Effect of Sodium Selenite on Pathological Changes and Renal Functions in Broilers Fed a Diet Containing Aflatoxin B₁

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Abstract: To evaluate the renal toxicity of dietary aflatoxin B₁ (AFB₁) and ameliorating effects of added dietary sodium selenite in broiler, renal histopathological changes, ultrastructural changes, and renal function parameters were monitored at 7, 14, and 21 days of age. Two hundred one-day-old healthy male Avian broilers were divided into four groups, namely control group, AFB₁ group (0.3 mg/kg AFB₁), +Se group (0.4 mg/kg Se), and AFB₁+Se group (0.3 mg/kg AFB₁+0.4 mg/kg Se). Compared with that of the control group, the relative weight of kidney was increased in the AFB₁ group. There were no significant differences between the AFB₁+Se group and the control group. By histopathological observation, the renal epithelia were swelling and necrosis at 7 and 21 days of age. Ultrastructurally, the lipid droplets and expanded endoplasmic reticulum appeared in the plasma of epithelia cells in the AFB₁ group. Enlarged mitochondria with degenerated cristae were observed in the +Se group. Compared with the control group, the contents of serum creatinine and serum uric acid in the AFB₁ group were increased,
while the activity of renal Na\(^+-\)K\(^+-\) ATPase was decreased. When 0.4 mg/kg selenium was added into the diet containing 0.3 mg/kg AFB\(_1\), there were no obvious histological changes in the AFB\(_1\)+Se group, and the contents of the serum creatinine and serum uric acid contents and the activity of renal Na\(^+-\)K\(^+-\) ATPase were close to those in the control group. In conclusion, sodium selenite exhibited protective effects on AFB\(_1\)-induced kidney toxicity in broilers.

Keywords: aflatoxin B\(_1\); sodium selenite; pathological observation; ultrastructural observation; renal function; broiler

1. Introduction

Aflatoxins (AFs) are potent carcinogens that are produced as secondary metabolites of strains of the fungi *Aspergillus parasiticus*, *Aspergillus nomius*, and *Aspergillus flavus* that contaminate agricultural commodities before or under post-harvest conditions [1]. Among a number of confirmed aflatoxins, aflatoxin B\(_1\) (AFB\(_1\)) is the normally predominant and most toxic form [2]. It was well documented that AFB\(_1\)-contaminated products may result in inhibition of growth performance, lesions of liver and kidney, and suppression of immune function, and so on [3–5]. Though AFB\(_1\) is firstly found to be a hepatotoxin, it also could cause damages to renal tissue and reduce renal function in vitro and in vivo [6].

Although a high level of selenium (Se) was toxic to animals, appropriate Se functions as an essential micronutrient in the animal diet. Se is incorporated as selenocysteines, some of which perform important enzymatic functions [7]. Se-deficiency diseases have been identified as reproductive impairment and growth depression [8], and White Muscle Disease [9] in animals. Selenium-containing compounds are important for the health of human beings and animals [10,11]. Appropriate Se could also protect against hepatocellular oxidative damages caused by lipopolysaccharide [12], jejunal apoptosis resulted from AFB\(_1\) [13], and renal damages induced by drugs [14] and some metallic element [15].

The kidney serves several essential roles, including producing urine, filtering blood, and removing harmful waste products [16]. As previous study reported, AFB\(_1\) decreased glomerular filtration rate, tubular reabsorption of glucose, and tubular transport for p-aminohippurate [17], and even cause tumors in kidney [18]. AFB\(_1\) treatment increases the relative weight of the kidney [6] which may be partly related to the presence of vacuolar degeneration of the renal tubules [19]. AFB\(_1\) exposure may markedly increase the level of lipid peroxide, decrease the activities of antioxidase [20], and decrease sodium-phosphate uptake [21]. However, dietary addition of selenium yeast partially counteracted the negative effects of AFB\(_1\) on weight gain and death rate [22]. Dietary Se could relieve liver lesion [23] and immunosuppression [24] induced by AFB\(_1\), and could protect renal cells from oxidative stress in vitro [25], and inhibit AFB\(_1\)-induced apoptosis and cell cycle blockage in renal cells of broiler [26].

Our earlier studies demonstrated that 0.3mg/kg AFB\(_1\) in diet had obvious adverse effects on broilers, and appropriate level of Se supplied in the diet (0.4 mg/kg) could provide optimal protective effects against AFB\(_1\)-induced toxicity in broilers [27,28]. Based on this information, toxin concentrations (0.3mg/kg AFB\(_1\)) and supplemented Se levels (0.4 mg/kg) were chosen in our present
research, and sodium selenite was chosen as the source of supplemented Se. In order to evaluate the effects of dietary sodium selenite on AFB1-induced lesions of kidney, relative weight, pathological and ultrastructural changes of kidney, the contents of serum creatinine and uric acid and the activity of renal \( \text{Na}^+\text{K}^+ \) ATPase were determined. The relationship of these parameters could deepen the knowledge on the mechanisms of renal lesions induced by AFB1 exposure.

2. Materials and Methods

2.1. Chickens and Diets

Two hundred one-day-old healthy male Avian broilers were purchased from a commercial rearing farm (Wenjiang poultry farm, Sichuan province, China) and randomly divided into four equal groups of three pen replicates, namely control group, AFB1 group (0.3 mg/kg AFB1), +Se group (0.4 mg/kg Se) and AFB1+Se group (0.3 mg/kg AFB1+0.4 mg/kg Se). Birds of each experimental group were housed in three cages with electrically-heated units and were provided with water, as well as aforementioned diets, ad libitum for 21 days. AFB1 farinose solid (3 mg) was completely dissolved in methanol (30 mL), and then the 30 mL mixture was mixed into 10 kg corn-soybean basal diet to formulate the AFB1 diet of experimental groups containing 0.3 mg/kg AFB1. The equivalent methanol was mixed into the corn-soybean basal diet to produce the control diet, then the methanol of the diets was evaporated at 98 °F (37 °C) [13]. By hydride-generation atomic absorption spectroscopy, the content of dietary Se in the control group was 0.332 mg/kg. Thus, the concentration of Se in each group was: 0.332 mg/kg (control group), 0.332 mg/kg (AFB1 group), 0.732 mg/kg (+Se group), and 0.732 mg/kg (AFB1+Se group), respectively. Aflatoxin B1 (AFB1) was obtained from Pribolab Pte. Ltd (Singapore, Singapore). All experimental procedures involving animals were approved by Sichuan Agricultural University Animal Care and Use Committee. Nutritional requirements were adequate according to National Research Council (1994) [29] and Chinese Feeding Standard of Chicken (NY/T33-2004).

2.2. Relative Weight of Kidney

At 7, 14, and 21 days of age during the experiment, after the body weight was weighed, six birds in each group were euthanized and necropsied. Kidney was dissected from each chick and weighed after dissecting connective tissue around the organ. Relative weight of kidney was calculated by the following formula:

\[
\text{Relative weight} = \frac{\text{organ weight (g)}}{\text{body weight (kg)}}
\]

(1)

2.3. Histopathological Observation

After weighing, kidneys were fixed in 4% paraformaldehyde for more than 24 h and routinely processed in graded alcohol, and then embedded in paraffin. Thin sections (5 \( \mu \)m) of each tissue were sliced and mounted on glass slide. Slides were stained with hematoxylin and eosin Y. Histological slides were examined on an Olympus light microscope. Histologic lesions were took photographs by Nicon micrographic system (Nicon, Tokyo, Japan).
2.4. Ultrastructural Observation

At 21 days of age during the experiment, three broilers in each group were euthanized and then immediately necropsied. The kidney of each broiler was dissected and then fixed in 2.5% glutaraldehyde for 48 h. After rinsed with phosphate buffer solution, the tissues were postfixed in 2% Veronal acetate-buffered O$_2$O$_4$ for 2 h. After dehydrated in graded alcohol, they were embedded in Araldite. Processing of renal slides for ultrastructural observation was performed according to Reynolds [30]. After obtained by Reichert-Jung Ultracut E (Leica, Germany, UC7), thin sections (70 nm) were stained with uranyl acetate and 0.2% lead citrate. After that, the samples were examined with an electron microscope (Hitachi H-600, Hitachi, Japan).

2.5. Detection of Serum Creatinine and Uric Acid

At 7, 14, and 21 days of the experiment, six chickens in each group were chosen and blood samples were collected through the jugular vein. The serum of each bird was analyzed for detecting the contents of serum creatinine and uric acid according to kit instructions (Jiancheng, Nanjing, China).

2.6. Detection of Na$^+$-K$^+$ ATPase in Kidney

At 7, 14, and 21 days of the experiment, six chickens in each group were euthanized and the renal tissues were immediately collected for detecting the activity of Na$^+$-K$^+$ ATPase. 1 g renal tissue was homogenized with 9 mL normal saline buffer through cell homogenizer in ice bath and centrifuged at 3000 r/min for 10 min to obtain a clear supernatant. The type of centrifuge was TD24-WS of Xiangyi Co. in China. After determining the amount of total protein in the supernatant of the renal homogenate by the method of Bradford (1976) [31], the Na$^+$-K$^+$ ATPase activities was measured by biochemical method following the instruction of reagent kits (Jiancheng, Nanjing, China).

2.7. Statistical Analysis

Statistical analysis was performed with SPSS software for Mac v16.0 (IBM Corp, Armonk, NY, USA). All parameters determined in this study were presented as mean ± standard deviation (mean ± SD). Statistical analyses were performed using one-way analysis of variance or t-test, and Dunnett’s T3 test was employed for multiple comparisons, differences were considered significant at $p < 0.05$ and very significant at $p < 0.01$.

3. Results

3.1. Changes of Relative Weight of Kidney

No significant differences were observed among the four groups at 7 and 14 days of age. At 21 days of age, the relative weight of kidney in the AFB$_1$ group was increased ($p < 0.05$) when compared with those in the control group and +Se group. However, there were no significant differences between the AFB$_1$+Se group and the control group during the experiment. The results were shown in Table 1.
Table 1. Relative weight of kidney (g/kg).

<table>
<thead>
<tr>
<th>Group</th>
<th>7 Days of Age</th>
<th>14 Days of Age</th>
<th>21 Days of Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>10.121 a ± 0.284</td>
<td>8.581 a ± 1.054</td>
<td>6.754 c ± 0.608</td>
</tr>
<tr>
<td>AFB1 group</td>
<td>10.250 a ± 0.257</td>
<td>8.413 a ± 0.749</td>
<td>7.355 a ± 0.460</td>
</tr>
<tr>
<td>+Se group</td>
<td>10.087 a ± 0.413</td>
<td>8.895 a ± 0.404</td>
<td>6.819 bc ± 0.346</td>
</tr>
<tr>
<td>AFB1+Se group</td>
<td>10.057 a ± 0.912</td>
<td>8.674 a ± 0.572</td>
<td>6.949 abc ± 0.226</td>
</tr>
</tbody>
</table>

Note: Data are presented with the means ± standard deviation (n = 5). The difference between data with different lowercase letters (a–c) within a column is significant (a,b,c p < 0.05).

3.2. Pathological Lesions

In the control group, the histological structure was normal, which showed as normal renal tubular epithelial cells with homogeneous plasma, and obvious renal tubular cavity (Figure 1a). At 7 days of age, compared with the control group, the renal cells were degenerated, and the renal tubule’s cavity was almost closed in the AFB1 group. The renal tubular epithelium were mainly granular degeneration or vesicular degeneration, which sometimes showed as hydropic degeneration and sometimes appeared as fatty degeneration with suborbicular small vacuoles in the cytoplasm (Figure 1b). In the +Se group, the renal tubular epithelium was mainly granular degeneration (Figure 1c). There were slightly granular degeneration of the renal tubular epithelium in the AFB1+Se group (Figure 1d).

![Figure 1](image_url)

**Figure 1.** (a) Kidney of the 7-day-old in control group; (b) kidney of the 7-day-old in AFB1 group: the renal cells were swelling and the renal tubules cavity seriously closure; (c) kidney of the 7-day-old in +Se group; (d) kidney of 7-day-old in AFB1+Se group. Bars = 100 μm.
At 14 and 21 days of age, compared with the control group (Figure 2a), the renal tubular epithelial cells in partial regions were necrotic in the AFB₁ group. The necrotic cells appeared pyknotic with shrinking and dark dyeing nuclei and a lighter color of the plasma when compared with the surrounding normal renal tubule (Figure 2b). In the +Se and AFB₁+Se groups, the kidneys had no obvious changes when compared with the control group (Figure 2c,d).

![Image](image_url)

**Figure 2.** (a) Kidney of the 21-day-old in control group; (b) kidney of the 21-day-old in AFB₁ group: a great number of necrotic cells was observed in renal tubular epithelial cells (→); (c) kidney of the 21-day-old in +Se group; (d) kidney of 21-day-old in AFB₁+Se group. Bars = 100 μm.

### 3.3. Electron Microscopic Appearance

At 21 days of age, the ultrastructure of kidneys in the control group appeared normal. In the cytoplasm of proximal convoluted tubular epithelial cells, a great number of mitochondria and rough endoplasmic reticulum were observed (Figure 3a). In the AFB₁ group, affected cells were mainly renal tubular epithelial cells, in which the endoplasmic reticulum expanded and a lot of lipid droplets appeared (Figure 3b). The lipid droplets were also observed in the cytoplasm of vascular epithelial cells (Figure 3c). In the +Se group, the mitochondria in renal tubular epithelial cells were swollen and enlarged (Figure 3d) with irregularly ranked and degenerated cristae (Figure 3e). In the AFB₁+Se group, the ultrastructure of kidneys appeared normal. The normal renal tubular epithelial cells with a lot of mitochondria were observed (Figure 3f).
Figure 3. (a) Kidney of the 21-day-old in control group: proximal convoluted tubular epithelial cell with a great numbers of mitochondria and rough endoplasmic reticulum; (b) kidney of the 21-day-old in AFB$_1$ group: lipid droplets appeared (*); (c) kidney of 21-day-old in AFB$_1$ group: lipid droplets appeared (*); (d) kidney of the 21-day-old in +Se group: The mitochondria were swollen and enlarged (→); (e) kidney of the 21-day-old in +Se group: The cristae of mitochondria were irregularly ranked and degenerated (→); (f) kidney of the 21-day-old in AFB$_1$+Se group: renal epithelial cell with a great number of normal mitochondria.

3.4. Changes of Serum Creatinine and Uric Acid contents

By biochemical detection, from 7 to 21 days of age, the contents of serum creatinine were higher ($p < 0.05$ or $p < 0.01$) in the AFB$_1$ group than those in the control group, and there were no significant differences between the +Se group and the control group. However, when compared with those in the AFB$_1$ group, the content of serum creatinine in the AFB$_1$+Se group were decreased ($p < 0.05$) at 7 and 14 days of age, and was evidently decreased ($p < 0.01$) at 21 days of age.

From 7 to 21 days of age, the contents of serum uric acid in the AFB$_1$ group were increased ($p < 0.05$) when compared with those in the control group. Meanwhile, there were no significant differences between +Se group and control group from 7 to 21 days of age. Compared with those in the AFB$_1$ group, the contents of serum uric acid in AFB$_1$+Se group were decreased ($p < 0.05$) from 7 to 21 days of age. The results were shown in Table 2.
Table 2. Changes of serum creatinine and uric acid.

<table>
<thead>
<tr>
<th>Content</th>
<th>Group</th>
<th>7 Days of Age</th>
<th>14 Days of Age</th>
<th>21 Days of Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control group</td>
<td>1206.126 ± 114.55</td>
<td>1029.423 ± 86.67</td>
<td>1173.729 ± 82.05</td>
</tr>
<tr>
<td>Creatinine (μmol/L)</td>
<td>AFB1 group</td>
<td>1373.289 ± 50.22</td>
<td>1277.720 ± 106.37</td>
<td>1298.965 ± 104.43</td>
</tr>
<tr>
<td></td>
<td>+Se group</td>
<td>1210.832 ± 121.37</td>
<td>1103.771 ± 160.97</td>
<td>1199.336 ± 23.05</td>
</tr>
<tr>
<td></td>
<td>AFB1+Se group</td>
<td>1208.176 ± 122.13</td>
<td>1063.861 ± 96.86</td>
<td>1142.524 ± 80.10</td>
</tr>
<tr>
<td>Uric acid (mg/L)</td>
<td>Control group</td>
<td>55.540 ± 7.08</td>
<td>55.706 ± 5.77</td>
<td>58.626 ± 6.09</td>
</tr>
<tr>
<td></td>
<td>AFB1 group</td>
<td>66.761 ± 10.60</td>
<td>67.441 ± 6.32</td>
<td>69.272 ± 6.68</td>
</tr>
<tr>
<td></td>
<td>+Se group</td>
<td>59.932 ± 5.86</td>
<td>58.804 ± 6.69</td>
<td>59.657 ± 6.30</td>
</tr>
<tr>
<td></td>
<td>AFB1+Se group</td>
<td>54.000 ± 7.17</td>
<td>57.538 ± 9.71</td>
<td>59.089 ± 7.51</td>
</tr>
</tbody>
</table>

Note: Data are presented with the means ± standard deviation (n = 5). The difference between data with different lowercase letters (a–d) within a column is significant (a,b,c,d p < 0.05).

3.5. Changes of Na⁺-K⁺ ATPase in Kidney

At 7 and 21 days of age, the activities of Na⁺-K⁺ ATPase in the AFB₁ group were lower (p < 0.05 or p < 0.01) than those in the control group. There were no significant differences between the +Se group and the control group from 7 to 21 days of age. Compared with those in the AFB₁ group, the activities of Na⁺-K⁺ ATPase in the AFB₁+Se group were increased (p < 0.05) from 7 to 21 days of age. The results were shown in Table 3.

Table 3. Changes of the activity of Na⁺-K⁺ ATPase in kidney.

<table>
<thead>
<tr>
<th>Group</th>
<th>7 Days of Age</th>
<th>14 Days of Age</th>
<th>21 Days of Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>9.661 ± 0.830</td>
<td>9.378 ± 0.761</td>
<td>11.947 ± 2.030</td>
</tr>
<tr>
<td>AFB1 group</td>
<td>8.125 ± 1.208</td>
<td>8.264 ± 1.322</td>
<td>9.007 ± 1.127</td>
</tr>
<tr>
<td>+Se group</td>
<td>9.118 ± 1.109</td>
<td>9.280 ± 0.888</td>
<td>11.407 ± 2.137</td>
</tr>
<tr>
<td>AFB1+Se group</td>
<td>9.675 ± 0.642</td>
<td>9.552 ± 1.065</td>
<td>11.526 ± 1.624</td>
</tr>
</tbody>
</table>

Note: Data are presented with the means ± standard deviation (n = 5). The difference between data with different lowercase letters (a,b) within a column is significant (a,b p < 0.05).

4. Discussion

As we known, the kidney serves several essential roles including producing urine, filtering blood, and removing harmful waste products to maintain organism homeostasis [32]. In our present study, the intake of AFB₁ could increase the relative weight of kidney in chickens. This result is in accordance with previous researches, which showed that an AFB-contaminated diet could increase the relative weight of kidney in broilers [6,33].

The histopathological lesions of kidney in the AFB₁ group include swelling and necrosis of renal epithelium. The cell swelling was appeared at 7 days of age, and the necrosis of renal tubular epithelia was observed at 21 days of age. The gradually deteriorated lesions may be caused by the accumulation of AFB₁ metabolites. The cell swelling (including granular degeneration and hydropic degeneration) of tubular epithelium might be related to the increased relative weight in the AFB₁ group. Ultrastructurally, lipid droplets appearance and endoplasmic reticulum enlargement in renal tubular
epithelial cells were observed in the AFB1 group. Those lesions were coincidence with the vesicular
degeneration of renal tubular epithelial cells in histological observation.

The activities of Na\(^+\)-K\(^+\) ATPase in the AFB1 group were lower than those in the control group, and
markedly increased contents of serum creatinine and serum uric acid were observed. The decrease of
Na\(^+\)-K\(^+\) ATPase activity may be caused by the combination of AFB1 with Na\(^+\)- and K\(^+\)-activated sites [34],
which affects exchange of Na\(^+\) and K\(^+\) in sodium pomp, and the ion exchange imbalances would
accordingly cause sodium and water retention in cells [35]. Thus, the increase of lipid droplets in
cytoplasm and the enlargement of endoplasmic reticulum might be concerned with the cell metabolism
disorders induced by the decline of Na\(^+\)-K\(^+\) ATPase activity. The obvious cell swelling could induce
the occlusion of the renal tubule and then could gradually decrease the excretory function of the
kidney. Therefore, the increased contents of serum creatinine and serum uric acid were deserved in the
AFB1 group, which was in accordance with Mathuria’s study that an elevation of creatinine in serum
was observed in mice receiving aflatoxin-contaminated feeds [36] and Santurio’s observation that
serum uric acid content increased in broilers intaking AFB1 [37]. The histopathological results showed
an occlusion of the renal tubule, which could be a causal relationship in the increase of serum
creatinine and uric acid contents. The increased contents of serum creatinine and uric acid may be
resulted from the excretion disorder of kidney because the kidney rapidly excretes creatinine and uric
acid in avians [38].

The kidney is critical for the urinary system and serves homeostatic functions [32]. Previous studies
found AFB1 could increase relative weight of kidney, decrease renal glomerular filtration rate, tubular
reabsorption of glucose tubular transport for p-aminohippurate [17], urine flow rate, sodium/potassium
excretion, and increasing urine hydrogen ion concentration [39]. In our present study, the inhibition of
relative weight of kidneys, an increased content of serum creatinine and uric acid, and the decline of
activities of Na\(^+\)-K\(^+\) ATPase were observed in the AFB1 group. These results indicated that 0.3 mg/kg
AFB1 could damage the renal function in broilers.

However, Se could effectively protect kidneys from adverse effects caused by AFB1. Previous studies
showed that 0.267 mg/kg–0.6 mg/kg Selenium supplemented could ameliorate the damages induced by
AFB1 to some extent [28,40,41]. In our present study, when 0.4 mg/kg selenium was added into the
AFB1 diet, the AFB1-associated lesions of kidneys, including the increased renal relative weight,
pathological and ultrastructural changes, the increased serum contents of creatinine and uric acid, and
the decreased activities of renal Na\(^+\)-K\(^+\) ATPase were all ameliorated, and there were no significant
differences for these parameters between the AFB1+Se group and the control group. The possible
mechanisms of protective role of sodium selenite might be associated with following factors: (1) Se
was the nucleus of antioxidant selenoenzymes which could alleviate oxidative-stress-associated kidney
injury [42]. Indeed, AFB1-induced tissue injury was mediated through oxidative reaction [28]; (2) Se
could reduce the formation of DNA adducts of aflatoxin in the chick [43,44]; and (3) Se could
attenuate the decreased activity of Na\(^+\)-K\(^+\) ATPase induced by AFB1. Our result showed that Se could
elevate AFB1-depressed Na\(^+\)-K\(^+\) ATPase activity which was accordance with the recent research [45].
Then, the reversal of the imbalance of Na\(^+\)-K\(^+\) ATPase activity could ensure the cellular normal
function. Therefore, 0.4mg/kg selenium supplemented as sodium selenite could appropriately protect
the kidney from pathology lesions and functional changes induced by AFB1 exposure.
5. Conclusions

In conclusion, 0.3 mg/kg AFB₁ could induce an increase in renal relative weight, cause pathological and ultrastructural changes, and have negative effects on renal functions. By contrast, 0.4 mg/kg supplemented selenium could ameliorate the AFB₁-associated damages in kidney in chickens.

Acknowledgments

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Author Contributions

Na Liang and Fengyuan Wang conducted the research, analyzed the data, wrote and revised the paper. Xi Peng and Jing Fang designed the research and corrected the paper. Hengmin Cui, Zhengli Chen, Weimin Lai, Yi Zhou, Yi Geng helped with portions of the research.

Conflicts of Interest

The authors declare no conflict of interest.

References


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