# The Effects of Dietary Lemongrass Oil (*Cymbopogon nardus*) and Selenium on Production Performances, Internal Organs, and Immune Organ Weights in Broiler Chickens

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## ABSTRACT

Raising broiler chickens in tropical countries faces challenges, primarily heat stress, which reduces feed intake, weakens immunity, increases infections and mortality, and impairs growth, leading to economic losses. This study aimed to evaluate the effect of dietary lemongrass oil and selenium on broiler production performance and internal organ weight. A total of 288 Cobb strain broilers were allocated into 6 treatments and 6 replicates with a completely randomized factorial design. The treatment was lemongrass oil (0 ml/kg, 2 ml/kg, 4 ml/kg) and selenomethionine (0 ppm, 0.4 ppm). Parameters measured were broiler production performances, internal organs, and immune organ weights. The inclusion of 4 ml/kg lemongrass oil significantly reduced ($P<0.05$) feed intake, body weight, and body weight gain. The inclusion of 0.4 ppm selenomethionine significantly increased ($P<0.05$) the body weight and reduced the FCR of broiler chickens. The inclusion of 4 ml/kg lemongrass oil significantly reduced ($P<0.05$) the feed intake, body weight gain, and body weight, and significantly increased ($P<0.05$) the proventriculus weight. The combination of 4 ml/kg lemongrass oil and 0.4 ppm selenomethionine significantly reduced ($P<0.05$) the weight of the ileum and gallbladder. The treatment did not affect ($P>0.05$) the weight of the ventriculus, heart, liver,

duodenum, jejunum, cecum, colon, abdominal fat, thymus, lymph, and bursa of Fabricius. The conclusion is that the inclusion of 0.4 ppm selenomethionine in the diet increases the body weight and feed efficiency, but the inclusion of up to 4 ml/kg lemongrass oil in the diet reduces the broiler's production performances and the weight of the ileum and gallbladder.

**Keywords**: body weight, essential oil, feed intake, lemongrass, selenomethionine

## 1. Introduction

Broiler chicken rearing in tropical countries faces many obstacles that can reduce chicken productivity. The most important constraint is heat stress due to extreme temperature and humidity outside the broiler's comfort zone, which results in decreased feed intake and immune system, increased pathogenic bacterial infections, and mortality, as well as impaired growth and economic losses (1). Recently, the use of natural ingredients to reduce the adverse effects of heat stress has gained growing attention, one of which is essential oils. Essential oils are safe as antioxidants, antibiotic substitutes, due to their antimicrobial properties, and digestive stimulants (2,3,4). One of the potential essential oils is lemongrass oil (*Cymbopogon nardus*) with its main content of citral, citronellal, geraniol, and citronellol, with its ability as antibacterial, anti-fungal, and anti-free radical (5). The provision of lemongrass oil in feed can increase broiler weight gain (6). The addition of lemongrass essential oil through broiler drinking water has been shown to increase growth and reduce feed conversion ratio and consumption (7).

The use of essential oils in feed can also be combined with antioxidant minerals such as organic selenium. Selenium plays a crucial role in minimizing oxidative stress in poultry by enhancing the activity of antioxidant enzymes, such as glutathione peroxidase and superoxide dismutase (8). Selenium is particularly important due to its involvement in immunity, thyroid hormone activity, and heat stress gene expression (9). Selenium supplementation in feed has been shown to increase antioxidant activity, body weight, sperm motility, feed efficiency, villi

height, and villi surface area of the broiler intestine (8, 10). The combination of lemongrass oil and selenium is expected to have a better effect than a single administration, as they have complementary mechanisms of action. Selenium increases resistance to oxidative stress, while lemongrass oil improves digestive health and nutrient digestibility. This synergy has the potential to increase feed efficiency, support optimal growth, and improve immune response without causing negative effects on internal organs. In addition, there has been no previous study on the effect of their combination in broiler diets. Therefore, this study aimed to evaluate the effects of the dietary combination of lemongrass oil and selenium on the production performance, the internal organs, and the immune organs' weight of broiler chickens.

## 2. Materials and Methods

### 2.1.Animal and Diet

A total of 288 one-day-old unsexed Cobb broiler chicks were allocated to partitioned cages using a completely randomized factorial design with 6 treatments and 6 replicates and raised for 33 days. A total of 36 cages measuring 1 x 1 x 0.5 m equipped with 1 feeder and 1 drinker were used in this study. The ambient temperature was maintained at 33°C for the first two days and then gradually reduced by 1°C until it reached 20°C during the finisher phase. A crumbled-form diet was prepared based on the standard nutritional requirements of Cobb broiler chickens for the starter phase with a crude protein content of 22% and a metabolizable energy of 2,900 kcal/kg, and the growth phase with a crude protein content of 20% and a metabolizable energy of 2,950 kcal/kg. The ingredients used were soybean meal, meat and bone meal, yellow corn, rice bran, crude palm oil, L-lysine, DL-methionine, salt, CaCO3, premix, selenomethionine, and lemongrass oil. The composition and nutrient content of diet treatments are presented in Table 1. Diet and drinking water were provided *ad libitum.*

Treatments were:

T1: control diet (without lemongrass oil and selenomethionine)

T2: diet containing 0.4 ppm selenomethionine without lemongrass oil

T3: diet containing 2 ml/kg lemongrass oil without selenomethionine

T4: diet containing 4 ml/kg lemongrass oil without selenomethionine

T5: diet containing 2 ml/kg lemongrass oil and 0.4 ppm selenomethionine

T6: diet containing 4 ml/kg lemongrass oil and 0.4 ppm selenomethionine

**Table 1.** Composition and nutrient content of diet treatments (as fed)

| Raw materials (%) | Starter | Grower |
|---|---|---|
| Yellow corn | 58.00 | 61.00 |
| Rice bran | 3.00 | 3.00 |
| Soybean meal | 26.50 | 26.00 |
| Meat and bone meal | 9.00 | 5.00 |
| Crude palm oil | 2.00 | 3.00 |
| CaCO3 | 0.15 | 0.70 |
| NaCl | 0.20 | 0.20 |
| Premix* | 0.50 | 0.50 |
| DL-Methionine | 0.35 | 0.30 |
| L-Lysine | 0.30 | 0.30 |
| Total | 100 | 100 |
| Nutrient content (%) | | |
| Crude protein | 22.45 | 20.47 |
| Metabolizable energy (Kcal/kg) | 2,920.25 | 2,960.50 |
| Crude Fat | 3.45 | 2.70 |
| Crude Fiber | 2.70 | 2.72 |
| Lysine | 1.34 | 1.23 |
| Methionine | 0.62 | 0.56 |
| Cystine | 0.28 | 0.26 |
| Methionine+Cystine | 0.90 | 0.81 |
| Calcium | 1.00 | 0.83 |
| Available Phosphorus | 0.65 | 0.44 |

*Premix composition (per kg premix): Vitamin A 200,000 IU, Vitamin D3 200,000, Vitamin E 800 IU, Vitamin K3 200 mg, Vitamin B2 500 mg, Vitamin B6 50 mg, Vitamin B12 1,200 mg, Vitamin C 2,500 mg, Calcium-D-pantothenate 600 mg, Niacin 400 mg, Choline chloride 1,000 mg, Manganese 1,200, Iron 2,000 mg, Iodine 20 mg, Zinc 10,000 mg, Cobalt 20 mg, Copper 400 mg.

### 2.2.Production Performance Measurements

At the beginning of rearing, broilers were weighed to obtain initial body weight. Feed intake was calculated from the difference between the initial feed and the residual feed at the end of the week. The feed conversion ratio was derived by dividing the feed intake by the body weight gain. Body weight gain was determined as the difference between the final body weight and the body weight measured in the previous week.

### 2.3. Internal and Immune Organs Weight Measurements

On day 33, chickens were fed overnight with access to drinking water. Then all chickens in each replication were weighed, and 2 chickens were slaughtered with a weight close to the average weight in each replication. The chickens were slaughtered at the front of the neck by cutting the trachea, jugular vein, carotid artery, and esophagus simultaneously to ensure complete bleeding and animal welfare. The chicken was immediately de-feathered, and the internal organs were removed. The weight of the proventriculus, ventriculus, heart, liver, abdominal fat, gallbladder, pancreas, intestinal, thymus, lymph, and bursa of Fabricius was measured with a 0.1 g digital balance. The weight percentage of internal and immune organs was calculated by dividing organ weight by live weight multiplied by 100.

### 2.4.Data Analysis

Data analysis was performed using analysis of variance (ANOVA) with the IBM SPSS Statistics 22 software. A significance level of $P < 0.05$ was applied, and Duncan's multiple range test was conducted for further comparison.

## 3. Results

### 3.1 Production Performances

The inclusion of selenomethionine in broiler chickens' diet significantly increased ($P<0.05$) body weight and reduced ($P<0.05$) feed conversion ratio (Table 2, Table 5). Conversely, lemongrass oil inclusion of up to 4 ml significantly reduced ($P<0.05$) body weight, body weight

gain, and feed intake. Meanwhile, the dietary 0.4 ppm selenomethionine did not affect body weight gain (Table 2; Table 3; Table 4).

**Table 2.** Impact of lemongrass oil and selenomethionine inclusion in the diet on body weight (g/bird) of broiler chickens

| Period | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| 1-14 days | 0 ml | 300.55 ± 26.13 | 297.90 ± 13.15 | 299.23 ± 19.55$^{b}$ |
| | 2ml | 282.75 ± 16.69 | 292.75 ± 10.92 | 287.75 ± 14.30$^{ab}$ |
| | 4 ml | 286.35 ± 17.99 | 271.65 ± 10.84 | 279.00 ± 16.00$^{a}$ |
| | Average | 289.88 ± 4.34 | 287.43 ± 4.34 | |
| 15-33 days | 0 ml | 1270.90 ± 92.70 | 1307.11 ± 114.22 | 1289.00 ± 99.91$^{b}$ |
| | 2ml | 1186.94 ± 84.82 | 1244.10 ± 99.226 | 1215.52 ± 92.11$^{ab}$ |
| | 4 ml | 1127.37 ± 24.41 | 1158.01 ± 56.64 | 1142.69 ± 44.18$^{a}$ |
| | Average | 1195.07 ± 21.73 | 1236.41 ± 21.73 | |
| 1-33 days | 0 ml | 1653.90 ± 114.74 | 1745.52 ± 159.65 | 1699.71 ± 139.68$^{b}$ |
| | 2ml | 1569.00 ± 91.22 | 1604.70 ± 145.86 | 1586.85 ± 116.23$^{ab}$ |
| | 4 ml | 1468.62 ± 17.82 | 1541.20 ± 64.75 | 1504.91 ± 58.89$^{a}$ |
| | Average | 1563.84 ± 28.43$^{a}$ | 1630.47 ± 85.44$^{b}$ | |

**Table 3.** Impact of lemongrass oil and selenomethionine inclusion in the diet on body weight gain (g/bird) of broiler chickens

| Period | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| 1-14 days | 0 ml | 374.82 ± 37.08 | 370.76 ± 21.80 | 372.79 ± 28.75$^{b}$ |
| | 2ml | 344.42 ± 23.07 | 360.64 ± 18.20 | 352.53 ± 21.38$^{ab}$ |
| | 4 ml | 349.24 ± 30.84 | 333.42 ± 15.95 | 341.33 ± 24.60$^{a}$ |
| | Average | 356.16 ± 6.60 | 354.94 ± 6.60 | |
| 15-33 days | 0 ml | 1232.50 ± 83.26 | 1327.92 ± 141.01 | 1280.21 ± 120.20$^{b}$ |
| | 2ml | 1178.00 ± 81.64 | 1196.60 ± 132.86 | 1187.30 ± 104.42$^{a}$ |
| | 4 ml | 1072.22 ± 37.60 | 1162.90 ± 53.50 | 1117.56 ± 64.69$^{a}$ |
| | Average | 1160.91 ± 24.81 | 1229.14 ± 24.81 | |
| 1-33 days | 0 ml | 1607.32 ± 114.02 | 1698.68 ± 159.60 | 1653.00 ± 139.35$^{b}$ |
| | 2ml | 1522.42 ± 90.82 | 1557.24 ± 145.09 | 1539.83 ± 115.58$^{a}$ |
| | 4 ml | 1421.46 ± 18.34 | 1496.32 ± 64.39 | 1458.89 ± 59.57$^{a}$ |
| | Average | 1517.07 ± 111.14 | 1584.08 ± 148.91 | |

**Table 4**. Impact of lemongrass oil and selenomethionine inclusion in the diet on feed intake (g/bird) of broiler chickens

| Period | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| 1-14 days | 0 ml | 515.52 ± 39.20 | 536.54 ± 27.84 | 526.03 ± 33.92 |
| | 2ml | 519.58 ± 38.80 | 506.88 ± 35.74 | 513.23 ± 35.80 |
| | 4 ml | 521.44 ± 41.43 | 511.26 ± 28.58 | 516.35 ± 33.98 |
| | Average | 518.85 ± 9.21 | 518.23 ± 9.21 | |
| 15-33 days | 0 ml | 2172.72 ± 182.55 | 2160.88 ± 220.01 | 2166.80 ± 190.69$^{a}$ |
| | 2ml | 2019.40 ± 159.76 | 1925.44 ± 111.11 | 1972.42 ± 138.86$^{b}$ |
| | 4 ml | 2069.26 ± 250.64 | 1894.58 ± 95.69 | 1981.92 ± 201.16$^{b}$ |
| | Average | 2087.13 ± 46.14 | 1993.63 ± 46.14 | |
| 1-33 days | 0 ml | 2688.24 ± 220.44 | 2697.42 ± 239.84 | 2692.83 ± 217.22$^{b}$ |
| | 2ml | 2538.98 ± 126.83 | 2432.32 ± 143.70 | 2485.65 ± 139.60$^{a}$ |
| | 4 ml | 2590.70 ± 268.13 | 2405.84 ± 110.34 | 2498.27 ± 216.46$^{a}$ |
| | Average | 2605.97 ± 207.66 | 2511.86 ± 210.68 | |

**Table 5.** Impact of lemongrass oil and selenomethionine inclusion in the diet on the feed conversion ratio of broiler chickens

| Period | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| 1-14 days | 0 ml | 1.38 ± 0.09$^{a}$ | 1.45 ± 0.05$^{ab}$ | 1.41 ± 0.08$^{a}$ |
| | 2 ml | 1.51 ± 0.03$^{bc}$ | 1.41 ± 0.07$^{ab}$ | 1.46 ± 0.08$^{ab}$ |
| | 4 ml | 1.50 ± 0.11$^{bc}$ | 1.54± 0.07$^{c}$ | 1.52 ± 0.09$^{c}$ |
| | Average | 1.46 ± 0.02 | 1.46 ± 0.02 | |
| 15-33 days | 0 ml | 1.77 ± 0.19 | 1.64 ± 0.21 | 1.71 ± 0.20 |
| | 2 ml | 1.73 ± 0.24 | 1.62 ± 0.12 | 1.67 ± 0.19 |
| | 4 ml | 1.93 ± 0.24 | 1.63 ± 0.06 | 1.78 ± 0.23 |
| | Average | 1.81 ± 0.05 | 1.63 ± 0.05 | |
| 1-33 days | 0 ml | 1.67 ± 0.16 | 1.59 ± 0.17 | 1.63 ± 0.16 |
| | 2 ml | 1.68 ± 0.19 | 1.56 ± 0.07 | 1.62 ± 0.15 |
| | 4 ml | 1.83 ± 0.21 | 1.61 ± 0.03 | 1.72 ± 0.18 |
| | Average | 1.73 ± 0.04$^{a}$ | 1.59 ± 0.04$^{b}$ | |

### 3.2. Internal and Immune Organs

The inclusion of 4 ml/kg lemongrass oil significantly increased ($P<0.05$) the proventriculus weight, however, the combination of 4 ml/kg lemongrass oil and 0.4 ppm selenomethionine significantly reduced ($P<0.05$) the weight of the ileum and gallbladder (Table 6). The treatments

did not affect the weight of the heart, liver, abdominal fat, gallbladder, pancreas, duodenum, jejunum, cecum, colon, thymus, lymph, bursa of Fabricius (Table 7).

**Table 6.** Impact of lemongrass oil and selenomethionine inclusion in the diet on the internal organs and abdominal fat weight of broiler chickens

| Parameter (%) | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| Ventriculus | 0 ml | 1.42±0.26 | 1.32±0.08 | 1.37±0.18 |
| | 2 ml | 1.42±0.04 | 1.58±0.42 | 1.50±0.29 |
| | 4 ml | 1.44±0.18 | 1.46±0.21 | 1.45±0.18 |
| | Average | 1.43±0.06 | 1.45±0.06 | |
| Proventriculus | 0 ml | 0.37±0.03 | 0.34±0.07 | 0.35±0.05$^{a}$ |
| | 2 ml | 0.43±0.07 | 0.43±0.10 | 0.43±0.08$^{ab}$ |
| | 4 ml | 0.51±0.10 | 0.43±0.06 | 0.47±0.08$^{b}$ |
| | Average | 0.44±0.02 | 0.40±0.02 | |
| Liver | 0 ml | 2.12±0.94 | 2.09±0.74 | 2.11±0.08 |
| | 2 ml | 2.01±0.23 | 2.23±0.37 | 2.12±0.31 |
| | 4 ml | 2.02±0.20 | 2.03±0.16 | 2.02±0.16 |
| | Average | 2.05±0.06 | 2.11±0.06 | |
| Heart | 0 ml | 0.45±0.78 | 0.46±0.06 | 0.45±0.06 |
| | 2 ml | 0.45±0.20 | 0.49±0.09 | 0.46±0.06 |
| | 4 ml | 0.45±0.06 | 0.45±0.05 | 0.44±0.05 |
| | Average | 0.44±0.01 | 0.46±0.01 | |
| Gallbladder | 0 ml | 0.06±0.01$^{a}$ | 0.07±0.02$^{ab}$ | 0.06±0.01 |
| | 2 ml | 0.07±0.02$^{ab}$ | 0.07±0.01$^{ab}$ | 0.07±0.01 |
| | 4 ml | 0.12±0.06$^{b}$ | 0.04±0.01$^{a}$ | 0.07±0.05 |
| | Average | 0.08±0.01 | 0.05±0.01 | |
| Pancreas | 0 ml | 0.24±0.04 | 0.27±0.02 | 0.25±0.03 |
| | 2 ml | 0.25±0.05 | 0.28±0.05 | 0.26±0.05 |
| | 4 ml | 0.22±0.04 | 0.28±0.07 | 0.24±0.06 |
| | Average | 0.23±0.01 | 0.27±0.01 | |
| Duodenum | 0 ml | 0.54±0.07 | 0.48±0.05 | 0.51±0.06 |
| | 2 ml | 0.52±0.14 | 0.48±0.10 | 0.50±0.11 |
| | 4 ml | 0.57±0.26 | 0.51±0.06 | 0.54±0.18 |
| | Average | 0.54±0.04 | 0.49±0.04 | |
| Jejunum | 0 ml | 0.99±0.14 | 0.91±0.11 | 0.95±0.12 |
| | 2 ml | 0.97±0.20 | 1.02±0.21 | 0.99±0.19 |
| | 4 ml | 1.02±0.22 | 1.08±0.38 | 1.05±0.29 |

| | | | | |
|---|---|---|---|---|
| | Average | 0.99±0.06 | 1.01±0.06 | |
| Ileum | 0 ml | 0.95±0.09[b] | 0.82±0.03[ab] | 0.88±0.09 |
| | 2 ml | 0.78±0.11[ab] | 1.01±0.19[b] | 0.89±0.19 |
| | 4 ml | 0.88±0.23[b] | 0.59±0.21[a] | 0.74±0.25 |
| | Average | 0.87±0.04 | 0.81±0.04 | |
| Cecum | 0 ml | 0.38±0.02 | 0.32±0.04 | 0.35±0.04 |
| | 2 ml | 0.35±0.14 | 0.29±0.02 | 0.32±0.10 |
| | 4 ml | 0.31±0.01 | 0.33±0.07 | 0.32±0.04 |
| | Average | 0.34±0.02 | 0.31±0.02 | |
| Colon | 0 ml | 0.11±0.01 | 0.11±0.02 | 0.11±0.02 |
| | 2 ml | 0.11±0.05 | 0.10±0.01 | 0.11±0.03 |
| | 4 ml | 0.12±0.04 | 0.09±0.05 | 0.10±0.05 |
| | Average | 0.11±0.01 | 0.10±0.01 | |
| Abdominal fat | 0 ml | 1.43±0.26 | 1.68±0.26 | 1.55±0.28 |
| | 2 ml | 1.40±0.71 | 1.53±0.50 | 1.46±0.57 |
| | 4 ml | 1.60±0.16 | 1.42±0.15 | 1.51±0.17 |
| | Average | 1.47±0.10 | 1.54±0.10 | |

**Table 7.** Impact of lemongrass oil and selenomethionine inclusion in the diet on immune organ weight of broiler chickens

| Parameter (%) | Lemongrass oil | Selenomethionine | | Average |
|---|---|---|---|---|
| | | 0 ppm | 0.4 ppm | |
| Thymus | 0 ml | 0.18±0.14 | 0.29±0.02 | 0.23±0.11 |
| | 2 ml | 0.28±0.12 | 0.29±0.10 | 0.28±0.10 |
| | 4 ml | 0.27±0.09 | 0.28±0.11 | 0.27±0.09 |
| | Average | 0.23±0.03 | 0.28±0.03 | |
| Lymph | 0 ml | 0.13±0.03 | 0.11±0.04 | 0.11±0.03 |
| | 2 ml | 0.15±0.04 | 0.16±0.06 | 0.15±0.05 |
| | 4 ml | 0.10±0.01 | 0.10±0.05 | 0.09±0.03 |
| | Average | 0.12±0.01 | 0.12±0.01 | |
| Bursa of Fabricius | 0 ml | 0.16±0.06 | 0.18±0.02 | 0.17±0.04 |
| | 2 ml | 0.15±0.07 | 0.19±0.02 | 0.16±0.05 |
| | 4 ml | 0.13±0.03 | 0.16±0.05 | 0.14±0.04 |
| | Average | 0.14±0.01 | 0.17±0.01 | |

## 4. Discussion

### 4.1.Production Performances

In the current study, the inclusion of selenomethionine in broiler chickens' diet significantly improved body weight and reduced the feed conversion ratio. Conversely,

lemongrass oil inclusion of up to 4 ml/kg decreased body weight and feed intake. Previously, Viera et al (11) reported that incorporating selenomethionine into corn-soybean meal diets significantly enhanced broiler growth performance and carcass and breast meat yields. Indeed, Selenomethionine has high bioavailability since its structure resembles an amino acid that can be easily absorbed through the same mechanism as methionine in the chicken digestive tract (12). This organic structure allows it to be directly utilized in various metabolic processes or stored in body tissues as a selenium reserve, which is not the case with inorganic selenium (11). This makes selenomethionine more efficient in supporting broiler health and productivity.

Selenium is an essential mineral that contributes significantly to improving feed efficiency and promoting body weight gain in broiler chickens through mechanisms as an antioxidant. Selenium contributes to the formation of the enzyme glutathione peroxidase (GPx), which protects cells from oxidative damage due to free radicals, thus maintaining tissue health, improving metabolic function, and supporting broiler growth (13). Selenium is reported to support immune function, which helps prevent stress and diseases that contribute to decreased feed efficiency (8). In addition, selenium also plays a role in thyroid function, supporting the conversion of T4 to T3 hormones that regulate energy and protein metabolism, and accelerating the formation of muscle tissue (14). Thus, broilers can utilize nutrients in feed more effectively for growth and production.

The inclusion of lemongrass oil in this study did not conform to the initial prediction that lemongrass oil would have a positive effect on broiler performance. On the contrary, the inclusion of lemongrass oil reduced the feed intake and body weight of broilers. These results were in line with the study of Nogueira et al (15) that the utilization of lemongrass oil in the diet reduced body weight, feed intake, and feed efficiency. Indeed, the effects of essential oils depended on the dose administered, where inclusion at high doses in the diet became toxic and impaired chicken growth (16). Furthermore, high levels of essential oils could irritate the

intestinal mucosal layer and induce inflammation, eventually reducing nutrient absorption (17). Moreover, previous studies reported that the utilization of citronella and β-citronellol essential oils decreased appetite. Inhalation of these oils increased sympathetic nerve activity associated with reduced feed intake (18). Essential oil components such as citral, limonene, β-citronellol, and thymol decreased appetite through changes in Cocaine and Proopiomelanocortin or Amphetamine-Regulated Transcript mRNA expression, which promote satiety, modulation of leptin release, and sympathetic and parasympathetic nerve activity (19). Reportedly, volatile compounds such as limonene and β-citronellol provide direct signals to the brain's emotion centers (e.g., amygdala and hippocampus), which may reduce feed cravings (20). In addition, some essential oils may affect the release of digestive hormones such as Cholecystokinin and Glucagon-Like Peptide-1, which promote satiety (21).

**4.2. Internal and Immune Organs Weight**

The inclusion of 4 ml/kg lemongrass oil significantly increased the proventriculus weight, however, the combination of 4 ml/kg lemongrass oil and 0.4 ppm selenomethionine significantly decreased the weight of the ileum and gallbladder. The treatments did not impact the weight of the immune organs ( bursa of Fabricius, thymus, lymph). The inclusion of 4 ml/kg lemongrass oil in the diet increased the weight of the proventriculus, possibly due to the bioactive compounds content, such as citral and geraniol, which have stimulating properties on the digestive tract. In the proventriculus, these compounds probably stimulate the secretion of hydrochloric acid and pepsinogen, which have also been proven to stimulate the secretion of protease, amylase, and lipase in the intestinal tract of poultry (22).

The combination of lemongrass oil inclusion and selenomethionine in the diet decreased ileal weight, indicating physiological changes reflecting reduced digestive activity attributed in part to lower feed intake in the lemongrass oil inclusion treatment. The decrease in feed intake reduced the amount of substrate passing through the ileum, thereby reducing the workload and

growth of ileal tissue. Similarly, a previous study reported a decrease in the intestinal weight of broiler chickens fed lemongrass oil and essential oil blends due to reduced intestinal wall thickness (23). On the other hand, selenium acts as an antioxidant through selenoprotein enzymes such as glutathione peroxidase (GPx), which protects cells from oxidative stress and improves the efficiency of digestion and nutrient absorption (8). This positive effect may reduce the workload of the ileum and lead to a lower weight. It can be attributed to the increased feed efficiency with selenomethionine addition in this study.

The combination of lemongrass oil and selenomethionine decreased gallbladder weight in broilers due to the synergistic effect of these two ingredients in optimizing lipid metabolism and liver function. Selenium improved metabolic efficiency through its role as a component of selenoproteins, which function as antioxidants and regulators of lipid metabolism in the liver (24). On the other hand, lemongrass oil's bioactive compounds have hypocholesterolemic properties, which can inhibit cholesterol synthesis in the liver (25), ultimately reducing the need for bile secretion. This combination results in decreased liver workload and reduced bile volume, thereby lowering gallbladder weight.

According to our study, the inclusion of 0.4 ppm selenomethionine in the diet increases body weight and feed efficiency without impairing the immune organs' weight (thymus, lymph, bursa of Fabricius). The inclusion of up to 4 ml/kg lemongrass oil in the diet reduces broiler performance and the weight of the ileum and gallbladder.

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**Authors' Contribution**

Conceptualization, validation, data analysis, writing, and reviewing: AD, S, RM. Research preparation, investigation, collecting, and data analysis: AL, DKN, JIP. Data collecting, editing, and visualization: ANH. All authors approved the final manuscript.

**Ethics**

The authors declared that all ethical standards were adhered to during the animal experiments and the writing of the manuscript.

**Conflict of Interest**

No conflict of interest is declared

**Data Availability**

The data are available from the author on reasonable request.

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