Effect of maca powder supplementation to growing quail diets on performance, carcass, serum constituents and hormones, and bone and ileum characteristics

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Abstract
The aim of this study was to investigate the effects of different levels of maca powder supplementation (0.0, 0.5, 1.0, 1.5, 2.0, and 2.5 g/kg) in the diet on performance, carcass characteristics, serum biochemical constituents and hormone concentrations, bone biomechanical properties, and ileum histomorphology in growing Japanese quails. In this 42-day trial, a total of 480 mixed sex Japanese quail chicks, aged 1 day, were randomly distributed among six experimental groups. Each experimental group contained four replicates of 20 chicks each. The addition of 2.0 g/kg of maca powder to the diet significantly decreased body weight, body weight gain compared to the control group (P < 0.05). In addition, with the 1.5 g/kg level of maca powder, feed efficiency improved considerably (P < 0.05). The testis weight increased significantly with the addition of maca powder at 1.0 g/kg level to the diet, and testesteron concentration of serum in male quails was also increased significantly at 1.5 g/kg level of maca powder compared to control group (P < 0.05). The addition of 2.5 g/kg level of maca powder significantly reduced the cholesterol concentration of serum in male quails compared to control group (P < 0.05). The administration of 2.0 g/kg level of maca powder to the diet caused a decrease in shear force (P < 0.05). The addition of maca powder to the diet significantly increased crypt depth and villus surface area at 0.5 g/kg level, villus width at 1.0 g/kg level, and villus height at 2.0 g/kg level in growing quails (P < 0.05). According to the results obtained from the present research, it can be said that the addition up to 2.0 g/kg maca powder to growing quail diets could improve feed efficiency, testesteron concentration of serum, and ileum properties.

Keywords Bone · Hormone · Ileum · Maca powder · Performance · Quail

Introduction
Since approximately the sixteenth century (Leon, 1964), maca (Lepidium peruvianum), known as Peruvian hypocotyls (Zheng et al., 2000), has been grown at an altitude of 3700–4500 in the Andes Mountains in central Peru (Dini et al., 1994), and it is used in medicine for humans and animals (Lentz et al., 2006; Clement et al., 2012). This biennial herbaceous plant belonging to the Brassicaceae family (Toledo et al., 1998) could be adapted greatly to different environmental conditions (Zhang et al., 2016). In the results obtained from various studies, it was declared that the moisture, protein, crude oil, total carbohydrate, and ash content (percentage of dry matter) of maca root differed between 4.63 and 10.40%, 9.56 and 21.90%, 0.59 and 2.20%, 46.1 and 74.8%, and 3.41 and 4.9%, respectively (Dini et al., 1994; Li et al., 2017a, 2017b, 2017c). Maca root also contains secondary metabolites such as glucosinolates, phenylpropanoids...
(polyphenols), isoprenoids (monoterpenes and sesquiterpenes), alkaloids, macaene, and macamides (Dini et al., 2002; Sandoval et al., 2002; Mc Collom et al., 2005; Zhao et al., 2005 Gonzales et al., 2012). A study examining the effects of maca on growing quails was found in the literature, and as a result, it was stated that some performance parameters were affected, while carcass parameters were not affected by treatments (Turgud and Narinç, 2022). Also, Korkmaz et al. (2016) demonstrated that the evaluated parameters such as performance and egg quality were not affected by the addition of maca powder to the diet in laying hens. Therewithal, in some studies conducted in rats, it was clarified that maca improved feed efficiency (Wan et al., 2018). In addition, it advanced fertility and sexual functions without changing hormone levels (Gonzales et al., 2005), it also increased the level of luteinising and follicle-stimulating hormones (Uchiyama et al., 2014) without affecting the oestrus cycle (Gasco et al., 2008). Besides, maca powder increased bone density (Meissner et al., 2006a), and it had effects of protective activity against bone resorption (Zhang et al., 2006; Gonzales et al., 2010) and balancing effect on hormone levels (Gonzales et al., 2005), it also increased advanced fertility and sexual functions without changing lipids (Wang et al., 2009; Meissner et al., 2006a) and lipid (Barraza et al., 2015) levels.

Based on this information, the hypothesis of the current research was maca powder would have a positive effect on performance, reproductive organs, and hormones by improving the digestive system and bone development in growing quails. Therefore, this study was carried out to determine the effects of maca powder added at different levels to growing quail diets on performance, carcass, serum biochemical parameters and hormone concentrations, bone traits, and ileum histomorphology.

Material and methods

Animal material and experimental diets

The current experiment was carried out to randomized arrangement design with six trial groups. A total of 480 1-day-old Japanese quail chicks were randomly distributed among six experimental groups. In each experimental group, there were four replicates, each with 20 quail chicks. For 42 days, the chicks were fed six experimental diets containing six levels of maca powder (0.0, 0.5, 1.0, 1.5, 2.0, and 2.5 g/kg). The basal diet was prepared as isocaloric and isonitrogenic according to the NRC (1994) recommendation for growing quail (Table 1). The distribution rates of female quail chicks in the groups are 50.00%, 55.00%, 53.75%, 52.50%, 52.50%, and 56.25%, respectively. The chicks were raised in cages in environmentally controlled house. During the trial, ahemeral lighting (23 h/day) was applied; water and feed were given ad libitum.

Table 1 Basal diet and its calculated nutrient contents

| Ingredients            | %       | Nutrient contents | %       |
|------------------------|---------|-------------------|---------|
| Corn                   | 51.90   | Metabolisable energy, kcal/kg | 2900    |
| Soybean meal           | 41.50   | Crude protein     | 24.02   |
| Soybean oil            | 2.80    | Calcium           | 1.00    |
| Limestone              | 1.06    | Available phosphorus | 0.50    |
| Dicalcium phosphate    | 1.90    | Lysine            | 1.32    |
| Salt                   | 0.35    | Methionine        | 0.52    |
| Premix                  | 0.25    | Methionine + cystine | 0.99    |
| DL methionine          | 0.24    |                    |         |
| **Total**              | 100.0   |                    |         |

1 Premix provided the following (per kg of diet): trans-retinol (vitamin A) 3.6 mg; cholecalciferol (vitamin D₃) 0.1 mg; α-tocopherol acetate (vitamin E) 75 mg; menadione (vitamin K₃) 5 mg; thiamine (vitamin B₁) 3 mg; riboflavin (vitamin B₂) 6 mg; pyridoxine (vitamin B₆) 5 mg; cyanocobalamin (vitamin B₁₂) 0.03 mg; nicotinic acid 40 mg; pantothenic acid 10 mg; folic acid 0.75 mg; D-biotin 0.075 mg; choline chloride 375 mg; manganese 80 mg; iron 40 mg; zinc 60 mg; copper 5 mg; iodine 0.15 mg; selenium 0.3 mg.

Determination of performance to traits

During the experiment, body weight and feed intake were determined as g/chick by group weighings with 1 g precision scales at the beginning, middle (3rd week), and final (6th week) of the trial. Body weight gain was also found from these measurements. Feed conversion ratio was calculated as g feed/g gain with feed intake/body weight gain formula.

Determination of carcass traits

At the end of the experiment, two quails at 6 weeks of age, one male and one female from each subgroup, were euthanized by cervical dislocation. Carcass, liver, heart, pancreas, ovaries, and testis were weighed with a 0.01-g precision scale, and then their relative weights were determined. Relative weights of carcass and some organs were calculated as percentage of body weight. After data were obtained for slaughtering parameters, bone and ileum samples were taken for biomechanical and histological analysis.

Determination of serum characteristic

At the end of the experiment, one female and one male quail chick (48 quails in total) of similar body weight (223.6 ± 6.3 and 180.6 ± 5.7 g, respectively) from each subgroup were randomly selected and used for blood sampling by the method of heart puncture. Serum was obtained by centrifuging the blood at 3000 rpm for 5 min. The serum was stored at – 20 °C until analysis, and serum glucose, triglyceride,
choline, HDL, total protein, albumin, globulin, creatinine, calcium, and phosphorus levels and follicle-stimulating hormone, luteinising hormone, estradiol, progesterone, and testosterone concentrations were determined in an auto-analyzer (Beckman Coulter LX20) device using commercial kits in a private laboratory.

**Determination of bone biomechanical properties**

Before the measurements, the tibia was kept for 6 h at room temperature and in an air-controlled place. Tibia mechanical properties were determined from the load-deformation curve generated from a three-point bending test (ASAE, 2001) using an Instron Universal Testing Instrument (Model 1122; Instron, Canton, MA, USA) and the TestWorks 4 software package (version 4.02; MTS System Corporation, Eden Prairie, MN, USA). Cross-head speed was fixed at 5 mm/min. The full-scale load of the load cell was 5.000 N. Shear tests on the tibia were performed using a double shear block apparatus. The shear force was applied on a 6.35-mm (0.25 inch) section located in the center of the diaphysis. These tests ensured evaluation of the ultimate shear force and shear stress for each bone. The mean cortex thickness of the fractured tibia, used to determine mechanical properties, was measured using digital calipers (0.001-mm precision) at two points on the central axis of the tibia. The determination of these mechanical properties of bone was regulated from Wilson and Ruszler (1996) and Armstrong et al. (2002).

**Determination of ileum histomorphological to traits**

The samples taken for ileum histomorphological measurements were immediately buffered in 10% formalin and kept in this solution for 72 h. After trimming process, the intact crypt-villus units of each sample were divided into three cross-sectional areas. Preparation and fixation for measurements of villus and crypts were carried out according to the protocol demonstrated by Xu et al. (2003). Villus height was taken from the crypt-villus junction to the tip brush border. In order to obtain accurate results, villus width was measured from the midpoint of the villus between the brush borders of the opposing epithelial cells, as far as possible. The crypt depth was taken at the level of the membranes of the crypt epithelial cells. Villus surface area was calculated with the formula \((2\pi) \times (\text{villus width} / 2) \times (\text{villus height})\) according to Sakamoto et al. (2000).

**Statistical analysis**

Data were analyzed in the SPSS 18.0 software package (SPSS Inc., Chicago, IL, USA) with model of one-way ANOVA, using the group mean as an experimental unit. Differences among the group means were determined by Duncan’s range tests. Additionally, orthogonal polynomial contrasts were used to evaluate the significance of linear and quadratic models to determine the response of the dependent variable to an increasing maca powder level. A probability value of \(P < 0.05\) was considered statistically significant. The model \(Y_{ij} = \mu + a_i + e_{ij}\) was used, where \(Y_{ij}\) is the dependent variable, \(\mu\) is the overall mean, \(a_i\) is the effect of addition of maca powder, and \(e_{ij}\) is the random residual error.

**Results**

**Performance to traits**

The performance traits such as body weight, body weight gain, feed intake, and feed conversion ratio obtained from the current research examining the effects of maca powder added to the growing quail diets are demonstrated in Table 2. While the addition of maca powder to the growing quail diets did not affect the feed intake \((P > 0.05)\), it significantly affected the body weight, body weight gain, and feed conversion ratio \((P < 0.05)\). The highest body weight (6th week) and body weight gain (3rd and 6th weeks) were obtained with the addition of 1.0 g/kg of maca powder to the growing quail diets. However, a decrease in these parameters was observed in these groups with further levels of maca powder compared to the control group, and it was minimum at the supplementation of 2.0 g/kg of maca powder. As of the final of research (0–6 weeks), the highest feed efficiency was observed in the group fed with diet added 1.5 g/kg of maca powder.

**Relative weights of carcass and some organs**

The effect of maca powder addition on the relative weight of carcass and some organs is given in the Table 3. The results showed that the supplementation of the maca powder did not affect the relative weight of carcass and some organs \((P > 0.05)\). However, the weight of the testis was considerably affected while receiving the maca powder 2.0 g/kg.

**Serum biochemical constituents**

Table 4 shows the effects of addition of maca powder to the diet at different levels on selected serum biochemical parameters of growing female and male quails. Serum glucose, total protein, globulin, creatinine, calcium, and phosphorus levels in female quail were not affected by the addition of maca powder to diet \((P > 0.05)\). However, serum albumin level was linearly affected by treatments in female quails \((P = 0.05)\). Albumin concentration significantly decreased with the addition of maca powder to the diet and it was found to be minimum at the highest level (2.5 g/kg). Treatments
did not statistically affect serum glucose, total protein, globulin, and creatinine levels of male quails \((P > 0.05)\). In terms of triglyceride concentration, the highest average was obtained in the group added 1.0 g/kg level of maca powder to the diet. Although there was no significant difference at the 1.0-g/kg level of maca powder compared to the control group (0.0 g/kg) and 0.5-g/kg level, it was considerably higher than the further levels \((P < 0.05)\). The serum cholesterol level of male quails was also significantly affected by the addition of different levels of maca powder to the diet \((P < 0.05)\). Compared to the other experimental groups, the cholesterol concentration was significantly reduced with the supplementation of maca powder at the highest level (2.5 g/kg). In addition, administration of maca powder to growing quail diets quadratically affected the serum albumin concentration in male quails \((P < 0.05)\). Serum albumin level ascended with the addition up to 1.5 g/kg level of maca powder, but it decreased at 2.0 and 2.5 g/kg levels. Addition of the maca powder to the diet, serum calcium and phosphorus \((P < 0.05)\) levels were significantly affected in male quails. Calcium level considerably increased with the addition of 0.5, 1.0, and 1.5 g/kg levels compared to the control group, and the difference between the other groups was statistically insignificant. On the other hand, phosphorus was maximum at the 1.0-g/kg level, and it was minimum in the control group.

**Serum hormone concentrations**

The effects of maca powder addition at different levels to growing quail diets on follicle-stimulating hormone, luteinising hormone, estradiol, progesterone, and testosterone in female and male quails are demonstrated in Table 5. The addition of maca powder to the diet did not have a statistically significant effect on serum hormone levels in female quails \((P > 0.05)\). However, the supplementation of maca...
powder to the diet considerably affected serum follicle-stimulating hormone, luteinising hormone, and testosterone levels \((P < 0.05)\) in growing male quails, but the effect on estradiol level was found to be insignificant \((P > 0.05)\). The highest follicle-stimulating hormone level in males was obtained in the control group without maca powder added, and the difference between the control group and the quails fed with the diet added 0.5, 1.0, and 2.0 g/kg levels of maca powder was found to be significant. The luteinising hormone level quadratically decreased with up to 2.0 g/kg level of maca powder, but it reached the highest mean at the 2.5-g/kg level. The testosterone concentration increased with the administration of maca powder to the diet; the difference between the control group and the 1.5, 2.0, and 2.5 g/kg levels was significant; the difference between 0.5 and 1.0 g/kg levels was insignificant.

### Table 4
Effects of supplementation different levels maca powder to growing quail diets on the selected serum biochemical constituents

| Parameters                  | Levels of maca powder, g/kg | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | \(R^2\) | SEM* | P-value | Linear | Quadratic |
|-----------------------------|-----------------------------|-----|-----|-----|-----|-----|-----|--------|------|----------|--------|-----------|
| **Female**                  |                             |     |     |     |     |     |     |        |      |          |        |           |
| Glucose, mg/dL              | 289                         | 314 | 303 | 291 | 297 | 315 | 20.49 | 10.4  | 0.486    | 0.476  | 0.758     |
| Total protein, g/dL         | 4.85                        | 4.85 | 4.68 | 4.30 | 4.55 | 3.73 | 14.39 | 0.518 | 0.697    | 0.152  | 0.637     |
| Albumin, g/dL               | 1.50                        | 1.43 | 1.35 | 1.38 | 1.18 | 1.15 | 24.97 | 0.106 | 0.349    | 0.050  | 0.651     |
| Globulin, g/dL              | 3.35                        | 3.43 | 3.23 | 2.93 | 3.18 | 2.58 | 12.21 | 0.416 | 0.772    | 0.206  | 0.644     |
| Creatinine, mg/dL           | 0.303                       | 0.330 | 0.318 | 0.293 | 0.315 | 0.323 | 26.79 | 0.011 | 0.301    | 0.767  | 0.718     |
| Calcium, mg/dL              | 20.30                       | 26.05 | 22.35 | 23.75 | 23.53 | 17.75 | 22.88 | 2.761 | 0.410    | 0.432  | 0.108     |
| Phosphorus, mg/dL           | 8.98                        | 9.10 | 7.03 | 8.65 | 8.38 | 7.43 | 16.88 | 0.956 | 0.609    | 0.331  | 0.843     |
| **Male**                    |                             |     |     |     |     |     |     |        |      |          |        |           |
| Glucose, mg/dL              | 318                         | 316 | 338 | 322 | 319 | 24.67 | 9.0   | 0.358 | 0.743    | 0.087  |           |
| Triglyceride, mg/dL         | 224^{a,b}                   | 259^{a,b} | 304^{a} | 183^{b,c} | 158^{b} | 177^{b,c} | 54.52 | 23.9  | 0.009    | 0.009  | 0.165     |
| Cholesterol, mg/dL          | 225^{a,b}                   | 215^{a} | 202^{a} | 196^{a} | 198^{a} | 165^{b} | 56.27 | 9.0   | 0.007    | 0.001  | 0.544     |
| Total protein, g/dL         | 2.95                        | 3.13 | 3.10 | 2.95 | 3.08 | 2.70 | 26.89 | 0.125 | 0.298    | 0.194  | 0.104     |
| Albumin, g/dL               | 1.00                        | 1.03 | 1.05 | 1.05 | 0.98 | 0.88 | 32.30 | 0.046 | 0.182    | 0.082  | 0.039     |
| Globulin, g/dL              | 1.95                        | 2.10 | 2.05 | 1.90 | 2.43 | 1.83 | 3675  | 0.230 | 0.114    | 0.873  | 0.296     |
| Creatinine, mg/dL           | 0.283                       | 0.278 | 0.280 | 0.293 | 0.295 | 0.288 | 8.21  | 0.011 | 0.893    | 0.396  | 0.913     |
| Calcium, mg/dL              | 8.38^{a,b}                  | 8.90^{a} | 8.98^{a} | 8.70^{b} | 8.65^{ab} | 45.87 | 0.112 | 0.036 | 0.506    | 0.003  |           |
| Phosphorus, mg/dL           | 6.30                        | 7.28 | 7.68 | 6.78 | 6.53 | 6.58 | 37.52 | 0.332 | 0.104    | 0.556  | 0.039     |

*Standard error means

### Table 5
Effects of supplementation different levels maca powder to growing quail diets on the serum hormone concentrations

| Parameters                        | Levels of maca powder, g/kg | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | \(R^2\) | SEM* | P-value | Linear | Quadratic |
|-----------------------------------|-----------------------------|-----|-----|-----|-----|-----|-----|--------|------|----------|--------|-----------|
| **Female**                        |                             |     |     |     |     |     |     |        |      |          |        |           |
| Follicle-stimulating hormone, IU/L| 0.213                       | 0.155 | 0.273 | 0.293 | 0.213 | 0.245 | 31.19 | 0.035 | 0.202    | 0.286  | 0.349     |
| Luteinising hormone, IU/L         | 0.170                       | 0.153 | 0.163 | 0.168 | 0.163 | 0.190 | 10.14 | 0.018 | 0.838    | 0.423  | 0.373     |
| Estradiol, pg/mL                  | 56.23                       | 53.23 | 52.27 | 45.79 | 52.47 | 45.25 | 18.74 | 4.221 | 0.545    | 0.131  | 0.833     |
| Progesterone, ng/mL               | 0.750                       | 0.903 | 1.100 | 1.298 | 0.858 | 1.130 | 32.14 | 0.143 | 0.185    | 0.150  | 0.189     |
| Testosterone, ng/dL               | 17.35                       | 22.49 | 23.14 | 26.13 | 25.77 | 27.55 | 20.07 | 3.401 | 0.500    | 0.063  | 0.563     |
| **Male**                          |                             |     |     |     |     |     |     |        |      |          |        |           |
| Follicle-stimulating hormone, IU/L| 0.283^{a}                  | 0.180^{b,c,d} | 0.100^{d} | 0.250^{b} | 0.143^{c,d} | 0.235^{b,c} | 60.20 | 0.026 | 0.003    | 0.433  | 0.005     |
| Luteinising hormone, IU/L         | 0.180                       | 0.140 | 0.140 | 0.138 | 0.140 | 0.190 | 22.55 | 0.019 | 0.420    | 0.810  | 0.045     |
| Estradiol, pg/mL                  | 13.22                       | 13.45 | 18.05 | 16.37 | 21.01 | 18.09 | 24.36 | 2.165 | 0.366    | 0.068  | 0.550     |
| Testosterone, ng/dL               | 217^{b}                     | 253^{ab} | 266^{ab} | 319^{a} | 321^{a} | 338^{a} | 43.49 | 23.1  | 0.050    | 0.002  | 0.579     |

*Standard error means
Bone biomechanical properties

The effect of administration of maca powder to growing quail diets on tibia cortex thickness, cortex cross-sectional area, shear force, and shear stress is given in Table 6. According to the results obtained from the study, tibia cortex thickness and cortex cross-sectional area of quails were not statistically affected by the addition of maca powder to the diet ($P > 0.05$). Tibia shear force was considerably decreased by the addition of 1.5 g/kg and further levels of maca powder to the diet ($P < 0.05$) when compared to the control group. However, the highest shear stress of tibia was obtained at the level of 0.5 g/kg, and the difference between this value and the levels 1.5 g/kg and further levels was significant, but it was found to be similar to the control group ($P < 0.05$).

Ileum histomorphological to traits

The effect of supplementation of maca powder to growing quail diets on ileum villus width, villus height, crypt depth, and villus surface area properties is shown in Table 7. When the results in the table were examined, it was seen that the administration of maca powder to the diet significantly affected ileum histomorphological parameters ($P < 0.05$). Villus width was significantly increased with levels of 1.0 g/kg and further levels, compared to the control group. In addition, villus height considerably improved at maca powder levels except for 1.0 g/kg compared to the control group, and the increase at 2.0 and 2.5 g/kg was more pronounced. The crypt depth and villus surface area were significantly increased with the addition of maca powder to the diet, and the difference between all treatment groups and the control group was considerably significant.

Discussion

Performance to traits

Performance traits are indicators of physiological processes and metabolic incidents in animals. In the current study examining the effects of different levels of maca powder added to growing quail diets, treatments considerably affected performance traits, excluding feed intake. In research conducted on growing quails, contrary to the current results, it was reported that body weight and feed efficiency were not affected in quails fed with diets containing of 0.05 and 0.1% maca powder, but feed intake increased at both levels compared to the control group (Turgud and Narınc, 2022). At the same time, Korkmaz et al. (2016) stated that the mentioned performance traits were not significantly affected by maca powder added to the diet at different levels (5 and 10 g/kg) in laying hens. Although not conducted on poultry in the literature, there are some other studies examining the effects of maca powder on different animal species. In the results of the studies conducted in rats, it was reported that maca powder did not affect the body weight or feed intake (Zhang et al., 2006; Uchiyama et al., 2014). However, in some other studies, it was stated that maca reduced body weight in hamsters (Wan et al., 2018) or rats (Meissner et al., 2006b; Wang et al., 2009). The results of the studies given

| Parameters                  | Levels of maca powder, g/kg | $R^2$ | SEM* | $P$-value | Linear | Quadratic |
|-----------------------------|-----------------------------|-------|------|-----------|--------|-----------|
| Cortex thickness, mm        | 0.438 0.413 0.431 0.429 0.406 0.406 | 11.65 0.019 0.790 0.297 0.822 |
| Cortex cross-sectional area, mm² | 1.533 1.342 1.492 1.553 1.478 1.431 | 26.85 0.057 0.300 0.935 0.771 |
| Shear force, N              | 214a 206ab 212ab 188bc 188bc 170c | 57.13 7.0 0.006 0.001 0.203 |
| Shear stress, N/mm²         | 139.4abc 153.6a 143.1ab 121.9a 127.8bc 118.9c | 54.12 6.08 0.010 0.002 0.418 |

*Standard error means

| Parameters                  | Levels of maca powder (g/kg) | $R^2$ | SEM* | $P$-value | Linear | Quadratic |
|-----------------------------|------------------------------|-------|------|-----------|--------|-----------|
| Villus width, µm             | 102.3b 103.2b 116.0a 117.2a 116.4a 113.2a | 6.97 2.76 <0.001 <0.001 0.003 |
| Villus height, µm            | 663ab 758bc 717cd 780b 917a 917a | 22.53 20.5 <0.001 <0.001 0.343 |
| Crypt depth, µm              | 77.79a 92.03a 91.43a 94.95a 101.40a 100.79a | 5.01 3.891 <0.001 <0.001 0.193 |
| Villus surface area, mm²     | 0.216d 0.250e 0.260d 0.291b 0.336a 0.328a | 17.46 0.011 <0.001 <0.001 0.390 |

*Standard error means
above disagree with the current research results. As Beharry and Henrich (2018) declared, the effects of maca powder or extract depend on parameters such as animal species, physiological biomarker, and experimental period, that is to say the susceptibility of the selected trial model systems. With this, performance traits could differ from the species of animal, breed, age, physiological period, environmental conditions, and raw materials used in the diets. For this reason, the mentioned factors should be taken into consideration when evaluating these parameters.

Relative weights of carcass and organs

In the current study that evaluated the effects of maca powder addition to the growing quail diets, carcass, liver, heart, pancreas, and ovary weights were not considerably affected by the treatments, while testis weight significantly increased. The results obtained by Turgud and Nariç (2022), who examined the effects of maca powder added at 0.05 or 0.1% levels to the growing quail diets, were similar to the present study in terms of carcass yield. In another research conducted on the issue, Gonzales et al. (2001b) stated that the aqueous extract of maca, used twice a day at the level of 66.7 mg/mL, ascended testis weight in rats. Most studies in the literature examined the effects of the plant on parameters such as sperm production (Gonzales et al., 2006), sperm quality (Melnikovova et al., 2015), ejaculation number (Zhang et al., 2016), and sexual activity (Avelar et al., 2016) rather than testis weight. However, Latif et al. (2008) noted that the low testis weight is also a marker of a possible change in the androgen status of the individual. While the same researchers expressed the importance of the pituitary in maintaining testis size and weight, Corbier et al. (1978) stated that there was a strong correlation between serum gonadotropins and testis weight. The significant escalate in luteinising hormone, which is effective in testosterone secretion, with increasing maca levels in the current experiment could be associated with an enlargement in testis weight. Therewithal, the mechanisms by which maca could affect the male or female reproductive system were expected to be clarified. Its effect on the reproductive system was primarily attributed to the lipid fraction of the plant containing fatty acids and macamides (Zheng et al., 2000; Hudson, 2008). Macamides and macaenes, which represented long chain saturated fatty acids and polyunsaturated fatty acid groups, are secondary metabolites in the plant and their amides are typical for this plant (Zheng et al., 2000). Another hypothesis is that this effect can be due to the influence of potentially active compounds such as alkaloids, isothiocyanates, and glucosinolates (Ruiz-Luna et al., 2005). One of these active compounds, indoly-3-methyl (glucobrassicin), a glucosinolate, could modulate androgenic activity as it can enzymatically hydrolyse 3,3-diindolylmethane, which is known as a specific antagonist of the androgen receptor (Chang et al., 1999; Le et al., 2003).

Serum biochemical constituents

In the current study, among the serum biochemical parameters, albumin was only affected by treatments and decreased significantly, in female quails. In male ones, on the other hand, triglyceride and cholesterol concentrations considerably decreased, and albumin, calcium, and phosphorus levels were affected by the treatments. There are some research results conducted on the issue in the literature. In one of these studies, contrary to the current trial, Canales et al. (2000) expressed that the addition of maca to the diet in mice increased the level of total serum proteins and albumin. However, in the aforementioned research, the use of maca at the level of 30% in the diet and as cooked is an issue that should be considered when comparing these two studies. Wan et al. (2018) stated that the supplementation of 300, 600, or 1200 mg/kg aqueous maca extract to the diet of male hamsters given high levels of fructose decreased cholesterol at all levels, while triglyceride concentration increased at all levels except for 300 mg/kg. These results agree with the current study in terms of cholesterol but disagree with regard to triglycerides. In another study, it was reported that blood glucose and plasma and liver cholesterol and triglyceride levels decreased when 10 g/kg of maca powder was added to the diets of rats and mice with hereditary hyper-triglyceridemia fed with diet containing high levels of sucrose. At the end of the experiment, the researchers noted that maca could be used in the prevention and treatment of chronic diseases (Vecera et al., 2007). With this, contrary to the present results, some other studies demonstrated that the administration of maca powder to the diet of rats did not affect cholesterol and triglyceride concentrations (Meissner et al., 2006b) and calcium and phosphorus levels (Zhang et al., 2006). In the present study, it was observed that the serum calcium level significantly increased in male quails. However, research did not find about this issue in the literature. It is already known that maca is rich in calcium (Peres et al., 2020). On the other hand, the reason for the increase in the serum level of calcium in male ones draws attention. In this regard, Hope et al. (1992) declared that intestinal calcium transport was suppressed by estrogen before sexual development was completed in female rats and the reason why this effect was not observed in males could be due to the fact that males are less sensitive to estrogen. Researchers also reported that gonadal status was directly proportional to duodenal calcium transport in males in which sexual development did not yet complete. Although quality, number, and motility of sperm were not evaluated in the current study, it can be said that high testosterone concentrations could support the above argument.
Serum hormone concentrations

In this study which examined the effects of maca powder addition to growing quail diets, treatments did not significantly affect serum hormone concentrations in female quails, but all parameters were affected in males, except for estradiol. Treatments decreased follicle-stimulating hormone and increased luteinising hormone and testosterone concentrations. Among the pituitary hormones that were affected from maca powder addition to diet in current experiment, follicle-stimulating hormone activates sperm production, and luteinising hormone stimulates testosterone secretion and sperm maturation. Testosterone is also an important hormone in the formation of masculine characteristics in males, in addition to sperm production. Some data in the literature showed that the use of additives for sexual activity did not affect considerably the males with normal serum testosterone levels (Gonzales et al., 2003). However, the reason for the rise in serum testosterone concentration with increasing maca powder levels in this trial can be related to the irregularity of hormones since quails were in the sexual maturity stage. In fact, previous researches were also claimed that the effects of maca on fertility and sexual activity can be modulated by the hypothalamic-pituitary axis through regulation of hormone secretion, but studies in both humans and animals presented that treatment with maca did not affect serum reproductive hormone levels (Gonzales et al., 2002). Another hypothesis, on the other hand, is that maca can contain testosterone-like compounds (Gonzales et al., 2003). Another reason could be the enzymatic digestion of the androgen receptor antagonist called 3,3-diindolylmethane, mentioned in the previous parts, by a glucosinolate (Chang et al., 1999; Le et al., 2003). Finally, the plant-specific macaenes and macamides, again also discussed in the previous parts, can be basis of this effect (Zheng et al., 2000; Hudson, 2008).

In one of the researches conducted in the literature on the issue, De la Cruz ve Arroyo (2012) stated that the testosterone level increased in mice fed with diets added 2 g maca per kg body weight. In another study were used as animal material of mice, it was noted that 5 g/100 mL of maca extract supplemented to drinking water increased the blood testosterone level in males and this increase was due to the synergistic effect of the saponin, arginine, lead, and vitamin E contained in maca (Oshima et al., 2003). Contrary to the current study, in studies conducted in men, it was stated that the gelatinized form containing 1.75 g daily (Melnikovova et al., 2015) and 1.5 or 3 g/day maca powder (Gonzales et al., 2003) did not affect the serum follicle-stimulating hormone, luteinising hormone, and testosterone level. Gonzales et al. (2001a) also identified that maca at 1500 or 3000 mg/day level increased sperm count and motility in each ejaculation without affecting these hormones in men. A research carried out in stallions demonstrated that the 4-g/100 kg body weight of maca did not affect serum testosterone levels (Del Prete et al., 2018).

Bone biomechanical properties

In this trial, cortex thickness and cortex cross-sectional area were not affected statistically by the supplementation of maca powder to the diet, but shear force and shear stress significantly decreased. Bone is a dynamic tissue that is affected by physiological factors, nutrition, and physical conditions such as mechanical stress and physical activity. Regarding the effect of hormones on bone, Rath et al. (1996) explained that the enlarged testosterone concentration increased bone breaking strength. In the literature, only one research was found that examined these parameters. Zhang et al. (2006) stated that the administration of 0.096 and 0.24 mg/kg maca ethanol extract to the diets of ovariectomized rats did not significantly affect the femoral shear force and shear stress parameters. Other results obtained from the study, which did not use maca powder, demonstrated that the use of low levels of oil mixture obtained from aromatic plant extracts advanced tibia shear force and shear stress, but as the level increased, bone biomechanical properties were negatively affected (Olgun, 2016).

Ileum histomorphological to traits

The results from the current research that examined the effect of maca powder addition to growing quail diets demonstrated that villus width, villus, height, crypt depth, and villus surface area increased significantly. Villus and crypts are two important components of the absorptive capacity of the small intestine (Heydarian et al., 2020). The production of enterocytes and desquamation in the crypts reflects a dynamic balance in the regeneration of the intestinal epithelium (Su et al., 2021). There is no study in the literature that evaluated the effects of maca on the histology of the small intestine. However, it was suggested to be used as a laxative in malabsorption syndrome (Aliaji and Aliaji, 1998) due to its digestive properties (Canales et al., 2000). According to Jin et al. (2018), on the other hand, daily administration of maca at the level of 0.54, 1.08, and 2.16 g/kg body weight to male and female mice with gastrointestinal motility disorder stimulated the repulsion of gastrointestinal contents. Although not related to maca, it was indicated that the essential oil mixture of active ingredients of certain aromatic plants did not affect the villus height in broilers but decreased the crypt depth with increasing level of maca powder (Su et al., 2021). Again, Kumar et al. (2017) clarified that essential oil obtained from an aromatic plant reduced the villus width and villus surface area, while the villus height and crypt depth were not significantly affected by the treatments.
Conclusions

In conclusion, it can be said that maca powder positively affected feed efficiency, testis weight, development of the ileum, cholesterol, calcium, and testosterone concentrations of serum up to 2.0 g/kg level but negatively affected the body weight and tibia traits in growing quails.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by O. Olgun, E.T. Gül, A.E. Tüzün, and A. Yıldız. The first draft of the manuscript was written by O. Olgun, E.T. Gül, A.E. Tüzün, and A. Yıldız. All authors read and approved the final manuscript.

Data availability The authors declare that all the data and materials used in this study comply with field standards and available on demand.

Code availability Not applicable.

Declarations

Ethics approval The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received. The authors confirm that they have followed EU standards for the protection of animals used for scientific purposes.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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