The effect of dietary cadmium supplementation on performance, egg quality, tibia biomechanical properties and eggshell and bone mineralisation in laying quails

O. Olgun†

Department of Animal Science, Faculty of Agriculture, Selcuk University, 42075 Konya, Turkey

(Received 13 November 2014; Accepted 19 March 2015; First published online 21 April 2015)

The aim of this study was to investigate the effects of different levels of cadmium supplementation (0, 5, 10, 20, 40 and 80 mg/kg) in the diet on performance, egg quality, tibia biomechanical properties and eggshell and bone mineral contents in laying quails. In this 10-week trial, a total of 96 laying quails, aged 21 weeks, were randomly distributed among six experimental groups. Each experimental group contained four replicates of four birds each. The performance parameters were adversely affected quadratically when cadmium was added to the diets in the concentrations of 20 mg/kg and above (P < 0.01). The specific gravity and eggshell weight were maximal with the addition of 20 mg/kg cadmium to the diet. The biomechanical properties of the tibia were negatively affected by cadmium supplementation in quails (P < 0.05). The eggshell boron content decreased linearly (P < 0.001) with cadmium supplementation to the diet. The cadmium content in bone increased when cadmium was added to the diets (P < 0.001). The bone boron concentration decreased as dietary cadmium supplementation was increased (P < 0.001).

Keywords: cadmium, bone, eggshell, performance, quail

Implications

Cadmium (Cd) is known as a toxic element for living organisms. However, low levels of Cd added to rations are also reported to have positive effects. In the present study, high levels of added Cd were toxic; however, when added in small amounts, positive effects were observed. There was a negative correlation between Cd and boron concentration in bones.

Introduction

Numerous reports have shown that exposure to cadmium (Cd), which is very toxic and non-essential for poultry, results in limitations on growth, increased mortality and decreased egg production (EP) and eggshell quality (Leach et al., 1979; Nolan and Brown, 2000; Sant’Ana et al., 2005; Rahman et al., 2007). Leach et al. (1979) indicated that the addition of Cd (48 mg/kg) to the diets of laying hen markedly decreased EP and eggshell thickness during a 48-week trial period. Similarly, Rahman et al. (2007) showed that exposure to Cd (0.1 to 10 mg/kg BW injection) decreased EP and eggshell thickness in quails.

Bones not only provide structural support for birds but are also an important mineral source for metabolic requirements such as for the formation of the eggshell in female birds. Cd has adverse effects on minerals such as calcium (Ca), which is the main component of bones and the eggshell. It has been reported that exposure to Cd decreased bone resistance and mineral levels in bones in rats (Brzoska and Moniuszko-Jakoniuk, 2004; Brzoska et al., 2005).

Cd is known to be toxic for humans and animals (Friberg et al., 1992; Jarup, 2002; Sataru et al., 2003; Jemai et al., 2007), but the results of some studies indicate that it may be useful when low levels are added to diets (Leach et al., 1979; Bokori and Fekete, 1995; Pribilincova and Marettova, 1996; Rahman et al., 2007). Leach et al. (1979) reported a positive effect of Cd supplementation (3 mg/kg) on EP during a 12-week study in laying hens. Pribilincova and Marettova (1996) reported that fertilisation rates and hatchability were not affected by Cd administration, with the best results observed in hens fed 3 mg/kg Cd. Similarly, Rahman et al. (2007) reported that Cd administration significantly increased the shell membrane weight after injections of 0.1 and 0.3 mg/kg BW in quails. The mechanisms behind these effects are unknown, and may be the result of antibiotic or pharmacological actions (NRC, 2005).

The purpose of this study was to determine the effect of different levels of dietary Cd supplementation on performance, egg quality, tibia biomechanical properties and mineral
contents of bone and eggshell in laying quails. Another objective of this study was to determine whether low levels of Cd added to the diets of quails had a positive effect on these parameters.

Material and methods

A total of 96 Japanese layer quails that were 21 weeks old were randomly distributed among six experimental groups. In each experimental group, there were four replicates, each with four quails. For 10 weeks, the birds were fed six experimental diets containing six levels of Cd as Cd sulphate (Sigma-Aldrich Chemie GmbH, Steinheim, Germany) (0, 5, 10, 20, 40 and 80 mg/kg). The experimental diets were balanced to meet or exceed the nutrient requirements of the Japanese quail (NRC, 1994) and formulated to be isocaloric and isonitrogenous, with only the levels of Cd in the diets being different (Table 1). The birds were housed in an environmentally controlled room, equipped with 24 metal battery cages (30 × 35 × 20 cm). They were offered feed and water ad libitum throughout the experiment (21 to 32 weeks of age). Light was provided for 16 h/day from 0600 to 2200 h throughout the experimental period. They were housed in individual layer cages in an environmentally controlled room (23 to 25°C). Criteria specified by the National Institute of Health Guide for the Care and Use of Laboratory Animals were followed during the study period.

The BW of the hens was recorded by weighing the hens at the beginning and at the end of the experiment. EP was recorded daily. Feed intake (FI) was calculated as the average for the sub-group, and egg weight (EW) was recorded bi-weekly. Egg mass (EM) was calculated from the bi-weekly EP and EW data by: \( EM = (EP \times EW)/\text{Period (days)} \). The feed conversion ratio was calculated using the following formula: FCR = FI/EM. The eggs were examined to determine the eggshell quality characteristics (specific gravity, shell breaking strength, shell weight and shell thickness) for all the eggshell quality characteristics (specific gravity, shell breaking strength, shell weight and shell thickness) for all the experimental groups containing six levels of Cd as Cd sulphate for the sub-group, and egg weight (EW) was recorded daily. Feed intake (FI) was calculated as the average for the sub-group, and egg weight (EW) was recorded bi-weekly. Egg mass (EM) was calculated from the bi-weekly EP and EW data by: \( EM = (EP \times EW)/\text{Period (days)} \). The feed conversion ratio was calculated using the following formula: FCR = FI/EM.

<table>
<thead>
<tr>
<th>Item</th>
<th>g/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>560.0</td>
</tr>
<tr>
<td>Soya bean meal</td>
<td>305.0</td>
</tr>
<tr>
<td>Sunflowers meal</td>
<td>25.0</td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>34.7</td>
</tr>
<tr>
<td>Limestone</td>
<td>56.0</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>11.6</td>
</tr>
<tr>
<td>Salt</td>
<td>3.5</td>
</tr>
<tr>
<td>Premix(^2)</td>
<td>2.5</td>
</tr>
<tr>
<td>DL methionine</td>
<td>1.7</td>
</tr>
<tr>
<td>Total</td>
<td>1000.0</td>
</tr>
</tbody>
</table>

Chemical composition

<table>
<thead>
<tr>
<th>Metabolisable energy (MJ)</th>
<th>12.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP (g/kg)</td>
<td>200.0</td>
</tr>
<tr>
<td>Lysine (g/kg)</td>
<td>10.48</td>
</tr>
<tr>
<td>Methionine (g/kg)</td>
<td>4.52</td>
</tr>
<tr>
<td>Methionine + cystine (g/kg)</td>
<td>8.24</td>
</tr>
<tr>
<td>Calcium (g/kg)(^2)</td>
<td>23.27</td>
</tr>
<tr>
<td>Total phosphorus (g/kg)(^2)</td>
<td>4.70</td>
</tr>
<tr>
<td>Non-phytate phosphorus (g/kg)</td>
<td>3.50</td>
</tr>
<tr>
<td>Cadmium (mg/kg)(^2)</td>
<td>0.32</td>
</tr>
</tbody>
</table>

TestWorks 4 software package (version 4.02; MTS System Corporation, Eden Prairie, MN, USA). The cross-head speed was constant at 5 mm/min. The full-scale load of the load cell was 5.000 N. Shear tests were performed on the tibia using a double-shear block apparatus. The shear force was exerted over a 6.35-mm (0.25 inch) section located at the centre of the diaphysis. These tests enabled the ultimate shear force and shear stress to be evaluated for each bone. An average wall thickness (cortex thickness) of the tibia was measured using digital callipers (precision of 0.001 mm) at two points on the central axis of the broken tibia that was used to determine the mechanical properties. These mechanical properties of the bone are described by Wilson and Ruszler (1996) and Armstrong et al. (2002).

Tibia and eggshell mineral contents were determined using MarsXpress Technology Inside an Inductively Coupled Plasma Atomic Emission Spectrometer (Vista AX CCD Simultaneous ICP-AES, Varian, Mulgrave, Australia). Approximately 0.20 g of dried sample (bone with marrow removed) was introduced into a burning cup and 5 ml nitric acid, 3 ml perchloric acid and 2 ml hydrogen peroxide were added. The sample was incinerated in a MARS 5 Microwave Oven (CEM, Corp., Mathews, NC, USA) at 190°C and 1.207 kPa pressure, and subsequently diluted to 50 ml with distilled water. The mineral concentrations were determined using an ICP-AES (Skujins, 1998).

Data were analysed by one-way ANOVA using the SPSS 18.0 software package (SPSS Inc., Chicago, IL, USA), using...
the cage mean as an experimental unit. A probability value of $P < 0.05$ was considered statistically significant. Orthogonal polynomial contrasts were used to assess the significance of linear and quadratic models to describe the response of the dependent variable to a rising Cd level.

### Results

The body weight change (BWC), EP, EW, EM, FI, FCR and mortality results are presented in Table 2. In the present study, the addition of Cd to the diets influenced BWC, EP, EW, EM, FI, FCR and mortality. The addition of increasing levels of Cd to the diets caused the BWC and EW to decrease linearly ($P < 0.001$). The dietary supplementation of Cd quadratically influenced EP, EM and FI ($P < 0.001$, $P < 0.001$ and $P < 0.01$, respectively). The EP, EW and FI were unaffected by increasing Cd levels to 10 mg/kg and then declined with further supplementation. The diets supplemented with Cd also showed significant quadratic ($P < 0.001$) effects on FCR and mortality in the quails. The diet supplemented with 80 mg/kg Cd increased FCR and mortality markedly in the quails.

The eggshell quality parameters such as cracked-broken egg, specific gravity, egg breaking strength, eggshell weight and eggshell thickness are presented in Table 3. The eggshell parameters were not examined in the group that received 80 mg/kg Cd because these birds did not produce enough eggs. There was a linear effect of Cd on cracked-broken egg ($P < 0.05$) and egg breaking strength ($P < 0.05$); therefore, the cracked-broken egg and egg breaking strength were negatively influenced by the additional dietary Cd. In this experiment, the specific gravity and eggshell weight were affected quadratically ($P < 0.01$ and $P < 0.001$, respectively) by the addition of Cd, reaching a maximum with a supplementation level of 20 mg/kg Cd in the diet. However, it decreased considerably with further addition of Cd. The eggshell thickness increased quadratically ($P < 0.01$) with the addition of Cd, but it was minimised by the addition of 40 mg/kg Cd.

The biomechanical properties of the bones in the quails supplemented with Cd are shown in Table 4. The cortical thickness and cortex cross-sectional area were not significantly affected by the dietary Cd levels. The shear force decreased quadratically ($P < 0.05$) when Cd was supplemented in the diets of quails. The shear stress also decreased linearly ($P < 0.001$) in quails supplemented with Cd.

The dietary Cd supplementation did not significantly change the Ca, phosphorus or magnesium contents in the eggshell, or phosphorus and magnesium concentrations in the bones (Table 5). Cd could not be detected in the eggshells. The boron concentration in the eggshells decreased linearly ($P < 0.001$) with dietary Cd levels. The addition of Cd to the diet caused the concentration of Cd in the bones to increase quadratically ($P < 0.001$). In contrast, the concentration of boron in the bones decreased quadratically ($P < 0.001$) with the addition of Cd. The Ca content in the bones was influenced ($P < 0.05$) by dietary Cd supplementation and the effect was maximal at the supplementation level of 5 mg/kg Cd.

### Table 2: Effect of dietary supplementation of cadmium on the performance in quails

<table>
<thead>
<tr>
<th>Cadmium (mg/kg)</th>
<th>P-value of contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
</tr>
<tr>
<td>s.e.m.$^1$</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>61</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td></td>
</tr>
<tr>
<td>67</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

$^1$Each value represents the mean of four replicates.

### Table 3: Effect of dietary supplementation of cadmium on the eggshell quality in quails

<table>
<thead>
<tr>
<th>Cadmium (mg/kg)</th>
<th>P-value of contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
</tr>
<tr>
<td>s.e.m.$^1$</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>61</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td></td>
</tr>
<tr>
<td>67</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

$^1$Each value represents the mean of four replicates.

$^2$nd: not determined (because of insufficient eggs).
Discussion

In the present study, the addition of Cd, especially 40 and 80 mg/kg, to the diet had a negative impact on performance parameters. These results agree with previous reports (Vodela et al., 1997; Nolan and Brown, 2000; Sant’Ana et al., 2005; Rahman et al., 2007). However, some studies have reported that low levels of Cd added to diet (3 mg/kg) or water (1.5 mg/l) had a positive effect on performance parameters (Leach et al., 1979; Pribilincova and Marettova, 1996; Toman et al., 2005). In this study, the FCR was the best in quails fed 10 mg/kg Cd.

The addition of Cd to the diet resulted in a quadratic weakening of the tibia shear force. These results agree with previous reports (Brzoska and Monioszko-Jakoniuk, 2004 and 2005). Brzoska and Monioszko-Jakoniuk (2004) demonstrated that exposure of female rats to Cd (1 mg/l) significantly decreased the ultimate load and stiffness. Another study by the same researchers revealed that exposure to 1 mg/l Cd did not affect the mechanical properties of the bone, but exposure to 50 mg/l Cd markedly reduced mechanical properties such as bone resistance, displacement at yield and bone stiffness in male rats (Brzoska and Monioszko-Jakoniuk, 2005). However, Comelekoglu et al. (2007) noted that femur resistance was not affected by 0.5 mg/kg BW injections into rats. Moreover, Brzoska et al. (2010) indicated that low chronic exposure to Cd (1 mg/l) did not have an effect on bone resistance to fracture, whereas moderate (5 mg/l) or relatively high (50 mg/l) exposure affected by Cd in quails. On the other hand, Pribilincova and Marettova (1996) stated that eggshell parameters were best in hens fed 3 mg/kg Cd. Similarly, Olgun and Yildiz (2014) reported that the addition of 20 mg/kg to the diet had a positive effect on eggshell quality in quails. Ca is the main component of the eggshell, and the Ca concentration in the eggshell was not affected by the addition of Cd to the diet. For all that, the eggshell quality improved with the addition of 20 mg/kg Cd to the diet; at present, there is no explanation for this observation.

Table 4: Effect of dietary supplementation of cadmium on tibia biomechanical properties

<table>
<thead>
<tr>
<th>Cadmium (mg/kg)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>80</th>
<th>s.e.m.</th>
<th>P-value of contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex thickness (mm)</td>
<td>0.314</td>
<td>0.273</td>
<td>0.265</td>
<td>0.348</td>
<td>0.291</td>
<td>0.304</td>
<td>0.026</td>
<td>0.702</td>
</tr>
<tr>
<td>Cortex cross-sectional area (mm²)</td>
<td>2.49</td>
<td>2.22</td>
<td>2.24</td>
<td>2.86</td>
<td>2.30</td>
<td>2.55</td>
<td>0.20</td>
<td>0.512</td>
</tr>
<tr>
<td>Shear force (N)</td>
<td>150</td>
<td>112</td>
<td>91</td>
<td>105</td>
<td>90</td>
<td>82</td>
<td>5</td>
<td>0.001</td>
</tr>
<tr>
<td>Shear stress (N/mm²)</td>
<td>61.37</td>
<td>51.13</td>
<td>41.65</td>
<td>37.25</td>
<td>39.90</td>
<td>33.13</td>
<td>4.12</td>
<td>0.001</td>
</tr>
</tbody>
</table>

1 Each value represents the mean of four replicates.

Table 5: Effect of dietary supplementation of cadmium on the mineral content of eggshells and bones in quails

<table>
<thead>
<tr>
<th>Cadmium (mg/kg)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>80</th>
<th>s.e.m.</th>
<th>P-value of contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggshell minerals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>33.88</td>
<td>32.21</td>
<td>31.89</td>
<td>32.16</td>
<td>33.46</td>
<td>nd² 1</td>
<td>1.02</td>
<td>0.801</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>0.262</td>
<td>0.275</td>
<td>0.274</td>
<td>0.297</td>
<td>0.237</td>
<td>nd² 1</td>
<td>0.028</td>
<td>0.782</td>
</tr>
<tr>
<td>Magnesium (%)</td>
<td>0.436</td>
<td>0.436</td>
<td>0.434</td>
<td>0.410</td>
<td>0.431</td>
<td>nd² 1</td>
<td>0.011</td>
<td>0.369</td>
</tr>
<tr>
<td>Boron (mg/kg)</td>
<td>6.66</td>
<td>6.12</td>
<td>6.15</td>
<td>5.15</td>
<td>4.74</td>
<td>nd² 1</td>
<td>0.28</td>
<td>0.001</td>
</tr>
<tr>
<td>Bone minerals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium (mg/kg)</td>
<td>0.034</td>
<td>0.251</td>
<td>0.673</td>
<td>0.707</td>
<td>1.533</td>
<td>2.706</td>
<td>0.104</td>
<td>0.001</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>26.53</td>
<td>27.49</td>
<td>27.11</td>
<td>25.28</td>
<td>25.58</td>
<td>25.50</td>
<td>0.65</td>
<td>0.039</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>11.30</td>
<td>11.35</td>
<td>11.50</td>
<td>10.87</td>
<td>10.76</td>
<td>10.68</td>
<td>0.28</td>
<td>0.057</td>
</tr>
<tr>
<td>Magnesium (%)</td>
<td>0.333</td>
<td>0.340</td>
<td>0.349</td>
<td>0.323</td>
<td>0.318</td>
<td>0.324</td>
<td>0.010</td>
<td>0.161</td>
</tr>
<tr>
<td>Boron (mg/kg)</td>
<td>34.30</td>
<td>24.91</td>
<td>20.52</td>
<td>14.95</td>
<td>15.27</td>
<td>14.17</td>
<td>1.14</td>
<td>0.001</td>
</tr>
</tbody>
</table>

1 Each value represents the mean of four replicates.
² nd: not determined (because of insufficient eggs).
seriously increased the risk of fracture of the long bones in males. The addition of Cd to the diet decreased the shear stress of the tibia linearly. Comelekoglu et al. (2007) showed that injection of 0.5 mg Cd/kg BW in rats had no effect on the stress of the femur.

The addition of Cd to the diets decreased the boron content of the eggshells linearly. Previously, Cd supplementation in diets was not shown to affect the boron content of eggshells. However, to our knowledge, only one report concerning the influence of Cd on the mineral content of eggshells is available. Mas and Arola (1985) noted that copper, iron, nickel and zinc contents in eggshells were not affected by injection of 100 μg Cd in 12th-day incubated eggs; however, the nickel and zinc contents of the eggshells were markedly decreased by the injection of 100 μg Cd in 17th-day incubated eggs.

The Cd content of the tibia was quadratically increased by Cd supplementation in the diet. Similar results have also been reported by Brzoska et al. (2001) and Brzoska and Monioszko-Jakoniuk (2005). Brzoska et al. (2001) showed that 50 μg/ml Cd added to the water decreased the levels of Ca, zinc and iron in the tibia and increased the Cd content, but did not affect the magnesium or copper contents. Brzoska and Monioszko-Jakoniuk (2005) showed that Cd levels in the blood and femurs of male rats were increased by the addition of Cd (1, 5 and 50 mg/l) to the water. The Ca concentration of the tibia was linearly influenced by dietary Cd supplementation. These results are in agreement with previous reports by Brzoska and Monioszko-Jakoniuk (2004 and 2005). The addition of Cd to the diets resulted in a decrease in boron concentrations in the tibia.

Cd added to the diets of quails resulted in a deterioration of biomechanical parameters (shear force and shear stress) of the tibia (Table 4) and a decrease in the boron concentrations in the tibia (Table 5). Dietary addition of boron is known to improve the biomechanical properties and mineral concentration of bones (Wilson and Ruszler, 1997 and 1998; Armstrong et al., 2000; Olgun et al., 2012) and stimulate cartilage growth and maturation (Hunt et al., 1994). In this study, we observed a negative relationship between Cd and boron. Therefore, one reason for the negative effect of Cd on bones may be due to a reduction in the boron content of bones.

After consuming a diet containing Cd, especially 40 and 80 mg/kg, for 10 weeks, the quails showed a number of well-known Cd effects such as decreased EP, EW and FL, deteriorated FCR and biomechanical properties of bones and increased mortality. However, the specific gravity, eggshell weight and eggshell thickness improved when low doses of Cd were added to the diet. Cd may be an element that is ultra-trace essential or has a pharmacological effect.

In conclusion, the layer quails fed a diet supplemented with 20 mg/kg Cd showed deteriorated performance parameters. The addition of 40 mg/kg Cd to the diet had a negative effect on eggshell quality parameters. The specific gravity, eggshell weight and eggshell thickness improved upon the addition of 20 mg/kg Cd to the diet. The bone biomechanical properties were negatively affected by dietary Cd supplementation. The eggshell and bone boron content decreased after the addition of Cd to the diets.

Acknowledgements

The quails used in this study were obtained from quails sold commercially by the Selcuk University, Turkey.

References


Mas A and Arola LL 1985. Cadmium and lead toxicity effects on zinc, copper, nickel and iron distribution in the developing chick embryo. Comparative Biochemistry and Physiology Part C: Comparative Pharmacology 80, 185–188.


Mas A and Arola LL 1985. Cadmium and lead toxicity effects on zinc, copper, nickel and iron distribution in the developing chick embryo. Comparative Biochemistry and Physiology Part C: Comparative Pharmacology 80, 185–188.


Olgun O and Yıldız AO 2014. The effects of supplementation boron, zinc and their cadmium combinations on performance, eggshell quality, reproductive and

Olgun


