Impact of dietary cold-pressed chia oil on growth, blood chemistry, haematology, immunity and antioxidant status of growing Japanese quail

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\textbf{ABSTRACT}

Chia (\textit{Salvia hispanica} L.) is a member of Labiate family and its seeds are rich in phenolic compounds and polyunsaturated fatty acids (PUFAs) which could enhance the performance and productivity of birds. This study was carried out to determine the effects of supplementation with cold-pressed chia oil at different concentrations on the growth performance, carcass traits, haematology, blood chemistry, immunity and antioxidant status of growing quails. A total of 240 growing quails (1 week-old) were divided equally into five groups (4 replicates with 12 birds each). The experimental groups were G\textsubscript{1} (basal diet), G\textsubscript{2} (basal diet + 0.4 g chia oil/kg diet), G\textsubscript{3} (basal diet + 0.8 g chia oil/kg diet), G\textsubscript{4} (basal diet + 1.2 g chia oil/kg diet) and G\textsubscript{5} (basal diet + 1.6 g chia oil/kg diet). Birds in the G\textsubscript{2} group exhibited the highest body weight at 3 and 5 weeks of age, and the highest body weight gain at 1–3 weeks (6.24 g) and 1–5 weeks (6.17 g). Birds fed diets enriched with 0.4% chia oil exhibited the best FCR values. Dietary supplementation with chia oil increased the red blood cells (RBCs), white blood cells (WBCs), haemoglobin (HGB) and haematocrit (HCT) when compared to the control group (G\textsubscript{1}). The antioxidant and immunity parameters were not affected by the supplementation of diet with chia oil. This study showed that quail diet supplementation with 0.4 g chia oil/kg diet improved the growth performance, certain blood parameters and lipid profile.

\textbf{HIGHLIGHTS}

- Phytobiotics recently achieved an attention in poultry feed.
- Cold-pressed chia oil dietary supplementation for quail diet.
- G\textsubscript{2} possessed the heaviest bodyweight and consumed the lowest feed with the best feed conversion ratio.
- Quail diet supplementing with 0.4 chia oil/kg diet, improved the growth performance, some blood parameters, lipids profile and immunity.

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\textbf{Introduction}

Quail is a suitable bird for intensive food production, therefore, an attempt was made to enhance its production, and consequently guarantee adequate nutrition for the fast-growing human population. Consumption of two quails per day is akin to eating 125–130 g pure meat, which provides a total of 27–28 g protein, containing 11 g essential amino acids, equivalent to 40% of the human protein demand (Nedkov 2004). Currently, due to the global ban of antibiotic as growth promoters by the European Union, continuous attempts are conducted focusing on natural feed additives particularly herbal plants and their extracts as antibiotic replacers in animal and poultry feed owing to their content of natural bioactive compounds that can influence animal growth and health (Alagawany et al. 2019; Mohamed et al. 2019; Abd El-Hack et al. 2016, 2020; Reda, El-Kholy, et al. 2020; Reda, El-Saadony et al. 2020; Reda, Alagawany, et al. 2020). Chia seeds (\textit{Salvia hispanica} L.)
belong to the Lamiaceae family, and are believed to be a high-quality source of plant oils, which can be used as alternatives to other plant oils (Ayerza and Coates 2011). This may be attributed to their high omega-3 fatty acid contents. The oil content of these seeds is about 40% of their weight. Chia oil contains 60–70% omega-3 fatty acids, in particular α-linolenic acid (ALA or LNA), and 20% omega-6 fatty acids, particularly linoleic acid (Alagawany et al. 2019; Kulczy-ski et al. 2019; Mendonça et al. 2020). In addition, they contain several functional components, including myricetin, quercetin, kaempferol and caffeic acid, which are multifaceted phenolic acids and flavonols. These components have anticancer, antibacterial, anti-inflammatory and antioxidant effects (Uribe et al. 2011). Chia seeds are mainly composed of 15–25% protein, 30–33% fat, 41% carbohydrate, 18–30% dietary fibre, 4–5% ash and 90–93% dry matter, with a wide range of polyphenols (Ixtaina et al. 2008; Kulczy-ski et al. 2019).

The consumption of herbal plants or cold-pressed oils can enhance human and animal health and inhibit several diseases (Dhama et al. 2018; Mahgoub et al. 2019). The beneficial health aspects of chia seeds and oils on have been investigated in humans and animal, however, to our knowledge; studies on the supplementation of quail diets with chia oil are scarce. Therefore, this study was undertaken to investigate the effects of cold-pressed chia oil supplementation on the growth performance, carcass traits, haematology and blood chemistry and antioxidant and immunity status of growing quails.

Material and methods

Animals, experimental design, and diets

A total of 240 growing Japanese quails (1 week old), with an average weight of 30.07 ± 0.65 g, were randomly distributed into 5 experimental groups, each with 4 replicates and 12 birds/replicate. This 5-week study was conducted at the Poultry Research Farm, Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, Egypt. The experimental groups were: (1) G1 (basal diet), (2) G2 (basal diet + 0.4 g chia oil/kg diet), (3) G3 (basal diet + 0.8 g chia oil/kg diet), (4) G4 (basal diet + 1.2 g chia oil/kg diet) and (5) G5 (basal diet + 1.6 g chia oil/kg diet). The chia oil was obtained from the Elhawag Company for Natural OILS, Cairo, Egypt. The basal diet (Table 1) was formulated to meet the birds’ requirements. Feed and water were provided ad libitum.

| Table 1. Ingredients and nutrient contents of basal diet (as-fed basis) for growing Japanese quail. |
| Items (g/kg) |   |
| Maize 8.5% | 518.0 |
| Soybean meal 44% | 367.0 |
| Maize gluten meal 62% | 52.1 |
| Soybean oil | 29.0 |
| Limestone | 7.0 |
| Di-calcium phosphate | 16.5 |
| Salt | 3.0 |
| Premix* | 3.0 |
| L-Lysine | 1.3 |
| Di-Methionine | 1.1 |
| Choline chloride | 2.0 |
| Total | 1000 |

*Provides per kg of diet: Vitamin A, 12,000 U.; Vitamin D3, 5000 U.; Vitamin E, 130.0 mg; Vitamin K3, 3.605 mg; Vitamin B1 (thiamin), 3.0 mg; Vitamin B2 (riboflavin), 8.0 mg; Vitamin B6, 4.950 mg; Vitamin B12, 17.0 mg; Niacin, 60.0 mg; D-Biotin, 200.0 mg; Calcium D-pantothenate, 18.333 mg; Folic acid, 2.083 mg; manganese, 100.0 mg; iron, 80.0 mg; zinc, 80.0 mg; copper, 8.0 mg; iodine, 2.0 mg; cobalt, 500.0 mg; and selenium, 150.0 mg.

Growth performance

Birds were weighed weekly to obtain the live body weight. Body gain for a given time interval was calculated by subtracting the average initial body weight of the birds from the final body weight during the same interval. The residual feed in the troughs was carefully collected and weighed. Feed consumption was calculated by subtracting the weekly residual feed from the offered feed. FCR was calculated weekly as the ratio of feed consumption (g) to body weight gain (g) (Reda, Alagawany, et al. 2020).

Carcass measurements

At the end of the experiment, five quails from each treatment group were selected, weighed and then slaughtered. The edible organs (carcass, gizzard, heart and liver) and intestine were removed and weighed. The carcass yield, or dressing percentage, was recorded. The whole organ weights were recorded in proportion to the pre-slaughter weight (Reda, Alagawany, et al. 2020).

Blood sampling and laboratory analyses

Blood samples from the slaughtered birds were collected into heparinised tubes, which were then closed with rubber stoppers. Haematological parameters (white blood cells [WBCs], lymphocytes [LYM], mid-
range (MID), granulocytes (GRA), red blood cells (RBCs), haemoglobin (HGB), haematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular HGB (MCH) and platelet count (PLT)) were determined according to Schalm (1961). For assessing biochemical parameters, blood samples were centrifuged (G force = 2146.56 × g) for 15 min. Plasma total protein (g/dL), globulin (g/dL), albumin (g/dL), aspartate transaminase (AST; IU/L), alanine transaminase (ALT; IU/L), creatinine (mg/dL), urea (mg/dL), total cholesterol (TC; mg/dL), triglyceride (TG; mg/dL), high-density lipoprotein (HDL) cholesterol (mg/dL) and low-density lipoprotein (LDL) cholesterol (mg/dL) levels were determined spectrophotometrically using commercial kits (Biodiagnostic Company, Giza, Egypt). The activities of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) and levels of malondialdehyde (MDA) and reduced glutathione (GSH) were determined spectrophotometrically using commercial kits (Biodiagnostic Company, Giza, Egypt). The activities of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) and levels of malondialdehyde (MDA) and reduced glutathione (GSH) were determined in the plasma, using commercial kits and a spectrophotometer (Shimadzu, Japan). The immunoglobulin G (IgG; mg/dL) levels were measured using the ELISA Kit from MyBiosource.com (Catalogue number; MB5701356).

**Statistical analysis**

Data were analysed statistically using SAS. The growth rate, feed intake and conversion, carcass traits and haematological and biochemical (liver and kidney function, lipid profile, immunity and antioxidant indices) blood parameters were assessed by one-way ANOVA (with diet as the fixed factor) using the post-hoc Tukey’s test. The significance level was established at p < .05.

**Results**

Based on our results outlined in Table 2, it can be concluded that supplementation of quail diets with chia oil significantly improved the growth performance parameters. In comparison to the control group, supplementation with cold-pressed chia oil at levels of 0.4 and 0.8 g/kg diet resulted in higher (p < .0001) body weight at 3 weeks of age. However, at 5 weeks of age, all diets supplemented with chia oil, except G3, improved quail body weight (p > 0.0005). Birds in the G2 group exhibited the highest body weight at 3 and 5 weeks of age. The body weight of birds in this group was 12.96, 9.17, 11.54 and 13.81% higher at 3 weeks and 8.26, 5.97, 1.53 and 1.75% higher at 5 weeks, when compared to the weight of birds in G1, G3, G4 and G5 groups, respectively. Moreover, these birds presented the highest body weight gain at 1 – 3 weeks (6.24 g) and 1 – 5 weeks (6.17 g) when compared to the birds in the other groups (Table 2). In comparison to the control, chia oil supplementation (G4 and G5) improved body weight gain at 3 – 5 and 1 – 5 weeks of age. Individuals in the G2 group not only exhibited the least feed consumption when compared to G1, G3, G4 and G5 at 1 – 3 weeks (6.24 g) and 1 – 5 weeks (6.17 g) when compared to the other groups, respectively, at 1 – 3 weeks of age, and by 26.56, 14.76, 5.53 and 9.59%, respectively, at 1 – 5 weeks, respectively (Table 2). However, no significant effects of chia oil could be observed on the carcass characteristics, including the dressing percentage and carcass, gizzard, liver, heart, intestine and giblet weights (p > 0.05; Table 3).

Dietary supplementation with chia oil resulted in higher RBCs, WBCs, HGB and HCT, when compared to the control group (G1), while LYM, MID, GRA, MCV, and G5 groups, respectively. Moreover, these birds presented the highest body weight gain at 1 – 3 weeks (6.24 g) and 1 – 5 weeks (6.17 g) when compared to the birds in the other groups (Table 2). In comparison to the control, chia oil supplementation (G4 and G5) improved body weight gain at 3 – 5 and 1 – 5 weeks of age. Individuals in the G2 group not only exhibited the least feed consumption when compared to G1, G3, G4 and G5 at 1 – 3 weeks (6.24 g) and 1 – 5 weeks (6.17 g) when compared to the other groups, respectively, at 1 – 3 weeks of age, and by 26.56, 14.76, 5.53 and 9.59%, respectively, at 1 – 5 weeks, respectively (Table 2). However, no significant effects of chia oil could be observed on the carcass characteristics, including the dressing percentage and carcass, gizzard, liver, heart, intestine and giblet weights (p > 0.05; Table 3).

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| Chia oil level (g/kg diet) | Item | 0 | 0.4 | 0.8 | 1.2 | 1.6 | SEM | p Value |
|---------------------------|------|---|-----|-----|-----|-----|-----|-------|
| Body weight (g)           |      |   |     |     |     |     |      |       |
| 1 week                    |      | 30.11 | 30.11 | 30.09 | 30.04 | 30.04 | 0.15 < .001 |
| 3 weeks                   | 102.22 | 117.44 | 106.66 | 103.89 | 101.22 | 0.70 < .001 |
| 5 weeks                   | 186.13 | 202.89 | 190.78 | 199.78 | 199.33 | 1.05 < .001 |
| Body weight gain (g)      |      | 5.15 | 6.24 | 5.47 | 5.27 | 5.08 | 0.09 < .001 |
| 1–3 weeks                 |      | 5.99 | 6.10 | 6.01 | 6.85 | 7.01 | 0.15 < .004 |
| 3–5 weeks                 | 5.57 | 6.17 | 5.74 | 6.06 | 6.05 | 0.01 < .001 |
| Feed intake (g)           |      | 15.34 | 12.33 | 13.75 | 12.40 | 13.62 | 0.12 < .001 |
| 1–3 weeks                 |      | 22.83 | 21.09 | 21.96 | 22.28 | 22.28 | 0.42 < .390 |
| 3–5 weeks                 | 19.09 | 16.71 | 17.85 | 17.34 | 17.95 | 0.22 < .005 |
| Feed conversion ratio (g feed/ g gain) | 1–3 weeks | 2.98 | 1.98 | 2.51 | 2.35 | 2.68 | 0.07 < .001 |
|                          |      | 3.81 | 3.46 | 3.67 | 3.25 | 3.18 | 0.10 < .011 |
|                          | 1–5 weeks | 3.43 | 2.71 | 3.11 | 2.86 | 2.97 | 0.05 < .001 |

Means in the same row with no superscript letters after them or with a common superscript letter are not significantly different (p < .05).

**Table 3. Effect of dietary supplementation on carcase traits and relative organ weights of growing Japanese quail.**

| Chia oil level (g/kg diet) | Item | 0 | 0.4 | 0.8 | 1.2 | 1.6 | SEM | p Value |
|---------------------------|------|---|-----|-----|-----|-----|-----|-------|
| Carcase %                  |      | 73.87 | 72.26 | 76.63 | 67.62 | 76.59 | 2.01 < .071 |
| Dressing %                 |      | 79.35 | 77.93 | 82.03 | 73.77 | 82.12 | 1.88 < .050 |
| Liver %                    |      | 2.67 | 3.00 | 2.72 | 3.53 | 2.54 | 0.55 < .547 |
| Gizzard %                  |      | 2.03 | 1.79 | 1.81 | 1.78 | 2.08 | 0.17 < .819 |
| Heart %                    |      | 0.78 | 0.87 | 0.87 | 0.84 | 0.91 | 0.09 < .263 |
| Intestine %                |      | 3.91 | 3.96 | 4.75 | 5.31 | 4.53 | 0.22 < .787 |
| Giblets %                  |      | 5.48 | 5.67 | 5.40 | 6.15 | 5.53 | 0.24 < .787 |

Means in the same row with no superscript letters after them or with a common superscript letter are not significantly different (p < .05).
Table 4. Effect of dietary supplementation on haematological parameters of growing Japanese quail.

| Chia oil level (g/kg diet) | Item | 0 | 0.4 | 0.8 | 1.2 | 1.6 | SEM | p Value |
|---------------------------|------|----|-----|-----|-----|-----|-----|--------|
| WBCs ($10^3$/µL) | 19.30a | 20.89a | 20.68b | 27.34b | 31.51a | 1.25 | <.001 |
| LYM (%) | 92.52 | 90.72 | 93.11 | 92.75 | 92.90 | 1.60 | .771 |
| MID (%) | 6.88 | 8.44 | 6.28 | 6.96 | 7.27 | 0.55 | .275 |
| GRA (%) | 0.61 | 0.84 | 0.57 | 0.67 | 0.73 | 0.11 | .571 |
| RBCs ($10^6$/µL) | 1.15a | 2.02a | 1.96a | 2.35a | 1.85a | 0.15 | .007 |
| HGB (g/dL) | 10.97b | 14.93a | 14.70a | 15.80a | 13.50b | 0.70 | .017 |
| HCT (%) | 11.10c | 18.40ab | 16.20b | 21.50a | 18.17ab | 1.30 | .005 |
| MCV (µm³) | 96.53 | 91.63 | 93.30 | 96.43 | 97.83 | 1.25 | .123 |
| MCH (pg) | 99.20 | 99.17 | 105.17 | 81.37 | 74.47 | 5.50 | .839 |
| MCHV (pg) | 38.00 | 37.00 | 42.00 | 30.00 | 25.00 | 2.50 | .571 |
| PLA (%) | 0.61 | 0.84 | 0.57 | 0.67 | 0.73 | 0.11 | .571 |
| CR (% m) | 38.00 | 37.00 | 38.00 | 38.00 | 38.00 | 1.25 | .123 |
| PLT ($10^3$/µL) | 70.33 | 33.33 | 30.33 | 32.33 | 115.00 | 12.01 | .499 |

Means in the same row with no superscript letters after them or with a common superscript letter are not significantly different (p < .05). WBCs: white blood cells; LYM: lymphocytes; MID: monocytes; RBCs: red blood cells; HGB: haemoglobin; HCT: haematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular haemoglobin; PLA: platelet count.

Table 5. Effect of dietary supplementation on liver and kidney functions of growing Japanese quail.

| Chia oil level (g/kg diet) | Item | 0 | 0.4 | 0.8 | 1.2 | 1.6 | SEM | p Value |
|---------------------------|------|----|-----|-----|-----|-----|-----|--------|
| TP (g/dL) | 2.49 | 2.85 | 2.50 | 2.45 | 2.82 | 0.18 | .582 |
| ALB (g/dL) | 1.20a | 1.08b | 1.13a | 1.22a | 1.20a | 0.04 | .052 |
| GLOB (g/dL) | 1.29 | 1.72 | 1.37 | 1.23 | 1.62 | 0.15 | .464 |
| A/G (%) | 0.93 | 0.63 | 0.80 | 0.75 | 0.75 | 0.16 | .471 |
| AST (IU/L) | 278 | 246 | 226 | 232 | 264 | 16.50 | .468 |
| ALT (IU/L) | 10.23a | 14.27a | 14.77a | 14.65a | 12.90a | 0.51 | .010 |
| Creatinine (mg/dL) | 0.28 | 0.37 | 0.32 | 0.41 | 0.32 | 0.04 | .272 |
| Urea (mg/dL) | 1.26a | 1.15a | 1.39b | 1.94b | 1.36bc | 0.09 | <.001 |

Means in the same row with no superscript letters after them or with a common superscript letter are not significantly different (p < .05). TP: total protein; ALB: albumin; GLOB: globulin; A/G: albumin/globulin ratio; AST: aspartate aminotransferase; ALT: alanine aminotransferase.

Table 6. Effect of dietary supplementation on the lipid profile of growing Japanese quail.

| Chia oil level (g/kg diet) | Item | 0 | 0.4 | 0.8 | 1.2 | 1.6 | SEM | p Value |
|---------------------------|------|----|-----|-----|-----|-----|-----|--------|
| TC (mg/dL) | 283.9a | 269.6a | 239.8ab | 189.2b | 243.1ab | 15.02 | .044 |
| TG (mg/dL) | 122.34ab | 119.30bc | 98.74a | 145.01ab | 157.83a | 4.01 | .001 |
| HDL (mg/dL) | 35.60 | 30.23 | 34.24 | 60.41 | 34.55 | 5.06 | .066 |
| LDL (mg/dL) | 226.03 | 138.27 | 166.47 | 148.50 | 131.41 | 20.20 | .012 |

Means in the same row with no superscript letters after them or with a common superscript letter are not significantly different (p < .05). TC: total cholesterol; TG: triglycerides; HDL: high-density lipoprotein; LDL: low-density lipoprotein.

MCH and PLT did not exhibit any significant differences (Table 4).

TP, GLOB, A/G, AST and creatinine did not show any significant differences between the experimental groups, while ALT was higher (p < .0109) in groups fed diet supplemented with chia oil at different concentrations, when compared to the control group (G1). Urea level was lower in G2 than in G3 and G4 (38.26 and 68.69%, respectively) (p < .0004; Table 5). TC was reduced by supplementation with chia oil, with LDL being the lowest in G2 and G3 (Table 6). The antioxidant and immunity parameters were not influenced by dietary supplementation with chia oil at any of the tested concentrations (p > .05; Table 7).

Discussion

The FCR is the imperative economic aspect which describes the effectiveness of feed consumption and its conversion into production unit. It combines two chief traits, i.e. weight gain and feed consumption. The results on body weight obtained in this study were comparable to those reported by Nasr et al. (2017), who stated that quail body weight at 6 weeks of age ranges from 175 to 205 g. Moreover, the FCR of the group fed the normal basal diet was within the normal reported range of 2.87–3.93 g feed/g gain (Rasul et al. 2019; Nasr et al. 2019). Chia oil supplementation not only improved the FCR, confirming the results of Rasul et al. (2019), who reported that chia seed supplementation improved the FCR by 4.74%, but also reduced the feed consumption, which was comparable to the findings of Abbasi and Samadi (2014) and Mendonça et al. (2020) who observed a reduction in feed intake (4% and 9.31) on chia supplementation, respectively. The feed intake in this study was similar to that reported in Abdelhady et al. (2018). On the same context, broiler diet containing 2.5% chia oil improved the FCR by 6.80% during the period from 29 to 42 d of age (Mendonça et al. 2020). In this study, chia oil supplementation reduced feed intake, improved body weight, body weight gain, and FCR, supporting the previous findings of Asad et al. (2019) and Rasul et al. (2019), who reported that chia seed increased the body weight and improved the FCR in broilers. This improvement may be due to several factors, such as; a) presence of a sufficient quantity of polyphenolic compounds in chia (caffeic...
acid, chlorogenic acid, kaemperol, myricetin and quercetin) which are potent antioxidants that can reduce the production of free radicals in the body, inhibit peroxidation of fats and have much stronger antioxidant activities than vitamin C, vitamin E and ferulic acid, b) presence of large amounts of vitamins (A, C and E) and minerals (sodium, potassium and chloride) in chia oil that might play a role in stress reduction, c) increased digestive secretion (bile and mucus) and stimulation of enzymatic activities, d) improved digestive tract motility, food taste, and immunity and antimicrobial status, e) increased trypsin, amylase and jejunal chyme secretion, f) diminished bacterial adherence (i.e. *Escherichia coli* and *Clostridium perfringens*) to the intestinal wall (Pandey and Rizvi 2009; Nadeem et al. 2014; Alagawany et al. 2018, 2019; Kulczyński et al. 2019; Mendonça et al. 2020).

In contrast, Ayerza et al. (2002) reported that chia seed supplementation resulted in lower feed conversion and reduced body weight. They attributed this to the presence of the polysaccharide mucilaginous gel, which firmly coats the seeds. The gum may pose a physical barrier to fat extraction from the seed, resulting in inferior metabolisable energy in broilers fed with chia seeds. Moreover, visual detection of whole chia seeds in the excreta of birds fed with chia confirmed these findings, and the authors suggested that supplementation with ground chia or chia oil may reduce this effect. However, this was not the case in our experiment.

Dressing percentage is a superior index of whole edible meat after the removal of viscera, blood and feathers (Mohamed et al. 2019). There are conflicting results regarding the effects of dietary phytogenic supplementation on carcase traits. Kana et al. (2017) found no difference in carcase traits, while Simsek et al. (2007) reported a significant effect on carcase yield and traits. Our results were consistent with those of the majority of investigations that did not find any significant effect of phytogenic oil supplementation on carcase traits (Reda, Alagawany, et al. 2020). The percentage carcase yield of the different experimental groups in this study was within the range reported by Abdelhady et al. (2018) for quails, i.e. 67–88.1%. However, it was lower than that reported by Nasr et al. (2017). Furthermore, Rasul et al. (2019) reported that chia supplementation had no significant impact on the dressing percentage (56.94% in basal diet vs. 57.86% in chia supplemented diet). The carcase yield percentage of Japanese quail is affected by slaughter age, breed, line and sex of quails (Abou-Kassem et al. 2019; Mohamed et al. 2019; Reda, Alagawany, et al. 2020). Our results regarding the percentage liver weight were almost similar to the findings (2.35–2.48%) of Rasul et al. (2019); however, the percentage gizzard and heart weights were found to be higher in this study, whereas the percentage giblet weight was comparable to the range (4.63–7.52%) reported by Abdelhady et al. (2018).

Haematology is a critical marker of physiological or pathophysiological conditions of the animal body (Farag et al. 2019). The HCT level represents the percentage of blood which is composed of RBCs after centrifugation. HCT is affected by RBC number and size. Moreover, it is a marker of the total number of RBCs, which determines the oxygen-carrying capacity (Maheswaran et al. 2008). The haematological parameters observed in this study were within the normal ranges reported for quails, i.e. $1.06–4.34 \times 10^6$ RBC/$\mu$L (Pravda et al. 1996), $7.57–15$ g/dL HGB (Mnisi et al. 2017), $88.24–433.96$ µm$^3$ MCV (Pravda et al. 1996) and $25.27–104.62$ pg MCH (Pravda et al. 1996).

In this study, chia oil supplementation improved the WBCs, RBCs, HGB and HCT%. These results may be attributed to the anabolic hormones (thyroid hormones), which are responsible for increasing the RBCs. Increasing WBCs is favourable as leukocytes provide quick and robust protection against substances that may trigger infection. Several factors affect leukocyte values in poultry, such as the genetic makeup, stress condition, rearing system, diet, production stage and lighting period (Hrabcakova et al. 2014). These factors may explain the contradiction between the results of this study and those of Toghyani et al. (2010), who did not observe any significant effect of phytogenic supplements (thyme powder) on broiler WBCs, RBCs, HGB and HCT%.

Liver is the site of protein synthesis and its cells normally contain AST and ALT. Disturbance of protein level and the leakage of ALT or AST into blood occurs in certain conditions, such as hepatitis, congestive heart failure, liver or bile damage and cellular necrosis; therefore, measuring serum levels of ALT, AST, total protein, albumin and globulin are important in determining liver performance (Evans 2009). In this study, chia oil did not alter liver function and did not exert any negative impact on liver weight, suggesting that chia does not contain high amounts of anti-nutritional compounds, which necessitate detoxification. The urea levels were higher in birds in G$_3$, G$_4$ and G$_5$ groups than in the group fed the basal diet. The observed urea level was within the range (1.14–3.05 mmol/L) reported by Mnisi et al. (2017). This is further supported by the findings of Ngouana Tadjong et al.
with some previous works. This reduction may be attributed to the presence of omega-3 and omega-6 fatty acids (Antruejo et al. 2011; Rahimi et al. 2011; Alagawany et al. 2019) and the activity of natural antioxidants in chia (Ahmed 2019).

Chia oil supplementation decreased the LDL levels, which is in agreement with the results obtained by supplementation of chia seeds (Ahmed 2019). This reduction confirmed the lower cholesterol levels observed in this study because HDL and LDL molecules are the chief transporters of cholesterol from its site of synthesis, i.e. the liver, to the body tissues and they consequently decrease cholesterol and triglycerides available for tissue metabolism, lipogenesis in liver and fat accumulation in carcases (Alvarenga et al. 2011). In the present investigation, LDL levels in the groups supplemented with chia oil (especially G2) were similar to those reported by Abdelhady et al. (2018).

The antioxidant systems in the body consist of antioxidant enzymes, i.e. SOD and GSH-Px that protect the body from oxidative stress. The concentrations of MDA and GSH are used as indicators for evaluating antioxidant systems. Total antioxidant capacity is commonly used to evaluate the antioxidant condition of biological samples and to detect the antioxidant response to free radicals released under stress conditions. The quantity of free radicals in the body increases during stress, and chia seeds can deactivate these radicals and defend the body during stress (Nadeem et al. 2014). Recent studies have shown that phenolic compounds have positive effects on the body because of their antioxidant, anti-inflammatory and antimicrobial properties. Akbarian et al. (2015) found that dietary supplementation with plant extracts rich in phenolic compounds in chickens exposed to chronic thermal stress resulted in an elevation of their blood GSH-Px activity. Several investigations have shown that chia seeds can be used as anti-stressors, as they are a good source of antioxidants, which can be used for health improvement (Uribe et al. 2011). Our results showed that there was no significant difference between groups supplemented with different levels of chia oil and the group fed the basal diet, which indicates that the feed used in this study was a good source of antioxidants.

Complement 3 plays a role in innate immunity (the chief component of the immune system) by attaching to the cell membranes of pathogenic microbes and enhancing the effectiveness of phagocytic cells and antibodies to get rid of microbes and injured cells from the body (Ricklin et al. 2016). Dietary supplementation with antioxidants may upgrade broiler performance and immunity by reducing the thiobarbituric
acid values in the liver and increasing serum and liver vitamin A and E levels (Tavárez et al. 2011). Moreover, broiler diet supplementation with plant products with high antioxidant compound contents can improve the oxygen scavenging responses to preserve fat sources both outside and inside the body (Ahmed 2019). Supplementing the diet with chia (0.4 g/kg diet) improved the immune status of quails, confirming the results recently reported by Asad et al. (2019), who observed an enhancement of the immune response of broilers fed a diet supplemented with chia seeds. These outcomes may be related to the presence of antioxidants in chia that can aid in improving health (Uribe et al. 2011), and it is also considered a good source of omega-3 fatty acids (n-3 polyunsaturated fatty acid (PUFA) and ALA). The n-3 PUFAs are more efficient than ALA in boosting the immune responses (Alagawany et al. 2019). Moreover, the protein content of chia has been proved to enhance the development of thymus gland and consequently the immune status (Fernandez et al. 2008). Ayerza and Coates (2005) also reported that all forms of chia did not induce abnormal behaviour, inflammations, digestive disturbances or other signs of diseases. On the other hand, chia oil reduced the Σω-6:Σω-3 ratio and the thrombogenicity and atherogenicity indices of the broiler chicken meat, providing improvements in the meat nutritional quality, with consequent health benefits for its consumers (Mendonça et al. 2020).

Conclusions

This study showed that supplementation of quail diet with 0.4 g chia oil/kg diet improved the growth performance, some blood parameters, lipid profile and immunity, supporting the idea that phytogenics may possess complicated mechanisms of action, which can alter feed colour and flavour, enhance gastric motility and upgrade the secretion of digestive enzymes, antioxidant levels and endocrine and immune functions.

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Ethical approval

Animal care and maintenance were performed in accordance with the guidelines of the Egyptian Research Ethics Committee and the guidelines specified in the Guide for the Care and Use of Laboratory Animals (2011).

Disclosure statement

No potential conflicts of interest declared.

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References

Abbasi F, Samadi F. 2014. Effect of different levels of artichoke (Cynara scolymus L.) leaf powder on the performance and meat quality of Japanese quail. Poult Sci J. 2:95–111.
Abd El-Hack ME, Alagawany M, Abdel-Moneim A-ME, Mohammed NG, Khafaga AF, Bin-Jumah M, Othman SI, Allam AA, Elnesr SS. 2020. Cinnamon (Cinnamomum zeylanicum) oil as a potential alternative to antibiotics in poultry. Antibiotics. 9(5):210.
Abdelhady AYM, El-Faham AI, Nematallah GM. 2018. Effect of different dietary fat sources on productive performance and breast meat quality in Japanese quails. Egypt J Nutr Feeds. 21:263–272.
Abou-Kassem DE, El-Kholy MS, Alagawany M, Laudadio V, Tufarelli V. 2019. Age and sex-related differences in performance, carcass traits, hemato–biochemical parameters, and meat quality in Japanese quails. Poult Sci. 98(4):1684–1691.
Ahmed SKH. 2019. Egg yolk fatty acids, blood parameters and some reproductive measurements of Japanese quail supplemented with chia seeds (Salvia hispanica L.). Int J Poult Sci. 18(3):129–135.
Akbarian A, Golian A, Kermanshahi H, De Smet S, Mic J. 2015. Antioxidant enzyme activities, plasma hormone levels and serum metabolites of finishing broiler chickens reared under high ambient temperature and fed lemon and orange peel extracts and Curcuma xanthorrhiza essential oil. J Anim Physiol Anim Nutr (Berl). 99(1):150–162.
Alagawany M, Elnesr SS, Farag MR, Abd El-Hack ME, Khafaga AF, Taha AE, Tiwari R, Yattoo MI, Bhatt P, Kurhana SK, et al. 2019. Omega-3 and omega-6 fatty acids in poultry
nutrition: effect on production performance and health. Animals. 9(8):573.

Alagawany M, Farag MR, Dhama K, Patra A. 2018. A review on nutritional significance and health benefits of designer eggs. World’s Poult Sci J. 74(2):317–330.

Alvarenga RR, Zangeronimo MG, Pereira LJ, Rodrigues PB, Gomide EM. 2011. Lipoprotein metabolism in poultry. World’s Poult Sci J. 67(3):431–440.

Antruejo A, Azcona JO, Garcia PT, Gallinger C, Rosmini M, Ayerza R, Coates W. 2011. Omega-3 enriched egg production: the effect of a-linolenic o-3 fatty acid sources on laying hen performance and yolk lipid content and fatty acid composition. Br Poult Sci. 52(6):750–760.

Asad T, Mehmood S, Mahmud A, Basheer A, Saleem G, Jatoi AS, Hussain J, Husnain F, Younis M. 2019. Ameliorating effect of different anti-stressors on growth performance, and immunophysiological responses in heat stressed broilers chickens. PVJ. 39(2):285–288.

Ayerza R, Coates W. 2011. Protein content, oil content and fatty acid profiles as potential criteria to determine the origin of commercially grown chia (Salvia hispanica L.). Ind Crops Prod. 34(2):1366–1371.

Ayerza R, Coates W, Lauria M. 2002. Chia seed (Salvia hispanica L.) as an o-3 fatty acid source for broilers: influence on fatty acid composition, cholesterol and fat content of white and dark meats, growth performance, and sensory characteristics. Poult Sci J. 81(6):826–837.

Ayerza R, Coates W. 1999. An o-3 fatty acid enriched chia diet: influence on egg fatty acid composition, cholesterol and oil content. Can J Anim Sci. 79(1):53–58.

Ayerza R, Coates W. 2005. Chia: rediscovering a forgotten crop of the Aztecs. Tucson (AZ): University of Arizona Press.

Dhama K, Karthik K, Khandia R, Munjal A, Tiwari R, Rana R, Khurana SK, Sana Ulah Khan RU, Alagawany M, Farag MR, et al. 2018. Medicinal and therapeutic potential of herbs and plant metabolites/extracts countering viral pathogens - current knowledge and future prospects. Curr Drug Metabol. 19(3):236–263.

Evans GO. 2009. Animal clinical chemistry. Boca Raton (FL): CRC Press.

Farag MR, Elhady WM, Ahmed SYA, Taha HSA, Alagawany M. 2019. Astragalus polysaccharides alleviate tilmicosin-induced toxicity in rats by inhibiting oxidative damage and modulating the expressions of HSP70, NF-κB and Nrf2/HO-1 pathway. Res Vet Sci. 124:137–148.

Fernandez I, Vidueiros SM, Ayerza R, Coates W, Pallaro A. 2008. Impact of chia (Salvia hispanica L.) on the immune system: preliminary study. Proc Nutr Soc. 67(OC1):E12.

Hrabacova P, Voslavova E, Bedanova I, Pisteckova V, Chloupek J. 2014. Changes in selected haematological and biochemical parameters in debeaked pheasant hens during the laying period. Ankara Univ Vet Fak Derg. 61:111–117.

Ixtaina VY, Nolasco SM, Tomas MC. 2008. Physical properties of chia (Salvia hispanica L.) seeds. Ind Crops Prod. 28(3):286–293.

Kana JR, Mube KH, Ngouana TR, Yangoue A, Kmguep R, Tsafong F, Teguia A. 2017. Growth performance and serum performance profile of broiler chickens fed on diets supplemented with Afrostryx lepidophylius fruit and bark as alternative to antibiotic growth promoters. J Vet Med Res. 4:1–7.

Kheiri F, Rahimian Y, Nasr J. 2015. Application of sumac and dried whey in female broiler feed. Arch Anim Breed. 58(1):205–210.

Kulczy-ski B, Kobus-Cisowska J, Taczanowski M, Kmieciak D, Gramza-Michalowska A. 2019. The chemical composition and nutritional value of chia seeds-current state of knowledge. Nutrients. 11(6):1242.

Maheswaran R, Devapaul A, Muralidhalan S, Velmurguban R, Ignacimuthu S. 2008. Haematological studies of fresh water fish, Clarais batrachus (L.) exposed to mercuric chloride. Int J Integ Biol. 2:49.

Mahgoub SAM, Abd El-Hack ME, Saadeldin IM, Hussein MA, Swelum AA, Alagawany M. 2019. Impact of Rosmarinus officinalis cold-pressed oil on health, growth performance, intestinal bacterial populations, and immunocompetence of Japanese quail. Poult Sci. 98(5):2139–2149.

Mendonca CNS, Sobrane Filho ST, Oliveira DH, Lima EMC, Rosa PV, Faria PB, Naves LP, Rodrigues PB. 2020. Dietary chia (Salvia hispanica L.) improves the nutritional quality of broiler meat. Asian-Aust J Anim Sci. 33(8):1310–1322.

Mnisi CM, Matshogo TB, van Niekerk R, Mlambo V. 2017. Growth performance, haemo-biochemical parameters and meat quality characteristics of male Japanese quails fed a Lippia javanica-based diet. SA J Anim Sci. 47(5):661–671.

Mohamed LA, El-Hindawy MM, Alagawany M, Salah AS, El-Sayed SA. 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(5):1380–1387.

Nadeem M, Situ C, Mahmoud A, Khalique A, Imran M, Rahman F, Khan S. 2014. Antioxidant activity of sesame (Sesamum indicum) cake extract for the stabilization of olein based butter. J Am Oil Chem Soc. 91(6):967–977.

Nasr MAF, Ali EMR, Hussein MH. 2017. Performance, carcass traits, meat quality and amino acid profile of different Japanese quails strains. J Food Sci Technol. 54(13):4189–4196.

Nasr MAF, Mohammed H, Hassan RA, Swelum AA, Saadeldin IM. 2019. Does light intensity affect the behaviour, welfare, performance, meat quality, amino acid profile and egg quality of Japanese quails? Poult Sci. 98(8):3093–3102.

Nedkov V. 2004. Biological value of the proteins. Retrieved on 01 December 2015 from http://www.bbteam.org/articles/860/.

Ngouana Tadjong R, Kana JR, Tsafack Necdem B, Yemdije Mane DD, Mube Kuiechc H, Kuiede S, Teguia A, Meimandipour A. 2017. Performances of broiler chickens fed on diet supplemented with thyme and oregano essential oils stabilized in a plant charcoal matrix. J World Poult Res. 7:79–87.

Pandey KB, Rizvi SI. 2009. Plant polyphenols as dietary anti-oxidants in human health and disease. Oxid Med Cell Longev. 25(5):270–278.

Pravda D, Bo’a K, Baumgartner J, Jejinek P, Kucinsky P, Okruihlica M, Petrovský E. 1996. Haematological parameters of Japanese quail (Coturnix coturnix japonica) kept in cages under normal conditions and exposed to long-term hypodynamy. Acta Vet Brno. 65(1):93–97.

Rahimi S, Teymourizadeh Z, Karimi-Torshizi MA, Omidbaigi R, Rokni H. 2011. Effect of the three herbal extracts on diet: influence on egg fatty acid composition, cholesterol and fat content of white and dark meats, growth performance, and sensory characteristics. Poult Sci J. 81(6):826–837.

Rokni H. 2011. Effect of the three herbal extracts on diet: influence on egg fatty acid composition, cholesterol and fat content of white and dark meats, growth performance, and sensory characteristics. Poult Sci J. 81(6):826–837.

Swelum AA, Alagawany M. 2019. Impact of Rosmarinus officinalis cold-pressed oil on health, growth performance, intestinal bacterial populations, and immunocompetence of Japanese quail. Poult Sci. 98(5):2139–2149.
growth performance, immune system, blood factors and intestinal selected bacterial population in broiler chickens. J Agri Sci Technol. 13:527–539.
Rasul M, Mehmood S, Ahmad S, Javid A, Mahmud A, Rehman A, Usman M, Hussain J, Ahmad M, Azhar M. 2019. Effects of different anti-stressors on growth, serum chemistry and meat quality attributes of Japanese. Br J Poult Sci. 21:1–10.
Reda FM, Alagawany M, Mahmoud HK, Mahgoub SA, Elnesr SS. 2020. 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(5):1025–1033.
Reda FM, El-Kholy MS, Abd El-Hack ME, Taha AE, Othman SI, Allam AA, Alagawany M. 2020. Does the use of different oil sources in quail diets impact their productive and reproductive performance, egg quality and blood constituents? Poult Sci. 99(7):3511–3518.
Reda FM, El-Saadony MT, Elnesr SS, Alagawany M, Tufarelli V. 2020b. Effect of dietary supplementation of biological curcumin nanoparticles on growth and carcass traits, antioxidant status, immunity and caecal microbiota of Japanese quails. Animals. 10(5):754.
Ricklin D, Reis ES, Mastellos DC, Gros P, Lambris JD. 2016. Complement component C3 – The “Swiss Army Knife” of innate immunity and host defense. Immunol Rev. 274(1):33–58.
Schalm OW. 1961. Veterinary hematology. Philadelphia (PA): Lea and Febiger; p. 165–187.
Simsek UG, Ciftci M, Dalkılıc B, Guler T, Ertas ON. 2007. The effects of dietary antibiotic and anise oil supplementation on body weight, carcass characteristics and organoleptic analysis of meat in broilers. Revue de Méd Vét. 158:514–518.
Tavárez MA, Boler DD, Bess KN, Zhao J, Yan F, Dilger AC, McKeith FK, Killefer J. 2011. Effect of antioxidant inclusion and oil quality on broiler performance, meat quality, and lipid oxidation. Poult Sci. 90(4):922–930.
Ting I, Brown J, Naqvi H, Kumamoto J, Matsumura M. 1990. Chia: a potential oil crop for arid zones. In: New industrial crops and products. Proceedings of the Association for the Advancement of Industrial Crops; Tucson (AZ): The University of Arizona, Office of Arid Lands Studies. p. 197–200.
Toghyani M, Toghyani M, Gheisari AA, Ghalamkari GH, Mohammadrezae M. 2010. Growth performance, serum biochemistry, and blood hematology of broiler chicks fed different levels of black seed (Nigella sativa) and peppermint (Mentha piperita). Livest Sci. 129(1-3):173–178.
Uribe JAR, Perez JIN, Kaul HC, Rubio GR, Alcocer CG. 2011. Extraction of oil from chia seeds with supercritical CO2. J Supercritical Fluids. 56(2):174–178.