Effect of Detoxified Nano Sulfur Supplementation on the Growth, Nutrient Digestibility, Meat Quality, Excreta Microbes, Gas Emissions, and Blood Profiles of Broilers

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A 35-day experiment was conducted to evaluate the effects of the supplementation of mineral detoxified sulfur dispersion (DSD; Patent No.: 10–1997773) on the growth performance, meat quality, excreta microbiota, gas emissions, nutrient digestibility, and blood profiles of broilers. In total, 720 one-day-old ROSS 308 broilers, with an initial body weight of 41.9±0.8 g, were divided into two (2) treatment groups with 20 replicate pens/groups composed of 18 birds per pen. Treatments consisted of 1) CON (the control), normal drinking water and 2) TRT (the treatment group), CON+0.001% DSD (1000:1 dilution ratio). Average daily feed intake (ADFI) and feed conversion ratio (FCR) increased in the TRT group (P<0.05) between days 1 to 7 and days 7 to 21 of the experimental period. Similarly, body weight gain (BWG) showed a significant increase (P<0.05) in the DSD-supplemented group throughout the length of the experiment. With regard to meat quality, redness (a*) was higher, while drip loss was lower, on the 7th day in the DSD group. Furthermore, DSD supplementation increased (P<0.05) Lactobacillus excreta but decreased E. coli concentrations in the TRT group compared to the CON group. Notably, nutrient digestibility, excreta gas emission, and blood profiles did not show any significant differences (P>0.05). DSD supplementation, administered through drinking water, has a positive impact on the growth performance, meat quality, and excreta microbiota of broiler chickens.

Key words: broiler, DSD, excreta microbiota, growth performance, meat quality

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Introduction

Sulfur is a macromineral and an essential component for normal physiological functions in animals. Sulfur is associated with micronutrients, amino acids, proteins, and enzymes. It can be found as volcanic sulfur and in the phyto-genic extracts of different plants. Additionally, small amounts of organic sulfur can be found in grains, meat, eggs, fish, unpasteurized milk, medicinal plants, spices, and vegetables (Aarti and Khusro, 2020). Humans and animals fulfill their sulfur requirements by eating these items; however, if their nutrient needs are lacking, inorganic sulfur additives may also be added to their diet.

Amino acids such as cysteine, methionine, taurine, and glutathione N-acetylcystine all contain sulfur. Inorganic sulfur is used in the form of a compound molecule, such as sodium sulfate or potassium sulfate. Meanwhile, the major organic sulfur feed additives are MSM and garlic (Allium sativum) extracts. In particular, garlic extract or oil contains 33 sulfur-containing compounds (Aarti and Khusro, 2020). Among the major components of garlic oil, diallylsulfide (57%), allylmethyl (37%), and dimethyl sulfides (6%) are very common. Different sulfur compounds have been tested for their antioxidant, antimicrobial, anti-carcinogenic, and antitoxic properties (Puvaca et al., 2015). The antioxidant, antimicrobial, and antitoxic properties of sulfur also protect against different diseases. Sulfur likely has growth-promoting abilities as significant improvements in body weight gain in broilers have been reported from using...
inorganic sulfur and garlic oil (Machlin and Pearson, 1956; Stanacev et al., 2011).

Nano materials are the product of nano biotechnology, a field in which particle sizes are reduced. Nano minerals are known to contribute to improved growth performance and immunomodulation, and have more bactericidal effects than more commonly used products (Swain et al., 2015). In addition, they are required at lower concentrations. Therefore, sulfur nanoparticles are being tested in animals for their growth-promoting, antioxidant, and antimicrobial properties, with the aim of replacing antibiotic growth promoters.

Mineral detoxified sulfur dispersion (DSD; Patent Reg. No.: 1019977730000) is a detoxified nano sulfur compound (Park, 2019). It is created using a new method of processing nano sulfur for supplementation in animals. DSD is sulfur converted to nanoparticles and detoxified by plant extract fumigation (Park, 2019). Therefore, because of its novelty, there is a scarcity of literature comparing the effects of DSD in broilers. Although no research has been conducted on the use of nano sulfur dispersion as animal feed additives, other forms of sulfur supplementation have shown a positive impact on animal production and microbial prevention (Chowdhury et al., 2012; Puvaca et al., 2015; El-Gogary et al., 2019). We hypothesized that like other sulfur compounds (whether organic or inorganic), DSD has a positive influence on growth performance, and antioxidant and antimicrobial mechanisms in broilers. Therefore, the aim of this study was to determine how DSD supplementation, administered through drinking water, affects the growth performance, meat quality, excreta microbiota, gas emissions, nutrient digestibility, and blood profiles of broilers.

Materials and Methods

The experimental procedure was approved (DK-1-1926) by the Animal Protocol Review Committee of Dankook University in the Republic of Korea.

Source of DSD

The mineral detoxified sulfur dispersion (DSD) was supplied by Five N Signature Co., (Incheon, Republic of Korea). The formulation process and product characteristics supplied by the company are as follows: First, mineral sulfur was detoxified by resin vapor that was produced by boiling pine in water. Thereafter, plant juices, such as radish juice, were mixed and stirred with the prepared sulfur, and left to ferment. The purified sulfur water was then mixed with purified nano sulfur juice. Subsequently, the mixture was heated to dissolve the vegetable sugar and chloride to obtain detoxified nano sulfur (Park, 2019). The final product was a water-stock solution of nano sulfur. For this experiment, the sulfur content of the water stock was fixed at 2%. The final product contained only water and nano sulfur molecules. The nano sulfur particles were spherical with an average size of 35 nm (nanometers).

Experimental Design and Animal Management

A total of 720 one-day-old ROSS 308 broiler chicks, with an initial body weight of 41.9±0.8 g, were randomly placed into two (2) treatment groups. Each treatment group contained 20 replication pens which comprised 18 birds each. The same commercial starter, grower, and finisher diets (Table 1) were administered to both groups. The test additive, DSD, was administered via the drinking water of the treatment group at a 1000:1 ratio (0.001%). Treatments were: 1) CON (the control), normal drinking water and 2) TRT (the treatment group) water + 0.001% DSD. Each pen was provided per kg of complete diet: 12mg Cu (as CuSO4·5H2O); 85mg Zn (as ZnSO4); 8 mg Mn (as MnO2); 0.28mg I (as KI); 0.15mg Se (as Na2SeO3) ;5

Table 1. Ingredient composition of experimental diets on an as-fed basis

| Ingredient, % | Starter | Grower | Finisher |
|--------------|---------|--------|---------|
| Corn         | 54.19   | 55.38  | 56.77   |
| Soybean meal | 33.80   | 26.1   | 18.23   |
| Canola meal  | 5.00    | 10.0   | 15.0    |
| Soybean oil  | 2.10    | 3.62   | 5.07    |
| MDCP1        | —       | 1.28   | 1.12    |
| DCP2         | 1.70    | —      | —       |
| Limestone    | 1.15    | 1.34   | 1.22    |
| L-lysine     | 0.50    | 0.65   | 0.81    |
| DL-Methionine| 0.46    | 0.47   | 0.52    |
| L-Threonine  | 0.20    | 0.25   | 0.32    |
| L-Tryptophan | —       | 0.01   | 0.04    |
| NaHCO3       | 0.10    | 0.10   | 0.10    |
| Salt         | 0.30    | 0.30   | 0.30    |
| Vitamin premix3 | 0.20  | 0.20   | 0.20    |
| Mineral premix4 | 0.20  | 0.20   | 0.20    |
| Choline      | 0.10    | 0.10   | 0.10    |
| ME, kcal/kg  | 3,000   | 3,100  | 3,200   |
| CP, %        | 23.0    | 21.5   | 20.0    |
| Lys, %       | 1.50    | 1.40   | 1.30    |
| Met + Cys, % | 1.08    | 0.99   | 0.94    |
| AP, %        | 0.48    | 0.44   | 0.41    |
| Ca, %        | 0.96    | 0.87   | 0.81    |

1 Monodicalcium phosphate
2 Dicalcium phosphate
3 Provided per kg of complete diet: 11,025 IU vitamin A; 1,103 IU vitamin D3; 44 IU vitamin E; 4.4 mg vitamin K; 8.3 mg riboflavin; 50 mg niacin; 4 mg thiamine; 29 mg d-pantothenic; 166 mg choline; 33 µg vitamin B12
4 Provided per kg of complete diet: 12 mg Cu (as CuSO4·5H2O); 85 mg Zn (as ZnSO4); 8 mg Mn (as MnO2); 0.28 mg I; 0.15 mg Se (as Na2SeO3) ;5

Growth and Digestibility

Body weight and feed intake were recorded for each broiler pen on the 7th, 21st, and 35th day of the experiment. Body weight gain (BWG), average daily feed intake (ADF), and the feed conversion ratio (FCR) were calculated from the values obtained for body weight and feed intake. From the 28th day, chromic oxide (0.2%) was mixed with feed as an
indigestible marker to determine apparent total tract diges-
tibility (ATTD). Additionally, from each treatment, 8 fresh
mixed fecal samples were randomly collected, yielding a
total of 16 samples. The fecal elements were then heated in
an oven at 70°C for 72 h. Thereafter, the dried fecal elements
were finely-ground, filtered through a 1 mm strainer and
stored at −20°C until further processing. Chromium inten-
sity was computed using a UV spectrophotometer (UV-
1201, Shimadzu, Kyoto, Japan) following William’s proce-
dure (Williams et al., 1962). Each diet sample and fecal
specimen was tested following the AOAC’s (2007) methods
for determining DM, nitrogen (N), and energy. Nitrogen was
determined using a Kjeltec 2300 Nitrogen Analyzer (Foss
Tecator AB, Hoeganaes, Sweden) and energy was measured
using an oxygen bomb calorimeter (Parr 6100 Instrument
Co., Moline, IL, USA). Nutrient digestibility was measured
using the following formula:

Digestibility (%) = \(1 - \left(\frac{Nf \times Cd}{Nd \times Cf}\right)\) × 100

where Nf is the nutrient density in fecal matter (%DM), Cd is
the Cr density in diet (%DM), Nd is the nutrient density in
diet (%DM), and Cf is the Cr density in fecal matter (%DM).

**Meat Quality**

On the 35th day, 20 broilers per treatment were randomly
selected and a total of 40 chickens were weighed and
butchered. A total of 40 samples of each of the following:
brast meat, gizzards, bursa of Fabricius, liver, spleen, and
abdominal fat were collected from the slaughtered broilers.
These were removed by experienced personnel. Each organ
was weighed and expressed as a proportion of body weight.
Meanwhile, only breast meat was stored at −20°C for further
analysis. Using a Minolta CR410 (Minolta Co., Tokyo,
Japan) Chroma Meter, breast muscle color parameters of
lightness (L *), redness (a *), and yellowness (b *) were
observed. Simultaneously, the pH values were recorded,
using a pH meter (Testo 205, Testo, Germany). The pH
measurement was done twice per specimen. Approximately
2 g of meat from the stored sample was used to measure drip
loss using a plastic bag (Honikel, 1998). Furthermore,
Kauffman’s procedures were implemented in the determina-
tion of the water-holding capacity (WHC) (Kauffman et al.,
1986). Briefly, a 0.3 g sample was pressed with 3,000 g of
weight for 3 min at 26°C on a piece of filter paper (125 mm
in diameter). Two different areas were found before and after
pressing the sample, and they were marked. Subsequently,
the two areas on each sample were measured using an areal-
line sensor (MT-10S; M.T. Precision Co. Ltd., Tokyo, Japan).
The WHC value was calculated from the ratio of water:meat
area (a smaller ratio indicates increased WHC). In addition
to this, meat samples were cooked at 80°C in a water bath
until the core temperature of the filet was 72°C. After
cooking, the samples were weighed and the cooking loss
percentage was calculated (Albercht et al., 2019).

**Excreta Microbiota**

On the 35th day, 20 excreta samples (1 sample/pen) were
collected and transported to the laboratory using an ice pack
to maintain the temperature. From each sample, one gram
was diluted with 9 mL of 1% peptone broth (Becton, Dickin-
son and Co., Franklin Lakes, NJ, USA) and homogenized
after 10-fold dilution. These samples were then cultured on
MacConkey agar plates (Difco Laboratories, Detroit, MI,
USA), Lactobacillus medium III agar plates (Medium 638,
DSMZ, Braunschweig, Germany), and Salmonella Shigella
(SS) agar plates (Becton, Dickinson and Company) to isolate
E. coli, Lactobacillus, and Salmonella, respectively. The in-
cubation period for Lactobacillus was 48 h at 39°C under
anaerobic conditions. Meanwhile, the MacConkey agar
plates and Salmonella Shigella (SS) agar plates were incu-
bated at 37°C for 24 h. The E. coli, Lactobacillus, and Sal-
monella colonies were counted immediately after removal
from the incubator. For each sample, three (3) culture plates
were counted. Bacteria were calculated by a visual count of
colonies that had 30–300 colonies per plate. The bacterial
count was expressed as log10 CFU for each gram of sample
(Hong et al., 2016).

**Excreta Gas Emission**

At the end of the experiment, twenty 300 g samples of
fresh excreta per treatment were placed in different sealed
plastic containers 2600 mL in volume. The samples were
then fermented in an incubator (28°C) for the gas emission
study (Lee et al., 2020). NH3, H2S, and methyl mercapta-
were measured using a multi-gas meter (MultiRAE Lite
model PGM-6208, RAE, San Jose, CA, USA) on days 1, 3,
and 5 of fermentation.

**Blood Lipid Profiles and Antioxidants**

Finally, on the 35th day, a total of 20 blood samples were
collected in vacuum tubes from the wing vein of one bird per
pen (Becton Dickinson), and stored at 4°C. For serum
analysis, approximately 3 mL of the blood samples were
centrifuged for 15 min at 4,000 × g and 4°C to separate the
serum. In addition, superoxide dismutase (SOD) activity in
the blood serum was analyzed using a commercial kit
(ab65354, Abcam, Cambridge, UK). Lipid profiles in the
blood were analyzed using commercially available kits
(Sigma Diagnostics, Taufkirchen, Germany) following the
manufacturer’s instructions.

**Statistical Analysis**

All data were statistically analyzed by the Student’s t-test
using the SAS program (SAS Inst. Inc., Cary, NC). Each pen
was considered as a replicate for each treatment. Results
were considered significant at P < 0.05, and P < 0.10 was
considered to be a trend.

**Results**

**Growth Performance**

The supplementation of DSD in drinking water showed a
significant increase in ADFI and FCR in the TRT group on
days 1 to 7 and days 7 to 21 (P < 0.05). Furthermore, BWG
underwent the only increase seen (P < 0.05) throughout the
study period (Table 2). In the TRT group, BWG showed a
tendency to increase (P = 0.057) between days 7 and 21,
whereas ADFI had an increasing trend (P = 0.052) through-
out the experiment.

**Nutrient Digestibility**

We did not find any difference (P > 0.05) in N, DM, and
energy digestibility (Table 3). Furthermore, both groups had similar nutrient digestibility values.

**Meat Quality**

The effects of DSD supplementation on broiler meat quality are presented in Table 4. Redness (a*) was higher ($P < 0.05$) in the DSD group than in the control group, while drip loss was reduced ($P<0.05$) in the TRT group on day 7. However, organ weight, cooking loss, water holding capacity (WHC), and pH did not vary in this experiment ($P>0.05$).

**Excreta Microbiota**

The results of DSD supplementation on excreta microbiota in broilers are shown in Table 5. DSD supplementation resulted in an increase ($P<0.05$) in *Lactobacillus* concentrations and a reduction ($P<0.05$) in *E. coli* bacterial concentrations when compared to the CON group. Moreover, *Salmonella* bacterial counts were not significantly different ($P > 0.05$) between the two experimental groups.

**Gas Emission**

Table 6 shows the influence of DSD supplementation on noxious gas emissions in broilers. The concentrations of NH$_3$, H$_2$S, and methyl mercaptans showed no difference ($P > 0.05$) between the two groups.

**Blood Profile**

As shown in Table 7, blood profiles comprising superoxide dismutase (SOD) and blood lipid profiles did not show

### Table 2. The effect of detoxified nano sulfur dispersion supplementation on growth performance in broilers$^{1,2}$

| Items$^3$ | CON | TRT | SEM | $P$-value |
|----------|-----|-----|-----|-----------|
| d 1 to 7 |     |     |     |           |
| BWG, g   | 125 | 132 | 5   | 0.210     |
| ADFI, g  | 153 | 169 | 6   | 0.015     |
| FCR      | 1.224 | 1.289 | 0.029 | 0.035   |
| d 7 to 21|     |     |     |           |
| BWG, g   | 650 | 655 | 10  | 0.057     |
| ADFI, g  | 968 | 998 | 11  | 0.015     |
| FCR      | 1.493 | 1.525 | 0.023 | 0.018   |
| d 21 to 35|    |     |     |           |
| BWG, g   | 956 | 986 | 18  | 0.107     |
| ADFI, g  | 1808 | 1811 | 18  | 0.878     |
| FCR      | 1.898 | 1.840 | 0.032 | 0.081   |
| Overall  |     |     |     |           |
| BWG, g   | 1730 | 1772 | 20  | 0.038     |
| ADFI, g  | 2929 | 2977 | 24  | 0.052     |
| FCR      | 1.694 | 1.680 | 0.014 | 0.336   |

$^1$CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion

$^2$Each mean represents 20 replicates with 18 chicks per replicate

$^3$BWG, body weight gain; FCR, feed conversion ratio Statistical significance was considered at 5%

### Table 3. The effect of detoxified nano sulfur dispersion supplementation on nutrient digestibility in broilers

| Items, % | CON | TRT | SEM | $P$-value |
|----------|-----|-----|-----|-----------|
| Dry matter | 71.37 | 72.85 | 1.06 | 0.179 |
| Nitrogen   | 69.60 | 70.88 | 1.16 | 0.288 |
| Energy     | 71.00 | 72.47 | 1.31 | 0.283 |

$^1$CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion

$^2$Each mean represents 20 replicates with 18 chicks per replicate

### Table 4. The effect of detoxified nano sulfur dispersion supplementation on organ weight and meat quality in broilers

| Items$^3$ | CON | TRT | SEM | $P$-value |
|----------|-----|-----|-----|-----------|
| pH value | 7.77 | 7.82 | 0.045 | 0.280 |
| Breast muscle color | | | | |
| Lightness (L$^*$) | 59.18 | 59.31 | 0.64 | 0.917 |
| Redness (a*) | 11.44 | 12.67 | 0.35 | 0.002 |
| Yellowness (b*) | 11.89 | 12.01 | 0.79 | 0.829 |
| WHC, % | 44.89 | 44.01 | 4.69 | 0.853 |
| Cooking loss | 18.57 | 18.27 | 2 | 0.886 |
| Drip loss, % | | | | |
| d 1 | 4.61 | 4.57 | 0.12 | 0.707 |
| d 3 | 7.73 | 7.52 | 0.22 | 0.382 |
| d 5 | 10.24 | 10.26 | 0.19 | 0.910 |
| d 7 | 15.06 | 14.59 | 0.20 | 0.033 |
| Relative organ weight, % | | | | |
| Breast muscle | 19.23 | 18.92 | 0.89 | 0.733 |
| Liver | 2.89 | 2.64 | 0.22 | 0.257 |
| Bursa of Fabricius | 0.14 | 0.13 | 0.01 | 0.954 |
| Abdominal fat | 2.95 | 2.83 | 0.43 | 0.716 |
| Spleen | 0.14 | 0.13 | 0.53 | 0.830 |
| Gizzard | 1.78 | 1.79 | 0.16 | 0.938 |

$^1$CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion

$^2$Each mean represents 20 replicates with 18 chicks per replicate

Statistical significance was considered at 5%
any significant differences ($P > 0.05$) between experimental groups.

**Discussion**

Our study found significant changes in the growth parameters of the broilers. Studies have shown that inorganic sulfur supplementation can increase the growth performance of broilers (Machlin and Pearson, 1956; Almquist, 1964; Ross et al., 1972). In contrast, other researchers (Onibi et al., 2009; Elagib et al., 2013; El-Gogary et al., 2019) have reported that organic sulfur compound supplementation yielded no effect on BW, BWG, and FCR. Interestingly, one study (Elagib et al., 2013) reported increased FI in broilers with garlic powder supplementation, while others (Jacobson et al., 1967; Kennedy and Siebert, 1972) found that inorganic sulfur supplementation increased feed intake in cattle and sheep. In our study, the increment in ADFI is similar to what was observed in the studies mentioned above and is the reason for the improvement in BWG. Nevertheless, the increase in ADFI might have had a negative effect on FCR in the earlier stages. Although FCR was negatively influenced in the earlier stage, it was neutralized during the later growth stage and in the overall calculations. Furthermore, nutrient digestibility of DM, N, and energy did not differ. This is similar to the findings of a study on dairy cows (Richter et al., 2012). Therefore, we can conclude that DSD supplementation had no effect on nutrient digestibility.

DSD supplementation resulted in changes in broiler meat color. The redness ($a^*$) value was higher in the TRT group than the CON group, which we considered to be bad quality. This consideration was made as literature (Allen et al., 1997) has reported that darker broiler meat had a shorter shelf-life. It has been suggested that the redness of the meat may be due to the iron content in broiler meat, as sulfur supplementation may influence heme-Fe binding in the myoglobin in meat (Mortimer et al., 2014). Because meat color is mainly affected by myoglobin pigmentation (Coggins, 2007), the increased redness ($a^*$) may be due to the antioxidative property of DSD, which delays metmyoglobin formation. In the current experiment, we found reduced drip loss in meat in the

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**Table 5. The effect of detoxified nano sulfur dispersion supplementation on microbial in broilers**

| Items   | log$_{10}$cfu/g | CON  | TRT  | SEM  | $P$-value |
|---------|-----------------|------|------|------|-----------|
| Lactobacillus | 7.22 | 7.55 | 0.13 |      | 0.021     |
| E. coli  | 5.51 | 5.29 | 0.09 |      | 0.032     |
| Salmonella | 2.98 | 2.79 | 0.30 |      | 0.543     |

1 CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion
2 Each mean represents 20 replicates with 18 chicks per replicate Statistical significance was considered at 5%

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**Table 6. The effect of detoxified nano sulfur dispersion supplementation on gas emission in broilers**

| Items   | ppm | CON  | TRT  | SEM  | $P$-value |
|---------|-----|------|------|------|-----------|
| NH$_3$  | 11.9| 12.0 | 1.26 |      | 0.951     |
| H$_2$S  | 2.6 | 2.8  | 0.59 |      | 0.796     |
| Methyl mercaptans | 2.2 | 1.2  | 0.55 |      | 0.108     |

1 CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion
2 Each mean represents 20 replicates with 18 chicks per replicate
3 NH$_3$, ammonia; H$_2$S, hydrogen sulfide

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**Table 7. The effect of detoxified nano sulfur dispersion supplementation on blood profile in broilers**

| Items     | CON  | TRT  | SEM  | $P$-value |
|-----------|------|------|------|-----------|
| SOD, %    | 75.1 | 71.4 | 3.68 | 0.323     |
| Total cholesterol, mg/dL | 108.4 | 119.0 | 7.60 | 0.181     |
| HDL/C, mg/dL | 73.1 | 75.7 | 5    | 0.606     |
| LDL/C, mg/dL | 20.6 | 25.7 | 3.87 | 0.201     |
| Triglyceride, mg/dL | 38.4 | 38.3 | 6.73 | 0.983     |

1 CON, Basal diet; TRT, CON + 0.001% detoxified nano sulfur dispersion
2 Each mean represents 20 replicates with 1 chicken per replicate
3 SOD, superoxide dismutase; HDL, high density lipoprotein; LDL, low density lipoprotein
measurement obtained on day 7. From this result, we considered that DSD may increase the meat’s water retention capacity in the later stages of storage. Organ weights and other parameters, such as pH, WHC, and cooking loss, were not significantly influenced by DSD supplementation.

Reduction of the bacterial count of excreta E. coli proved the antimicrobial property of sulfur. In a study, on nano sulfur components versus antibiotic-resistant bacteria, there was a positive result that was evidence to the antimicrobial property of nano sulfur (Chowdhury et al., 2012). A positive effect of nano sulfur against dandruff-causing microorganisms (Baskar et al., 2015) and the effect of processed sulfur against human skin pathogens (Ha et al., 2009) have also been reported in the literature. It is important to note that the absence of competing bacteria can increase the population of other bacteria in the digestive system, such as Lactobacillus (Wang et al., 2017). However, this factor did not affect the Salmonella count in this experiment.

Silva et al. (2014) mentioned that sulfur is an important component of sulfur-containing amino acids used by microbes in microbial digestion. We found that sulfur had a positive effect on the Lactobacillus population, which may have partly increased microbial digestion and, consequently, increase feed intake. However, it has been reported that this increase in microbial digestion mainly utilizes cellulose, and the broiler diet does not contain a large amount of cellulose like that of ruminants. Therefore, our digestibility parameters were not affected by bacterial growth or microbial digestion. Again, Ghavi et al. (2020) reported that sulfur-containing amino acids can improve FI by balancing amino acid requirements. Although supplemented DSD does not have a direct effect like amino acid supplementation, it may take part in synthesizing a small amount of sulfur-containing amino acids in the broiler. In short, DSD supplementation increased BWG by increasing FI and not by nutrient digestion.

Very little evidence is available concerning the influence of DSD on excreta gas emission. Therefore, we do not know the actual reason for the lack of a significant difference in excreta gas emissions in our experiment. We are aware that higher nutrient digestibility will cause less noxious gas emissions (Yan et al., 2011). However, as our experiment has no variation in nutrient digestibility, stating that there is no difference in noxious gas emissions is probably a reasonable conclusion. Sharma et al. (2017) reported that increased breakdown of protein and sulfur-containing amino acids increases NH₃, H₂S, and mercaptan emissions in excreta. However, our supplied DSD is just inorganic sulfur and while it may increase the synthesis of sulfur-containing amino acids, this is not the same as the direct supplementation of sulfur-containing amino acids. Therefore, we did not observe any changes in digestibility or gas emission. Further studies with higher concentrations of DSD may be conducted for greater insight on excreta gas emissions.

It has been reported that bioactive sulfur components have anti-inflammatory and antioxidant effects (Puvaca et al., 2015). Sulfur components have the ability to reduce reactive oxygen species, bind to metal, perform antitumor activity, and reduce oxidation (Amirshahrokhi and Khalili, 2016; Faten et al., 2018). In a recent study, 2-mercaptoethane sulfate reduced alcohol-induced oxidation and inflammation in gastric tissues (Amirshahrokhi and Khalili, 2016). However, our study showed that DSD supplementation did not affect serum superoxide dismutase (SOD) levels. Because our experiment was conducted in an environmentally controlled facility where no scavenging facility was provided, the birds did not have any variation in levels of stress or oxidative damage. As a result, SOD did not vary. Similar data are not available to discuss the reasons for this result. Nevertheless, for SOD, we can say that DSD might not provide efficient antioxidant or free radical-removing activity in broilers. Garlic extract contains a high amount of sulfur compounds and reduces cholesterol, triglycerides, and LDL, while increasing HDL in broilers (Hosoda et al., 2006). However, our study showed no changes in blood lipid profile. It is noteworthy to mention that blood profile concentrations, such as total cholesterol, triglyceride, HDL, and LDL can be used to assess glucose and lipid N metabolism (Hosoda et al., 2006). As our study showed no effect on nutrient digestibility and possibly had unaffected lipid digestibility, the cholesterol, triglyceride, LDL, and HDL in blood did not change between treatment groups. We can also conclude that DSD may not have antioxidant and LDL-reducing capabilities like that of other chemical and phyto-genic sulfur components.

Although detoxified sulfur dispersion (DSD) supplementation showed a negative effect on the feed conversion ratio (FCR), due to increased feed intake (FI), overall body weight gain (BWG) was positively influenced. Moreover, the microbial population in the digestive system was distinctly influenced in a positive way. Drip loss properties were also positively influenced by the DSD. Therefore, DSD as a feed additive in broiler production may be partially beneficial.

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Conflicts of Interest

The authors declare no conflict of interest.

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