclusion levels of FFCS in birds’ diets, in addition, there was numerical increase in serum glutathione content (Fig. 1, C) by increasing the inclusion levels of FFCS. While, serum malondialdehyde contents of birds in these groups as shown in (Fig. 1, B) significantly reduced compared to the control values.

Inclusion of FFCS at a level of 5, 10 and 15% in laying quail diets did not significantly affect serum level of T₄. In agreement with our findings Ramesh et al. (2006) showed that plasma concentrations of T₄ were not affected by the addition of rapeseed meal. Taraz et al. (2006) also observed insignificant changes in serum T₄ level of broilers fed rapeseed meal. In contrast, Ahmed et al. (2015) demonstrated that 10 and 20% canola meal included in broiler diets decreased serum concentration of T₄. It was suggested that rapeseed meal contains anti-thyroid compounds that could alter the de-iodination process of the outer ring of T₄ (Darras et al., 2000) and destroy nuclear receptors of thyroid hormones in the peripheral tissues (Schöne et al., 1993). However, genetically enhanced CS seems to be lower in these compounds, thus no alterations in serum T3 levels were observed in the present study. Moreover, the unchanged levels of T₃ may be attributed to the physiological equilibrium in the thyroid gland of quails after 42 days of age (Ahmed et al., 2015).

The significant enhancement in serum anti-oxidative status of laying quail treated with FFCS may be attributed to the major role of unsaturated fatty acids and phytochemical constituents present in FFCS as a natural source of antioxidants (Sameh et al., 2018), and its responsibility for health promoting action (Vallejo et al., 2003). Furthermore, the high antioxidant capacity of canola oil seeds and its high content of vitamin E (tocopherols) and phenolic compounds with levels ranging from 82 to 122 mg/g dry matter (Riaz et al., 2012; Farag et al., 2013; Jun et al., 2014; Chandrasekara et al., 2016; Rozan et al., 2018). In this context, Flakelar et al. (2015) and Sameh et al. (2018) showed a high total phenols, total flavonoids and α-tocopherol contents with superior antioxidant activity for canola meal. Lastly, this finding reflects the advantages of CS as a good source of unsaturated fatty acids, Phenolics, flavonoids and α-tocopherols which all play an important role in the antioxidant activity.

CONCLUSION

The current study suggests that using plant breeding technologies either to produce new plant varieties or to improve the characteristics of existing varieties, including amendment of their nutritional value and reducing anti-nutritional compounds, can contribute significantly to finding potential promising alternatives to conventional feedstuffs. Replacing soybean meal and yellow maize by mutant full-fat canola seeds at levels up to 15% in laying quail diets improved laying performance indices along with the associated changes in blood biochemistry, lipids profile and antioxidative status without altering hepatic and renal function biomarkers. Thus, mutant full-fat canola seeds can be regarded as a suitable dietary alternative ingredient in laying quail diets.

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COMPLIANCE WITH ETHICAL STANDARDS

The study was approved by the Ethics Committee of Local Experimental Animals Care Committee, Egyptian Nuclear Research Center.
CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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