Impact of ginger powder (Zingiber officinale) supplementation on the performance, biochemical parameters, antioxidant status, and rumen fermentation in Ossimi rams

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Abstract

Background and Aim: Ginger (Zingiber officinale) has great potential as a growth promoter and immunostimulant in ruminant nutrition. This study assessed the impact of ginger powder supplementation on Ossimi rams’ rumen fermentation, biochemical parameters, and antioxidant levels.

Materials and Methods: Fifteen Ossimi rams, aged 10 ± 1.3 months and weighing 30 ± 1.5 kg. Rams were randomly divided into three experimental groups: The control group (G1) received standard feed, while ginger powder (5 g and 7 g/kg body weight [BW] for G2 and G3, respectively) mixed in water was administered to groups G2 and G3 before their standard feed.

Results: The control group recorded higher dry matter (DM) intake values (p < 0.05) than the ginger-treated groups. The ginger-treated groups showed superiority (p < 0.05) in weight gain and feed conversion compared to the control group. The digestion coefficients of DM, crude protein, and crude fiber were significantly (p < 0.05) increased by a high dose (7 g/Kg BW) of ginger supplementation, whereas organic matter, ether extract, and nitrogen-free extract digestibility remained unchanged.

Compared to the control group, the rams given 5 g of ginger had significantly more (p < 0.05) total protein and globulin in their serum, but the rams given 7 g of ginger had significantly more (p < 0.05) of these proteins. In the ginger groups, these levels were significantly (p < 0.01) lower than those in the control group for serum creatinine, uric acid, urea, total lipids, triglycerides, total cholesterol, glucose, serum alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase, and gamma-glutamyl transferase. Rams given ginger had significantly (p < 0.05) lower total protein and globulin, total cholesterol, glucose, serum alanine aminotransferase, aspartate aminotransferase, gamma-glutamyl transferase, and total protein and globulin in their serum, but the rams given 7 g/kg body weight [BW] for G2 and G3, respectively) mixed in water was administered to groups G2 and G3 before their standard feed.

Conclusion: Ginger powder (5 g and 7 g) can improve growth, immune responses, antioxidant status, and ruminal parameters in rams. Further study is needed to evaluate the effect of ginger on different types of animals (cow, buffalo, and goat) to develop new feed additives.

Keywords: antioxidant status, biochemical parameters, ginger powder, rams, rumen fermentation.

Introduction

Sheep convert forage into meat and milk, making them indispensable sources of protein in the human diet. Sheep are the most common animal raised in Egypt for meat [1–3]. Boosting the health and productivity of these animals benefits the human population [1–3]. Researchers have begun integrating alternative natural materials, such as medical herbs, into animal feed instead of antibiotics to mitigate health risks for animals and humans, reduce the development of antibiotic-resistant bacteria, and eliminate potential harmful residues in dairy and meat products. This led to the ban of the use of antibiotics in animal feed in the European Union by the European Union’s Agricultural Ministry on the first of January 2006 [4].

Cinnamon, oregano, thyme, ginger, garlic, and other herbs/spices possess health benefits (stimulating appetite/digestion, inhibiting microbes, reducing
inflammation, neutralizing free radicals, and boosting immunity) when incorporated as feed additives in animal nutrition [5]. In particular, Ginger (Zingiber officinale) is highly valued for its beneficial properties. Ginger is a member of the Zingiberaceae family, with the genus name Zingiber [6]. Ginger, rich in gingerols and shogaols, is a significant source of potassium, magnesium (Mg), copper, and manganese. Ginger, in small quantities, contains vitamins A, E, B, and C [7]. Numerous studies have shown ginger possesses antioxidant, anti-inflammatory, and antimicrobial properties [8]. In response to a request from the European Commission, the European Food Safety Authority (EFSA), Panel recommended a maximum addition of 20 mg/kg ginger to the complete feed for sheep and goats [9].

This study investigated the production performance, rumen fermentation, kidney function, liver function, and antioxidant status in Ossimi rams supplemented with two doses (5 g and 7 g) of ginger powder to determine the optimal dose.

**Materials and Methods**

**Ethical approval**

The care and use of animals were approved by the ethics committee of Assiut University, Faculty of Veterinary Medicine, and practiced in accordance with the laws and regulations of Egypt (Approval no. 06/2024/0183).

**Study period and location**

This study was conducted from March to May 2023 at the Agricultural Farm of Al-Azhar University, Assiut, Egypt.

**Animals management**

The present study included 15 Ossimi rams equal in size, aged 10 ± 1.3 months and weighing 30 ± 1.5 kg. During the study, the animals fed individually in digestion boxes, during which time urine, manure, food intake, and remains are collected. The number of digestion boxes on the sheep farm was limited, so we selected the sample size accordingly. Before and during the study, all animals were healthy and had normal clinical indications. Before the study began, each ram received vaccinations compared with the majority of the illnesses and deworming in accordance with Veterinary advice. Oxytetracycline LA (1 mL/10 kg) was administered to the animals as a prophylactic treatment against bacterial disease. They were also treated for ecto- and endoparasites using Ivermectin (1 mL/10 kg body weight [BW]; Sigma Co. USA).

All animals were housed in individual pens with individual feeding and watering facilities. All animals were maintained under natural photoperiods and ambient temperatures. Fresh water was available at all times. All animals received a daily ration based on the National Research Council [10] for sheep. The rations were developed and comprised of concentrate mixture and roughage (wheat straw). The physical and chemical compositions of the experimental rations are listed in Table-1.

**Experimental design**

Before starting the study, rams were acclimatized for 1 week and, after that, were assigned randomly into three experimental groups: The first group (control group, G1) fed on a traditional ration and the second (G2) and the third (G3) groups were given ginger powder obtained from a local market, dissolved in a sufficient amount of water; in the morning before feeding on the traditionally offered ration. The doses of ginger dry powder were 5 g and 7 g/kg BW for G2 and G3, respectively. The animals were fed twice daily at 8:00 a.m. and 5:00 p.m., and any residues were collected and weighed throughout the experimental period. Animals were weighed at the beginning and end of the experiment (After 60 days of the treatment), and feed intake was recorded throughout the experimental period.

**Apparent digestibility trial**

All experimental animals were used in the digestibility trial (after 2 months of the experiment). The digestibility trial consisted of 7 days as the collection period. Animals were weighed on the 1st day of the primary and last days of the collection period. Feces were collected daily, every 24 h, in plastic bags and weighed. A 5% sample of the total daily feces of each animal was taken as a sample, sprayed with a solution of 10% formaldehyde, and 10% H2SO4 and stored in an airtight container for chemical analysis. The digestion coefficients of nutrients for the different experimental rations were calculated using direct methods.

**Chemical analysis**

Ration ingredients were sampled, dried, ground, and analyzed for nutrients. The total amount of the daily fecal matter excreted per animal was collected daily, weighed, recorded, and mixed thoroughly throughout the collection period, and representative samples were taken from each animal, dried for 24 h at 60°C, pooled together, mixed, ground and stored until analysis. The proximate compositions (dry matter [DM], crude protein [CP], ether extract, crude fiber, ash, and nitrogen-free extract) of the experimental diets and feces were determined according to Association of Official Analytical Chemists (AOAC) [11].

**Table-1: Apparent digestibility of experimental rations.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentrate mixture (%)</th>
<th>Wheat straw (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>92.5</td>
<td>92.5</td>
</tr>
<tr>
<td>Organic matter</td>
<td>93.3</td>
<td>83.6</td>
</tr>
<tr>
<td>Crude protein</td>
<td>14</td>
<td>2.6</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>2.81</td>
<td>0.68</td>
</tr>
<tr>
<td>Ether extract</td>
<td>7.3</td>
<td>36.30</td>
</tr>
<tr>
<td>Ash</td>
<td>6.7</td>
<td>10.11</td>
</tr>
<tr>
<td>Nitrogen free extract</td>
<td>69.19</td>
<td>44.02</td>
</tr>
</tbody>
</table>
Sampling and analysis of blood

Fifteen blood samples (5 animals × 3 groups × 1 time; 5 mL each) were individually collected from the jugular vein at the end of the experiment in the morning (2 h before meal). The blood samples were centrifuged at 3000×g for 15 min, and the resulting serum samples were harvested and stored at −20°C until further analysis.

The metabolic energy profile included data on glucose, cholesterol, triglycerides (TG), high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, and very-LDL (VLDL) cholesterol; the metabolic protein profile included the metabolites total protein (TP), albumin, uric acid, urea, and creatinine; the metabolic mineral profile included data on calcium (Ca), phosphorus (P), and Mg; and the metabolic enzymatic profile included the enzymes aspartate aminotransferase (AST), gamma-glutamyl transferase (GGT), alkaline phosphatase (ALP), Alanine transferase (ALT). The analyses were performed using commercial kits (Spectrum Diagnostics, Cairo, Egypt) according to the manufacturer’s instructions specific to each metabolite. Serum globulin levels were calculated mathematically by subtracting albumin values from the total serum protein values, and the albumin-to-globulin (A/G) ratio was calculated by dividing the albumin value by the globulin value. The VLDL and LDL values were obtained using the equations proposed [10] based on total serum cholesterol, HDL, and TG: VLDL = TG/5; LDL = TC-HDL–VLDL.

Serum growth hormone (GH) and insulin-like growth factor-1 (IGF-1) concentrations were determined using enzyme-linked immunosorbent (ELISA) kits from Antibodies (A79860; Antibodies.com, Missouri, USA) and Cusabio Co. (E-EL-S1275; Wuhan, P.R. China), respectively.

Oxidative stress biomarkers

Serum total antioxidant capacity (TAC), superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and Malondialdehyde (MDA) activities were analyzed colorimetrically by STAT LAB SZSL60-SPECTRUM using, Bio-Dignostic kits (Bio-Dignostic Company, Egypt). The analyses were performed using commercial kits (Spectrum Diagnostics, Cairo, Egypt) according to the manufacturer’s instructions specific to each metabolite. Serum globulin levels were calculated mathematically by subtracting albumin values from the total serum protein values, and the albumin-to-globulin (A/G) ratio was calculated by dividing the albumin value by the globulin value. The VLDL and LDL values were obtained using the equations proposed [10] based on total serum cholesterol, HDL, and TG: VLDL = TG/5; LDL = TC-HDL–VLDL.

Serum growth hormone (GH) and insulin-like growth factor-1 (IGF-1) concentrations were determined using enzyme-linked immunosorbent (ELISA) kits from Antibodies (A79860; Antibodies.com, Missouri, USA) and Cusabio Co. (E-EL-S1275; Wuhan, P.R. China), respectively.

Immunoglobulin (Ig)

The concentrations of IgA and IgG were determined using a sandwich ELISA detection kit for bovine IgA and IgG against standards, according to the manufacturer’s suggested protocol (CUSAbio Biotech Inc., Wuhan, China).

Sampling and analysis of rumen liquor

Toward the end of the digestion trials, the rumen liquor samples (about 100 mL) were taken from the experimental animals through a rubber stomach tube in a dry clean cup and taken to the laboratory for examination. The rumen liquor samples were taken before morning feeding. Rumen samples were immediately analyzed for pH by a digital pH-meter (Mettler-Toledo Ltd., England), and then samples were sieved through four-folds of sterile gauze and used as 2 mL fixed with strong acids to determine the volatile fatty acid concentration, 2 mL for determination of ammonia concentration, and 2 mL fixed and stained with methylene green formal saline for microscopic examination. Total rumen protozoal count according to Clergue et al. [11], biochemical examination including total volatile fatty acid (TVFAs) concentration estimated by Macro Kjeldahl steam distillation method as described by Hall et al. [12], and rumen ammonia nitrogen concentration estimated using kits produced by Spectrum Company, Egypt, according to the method of Zaki et al. [13].

Economical evaluation

Economic gain was calculated as the market value of total income from total weight gain (TWG) after subtracting feed cost and the cost of medicinal plants (ginger dry powder) during the experimental period. Feed cost and cost per kg gain were calculated in Egyptian pounds.

Statistical analysis

Data were subjected to analysis of variance using the Statistical Package for the Social Sciences version 20.0 (IBM Corp., NY, USA). Tukey’s range test was used for the mean value of each experimental group in the study. A p-value of 0.05 was considered significant.

Results

Growth performance

DM intake, average daily gain, and feed conversion of the different experimental groups are presented in Table-2. There were significant differences (p < 0.05) in DM intake between the different experimental groups and the groups treated with ginger had the lowest values compared to the control group. There were significant differences (p < 0.05) in the TWG between the experimental groups and the groups treated with ginger had the highest values compared with the control group. The groups treated with ginger showed significantly (p < 0.01) better feed conversion compared to the control group.

Digestion coefficient of nutrients

The nutrient digestibility of rams supplemented with ginger is presented in Table-3. The digestion coefficient of nutrients was significantly (p < 0.05) affected by ginger supplementation and high-dose of ginger (7 g/kg BW) had higher values of the digestion coefficient of nutrients (DM, CP, and crude fiber [CF]), while no significant difference was observed in the organic matter (OM), ether extract (EE), and nitrogen free extract (NFE) digestibility.

Protein parameters

Serum protein constituents (Table-4) showed a significant decrease (p < 0.05) in total serum protein and globulin in the rams group supplemented with 5 g ginger, while a significant (p < 0.05) increase was observed in the rams groups supplemented with 7 g ginger and the control group. Serum albumin showed
a significant (p < 0.05) increase in the ginger groups than in the control group. Regarding the serum A/G ratio, there was a significant (p < 0.05) difference between groups, and a high level was found in the group supplemented with 5 g ginger.

Kidney function
Serum creatinine, uric acid, and urea levels were significantly (p < 0.01) decreased in the ginger groups compared with the control group, especially with high doses (7 g/kg BW), as shown in Table-4. There were no significant differences in the creatinine and uric acid levels between the rams group supplemented with 5 g/kg BW and the control group.

Metabolic energy
Rams supplemented with ginger (5 and 7 g/kg BW) showed a significant (p < 0.01) decrease in total lipids, TG, total cholesterol (TC), and glucose compared with the control group (Table-5). Furthermore, the ginger-treated groups showed a highly significant (p < 0.01) increase in HDL-cholesterol (HDL-C) and a high decrease (<0.01) in LDL-cholesterol and VLDL-cholesterol compared with the control group.

Liver function
The serum enzyme activities of rams supplemented with ginger are presented in Table-6. All treatment groups showed a significant (p < 0.01) decrease in serum alanine and ALT, AST, ALP, and GGT activities compared with the control group.

Hormone activity
There was a significant (p < 0.01) increase in the GH and IGF-1 in the ginger groups compared with the control one (Table-6).

Immune activities
Antioxidants activity
The serum total SOD (T-SOD), glutathione peroxidase (GSH-Px), total antioxidant capacity (T-AOC), and MDA contents in rams supplemented with ginger
powder are presented in Table-7. All treated groups showed a significant \( p < 0.01 \) increase in T-SOD, GSH-Px, and TAC and a decrease \( p < 0.01 \) in MDA concentration compared with the control group.

**Ig**

Concerning the serum immune response, ginger supplementation in rams significantly \( p < 0.01 \) increased the cytokines levels of IgA and IgG compared with the control group (Table-7).

**Blood minerals**

The concentrations of Ca, P, and Mg in rams were significantly \( p < 0.05 \) increased in treatment groups by ginger, especially high dose (7 g/kg BW) compared with the control, as shown in Table-8.

**Ruminal parameters**

The ruminal parameters of rams supplemented with ginger powder are presented in Table-9. There were no significant differences in the rumen pH. There was a significant \( p < 0.05 \) increase in the total short-chain volatile fatty acid, acetic, propionic, and isovaleric acids, while no significant differences were observed in the butyric, valeric acids, and acetate: propionate (C2:C3) ratio between the rams groups. Furthermore, ginger powder supplementation significantly decreased NH3N and protozoa levels compared with the control group.

**Discussion**

**Growth performance**

In the ginger-supplemented groups, DM intake was significantly lower \( p < 0.05 \) than in the other experimental groups. On the contrary, there were no significant differences in the intake of rams fed rations supplemented with different dosages of ginger [14]. Shams Al-Dain and Jarjeis [15] reported a notable enhancement of cows’ daily intake when provided

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**Table-5:** Metabolic energy profile of rams supplemented by ginger powder.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groups</th>
<th>Standard error of the mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
<td>G2</td>
<td>G3</td>
</tr>
<tr>
<td>Total lipids (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triglycerides (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VLDL (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table-6:** Liver Functions and hormone activity of rams supplemented by ginger powder.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groups</th>
<th>Standard error of the mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AST (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALP (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GGT (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GH (ng/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGF-1 (ng/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table-7:** Immune stimulatory effects of supplementation of ginger powder on rams.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groups</th>
<th>Standard error of the mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-SOD (IU/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSH-Px (IU/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAC (IU/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDA (nmol/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IgA (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IgG (IU/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-SOD</td>
<td>10.11a</td>
<td>14.48b</td>
<td>15.57a</td>
</tr>
<tr>
<td>GSH-Px</td>
<td>150.00a</td>
<td>151.07a</td>
<td>152.20a</td>
</tr>
<tr>
<td>TAC</td>
<td>70.19a</td>
<td>72.27a</td>
<td>74.50a</td>
</tr>
<tr>
<td>MDA</td>
<td>4.47a</td>
<td>2.23b</td>
<td>2.17a</td>
</tr>
<tr>
<td>IgA</td>
<td>0.88b</td>
<td>1.09b</td>
<td>1.97a</td>
</tr>
<tr>
<td>IgG</td>
<td>1.08b</td>
<td>1.17b</td>
<td>2.35a</td>
</tr>
</tbody>
</table>

**Table-8:** Blood minerals.

**Table-9:** Ruminal parameters.

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with rations containing high and low amounts of ginger.

In comparison to the control group, groups supplemented with ginger had significantly greater (p < 0.05) TWG. Abo Bakr [14] found that the addition of ginger products in the supplementation enhanced rams growth performance. Shams Al-Dain et al. [16] reported significant (p ≤ 0.05) increases in average daily gain, total gain, and final weight of rams fed with 15 and 30 g of ginger/kg compared to the control group, consistent with our findings. The study findings of Oleru-Okoleh et al. [17] on broiler growth promotion using ginger and garlic were supported by the significant boost in daily weight gain and final BW in this study.

The significantly (p < 0.05) higher final weight and weight gain of rams supplemented with ginger can be attributed to their bioactive components, such as gingerol and shogaol. Gingerols and shagaols, the most powerful phenolic components in ginger, cause health benefits in both animals and humans [18, 19]. Medicinal plants can enhance digestive enzyme activity [20], thus boosting feed efficiency and growth performance [21]. Ginger rhizomes, rich in protease, improve protein digestion, enhance nutrient absorption from amino acids, and promote beneficial bacteria in the intestine [22]. The control group had poorer feed conversion than the ginger-supplemented groups (p < 0.01). Studies have shown that herbs used as animal feed additives can enhance feed conversion ratio, BW, feed intake, feed palatability, and animal acceptability [23].

**Digestion coefficient of nutrients**

Consuming 7 g/kg BW of ginger led to increased nutrient (DM, CP, and CF) digestibility without affecting OM, EE, and NFE digestibility. Ginger, functioning as a rumen modifier, may contribute to enhanced digestibility of DM and fiber in herb-supplemented animals [24]. Ginger reportedly improves digestion and boosts DM and fiber digestibility [25]. Ginger, as an antioxidant, can boost the efficiency of the rumen by mitigating the harmful effects of excessive unsaturated fatty acids, as per Windisch et al. [26], and enhances pancreatic enzyme activity to improve digestion. Due to its phenolic nature and potency in stimulating feed digestion bacteria, Eugenol enhances protein digestibility [27].

**Biochemical parameters**

**Protein parameters**

The findings corroborated earlier reports [28], indicating statistically significant enhancements in TPs and globulins subsequent to ginger powder administration (p < 0.05). The increase in TPs might be due to enhanced secretion of saliva, efficiency of digestion enzymes, digestion and metabolism, and slow time of feed passage, which increased the absorption of protein in the small intestine by ginger supplementation [25]. Blood albumin levels rose, possibly because of enhanced ruminal microbial protein synthesis, causing increased absorption [29].

Rams receiving high-dose ginger showed significantly (p < 0.05) higher globulin levels than the other treated groups. This increase can be attributed to ginger powder’s anti-inflammatory and immune-boosting properties in the body, which in turn increases globulin levels [30]. This study observed a statistically significant increase (p < 0.05) in serum A/G ratio with low-dose ginger intake. Compared to the control, a

### Table-8: Serum minerals of rams supplemented by ginger powder.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groups</th>
<th>Standard error of the mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (mg/dL)</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.55*</td>
<td>9.33*</td>
<td>10.53*</td>
</tr>
<tr>
<td>Phosphorus (mg/dL)</td>
<td>6.95*</td>
<td>7.50*</td>
<td>8.15*</td>
</tr>
<tr>
<td>Magnesium (mg/dL)</td>
<td>3.27*</td>
<td>4.85*</td>
<td>5.07*</td>
</tr>
<tr>
<td><strong>means</strong></td>
<td></td>
<td>a,b,c</td>
<td>1.95</td>
</tr>
</tbody>
</table>

*Means with different superscripts in the same row are significantly different (p < 0.05). Figures in the same row having the same superscripts are not significantly different.

### Table-9: Ruminal parameters of rams supplemented by ginger powder.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groups</th>
<th>Standard error of the mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.50</td>
<td>6.70</td>
<td>6.61</td>
</tr>
<tr>
<td>TVFAs (mEq/100 mL)</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.417*</td>
<td>5.473*</td>
<td>5.667*</td>
</tr>
<tr>
<td>Acetic acid (mEq/100 mL)</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.350*</td>
<td>4.363*</td>
<td>4.503*</td>
</tr>
<tr>
<td>Propionic acid (mEq/100 mL)</td>
<td>1.95*</td>
<td>1.98*</td>
<td>2.06*</td>
</tr>
<tr>
<td>Butyric acid (mEq/100 mL)</td>
<td>2.237</td>
<td>2.207</td>
<td>2.187</td>
</tr>
<tr>
<td>Acetic/Propionic acid</td>
<td></td>
<td>a,b,c</td>
<td>1.00</td>
</tr>
<tr>
<td>Valeric acid (mEq/100 mL)</td>
<td>0.261</td>
<td>0.263</td>
<td>0.273</td>
</tr>
<tr>
<td>Isovaleric acid (mEq/100 mL)</td>
<td>0.123b</td>
<td>0.127a</td>
<td>0.132a</td>
</tr>
<tr>
<td>NH3 N (mg/100 mL)</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21.140*</td>
<td>20.403*</td>
<td>16.967*</td>
</tr>
<tr>
<td>Protozoa (×10³ cell/mL)</td>
<td>G1</td>
<td>G2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.737*</td>
<td>4.140*</td>
<td>3.957*</td>
</tr>
</tbody>
</table>

*Means with different superscripts in the same row are significantly different (p < 0.05). Figures in the same row having the same superscripts are not significantly different.
significant decline (p < 0.05) in the A/G ratio occurred following ginger supplementation [31].

Kidney functions

Ginger’s polyphenols and flavonoids decrease serum creatinine, uric acid, and urea levels by influencing blood waste product removal. Ajith et al. [32] reported that ginger extract’s antioxidant nephroprotective effects and reductions of serum urea and creatinine levels could be attributed to the presence of polyphenols and flavonoids. Ginger’s inhibitory effect on ruminal deamination could account for the observed decrease in urea concentration [33]. With ginger oil supplementation, the serum urea level dropped significantly [14]. In the ginger groups, creatinine levels decreased compared to the control. Abo Bakr [14] found no significant difference in creatinine levels for ewes given water with ginger extract versus the control, but Nassar [33] reported a higher creatinine value in the ginger group.

The data obtained in this study regarding the effect of ginger on reduced uric acid levels confirmed the use of ginger as a therapeutic herb to remove uric acid from the body [34]. In rats and broilers, ginger and ginger oil lower uric acid levels [35]. Previously researched ginger components, including gingerol, shogaol, paradol, zingerone, flavonoids, polyphenols, riboflavin, and vitamins, have the ability to decrease uric acid levels [36].

Metabolic energy profile

Serum triglyceride and cholesterol levels indicate the lipid metabolism status of animals. Reducing serum TG with ginger extract is linked to a decreased risk of metabolic diseases [37]. In accordance with Bhandari and Pillai [38], who proved the extract lessened serum TC and TG and amplified HDL-C levels. The observed reduction in triglyceride levels in rations supplemented with ginger may be due to ginger’s effects on liver tissues, its benefits in metabolism, and the negative effect of ginger on rumen microflora activity and digestion [14]. According to a prior investigation, ingestion of ginger daily reduced LDL, TC, and TG in serum while boosting HDL-C levels [39]. In addition, it was concluded that ginger’s hypocholesterolemic effect could result from inhibiting cellular cholesterol biosynthesis, increasing bile acid biosynthesis to eliminate cholesterol from the body, and increasing fecal cholesterol excretion after the consumption of ginger [40].

According to Farhan [41], Awassi lambs fed a ration with 5% or 10% ginger root had significantly lower blood glucose levels than reported, which agrees with our study. Recent studies indicate that ginger’s hypoglycemic effect may be attributed to its tannin and polyphenol content with antioxidant properties [42]. β-Sesquiphellandrene in ginger increases insulin sensitivity and contributes to its antidiabetic effect by inhibiting glucosidase [43]. The improvement in insulin sensitivity lowered circulating insulin levels as the cells no longer require as much insulin to be signaled [44]. In addition, the mechanism for reducing blood glucose by ginger through inhibition of hepatic phosphorylase enzyme, thereby preventing the breakdown of hepatic glycogen stores, increases the activity of enzymes, improving glycogen synthesis and suppressing the activity of hepatic “glucose 6-phosphatase” enzyme, that causes degradation of glucose 6-phosphate to glucose and, consequently, increases blood glucose levels [45].

Liver functions

Consuming ginger improved liver function, as indicated by decreased liver enzyme activity. Our findings agree with those of Novakovic et al. [46], showing decreased AST, ALT, ALP, and lipid peroxide levels after ginger administration. Another study found that ginger supplementation lowered AST, ALT, TG, and TC levels [46, 47]. While previous research by Fasseas et al. [31] and Zaki et al. [48] found no significant differences in AST, ALT, and GGT levels between ginger and control groups, contrastingly, Abo Bakr [14] observed notable rises.

Hormone activity

Dietary ginger may improve nutrient usage and increase GH expression, with subsequent increases in IGF-1 and IGF-2 expression, indicating a physiological mechanism for better growth performance [49]. In this study, a larger body size was observed. The study by Yang et al. [50] revealed that enhancing serum IGF-1 concentrations in laying hens through herbal active ingredients led to improved production performance. In mammals, IGF1 regulates growth before and after birth [51]. It is the key mediator of GH function, overseeing tissue repair, intermediary metabolism, and disease pathogenesis throughout life [52]. An increase in IGF-1 expression can improve liver function and fibrosis, as demonstrated by Adamek and Kasprzak [53]. Reduced liver enzymes were observed in this study. IGF-1 enhances intestinal ion transport, boosting Ca absorption in animals [54]. In our study, there was a higher increase in serum Ca levels for treatment groups with ginger, especially at high doses, compared to the control.

Immune activities

Antioxidants activity

These enzyme systems (SODs, GSH-PX, among others) in the body are induced by the presence of elevated free radical numbers to produce more antioxidants. This system’s augmented enzymatic activity signifies improved cellular defense against free radicals. According to reports, ginger reduces lipid peroxidation [8]. The strong antioxidant properties of ginger can be attributed to the presence of gingerol, as ginger exhibits various bioactivities, such as anti-inflammatory, antioxidant, growth promoter, and antimicrobial effects. The antioxidant properties of Z. officinale have been established through previous research by Heeba and Abd-Elghany [40]. Ginger promotes antioxidant
defenses by stimulating antioxidant enzyme expression and decreasing reactive oxygen species generation and lipid peroxidation [55]. Ginger significantly enhanced antioxidant enzyme activities and levels of GSH and SOD [56]. Ginger has antioxidant activities due to the presence of tocopherols, phenols, and flavonoids; therefore, SOD activities may be mediated by these components present in the ginger extract [57].

Igs

The detection of IgA, IgG, and IgM in serum can represent the level of Ig in serum. The results of the study agreed with those reported by Nassar [33], who found that lambs fed ginger, either powder or oil additives, had higher IgG and IgG levels than the control group. In the feed mix, the addition of herbs led to an increase in the levels of IgA, IgG, and IgM, enhancement of the phagocytic activity of macrophages, and an increase in the number of stimulated B and T lymphocytes [58]. Animals fed ginger rations had higher IgG levels than the control group, which might be attributed to the effect of medicinal plants, which improve immunity [59].

Blood minerals

For ruminants, ginger consumption has led to enhanced serum mineral levels [60]. According to El-Gohary et al. [28], there was a significant increase (p < 0.05) of Ca in the blood of does, whereas ginger had no effect, according to Fasseas et al. [31], administering ginger to dairy cows did not alter their blood minerals. In the study by Afele et al. [56], serum Ca concentrations were significantly lower (p < 0.05) for mixed-breed rams in the ginger group. Previous studies by Al-Dain and Jarjeis [15] and Fasseas et al. [31] have revealed no impact of ginger supplement intake on Ca, P, and Mg levels.

Ruminal parameters

The response of the rumen to internal stability depends on ruminal pH, which should be maintained between 6.56 and 6.95. Previous studies by Fasseas et al. [31] and Zhang et al. [45] showed that ginger did not alter rumen pH. According to Fasseas et al. [31], the results of total short-chain TVFA in our study exhibited a slight increase, consistent with their findings. The levels of TVFA, acetate, propionate, and isovalerate found in this study correspond with Ikyume et al.’s [24] results, indicating enhanced microbial activity and dietary fermentability due to ginger consumption.

The decreased ammonia-N concentrations in the treated groups in this study could be attributed to the inhibition of protein hydrolyzing microorganisms in the rumen, as reported by Patra [61]. Ammonia nitrogen was affected by both ginger powder and oil additives and significantly decreased in groups fed ginger compared with the control group [33].

The addition of ginger powder to sheep diets resulted in a decrease in the TVFA concentration but no change in the acetate-to-propionate ratio, pH, or ammonia-N concentration [45]. With regard to Protozoa number, the reduction effect of ginger was clearly observed, and the number of protozoa was significantly decreased in the group supplemented with ginger compared with the control group. Ginger powder likely reduces microbial activity and diet fermentability because ginger increases feed stability and benefits the gastrointestinal ecology by inhibiting pathogenic microorganism growth [25]. The findings confirmed these observations, as the levels of protozoa in the rumen decreased, and the reduction rate increased with increasing ginger concentration. Previous studies by Muhammad et al. [60] and Soroor and Moieni [62] have reported that supplementation with ginger extracts decreases the protozoa population. The decreased number of total protozoa was probably due to secondary metabolites and antiprotozoal activities of ginger components [61]. Some previous studies by Fasseas et al. [31] found no significant difference (p > 0.05) in the total protozoal count in the rumen of sheep, whereas Patra et al. [61] demonstrated an increase in the protozoa count following the addition of ginger extract.

Economical evaluation

Feeding ginger to rams led to a higher total feed cost compared to the control group. The control group’s total feed cost per unit weight gain was greater than that of the treatment groups. According to Allam and El-Elame [63], using certain medicinal herbs in rams rations enhanced the economic and relative efficiency of rams production.

Conclusion

The present study revealed that ginger powder significantly improved ram growth, nutrient digestion efficiency, immune responses, antioxidant status, and ruminal fermentation. This study concludes that 5 or 7g/kg BW of ginger powder should be supplemented to rams. Finally, more research is needed to evaluate ginger’s effect on different farm animals and develop new feed additive.

Authors’ Contributions

MEA: Statistical analysis and drafted the manuscript. HAN and MAN: Study design, collected the data, and revised the manuscript. SAA, SAAI, and NB: Data analysis interpretation, critically reviewed, and revised the manuscript. AEA: Statistical analysis and editing of the manuscript. All authors have read, reviewed, and approved the final manuscript.

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Competing Interests
The authors declare that they have no competing interests.

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