Effects of dietary supplementation with leonurine hydrochloride on growth performance, immune response, antioxidant capacity and blood parameters in male broiler chicks

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ABSTRACT
The aim of the present study was to explore the effects of different dietary levels (0, 15, 30, 60, 120 mg/kg) of leonurine hydrochloride (LHy) supplementation on growth performance, immune response, antioxidant capacity, hematological parameters and serum lipid profiles in broiler chicks. A total of 600 1-day-old Ross × Ross male broilers were randomly allocated to five treatment groups consisting of eight pens of fifteen birds. The feeding programme included a starter diet until day 21 and a finisher diet from day 22 to day 42. The results indicate that LHy did not alter the growth performance of broilers (P > 0.05). Supplementation of the basal diet with LHy increased (linear, P < 0.05) relative spleen weights at d 21 and 42. In both 21- and 42-day-old chicks, dietary LHy supplementation linearly increased (P < 0.05) the serum immunoglobulin A (IgA) and M (IgM) concentrations, catalase (CAT), total superoxide dismutase (T-SOD), total antioxidant capacity (T-AOC) activities, low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) levels, while linearly (P < 0.05) decreased serum malondialdehyde (MDA) activity, red blood cell (RBC) count, hemoglobin, triglyceride (TC) levels and total cholesterol (CHOL) content. In addition dietary LHy supplementation linearly (P < 0.05) increased the GSH activity in 42-day-old broilers. Taken together, dietary LHy supplementation was able to promote immune function and antioxidant capacity, and decrease blood lipid levels in broilers.

1. Introduction
The use of antibiotics in poultry feed is becoming increasingly prevalent, since these drugs can improve performance, combat poultry pathogens and prevent disease. However, it has been shown that antibiotics can give rise to drug-resistant strains and drug residues, pollute the environment and seriously damage human health (Schwarz et al. 2001; Alipour et al. 2015). Therefore, research regarding phytogenic feed additives that originate primarily from herbs and spices is now attracting greater interest due to these supplements being natural, exerting multiple beneficial functions, and having minimal side effects and no residue or residues (Kumar et al. 2017).

In traditional Chinese herbal medicine, Leonurus sibiricus (also known as Siberian motherwort) is widely-used for the treatment of various cardiovascular and digestive disorders and climacteric symptoms in gynecological and menstrual disorders, due to its relatively low toxicity (Kong et al. 1976; Liu et al. 2007). Recently, leonurine (C_{14}H_{21}N_{3}O_{5}), a natural alkaloid compound of Leonurus sibiricus, was extracted and confirmed to display vasodilatory, antioxidant and anti-inflammatory properties (Song et al. 2015; Yuan et al. 2015). Leonurine hydrochloride (LHy) [3,5-dimethoxy-4-hydroxy-benzoic acid (4-guanidino)-1-butyl ester hydrochloride monohydrate; Figure 1] is a synthetic compound related to leonurine. A previous study showed that LHy can increase cellular protection by scavenging free radicals and inhibiting the formation of reactive oxygen species (ROS) in rats (Sitarek et al. 2015). In recent years, the study of phenolic compounds as replacements for antibiotic feed additives has become a popular field of research; however, investigation into the possible stimulatory roles of LHy on the immune system has been limited. To the best of our knowledge, no studies related to the effects of LHy in chicks have been published. Here, we determined the effects of LHy dietary levels on growth performance, immune response, antioxidant capacity, blood biochemistry and hematological parameters of modern fast-growing broilers. In addition, we elucidated the optimal range of LHy supplementation in the diet of broiler chicks, which will be the basis for further studies.

2. Materials and methods
2.1. Experimental design
All experimental procedures complied with the regulations of the Animal Care and Use Committee of the College of Animal Science and Technology, Shihezi University, and were based on a single-factor experimental design. LHy (98% purity) was obtained from AnHui New Star Pharmaceutical Development Co., Ltd., HeFei, China. The chemical structure of synthesized...
LHy (Figure 1) was in accordance with that of natural leonurine from *Leonurus sibiricus*.

A total of 600 one-day-old male Ross broilers (average body weight 44.5 ± 0.3 g), obtained from a local commercial hatchery (Taikun Poultry Co. Xinjiang, China), were randomly distributed into five treatment groups containing eight replicates of fifteen birds. A standard corn-soybean meal diet or the standard diet supplemented with 0, 15, 30, 60, or 120 mg/kg LHy was fed to the chicks. Antimicrobial and anticoccidial drugs were not added to the standard diet, which was formulated to meet or slightly exceed the NRC (1994) broilers requirements for all nutrients and provided in mash form (Table 1). All birds were housed in a temperature-controlled room with feeders, nipple drinkers, and steel cages. Feed and tap water were available ad libitum. The temperature was maintained at 32–35°C during the first week and then gradually reduced by 2–3°C per week until the birds were 4 weeks old.

### 2.2. Performance responses

On days 0, 21 and 42 of the experiment, body weight and feed intake of the broilers were recorded on a cage basis after a 12-h feed withdrawal. The average daily feed intake (ADFI), average daily gain (ADG) and the feed conversion ratio (ADFI/ADG) were calculated. The mortality was recorded during the entire feeding trial to estimate the survival percentage.

### 2.3. Lymphoid organ weights

On days 21 and 42, one bird from each replicate was selected at random, weighed and exsanguinated under anesthesia. The relative organ weights were calculated as a percentage of body weight \([(organ\ weight/\ body\ weight) \times 100]\).

### 2.4. Immunological tests

On days 21 and 42, one bird from each replicate was selected at random for blood sampling, with 3–5 ml being taken from the wing vein. Samples were left at room temperature for 30 min and subsequently centrifuged at 6000 rpm for 15 min at 4°C to separate serum, followed by storage at −2°C. Serum levels of immunoglobulin A (IgA), G (IgG) and M (IgM), and interleukin-1β (IL-1β) and −6 (IL-6) were measured using commercial chicken-specific IgA, IgG, IgM, IL-1β and IL-6 ELISA kits (Shanghai Bluegene Biotechnology Co., Ltd., Shanghai, China), according to the manufacturer's instructions.

### 2.5. Assessment of antioxidant activity

The serum activities of catalase (CAT), malondialdehyde (MDA), total superoxide dismutase (T-SOD), total antioxidant capacity (T-AOC) and glutathione (GSH) were measured using CAT, MDA, T-SOD, T-AOC and GSH assay kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) and an automated spectrophotometric analyzer (Cobas FARA II, Roche, Palo Alto, CA). All procedures were carried out according to the manufacturers' instructions.

### 2.6. Hematological parameters and serum lipid profile

On days 21 and 42, one bird from each replicate was selected at random for blood sampling as described in section 2.4. For hematological determination, blood samples were collected in tubes containing ethylenediaminetetraacetic acid (EDTA) to prevent clotting, and for biochemical analysis, in non-heparinized tubes. EDTA-treated samples were stored at 4°C for 30 min and then transferred to room temperature for analysis. The remaining samples were centrifuged for 15 min at 2000 × g to obtain serum, and then frozen at −20°C until analysis.

The red blood cell (RBC) and white blood cell (WBC) counts, hematocrit, and hemoglobin levels were measured using a PE-6800 fully automatic hematology analyzer (Shenzhen Prokan Electronics Inc. Co., Shenzhen, China). Individual serum samples were analyzed for triglyceride (TC), total cholesterol (CHOL), low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) levels using a kit (Nanjing Jiancheng Bioengineering Institute, Nanjing, China). All procedures were carried out according to the manufacturers’ instructions.

### 2.7. Statistical analysis

The data were subjected to ANOVA analysis using the General Linear Model (GLM) procedure of SAS (version 9.4, SAS Institute, Cary, NC, USA). The orthogonal polynomial contrast test was performed to determine linear and quadratic effect of inclusion.
level of LHy in diets. Differences among treatments were separated by Duncan’s multiple range test. Variability in the data was expressed as the pooled standard error of the mean (SEM). All declarations were considered significant at \( P < 0.05 \).

### 3.1. Growth performance

As shown in Table 2, broiler chicks fed diets supplemented with different levels of LHy exhibited similar growth performance (ADG, ADFI and F:G) to those in the control group throughout the experimental period (\( P > 0.05 \)).

### 3.2. Relative immune organ weight

As shown in Table 3, broiler chicks fed diet containing LHy during the feeding trial had increased (linear, \( P < 0.05 \)) relative spleen weights, as dietary levels of LHy increased. However, no significant differences were observed with respect to the relative weights of the bursa or thymus among any of the treatments (\( P > 0.05 \)).

### 3.3. Immune response

Table 4 summarizes the effects of the dietary treatments on plasma immunoglobulin (IgA, IgG, IgM) and interleukin (IL-1\( \beta \), IL-6) concentrations in 21- and 42-day-old chicks. On days 21 and 42, dietary LHy supplementation linearly (\( P < 0.05 \)) increased the concentrations of IgA and IgM in the serum. However, serum IL-1\( \beta \), IL-6 and IgG concentrations remained similar among the groups throughout the experimental period (\( P > 0.05 \)).

### Table 2. The effects of dietary LHy on growth performance in broilers at 21 and 42 d of age.

| Item         | The level of dietary LHy (mg/kg) | SEM\( ^a \) | ANOVA | Linear | Quadratic |
|--------------|---------------------------------|-------------|-------|--------|-----------|
| 1–21 d       |                                 |             |       |        |           |
| ADG, g/bird  | 40.05                           | 0.134       | 0.655 | 0.342  | 0.721     |
| ADFI, g/bird | 54.50                           | 0.051       | 0.542 | 0.674  | 0.654     |
| FCR, g/g    | 1.36                            | 0.004       | 0.520 | 0.842  | 0.472     |
| 21–42 d     |                                 |             |       |        |           |
| ADG, g/bird  | 83.21                           | 0.226       | 0.729 | 0.580  | 0.694     |
| ADFI, g/bird | 165.99                          | 0.099       | 0.992 | 0.838  | 0.534     |
| FCR, g/g    | 2.00                            | 0.006       | 0.728 | 0.689  | 0.454     |

\( ^a \) SEM, standard error of means (\( n = 8 \)).

### Table 3. The effects of dietary LHy on lymphoid organ weights of broiler chicks at 21 and 42 d of age.

| Item          | The level of dietary LHy (mg/kg) | SEM\( ^c \) | ANOVA | Linear | Quadratic |
|---------------|---------------------------------|-------------|-------|--------|-----------|
| 21 d          |                                 |             |       |        |           |
| Thymus index, g/kg | 4.87                           | 0.021       | 0.751 | 0.217  | 0.945     |
| Spleen index, g/kg | 0.93\( ^a \)                   | 0.013       | 0.049 | 0.001  | 0.559     |
| Bursa index, g/kg | 2.35                           | 0.009       | 0.0984| 0.639  | 0.726     |
| 42 d          |                                 |             |       |        |           |
| Thymus index, g/kg | 3.22                           | 0.006       | 0.856 | 0.409  | 0.713     |
| Spleen index, g/kg | 1.61\( ^a \)                   | 0.005       | 0.031 | 0.002  | 0.343     |
| Bursa index, g/kg | 0.60                           | 0.003       | 0.769 | 0.194  | 0.764     |

\( ^a \) Means with no common superscript within each column are significantly (\( P < 0.05 \)) different.

### Table 4. Effect of dietary LHy on serum immunoglobulins and interleukins in broilers at 21 and 42 d of age.

| Item          | The level of dietary LHy (mg/kg) | SEM\( ^b \) | ANOVA | Linear | Quadratic |
|---------------|---------------------------------|-------------|-------|--------|-----------|
| d 21          |                                 |             |       |        |           |
| IL-1\( \beta \), ug/mL | 68.81                           | 2.07        | 0.529 | 0.160  | 0.324     |
| IL-6, ug/mL   | 62.55                           | 1.84        | 0.587 | 0.174  | 0.314     |
| IgA, ug/mL    | 306.98\( ^a \)                  | 7.74        | 0.008 | <0.001 | 0.960     |
| IgG, ug/mL    | 236.03                          | 7.65        | 0.758 | 0.949  | 0.550     |
| IgM, ug/mL    | 303.86\( ^a \)                  | 8.01        | 0.014 | 0.001  | 0.699     |
| d 42          |                                 |             |       |        |           |
| IL-1\( \beta \), ug/mL | 64.80                           | 2.57        | 0.527 | 0.082  | 0.710     |
| IL-6, ug/mL   | 87.22                           | 3.33        | 0.734 | 0.189  | 0.948     |
| IgA, ug/mL    | 545.06\( ^a \)                  | 13.64       | 0.021 | 0.001  | 0.371     |
| IgG, ug/mL    | 257.81                          | 7.164       | 0.957 | 0.462  | 0.727     |
| IgM, ug/mL    | 317.54\( ^a \)                  | 8.91        | 0.003 | <0.001 | 0.735     |

\( ^a \) Means with no common superscript within each column are significantly (\( P < 0.05 \)).

\( ^b \) SEM, standard error of means (\( n = 8 \)).

IL-1\( \beta \), interleukin-1\( \beta \); IL-6, interleukin-6; IgA, immunoglobulin A; IgG, immunoglobulin G; IgM, immunoglobulin M.
3.4. Antioxidant system

The antioxidant status is presented in Table 5. On days 21 and 42, dietary LHy supplementation linearly (P < 0.05) increased the CAT, T-SOD and T-AOC activities in the serum, while the serum MDA activity linearly reduced (P < 0.05). Dietary LHy supplementation had no effect on serum GSH activity in 21-day-old chicks (P > 0.05). However, dietary LHy supplementation linearly (P < 0.05) increased the GSH activity in 42-day-old broilers.

Table 5. The effects of dietary LHy on serum antioxidant activity in broilers at 21 and 42 d of age.

| Item | The level of dietary LHy (mg/kg) | SEMb | P-value | ANOVA | Linear | Quadratic |
|------|--------------------------------|------|---------|--------|--------|-----------|
|      | 0 | 15 | 30 | 60 | 120 | | |
| CAT, U/mL | 4.53a | 4.75a | 4.65a | 5.49a | 5.89a | 0.127 | <0.001 | <0.001 | 0.064 |
| MDA, nmol/mL | 3.17a | 3.10a | 2.85a | 2.00a | 2.06a | 0.108 | <0.001 | <0.001 | 0.634 |
| T-SOD, U/mL | 268.26a | 276.77a | 285.53a | 322.49a | 338.55a | 5.391 | <0.001 | <0.001 | 0.130 |
| T-AOC, U/mL | 21.49a | 21.48a | 22.24a | 27.80a | 28.17a | 0.556 | <0.001 | <0.001 | 0.055 |
| GSH, µmol/L | 15.28 | 15.43 | 15.74 | 16.67 | 17.13 | 0.248 | 0.376 | 0.076 | 0.665 |
|      | 0 | 15 | 30 | 60 | 120 | | |
| CAT, U/mL | 6.44a | 6.32a | 6.61a | 7.54a | 7.92a | 0.127 | <0.001 | <0.001 | 0.021 |
| MDA, nmol/mL | 3.03a | 2.95a | 2.77a | 2.34a | 2.20a | 0.077 | 0.001 | 0.001 | 0.475 |
| T-SOD, U/mL | 352.17a | 358.24a | 370.13a | 423.93a | 428.11a | 6.799 | <0.001 | <0.001 | 0.344 |
| T-AOC, U/mL | 23.82a | 24.16a | 25.25a | 29.79a | 30.69a | 0.528 | 0.001 | <0.001 | 0.065 |
| GSH, µmol/L | 15.43a | 16.67a | 17.28a | 18.83a | 18.98a | 0.396 | 0.014 | 0.001 | 0.607 |

* Means with no common superscript within each column are significantly (P < 0.05) different.

b SEM, standard error of means (n = 8).

CAT, catalase; MDA, malondialdehyde; T-SOD, total superoxide dismutase; T-AOC, total antioxidant capacity; GSH, reduced glutathione.

3.5. Hematological parameters and blood biochemistry

Table 6 summarizes the effects of dietary treatments on blood constituents on days 21 and 42. On days 21 and 42, broiler chicks fed with supplemented diets at different levels of LHy showed significantly reduced (linear, P < 0.05) in RBC and hemoglobin. However, WBC and hematocrit levels remained unaffected by LHY supplementation (P > 0.05).

Table 6. Effect of dietary LHy on hematological parameters in broilers at 21 and 42 d of age.

| Item | The level of dietary LHy (mg/kg) | SEMb | P-value | ANOVA | Linear | Quadratic |
|------|--------------------------------|------|---------|--------|--------|-----------|
|      | 0 | 15 | 30 | 60 | 120 | | |
| WBC, × 10³/µl | 88.05 | 87.09 | 87.34 | 88.56 | 90.39 | 0.955 | 0.84 | 0.371 | 0.421 |
| RBC, × 10⁶/µl | 2.01a | 1.99a | 2.00a | 1.94a | 1.88a | 0.014 | 0.003 | <0.001 | 0.103 |
| Hemoglobin, g/dl | 105.25a | 101.13a | 101.00a | 96.95a | 94.25 | 1.035 | 0.004 | <0.001 | 0.883 |
| Hematocrit, % | 25.89 | 24.2 | 24.74 | 24.36 | 24.18 | 0.277 | 0.261 | 0.099 | 0.361 |
|      | 0 | 15 | 30 | 60 | 120 | | |
| WBC, × 10³/µl | 95.05 | 93.75 | 91.54 | 91.28 | 90.19 | 0.787 | 0.285 | 0.058 | 0.709 |
| RBC, × 10⁶/µl | 2.39a | 2.40a | 2.30a | 2.17a | 2.12a | 0.026 | <0.001 | <0.001 | 0.436 |
| Hemoglobin, g/dl | 122.00a | 120.88a | 117.50a | 109.25a | 107.63a | 1.742 | 0.014 | 0.001 | 0.646 |
| Hematocrit, % | 26.94 | 26.09 | 26.35 | 26.28 | 25.68 | 0.366 | 0.883 | 0.380 | 0.959 |

* Means with no common superscript within each column are significantly (P < 0.05) different.

b SEM, standard error of means (n = 8).

RBC, red blood cell; WBC, white blood cell.

4. Discussion

In order to understand the mechanisms by which LHy could beneficially affect broiler immune function, its effects on

Table 7. Effect of dietary LHy on serum lipid profiles of broilers at 21 and 42 d of age.

| Item | The level of dietary LHy (mg/kg) | SEMb | P-value | ANOVA | Linear | Quadratic |
|------|--------------------------------|------|---------|--------|--------|-----------|
|      | 0 | 15 | 30 | 60 | 120 | | |
| Triglyceride, mg/dl | 2.30a | 2.27a | 2.18a | 1.95a | 1.95a | 0.038 | 0.025 | 0.001 | 0.348 |
| CHOL, mg/dl | 4.43a | 4.23a | 3.82a | 3.68a | 3.62a | 0.814 | 0.001 | <0.001 | 0.345 |
| LDL-C, mg/dl | 1.79a | 1.84a | 2.07a | 1.93a | 2.09a | 0.039 | 0.048 | 0.013 | 0.669 |
| HDL-C, mg/dl | 1.03a | 1.17a | 1.31a | 1.29a | 1.38a | 0.037 | 0.016 | 0.001 | 0.345 |
|      | 0 | 15 | 30 | 60 | 120 | | |
| Triglyceride, mg/dl | 2.23a | 2.20a | 2.13a | 2.06a | 2.02a | 0.023 | 0.036 | 0.004 | 0.920 |
| CHOL, mg/dl | 4.04a | 3.68a | 3.59a | 3.01a | 2.95a | 0.085 | <0.001 | <0.001 | 0.814 |
| LDL-C, mg/dl | 0.99a | 1.07a | 1.13a | 1.18a | 1.29a | 0.030 | 0.018 | 0.001 | 0.797 |
| HDL-C, mg/dl | 1.05a | 1.14a | 1.30a | 1.37a | 1.42a | 0.040 | 0.011 | <0.001 | 0.545 |

* Means with no common superscript within each column are significantly (P < 0.05) different.

b SEM, standard error of means (n = 8).

CHOL, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high density lipoprotein cholesterol;
lymphoid organ weight, serum immunoglobulin concentrations and inflammatory cytokine levels were examined. As far as we know, there is scarce information on the effect of LHy on the growth performance of broiler chicks. The current study indicates that broiler chicks fed a diet supplemented with LHy had no significant difference in growth performance compared to fed unsupplemented diets. These findings confirm those reported by Sun et al. (2013) that dietary Motherwort had no effect on the mean FI, BWG or FCR of chickens. In a previous study, Han et al. (2013) demonstrated that feeding rats different doses of L. sibiricus aqueous extract had no effect on body weight in the experimental group compared with that of the control group. The relative weights of lymphoid organs are used to investigate the immune status of birds and may be associated with alterations in the function of these organs (Cooper et al. 1966). Among the evaluated immunological parameters, the spleen weight was the most reliable stress parameter. Since it is easily accessible during slaughter, the spleen provides a means of evaluating the avian immune system (Pope 1991). The spleen plays a key role in sieving and storing blood, responding to immune stimuli, producing immunoglobulins and promoting cell differentiation (Tiron and Vasilescu 2008). The present results suggest that spleen differ in their responses to LHy, likely due to different roles of the immune system. When comparing the different concentrations of supplementary LHy, 120 mg/kg can greatly improve both humoral and cellular immunity. Studies have shown that LHy positively affects immune function and response in numerous disease models (Liu et al. 2012; Zhang et al. 2012). The active components of LHy, which have antioxidant and anti-inflammatory activities, may induce positive effects in these organs. Serum immunoglobulin concentrations are often used to evaluate the condition of the immune system due to their important roles in immunity and response to infection (Bai et al. 2017). Immunoglobulins can be divided into five classes, of which IgA, IgG and IgM mainly indicate the level of immune response (Jolles et al. 2009). The present study shows that serum IgA and IgM concentrations tended to increase with increasing doses of LHy, suggesting that high levels of LHy were able to regulate humoral immunity in broilers. The spleen can produce IgM and certain cytokines through the control of B lymphocytes, and cytokines can in turn cause production of IgA and IgG. The present study demonstrates that LHy can improve the immunological function of spleen, indicating that the spleen can have an impact on both B lymphocytes and immunoglobulins.

Oxidative stress is a common process that results in the production of various reactive oxygen species, such as hydroxyl free radicals and superoxide anions (Bai et al. 2017). Mounting evidence indicates that when ROS concentrations exceed the body’s antioxidant protection capabilities, proteins, nucleic acids and other biological macromolecules become damaged. In addition, high levels of the lipid peroxidation byproduct, MDA, cause tissue damage, leading to the development of disease (Yu 1994). Moreover, antioxidant enzymes have an important role in eliminating free radicals and ROS. Studies support the potential therapeutic use of LHy due to its significant cardioprotective and antioxidant effects in vivo (Liu et al. 2010; Zhang et al. 2012). However, to the best of our knowledge, no major studies have evaluated the antioxidant effects of LHy in broilers. In the present study, an increase in antioxidant enzyme activities and a decrease in the levels of MDA were observed in broilers fed the LHy-supplemented diets as compared with those fed the control diet. Similarly, Liu et al. (2010) found that LHy positively affected ROS scavenging, which improved antioxidant capacity. Moreover, several studies have found that the endogenous antioxidant defense system in animals is often insufficient to deal with external stressors (El-far et al. 2016; Abu Hafsa and Ibrahim 2018); therefore, supplementation with suitable antioxidants, such as herbal products, may prevent oxidative stress from causing the production of ROS. Furthermore, several studies have shown that LHy can improve antioxidant levels and modulate pathogen-induced oxidation via the nuclear factor kappa B (NF-kB) signaling pathway (Xu et al. 2014; Jia et al. 2017). Jia et al. (2017) showed that 60 mg/kg LHy was able to significantly inhibit the production of molecules related to the NF-kB signaling pathway in mice. Our present results show that LHy confers antioxidant protection by affecting the activity of antioxidant enzymes and decreasing ROS, in addition to stimulating the immune system and inhibiting pathogen growth, thus reducing inflammation and its associated oxidative damage.

Blood indices have been adopted by the poultry industry as critical markers for the health status of broilers. Dietary LHy supplementation decreased RBC counts and blood hemoglobin levels in broiler chicks, which is the result of increased microcirculation and decreased blood viscosity elicited by LHy. Further studies evaluating the effects of LHy concentration on blood parameters in broilers are needed. The present study reveals that dietary supplementation with 60 or 120 mg/kg LHy was effective in reducing TC and CHOL levels and increasing LDL-C and HDL-C levels during the feeding trial. These results are consistent with those of previous studies (Qian et al. 2012; Zhang et al. 2012). Zhang et al. (2012) found that LHy was able to reduce TG levels and improve HDL-C levels, in addition to reducing the hemorheological status in mice. As important plant compounds, phenols possess the ability to scavenge ROS due to their hydroxyl group (Hakimoglu et al. 2007). Many studies have demonstrated that high concentrations of phenols can decrease serum triglycerides and CHOL (Li et al. 2015; Abu Hafsa and Ibrahim 2018). Therefore, the mechanism by which LHy lowers blood lipid concentrations may be related to its phenolic alkaloid and natural antioxidant properties.

5. Conclusion

Dietary LHy supplementation can improve immune function and antioxidant capacity and reduce serum fat levels in broilers. Following a comprehensive analysis, the ideal range of LHy supplementation was elucidated to be between 60 and 120 mg/kg. Thus, LHy may be considered as a novel herbal additive for use in the poultry production industry. Nevertheless, further research at the molecular level is needed to quantify the effects of these herbal components on cellular and humoral immune functions in broiler chicks.
Disclosure statement

No potential conflict of interest was reported by the authors.

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