Effects of Silver Nitrate as Alternative to Antibiotic on Production Performance, Bacterial Count and Intestinal Histological Features of Broiler under Escherichia coli Challenge

Daud Khan¹, Naila Chand¹, Muhammad Saeed², Muhammad Tahir³, Alam Zeb⁴ and Rifat Ullah Khan⁵*

¹Department of Poultry Science, Faculty of Animal Husbandry and Veterinary Sciences, The University of Agriculture, Peshawar, Pakistan
²Department of Poultry Science, Cholistan University of Veterinary and Animal Science, Bahawalpur, 6300, Pakistan
³Department of Animal Nutrition, Faculty of Animal Husbandry and Veterinary Sciences, The University of Agriculture, Peshawar, Pakistan
⁴Directorate General (Extension), Livestock and Dairy Development Department Khyber Pakhtunkhwa, Peshawar, Pakistan; ⁵College of Veterinary Sciences, Faculty of Animal Husbandry and Veterinary Sciences, The University of Agriculture, Peshawar, Pakistan

ABSTRACT

Little information is available on silver nitrate as alternative to antibiotic in poultry diet. The aim of the present research was to evaluate the effects of different levels of silver nitrate on the production performance, bacterial count and intestinal histology of broilers under E. coli infection. A total of 800 broilers were assigned to 5 experimental groups: Negative control (birds fed a basal diet and not challenged), positive control (birds fed a basal diet and orally challenged with E. coli O157 H7 at the rate of 1 × 10⁹ CFU/ml; positive control), infected + enrofloxacin, infected + silver nitrate at the rate of 100 mg/kg (SN100) and infected + silver nitrate at the rate of 150 mg/kg (SN150). Overall feed intake, body weight gain, feed conversion ratio (FCR) and dressing percentage were significantly (P<0.05) higher in infected +SN100 compared to positive control. Fecal E. coli count was similar in infected + SN100 and infected + SN150. The pH in gizzard and small intestine was similar (p>0.05) in infected + SN100 and infected + enrofloxacin, however, it was significantly (p<0.01) different from infected + SN150. Villus height, crypt depth, goblet cells and epithelial thickness were significantly (p<0.01) higher in negative control compared to positive control. It was concluded that silver nitrate at the rate of 100 mg/kg has positive effects on growth performance, carcass characteristics, decreased E. coli count and enhanced gut histological features in broilers infected with E. coli challenge.

INTRODUCTION

One of the most likely causes of antibiotic resistance microorganisms is the use of antibiotics in livestock production (Khan et al., 2021). Antibiotics are fed to the birds, often at subtherapeutic doses, to enhance production efficiency, allowing bacterial populations to develop genetic resistance. Because of the development of antimicrobial resistance, the use of antibiotic as growth promoters has been discouraged. The prohibition of antibiotics in Europe was quickly followed by epidemic of bacterial infections. Probiotics and prebiotics (Chand et al., 2016; Tufail et al., 2019), organic acids (Khan et al., 2016, 2022; Abudabos et al., 2017), phytotherapeutics (Ali et al., 2019; Wahab et al., 2019; Ahmad et al., 2020; Alam et al., 2020; Hafeez et al., 2020; Khan et al., 2021; Ullah et al., 2022), vitamins, minerals and other compounds (Khan et al., 2014, 2022; Hafeez et al., 2021) have all been studied as alternatives.
to antibiotics.

Colibacillosis caused by \textit{E. coli} is a prevalent bacterial illness that has economic implications in poultry due to decreased production, higher mortality, and the expense of prevention and treatment. \textit{E. coli} is a severe public-health concern because they may be transmitted to people via the food chain or through direct contact with sick birds. Furthermore, resistant \textit{E. coli} might serve as carriers for other diseases (Ibrahim \textit{et al.}, 2019). Management treatments, infection control, and immunization techniques are all important aspects of avian colibacillosis control (Lutful-Kabir, 2010). In the treatment of chicken colibacillosis, a variety of antibiotic drugs are employed. Antibiotic drugs are often used, resulting in selection pressure that leads to antimicrobial resistance in \textit{E. coli} (Zakeri and Kashefi, 2012).

Silver (Ag$^+$) is a lustrous white metal and known for antimicrobial characteristics even before penicillin was discovered (Klasen, 2000). Silver ions are very efficient against germs, do little damage to the host, and rarely develop resistance. Due to its multifactorial antibacterial activities, silver is an effective tool against wide range bacteria (Hindi \textit{et al.}, 2009). The NRC (2005) concluded that the greatest permissible level of silver in chicken with no deleterious effects. There is little research on the potential for ionic silver to have less negative impacts on broiler or possible \textit{in vivo} effectiveness in a chicken disease model. This is mostly due to the reason that ionic silver may be more harmful to the host than particulate silver, since the dissociation rate of Ag$^+$ is linked with its biological activity. Oral supplementation of silver nanoparticles has effect to silver acetate and silver nitrate (Loeschner \textit{et al.}, 2011; van der Zande \textit{et al.}, 2015) in terms of \textit{in vivo} antimicrobial action (Bouwmeester \textit{et al.}, 2011; Williams \textit{et al.}, 2015).

Silver in particulate form has recently been evaluated as a supplement in poultry as an antibiotic to improve health and growth (Sawosz \textit{et al.}, 2007, 2009; Chauke and Siebrits, 2012; Pineda \textit{et al.}, 2012; Vadalasetty \textit{et al.}, 2018). Because silver ion has antibacterial properties, it has been postulated that it might alter the microbiota makeup of the gastrointestinal tract (GIT), boost feed consumption, and hence improve avian performance in a way similar to antibiotic growth promotion. The objective of the present study is to evaluate silver nitrate as a potential alternative to antibiotic in broiler. Therefore, the goal of this research was to find different concentrations of silver nitrate on growth performance, bacterial count, histopathological changes in dimensions of villus and gut pH in broilers experimentally challenged with \textit{E. coli}.

\textbf{MATERIALS AND METHODS}

All procedures in this study were approved by The Committee on Ethics and Animal Welfare, The University of Agriculture, Peshawar, Pakistan.

\textit{Birds husbandry and experimental design}

A total of 800 one day old chicks of male sex were procured. After one week, chicks were weighed individually and assigned to 5 experimental groups: (1) negative control (NC) group, (2) positive control group (birds were orally challenged with \textit{E. coli} O$_{157}$H$_{7}$ at the rate of $1 \times 10^9$ CFU/ml), (3) infected + enrofloxacin group (challenged with \textit{E. coli} O$_{157}$H$_{7}$ + enrofloxacin (1 mg/kg), (4) infected + SN100 group (challenged with \textit{E. coli} O$_{157}$H$_{7}$ + silver nitrate 100 mg/kg and (5) infected + SN 150 group (challenged with \textit{E. coli} O$_{157}$H$_{7}$ + silver nitrate 150 mg/kg). All treatments began on day 7 of the experiment. The chickens were kept in stainless-steel wire cages with a feeder and a drinker, which provided \textit{ad libitum} feed (Ali \textit{et al.}, 2019) and water. The room temperature was set at 35°C for the first week and subsequently dropped to 25°C at the conclusion of the trial, using a 24-h constant-lighting regimen.

\textit{Oral challenge}

The \textit{E. coli} O$_{157}$H$_{7}$ strain was cultured for 24 h at 37°C in Luria Bertani broth with shaking (120 rpm). On day 7, except NC, all birds were orally challenged with 1.0 mL ($1 \times 10^9$ cfu/mL) of freshly grown \textit{E. coli} O$_{157}$H$_{7}$, using a 1-mL pipette.

\textit{Growth performance}

Birds were weighed on weekly basis to determine body weight. Feed intake was measured on daily basis. The obtained data on weight gain and feed intake was used to calculate feed conversion ratio (FCR). After the removal of the visceral organs the dressed carcass was weighed as percentage of live body weight.

\textit{Sample collection}

Two birds were chosen at random from each replicate, slaughtered, and sampled. For histological analysis, tissue samples from the ilium were measured under a 40X magnification (Olympus Optical Company, Shenzhen, China) using a confocal laser scanning microscope. Each broiler had at least 15 villi that were well-oriented and undamaged when they were measured. The villus height/crypt depth ratio was determined based on the results of these observations.

\textit{Cecal Escherichia coli}

About 0.5 g cecal contents were mixed with 4.5
mL sterile buffered peptone for 1 h, and then diluted ten folds in sterile buffered peptone for an additional h. *E. coli* was isolated from cecal contents by plating them on MacConkey’s agar at 37°C for 24 h and then plating them on MRS agar under anaerobic conditions at 37°C for 24 h. Bacteria were enumerated and represented as total cfu/g digesta, and the log10-transformed data was presented.

**Statistical analysis**

All data were analyzed using a one-way ANOVA in a totally randomized design utilizing statistical software (Statistix” version 17). All means are reported as least-squares means (SEM). The treatment was incorporated as a fixed effect in the statistical model at each stage of the experiment. Before analysis, the data for cecal bacterial enumeration were converted using the log_{10} transformation. The Tukey test was used to test if there were statistical differences between treatments. In order to be declared statistical significant, a P-value of less than 0.05 was required.

**RESULTS**

**Growth performance**

On a weekly basis and over all feed intake data of *Escherichia coli* challenged broilers fed changed levels of silver nitrate is given in Table I. During 2nd week of age feed intake was not significantly different (p>0.05) among the groups. In the trial of the 3rd week, the maximum feed intake (g) data was noted in NC, Infected + enrofloxacin and Infected + SN100. Infected +SN150 and PC showed the lowest feed intake data. During 4th, significantly (P<0.01) higher feed intake was recorded in NC followed by Infected + enrofloxacin and Infected + SN100. During 5th week and overall, significantly (P<0.01) higher feed intake was noted in NC, Infected + enrofloxacin and Infected + SN100. Significantly (p<0.01) lower feed intake was found in PC and infected +SN150 in all stages except week 2. Overall feed intake was significantly (P<0.05) higher in infected +SN100 compared to positive control.

The effect of different levels of silver nitrate on body weight gain (g) in *E. coli* challenged broilers is shown in Table II. Among all groups during 2nd week no significant difference was noted in body weight. In the 3rd and 4th weeks, significantly (p<0.01) higher weight gain was found NC followed by Infected + enrofloxacin and Infected + SN100. Significantly (p<0.01) higher weight gain was recorded in NC followed by infected + enrofloxacin, infected + SN100 and infected + SN150. Overall weight gain was significantly (p<0.01) higher in NC followed by infected + enrofloxacin and infected + SN100. Lowest (p<0.01) weight gain was recorded in PC and infected + SN150.

Table I. Efficacy of the different levels of silver nitrate on the feed intake (g) in broilers infected with *E. coli* challenged.

<table>
<thead>
<tr>
<th>Groups</th>
<th>2nd Week (g)</th>
<th>3rd Week (g)</th>
<th>4th Week (g)</th>
<th>5th Week (g)</th>
<th>Overall (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>336.27±2.85</td>
<td>570.03a±4.67</td>
<td>922.50±7.25</td>
<td>1160.3±4.5</td>
<td>2989.1±18.7</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>333.43±1.52</td>
<td>547.37a±2.73</td>
<td>892.03a±6.31</td>
<td>1130.4±5.3</td>
<td>2903.2±5.8</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>335.7±2.23</td>
<td>563.73±11.11</td>
<td>911.10±4.85</td>
<td>1151.9±7.6</td>
<td>2961.9±23.8</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>334.27±2.20</td>
<td>562.70±10.92</td>
<td>909.90±4.7</td>
<td>1150±8.7</td>
<td>2956.8±24.1</td>
</tr>
<tr>
<td>Infected +SN150</td>
<td>335.20±0.85</td>
<td>557.03±6.35</td>
<td>902.43±6.0</td>
<td>1145.4±3.8</td>
<td>2940.1±6.3</td>
</tr>
<tr>
<td>P-value</td>
<td>0.543</td>
<td>0.0498</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Values bearing different superscript in a row different significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.

Table II. Effect of silver nitrate on body weight (g) in broilers infected with *E. coli* challenge.

<table>
<thead>
<tr>
<th>Groups</th>
<th>2nd Week (g)</th>
<th>3rd Week (g)</th>
<th>4th Week (g)</th>
<th>5th Week (g)</th>
<th>Overall mean (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>257.77±2.02</td>
<td>350.37±7.2</td>
<td>525.20±3.45</td>
<td>547.80±3.04</td>
<td>1681.1±14.52</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>257.83±2.81</td>
<td>329.20±3.7</td>
<td>480.10±5.29</td>
<td>512.43±1.52</td>
<td>1579.6±1.73</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>259.10±3.10</td>
<td>342.70±1.24</td>
<td>513.5±5.29</td>
<td>531.10±6.85</td>
<td>1645.9±7.93</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>258.27±2.76</td>
<td>341.67±5.10</td>
<td>511.57±5.10</td>
<td>528.80±6.71</td>
<td>1640.3±10.76</td>
</tr>
<tr>
<td>Infected +SN150</td>
<td>256.67±1.76</td>
<td>336.10±2.4</td>
<td>501.23±7.33</td>
<td>522.80±4.95</td>
<td>1616.8±3.30</td>
</tr>
<tr>
<td>P-value</td>
<td>0.831</td>
<td>0.0007</td>
<td>&lt;0.001</td>
<td>0.0001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values bearing different superscript in a row different significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.
Table III. Effect of different levels of silver nitrate on FCR in broilers infected with \textit{E. coli} challenge.

<table>
<thead>
<tr>
<th>Groups</th>
<th>2\textsuperscript{nd} Week</th>
<th>3\textsuperscript{rd} Week</th>
<th>4\textsuperscript{th} Week</th>
<th>5\textsuperscript{th} Week</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>1.29±0.77</td>
<td>1.62±0.02</td>
<td>1.75±0.01</td>
<td>2.1±0.00</td>
<td>1.77±0.77</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>1.29±0.02</td>
<td>1.68±0.03</td>
<td>1.85±0.02</td>
<td>2.2±0.00</td>
<td>1.83±0.77</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>1.28±0.02</td>
<td>1.64±0.03</td>
<td>1.77±0.028</td>
<td>2.16±0.023</td>
<td>1.79±0.02</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>1.28±0.02</td>
<td>1.64±0.03</td>
<td>1.77±0.025</td>
<td>2.17±0.017</td>
<td>1.80±0.01</td>
</tr>
<tr>
<td>Infected + SN150</td>
<td>1.30±0.01</td>
<td>1.65±0.03</td>
<td>1.8±0.04</td>
<td>2.18±0.015</td>
<td>1.81±0.77</td>
</tr>
<tr>
<td>P-value</td>
<td>0.7059</td>
<td>0.2575</td>
<td>0.0097</td>
<td>0.0001</td>
<td>0.0034</td>
</tr>
</tbody>
</table>

Values bearing different superscript in a row different significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.

The efficacy of different levels of silver nitrate on FCR in \textit{E. coli} challenged broilers is presented in Table III. During 2\textsuperscript{nd} week of age there was no significant difference in FCR among all groups. Significantly (p<0.05) better FCR was found in NC compared to PC in 3\textsuperscript{rd}, 4\textsuperscript{th}, 5\textsuperscript{th} weeks and overall basis. Overall FCR was significantly (P<0.05) higher in infected + SN100 compared to positive control.

Carcass yield and fecal \textit{E. coli} count

On dressing percentage, the effect of different levels of silver nitrate in \textit{E. coli} challenged broiler chicks is shown in Table IV. Dressing percentage was significantly (p<0.01) higher in NC followed by infected + SN100 and infected + enrofloxacin. The lowest dressing percentage was found in PC and infected + SN150. Similarly, \textit{E. coli} in feces was also significantly (p<0.01) higher in PC and infected + SN150. \textit{E. coli} count was similar in infected + SN100 and infected + SN150 (Table IV).

Table IV. Effect of different levels of silver nitrate on dressing percentage and total \textit{E. coli} count (Log\textsubscript{10} CFU/g faeces) of broiler chicks.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Dressing percentage</th>
<th>Total \textit{E. coli} count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>66.397±0.935</td>
<td>3.00±0.00</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>58.247±0.509</td>
<td>5.00±0.00</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>63.597±1.30</td>
<td>3.33±0.57</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>62.857±0.697</td>
<td>3.66±0.57</td>
</tr>
<tr>
<td>Infected + SN150</td>
<td>60.477±0.525</td>
<td>4.33±0.57</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Values bearing different superscript in a row different significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.

Histological dimensions of ilium

Effects of different levels of silver nitrate on histology of ileum in broilers chicks challenged with \textit{E. coli} are shown in Table V. Villus height, crypt depth, goblet cells and epithelial thickness were significantly (p<0.01) higher in NC compared to PC. These parameters had statistically no significant difference between infected + SN100 and infected + enrofloxacin. Resultantly, villus height and crypt depth ratio was significantly (p<0.01) higher in PC compared to NC followed by infected + SN150.

DISCUSSION

In the present study, growth performance in terms of feed intake, weight gain, FCR and dressing percentage of birds supplemented with silver nitrate at the rate of 100 mg/kg was significantly higher compared to the PC. Similar results were reported by Saleh and El-Magd (2018), who supplemented 100ppm silver nitrate in broiler ration for 12 days and reported significantly higher feed intake, weight gain and FCR in the supplemented group. Slight improve in growth was also reported by Yemdjie et al. (2017) in broilers, however, dose of silver nitrate was low (10 mg/kg). Because silver ion has antibacterial properties, it has been postulated that it might alter the microbiota makeup of the gastrointestinal tract (GIT), boost nutrient utilisation, and hence improve bird performance in a way similar to antibiotic growth promotion. Little information is available on the use of silver nitrate on broiler production in a disease or without disease model.
Table V. Effect of different levels of silver nitrate on villus height (µm), crypt depth (µm), ratio of the villus height to crypt depth, goblet cell count and epithelial thickness (µm) in broiler chicks challenged with *E. coli*.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Villus height (µm)</th>
<th>Crypt depth (µm)</th>
<th>V length: C depth</th>
<th>Goblet cell count</th>
<th>Epithelial thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>854.23±0.85</td>
<td>114.50±1.05</td>
<td>7.44±0.06</td>
<td>140.5±0.91</td>
<td>37.43±0.70</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>620.57±1.05</td>
<td>66.47±0.97</td>
<td>9.3±0.1</td>
<td>91.33±1.15</td>
<td>20.76±0.47</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>817.37±0.95</td>
<td>93.47±1.06</td>
<td>8.7±0.1</td>
<td>130±1.0</td>
<td>31.36±0.85</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>816.07±1.30</td>
<td>92.53±0.95</td>
<td>8.76±0.05</td>
<td>129±1.0</td>
<td>30.43±0.86</td>
</tr>
<tr>
<td>Infected + SN150</td>
<td>777.30±1.05</td>
<td>84.40±0.81</td>
<td>9.13±0.05</td>
<td>117.27±0.9</td>
<td>26.9±0.45</td>
</tr>
</tbody>
</table>

P-value < 0.001 < 0.001 < 0.001 < 0.001 < 0.001

Values bearing different superscript in a row differ significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.

Table VI. Efficacy of the different levels of silver nitrate on the gut pH of broiler chicks challenged with *E. coli*.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gizzard</th>
<th>Duodenum</th>
<th>Jejunum</th>
<th>Ileum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control (NC)</td>
<td>3.1±0.05</td>
<td>5.8±0.1</td>
<td>6.2±0.1</td>
<td>6.6±0.057</td>
</tr>
<tr>
<td>Positive control (PC)</td>
<td>3.8±0.05</td>
<td>5.2±0.057</td>
<td>5.4±0.057</td>
<td>5.8±0.057</td>
</tr>
<tr>
<td>Infected + enrofloxacin</td>
<td>3.3±0.05</td>
<td>5.6±0.57</td>
<td>5.9±0.057</td>
<td>6.5±0.057</td>
</tr>
<tr>
<td>Infected + SN100</td>
<td>3.4±0.05</td>
<td>5.5±0.57</td>
<td>5.8±0.057</td>
<td>6.4±0.057</td>
</tr>
<tr>
<td>Infected + SN150</td>
<td>3.6±0.05</td>
<td>5.5±0.057</td>
<td>5.5±0.057</td>
<td>5.9±0.057</td>
</tr>
</tbody>
</table>

P-value 0.0000 0.0000 0.0000 0.0000

Values bearing different superscript in a row differ significantly (P<0.05). SN100, silver nitrate at the rate of 100 mg/kg; SN150, silver nitrate at the rate of 150 mg/kg.

Moreover, it is also clear that SN150 had negative effects on growth performance. There is little research on the potential for ionic silver to impact broiler performance or possible in vivo effectiveness using a disease model in chicken. This is mostly due to the fact that ionic silver may be more harmful than particle silver, since the dissociation rate of silver ion (Ag⁺) affects its biological activity. In terms of organ distribution and removal following oral administration, oral exposure to silver nanoparticles was observed to be very similar to oral exposure to silver nitrate (Loeschner et al., 2011; van der Zande et al., 2012).

In the current study, total *E. coli* count was significantly lower in SN100 compared to the positive control. Silver as a metal is not reactive with microorganisms unless it is ionised, and the bioactive form of silver is known as Ag⁺ ion. Silver ions’ antibacterial action is characterized by high efficacy, minimal toxicity, and a low rate of resistance development. Silver is active against multidrug resistant bacteria, under aerobic and anaerobic conditions. These mechanisms include damage to cell membrane, changing ion homeostasis and inhibiting respiratory enzymes, affecting antioxidant status which eventually leads to damage to lipids and proteins. The effect of silver ions with bacterial membranes has been identified as a key process by which silver ion toxicity is initiated (Randall et al., 2013). Previous investigations utilizing silver nitrate against *E. coli* under anaerobic and aerobic settings revealed that silver reduced bacteria (Park et al., 2009).

The gut is another important organ for water born toxicant exposure, and as a result, it is utilized as a biomarker in toxicological investigations. In the current study, the pH and histological structures of ileum were improved in SN-100 compared to the positive control. Further, high dose (SN-150) had negative impact on the ultrastructures of intestines. In the study of Sawosz et al. (2007), administration of particulate silver had no negative impact on intestinal villi of Japanese quails. In another study, Ognik et al. (2016) reported that the jejunum histological structures were not different from that of normal when broilers were supplemented with lipid coated nanosilver hydrocolloid. Similar to our study, Salem et al. (2021) reported that silver nanoparticles significantly improved the intestinal villi and the inflammatory reaction was substantially reduced. Kumar et al. (2020) also reported that 50 ppm silver nanoparticles had no negative effects on the structural composition of intestines in broilers.
From the results of the present study, it was concluded that silver nitrate at the rate of 100 mg/kg enhanced growth performance, carcass characteristics, decreased *E. coli* count and enhanced gut histological features in broilers infected with *E. coli* infection.

**Ethical 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 and all the procedures with animals were approved by the Local Ethics Committee of Animal Experiments of the University (Protocol no. 2020-1-134).

**Competing interest**

There is no potential competing interest with this study.

**Consent to participate and consent to publish**

All the authors have equally participated in this study and agreed to publish this work in this journal.

**Data availability**

Data is available in the thesis.

**Statement of conflict of interest**

The authors have declared no conflict of interest.

**REFERENCES**


Effects of Silver Nitrate as Alternative to Antibiotic on Production Performance


