Relative growth, blood profiles, antioxidant status and electrolyte balance of broilers fed high monosodium glutamate supplemented with ginger (*Zingiber officinale*) meal

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ABSTRACT

Background and Objectives: The potential of monosodium glutamate (MSG) in enhancing feed palatability has been studied. However, it may cause growth and physiological imbalances in animals. In contrast, herbal additives, like ginger rhizome meal (GRM), rich in bioactive compounds, act as antioxidants to mitigate nutritional-induced oxidative stress. This study aims to investigate the ameliorative effects of GRM on broilers fed diets with high MSG inclusion on growth, blood profile, serum antioxidant status, and electrolyte balance.

Methodology: Three hundred sixty (360) day-old chicks were equally divided into 4 groups: A (Basal diet), B (Basal + 1.25 g MSG/kg diet), C (Diet B + 1.25 g GRM/kg diet), and D (Diet B + 2.50 g GRM/kg diet), with 6 replications containing 15 birds each (90 birds/diet). Experimental diets and water were provided *ad libitum* for 6 weeks. Data were analyzed using one-way analysis of variance (ANOVA).

Main Results: Average weekly weight gain (g/bird/week) significantly increased ($P < 0.05$) in diets B (272.71 ± 1.75), C (295.31 ± 2.33), and D (311.10 ± 4.67) compared to the control (244.27 ± 0.96). Diet B showed a higher mortality rate (18.89 ± 2.22%) than diets A (11.56 ± 0.73%), C (7.67 ± 0.00%), and D (5.00 ± 0.96%). Hematological and serum biochemical indices were adversely affected by diet B ($P < 0.05$). Serum antioxidative enzymes decreased ($P < 0.05$) in diet B, while serum potassium and sodium were unaffected ($P > 0.05$). Serum chloride concentration increased significantly ($P < 0.05$) in diet B.

Conclusions: The inclusion of MSG at 1.25 g/kg with 1.25 to 2.50 g GRM/kg diet enhanced the growth rate without compromising the health status of the birds.

Keywords: Chickens, antioxidative enzymes, ginger, hematology, serum biochemistry, MSG

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INTRODUCTION

Monosodium glutamate (MSG) has been reported as a veritable taste enhancer in both human foods and animal feeds (Khadiga *et al*., 2009). Using MSG as a flavor enhancer in poultry nutrition was justified partly due to its potential to enhance weight gains of broiler chickens (Olarotimi, 2020) and also improve the palatability of non-conventional feed resources thought to be rich in nutrients but grossly underutilized because of their bitter taste (Khalil and Khedr, 2016). For instance,

the feed intake of broilers fed 1.00 g/kg MSG was reportedly increased with a corresponding increase in body weight (BW) gain (Olateju *et al*., 2019). Gbore *et al.* (2016) equally documented an elevated average feed consumption and weight gain by rabbits administered 1 to 4 mg/kg BW of 40% aqueous solution of MSG. In lactating sows, the inclusion of 1.15 g/kg MSG in the diet was also reported to have significantly enhanced the feed intake and piglet growth rates without any adverse effect on the piglets (Hewitt and van Barneveld, 2012). In laying hens, Olarotimi (2021) reported enhanced internal and external egg quality parameters among birds fed up to 0.75 g MSG/kg diet.

However, despite the numerous potentials of MSG as a taste enhancer in poultry nutrition already highlighted, some authors have also stressed the negative impact inherent in high MSG inclusion. The inclusion of high dietary MSG was reported by Olarotimi (2020) to increase the serum Na^+ and K^+ concentrations of broiler chickens as well as enhance oxidative stress in broiler chickens. High inclusion of MSG was also reported to have toxic impacts on the testis by causing a significant reduction in daily sperm production and an increase in abnormal sperm morphology in Wistar rats (Lindemann *et al.,* 2002) and cocks (Olarotimi and Adu, 2020). The hemoglobin, mean corpuscular hemoglobin concentration, mean corpuscular volume, and the leukocytes of rabbit does were significantly reduced when the administration level was above 1 mL MSG/kg BW, whereas increased aspartate aminotransferase concentration was observed in rabbit does gavage MSG at 4 mL MSG/kg BW (Olarotimi *et al.,* 2021).

On the other hand, the beneficial effect of ginger meal *(Zingiber officinale)* as a natural antioxidant has been documented. The ginger meal contains bioactive components that have antioxidant, anti-inflammatory, anticarcinogenic, and antibacterial properties (Ozkur *et al.,* 2022). The hemoglobin counts and packed cell volume of the birds fed diets containing 0.2% ginger meal were found to be better than the values recorded on the control diet (Agu *et al.,* 2017). In another development, improved body weight gain, feed conversion ratio, and feed intake were recorded in broiler chickens fed diets containing 0.1 to 0.2 g ginger meal (Mohamed *et al.,* 2012). Ginger meal was also reported to decrease serum cholesterol and increase the total protein, albumin, and globulin of broilers significantly when included in the diets (Al-Khalaifah *et al.,* 2022). The ginger meal was therefore found to boost immunity and improve the general well-being of broiler chickens (Shah *et al.,* 2022). Therefore, the present study was aimed at examining the effects of ginger meal supplements on the relative growth rate and health status of broiler chickens fed high dietary monosodium glutamate.

MATERIALS AND METHODS

Experimental Materials, Design, and Animals

Monosodium glutamate (MSG) was sourced from a reputable supermarket. Fresh ginger rhizomes, bought from the local market, were washed and sliced unpeeled into smaller pieces and air dried for 14 days. The dried ginger rhizome chips were ground into powder to make ginger rhizome meal (GRM) using a laboratory hammer mill. Three hundred and sixty (360) day-old, unsexed Arbor-Acres broiler chicks were used for the study for 6 weeks at the Poultry Unit, Teaching and Research Farm, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria. The birds were raised on the floor covered with wood shavings (2 cm depth). The temperature of the house was stabilized at 32 °C and relative humidity at 70% before the introduction of the chicks. The temperature was reduced by 2.7 °C weekly until it reached 18.5 °C at week 6. The house was divided into 4 apartments representing 4 treatment groups. Each apartment was further subdivided into 6 units representing the replicates per treatment. Each unit containing 15 birds has a dimension of 40 ft^2. The approval of the University's Research Ethics Committee for the care and use of animals was granted before the commencement of the study. The chicks were weighed and randomly distributed into 4 isocaloric and isoproteineous starter (22.20% CP, 3,067.55 kcal/ME) and finisher (18.83% CP, 3,186.49 kcal/ME) treatment diets (Table 1): A, B, C, and D containing 0 g MSG and

GRM (control), 1.25 g MSG, 1.25 g MSG + 1.25 g GRM, and 1.25 g MSG + 2.50 g GRM/kg diet respectively in a completely randomized design (CRD). The birds were given broiler starter (1–3 weeks) and finisher (4–6 weeks) diets (Table 1) with fresh, clean water *ad libitum.* All the necessary vaccinations and medications for broilers were carried out. Briefly, Lasota (F1 strain) and Gumboro (IBD) vaccines were respectively administered intraocularly on the 7th and 14th days of age while the booster doses of Gumboro and Lasota vaccines were respectively administered through drinking water at age 24 and 28 days.

Average Weekly Weight Gain, Relative Growth, and Mortality Rates of the Broilers

The average weekly weight gains (AWWG) of the birds were determined at the end of each week, starting from the 7th day (week 1) through the 42nd day (week 6) of the experiment. The AWWG was calculated as the ratio of the summation in the differences in the weights at the beginning and end of each week to the number of live birds per week. The relative growth rate (RGR) of the bird was calculated as described by Adebayo et al. (2020) thus:

$$RGR\ (\%) = \frac{W2 - W1}{½\ (W2 + W1)} \times 100$$

where W_1 is the body weight of the birds at the beginning of the experiment and W_2 is the body weight of the birds at the end of the experiment.

The mortality rate (MR) was calculated as

$$MR\ (\%) = \frac{I - E}{E} \times 100$$

where I is the initial number of the birds at the beginning of the experiment and E is the number of the live birds at the end of the experimental period.

Table 1 Ingredient compositions of the experimental starter and finisher diets (kg)

Composition	Starter phase				Finisher phase			
	Diet A	Diet B	Diet C	Diet D	Diet A	Diet B	Diet C	Diet D
Ingredients								
Maize	52.35	52.35	52.35	52.35	59.35	59.35	59.35	59.35
Soybean meal	30.00	30.00	30.00	30.00	24.00	24.00	24.00	24.00
Fish meal (72% CP)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Soya oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Wheat bran	7.00	7.00	7.00	7.00	0.00	0.00	0.00	0.00
Rice bran	0.00	0.00	0.00	0.00	6.00	6.00	6.00	6.00
Bone meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Lysine	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Methionine	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Broiler premix	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ginger rhizome meal	0.00	0.00	1.25	2.50	0.00	0.00	1.25	2.50
Monosodium glutamate	0.00	1.25	1.25	1.25	0.00	1.25	1.25	1.25

Table 1 Cont.

Composition	Starter phase				Finisher phase			
	Diet A	Diet B	Diet C	Diet D	Diet A	Diet B	Diet C	Diet D
Analyzed nutrient composition								
ME (kcal/kg)	3,067.55	3,067.55	3,067.55	3,067.55	3,186.49	3,186.49	3,186.49	3,186.49
Crude protein (%)	22.20	22.20	22.20	22.20	18.83	18.83	18.83	18.83
Fat	6.43	6.43	6.43	6.43	7.00	7.00	7.00	7.00
Calcium (%)	1.55	1.55	1.55	1.55	1.53	1.53	1.53	1.53
Phosphorus (%)	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.69
Lysine (%)	1.42	1.42	1.42	1.42	1.23	1.23	1.23	1.23
Methionine (%)	0.64	0.64	0.64	0.64	0.61	0.61	0.61	0.61
Crude fiber (%)	4.00	4.00	4.00	4.00	3.94	3.94	3.94	3.94

Note: *Composition of premix: 2.5 kg of premix contains: vitamin A (10,000,000 IU), vitamin D3 (2,500,000 IU), vitamin E (12,000 IU), vitamin B1 (2,000 mg), niacin (15,000 mg), vitamin B6 (1,500 mg), vitamin B12 (10 mg), vitamin K3 (2,000 mg), biotin (20 mg), folic acid (600 mg), pantothenic acid (7,000 mg), chlorine chloride (150,000 mg), manganese (80,000 mg), iron (40,000 mg), copper (10 mg), zinc (60,000 mg), selenium (150 mg), iodine (1,000 mg), magnesium (100 mg), ethoxyquine (500 g), and BHT (700 g). CP = crude protein, ME = metabolizable energy.

Blood Sampling and Analyses

On the last day of the study, 10 birds per replicate (60 birds per treatment) were randomly selected for blood sampling after being fasted overnight. Blood samples were collected from the jugular veins of the birds into both heparinized tubes for the determination of hematological indices and dry clean plain centrifuged glass tubes for the determination of serum biochemical parameters. The plain blood samples were allowed for 15 min at room temperature before being centrifuged for 10 min at 3,000 rpm to obtain a clear supernatant serum. The harvested serum samples were kept at -20 °C until the determination of serum enzymes, creatinine, cholesterol, proteins, antioxidant enzymes, and electrolytes balance. Serum electrolytes (Na^+, K^+, and Cl^-) and antioxidative enzymes [glutathione peroxidase (GSH-Px), superoxide dismutase (SOD), and catalase (CAT)] activities were determined as previously described by Olarotimi (2020) using commercially available assay kits. The serum enzymes [alanine aminotransferase (ALT) and aspartate aminotransferase (AST)], creatinine, total protein (TP), and globulin (GLB) were determined as described by Adu *et al*. (2018). Albumin (ALB) was calculated as the difference between the TP and GLB.

Hematological Indices Determination

The microhematocrit method was used to determine the packed cell volume (PCV, %), and the cyanmethemoglobin method was applied to measure the hemoglobin concentration (Hb; Cannan, 1958) while the hemocytometer with the improved Neubauer slide was used to determine the red blood cell (RBC, cells × 10^6 mL^{-1}) and white blood cell counts (WBC, cells × 10^3 mL^{-1}; Weiss and Tvedten, 2004). The equations postulated by Tazawa *et al.* (2011) were used to derive the mean corpuscular volume (MCV, fL), mean corpuscular hemoglobin (MCH, pg), and mean corpuscular hemoglobin concentration (MCHC, g/dL) from the PCV, RBC, and Hb. Blood smears stained with May-Grunwald–Giemsa stain were used to carry out the leucocyte differential counts (heterophils, lymphocytes, eosinophils, basophils, and monocytes).

Statistical Analysis

All data collected were subjected to one-way analysis of variance (ANOVA) using SAS (2008) version 9.2. Duncan's new multiple range test of the same software was used for means comparison where significant differences existed at $P < 0.05$. The completely randomized design (CRD) with the model equation: $\beta_{xt} = \mu + \alpha_x + \gamma_{xt}$ was used in this experiment. Where β_{xt} = any of the response variables, μ = the overall mean, α_x = effect of the x^{th} treatment (x = diets A, B, C, and D), and γ_{xt} = random error due to experimentation.

RESULTS AND DISCUSSION

Average Weekly Weight Gain, Relative Growth, and Mortality Rates

The AWWG (Figure 1) observed among the broilers fed the diet containing 1.25 g MSG/kg diet (272.71 ± 1.75 g/bird/week) was significantly ($P < 0.05$) higher than the AWWG recorded by birds on the control diet (244.27 ± 0.96 g/bird/week). Furthermore, a non-significant ($P > 0.05$) increase in AWWG (295.31 ± 2.33 g/bird/week) was observed among broilers fed 1.25 g GRM/kg diet (Diet C) when compared with birds on diet B (272.71 ± 1.75 g/bird/week) but increase in AWWG was significant ($P < 0.05$) when compared with the birds on the control diet (244.27 ± 0.96 g/bird/week). The inclusion of a 2.50 g GRM/kg diet further enhanced the AWWG among birds on diet D (311.10 ± 4.67 g/bird/week). The increases in AWWG, however, between birds on diets C and D were not statistically ($P > 0.05$) different, but a significant ($P < 0.05$) increase was observed between birds on diet D and the birds on diets A and B, respectively. However, the RGR (Figure 2) among the birds on diets A (193.62 ± 0.12%), B (194.20 ± 0.05%), C (194.21 ± 0.04%), and D (194.47 ± 0.28%) were not different significantly ($P > 0.05$) from one another when compared. Furthermore, MR (Figure 3) recorded among the birds fed 1.25 g MSG/kg diet (18.89 ± 2.22%) was significantly ($P < 0.05$) higher than what was recorded among birds on other experimental diets (11.56 ± 0.73, 7.67 ± 0.00, and 5.00 ± 0.96% for diets A, C, and D respectively). The inclusion of 1.25 g GRM/kg diet significantly ($P < 0.05$) reduced the MR when compared with the value recorded among birds on diet B and this was comparable ($P < 0.05$) with the values recorded among the birds on the control diet. Birds on diet D which received a 2.50 g GRM/kg diet, recorded a further decrease in the MR though not statistically ($P > 0.05$) different when compared with the birds on diet C but significantly lower than the values recorded by broilers on diets A and B respectively.

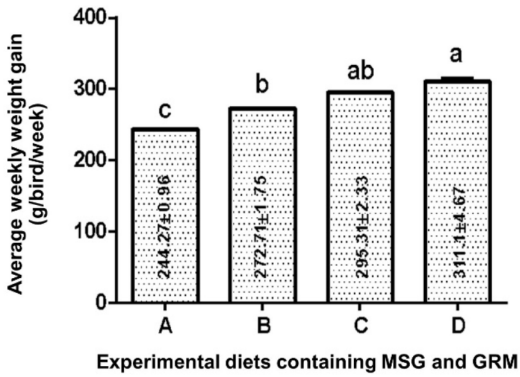

Figure 1 Effects of monosodium glutamate (MSG) and ginger rhizome meal (GRM) on average weekly weight gain. Bars without common superscripts differ significantly ($P < 0.05$). Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg.

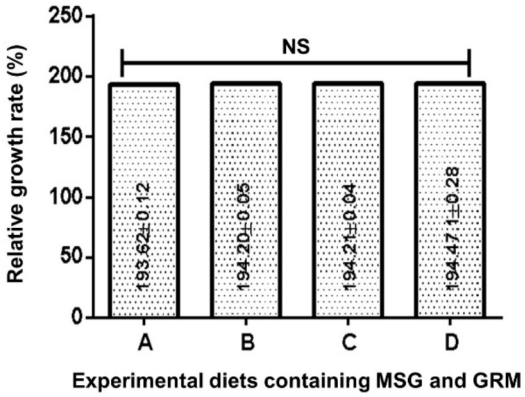

Figure 2 Effects of monosodium glutamate (MSG) and ginger rhizome meal (GRM) on relative growth rate. Bars without superscripts are statistically similar (P > 0.05). Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg.

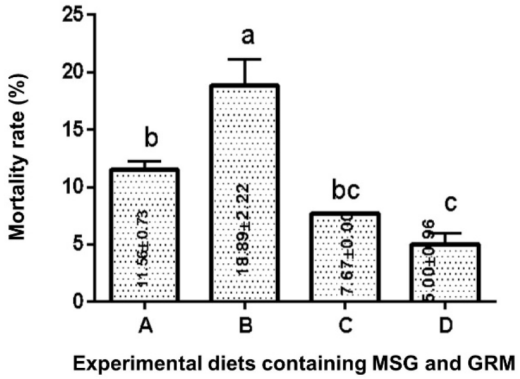

Figure 3 Effects of monosodium glutamate (MSG) and ginger rhizome meal (GRM) on mortality rate. Bars without common superscripts differ significantly (P < 0.05). Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg.

The significant increase observed in the AWWG among the birds on diet B when compared with that on diet A was indicative of the ability of MSG to enhance weight gain in broilers. This was in agreement with previous studies that highlighted the positive influence of MSG on the body weight gain of farm animals (Gbore *et al.,* 2016; Olateju *et al.,* 2019; Olarotimi, 2020). However, the inclusion of GRM at 2.50 g/kg diet that brought about a further increase in the weekly weight gain was suggestive of the fact that the polyphenolic compounds inherent in the GRM have played a stimulating role on the digestive enzymes of the birds, and hence, improved the overall digestion, nutrient availability, and body weight gain of the birds on diet D. Our result, in a way, has given credence to the earlier claim of Hussein *et al.* (2017) on the ability of ginger to bring about the enhancement of body weight gain in animals. However, the reduced viability rate observed among the broilers on diet B, as indicated by the significant increase in the mortality rate, justified earlier positions that high inclusion of MSG was culpable in conferring negative effects on farm animals (Diniz *et al.,* 2004; Eweka and Om'Iniabohs, 2006). According to El-Ezaby *et al.* (2018) and Sharma (2015), the mortality observed on diet B

may be related to the induction of oxidative stress and the subsequent production of oxygen radicals and hydrogen peroxide, which cause oxidative DNA damage, peroxidation of cell membranes, and cell death. However, the substantial reduction in the mortality rate, which translated to improved viability percentage among the birds fed diets C and D, indicated the ameliorative effects of GRM at the inclusions used in the present study on the negative impact of high inclusion of MSG as a taste enhancer in broiler nutrition. By scavenging superoxide anion and hydroxyl radicals, GRM, which has anti-oxidative, hepatoprotective, anti-inflammatory, anti-bacterial, and anti-tumor properties, contributes significantly to the reduction of lipid oxidation in birds fed diets C and D, preventing the pathogenesis of illnesses and death (Rahmani *et al.,* 2014). Hence, the inclusion of GRM, especially at 2.50 g/kg diet, in broiler rations containing MSG at 1.25 g/kg diet could make the non-conventional feed resources, considered not suitable for poultry diets due to their poor palatability, become generally useful and acceptable, thereby, bringing about the provision of feed at lower cost and subsequent better profitability for the farmers.

Hematological Indices of Broilers Fed MSG and GRM

From the present study, we observed significant ($P < 0.05$) reductions in the hematological parameters such as PCV, RBC, and Hb (Table 2) among the broilers on diets containing 1.25 g MSG/kg diet when compared with birds on other treatment diets. Conversely, this inclusion level of MSG significantly ($P < 0.05$) led to increased levels of MCV and MCH among birds on diet B but did not significantly ($P > 0.05$) influence the MCHC concentration across all the treatment diets. For the differential WBC counts, significant ($P < 0.05$) reductions in lymphocytes, heterophils, eosinophils, and basophils were equally observed among the broilers fed diet B, whereas the birds' monocytes concentrations were not statistically ($P > 0.05$) affected by the treatment diets. However, the varied inclusions of GRM played a restorative role by significantly ($P < 0.05$) enhancing the concentrations of the blood parameters that were previously affected by the inclusion of 1.25 g MSG/kg diet alone.

Table 2 Hematological indices of broilers fed monosodium glutamate and ginger rhizome meal

Parameters	Diet A	Diet B	Diet C	Diet D	P-value
Packed cell volume (%)	29.20 ± 0.69^{b}	20.40 ± 0.70^{c}	31.50 ± 1.08^{ab}	35.70 ± 0.99^{a}	0.01
Red blood cells (×10^{6} mm^{3})	2.14 ± 1.01^{b}	1.24 ± 1.22^{c}	2.53 ± 0.98^{a}	2.68 ± 1.41^{a}	0.02
MCHC (g/dL)	33.50 ± 0.03	33.00 ± 0.04	33.80 ± 0.02	31.00 ± 0.03	0.15
MCV (fL)	102.00 ± 0.34^{b}	137.13 ± 0.34^{a}	109.01 ± 0.34^{b}	103.00 ± 0.34^{b}	0.04
MCH (pg)	37.22 ± 1.09^{b}	47.71 ± 1.01^{a}	36.50 ± 0.92^{b}	35.71 ± 1.11^{b}	0.03
Hemoglobin (g/dL)	9.72 ± 0.12^{b}	5.12 ± 0.29^{c}	10.92 ± 0.41^{a}	11.24 ± 0.18^{a}	0.01
Lymphocytes (%)	28.20 ± 2.19^{b}	24.50 ± 1.39^{c}	27.98 ± 2.11^{b}	35.52 ± 1.69^{a}	0.02
Monocytes (%)	2.03 ± 1.06	2.13 ± 2.17	2.04 ± 0.97	1.86 ± 1.76	0.25
Heterophils (%)	28.30 ± 2.14^{b}	21.30 ± 2.05^{c}	33.80 ± 1.97^{a}	31.30 ± 2.15^{ab}	0.01
Eosinophils (%)	2.83 ± 0.42^{a}	2.13 ± 0.41^{c}	2.81 ± 0.69^{a}	2.86 ± 1.66^{a}	0.02
Basophils (%)	3.12 ± 0.88^{a}	2.62 ± 0.48^{b}	3.10 ± 1.18^{a}	3.08 ± 0.82^{a}	0.04

Note: Values are means ± standard deviation. Means in a row without a common superscript letter differ significantly ($P < 0.05$). MSG = monosodium glutamate, GRM = ginger rhizome meal, Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg, MCHC = mean corpuscular hemoglobin counts, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin.

The hematological and biochemical components of blood form the yardstick for the critical diagnosis of diseases and the general well-being management of farm animals. The significant reduction in some hematological indicators, such as PCV, RBC, Hb, lymphocytes, heterophils, eosinophils, and basophils, in this study among the broilers on diet B indicated a serious impact of high inclusion of MSG on the health status of the birds. The reduction in the PCV values among the birds on diet B could come from the interference of high inclusion of MSG with some physiological processes, which might culminate in cell damage, failure of bone marrow production, or loss of blood. Therefore, the reduced mean values of PCV, Hb, and RBC recorded among the birds on diet B signified that the birds were anemic. Previous studies have also reported the negative hematological effects of MSG on animals, including but not limited to anemia and the generation of reactive oxygen species (Ibrahim *et al.,* 2012; Abdulsalam *et al.,* 2017). This study further revealed that the inclusion of MSG in a 1.25 g/kg diet negatively influenced the differential WBC. The results of the present study were in agreement with the findings of Ashaolu *et al.* (2011) and Ghadhban (2017), which reported that MSG had a significant effect on the heterophil and lymphocyte counts in Wistar rats. The heterophils and basophils functionally provide the defense against invading micro-organisms, toxic substances, and foreign substances (Hall, 2016). Therefore, the reduction observed among the birds on diet B indicated that their immunity had been compromised. However, the increase observed in the MCV and MCH of the birds on diet B is indicative of macrocytic anemia in the birds, which is evidence that high inclusion of MSG could induce a folic acid deficiency in the broilers. The restoration to normalcy in the affected hematological parameters observed among broilers on diets C and D was clear evidence that GRM at the inclusions used in this study could offset the hematological imbalance imposed by the inclusion of high MSG in broiler diets. This result was in agreement with the reports of Agu *et al.* (2017) and Mohamed *et al.* (2012), stressing the enhancement roles of ginger on the hematological indices of animals. This could, therefore, suggest that herbal supplements are a viable solution to the negative effect of MSG in broiler chickens.

Serum Biochemicals of Broilers Fed MSG and GRM

The effects of high dietary inclusion of MSG on serum proteins, enzymes, cholesterol, and creatinine are shown in Table 3. The results of the present study indicated that MSG inclusion in broilers' diets at 1.25 g/kg diet had a significant ($P < 0.05$) negative impact on the serum proteins. Albumin, globulin, and total protein were significantly ($P < 0.05$) reduced at this inclusion level when compared with the values recorded by the birds on the control diet, whereas serum creatinine, cholesterol, and AST concentrations were significantly ($P < 0.05$) elevated at this same inclusion level. The ALT concentrations were not significantly ($P > 0.05$) affected by feeding diets supplemented with MSG and GRM. However, inclusions of 1.25 and 2.50 g GRM/kg diet significantly ($P < 0.05$) increased the serum protein concentrations of the broilers on diets C and D when compared with birds fed 1.25 g MSG/kg diet without GRM inclusion. The elevated serum creatinine, cholesterol, and AST concentrations observed among the birds on diet B were significantly ($P < 0.05$) reduced among broilers fed high MSG with varied inclusions of GRM.

The significant reduction observed in the serum proteins among broilers on diet B in this study was indicative of problems in the liver, which is the site of protein synthesis. Our study did not disagree with a previous report which documented a similar trend in albumin and total protein of rats fed high the inclusion of MSG (Oladipo *et al.,* 2015). However, the resultant increase in the serum proteins among birds on diets C and D was indicative of the ameliorative effects of GRM at the inclusion levels used in our study to correct the disturbance of protein synthesis in the liver caused by impaired hepatic. The result of this study also agreed with Oleforuh-Okoleh *et al.* (2014) in reporting a significant increase in serum protein concentrations among broilers fed high MSG. The significant increase observed in

serum creatinine, cholesterol, and AST further highlighted the negative influence of the high inclusion of MSG on broiler chickens. Creatinine is a biomarker used to determine kidney function. Abnormal serum creatinine elevation has been linked with a decline in the ability of the kidney to filter fluid within the body (Gounden *et al.,* 2021). This could be interpreted to mean a potential sign of renal impairment among the birds on diet B. On the other hand, hepatic cell damage is also linked to a significant increase in serum enzyme activities. The observed rise in the AST concentration among the birds on diet B in this study indicated alterations in liver function (Kim *et al.,* 2008). The AST is also used as a marker enzyme in the cytosol of hepatocytes to quantitatively assess the degree of damage in the liver (Aniagu *et al.,* 2004). The recorded significant increase in serum cholesterol among the birds on diet B agreed with El Malik and Sabahelkhier (2019). The increased level of serum cholesterol was a signal of impairment of cholesterol metabolism and could result in coronary heart disease in broiler chickens (Kondoh and Torii, 2008). However, the inclusion levels of GRM used in the study also played a restorative role in each of the parameters studied. The reason for this could not be farfetched the activities of the bioactive compounds in the GRM, such as flavonoids which are highly effective polyphenolic compounds in scavenging free radicals already generated by the dietary high MSG, thereby protecting the cells from oxidative stress.

Table 3 Serum biochemicals of broilers fed monosodium glutamate and ginger rhizome meal

Parameters	Diet A	Diet B	Diet C	Diet D	P-value
Total protein (g/dL)	59.60 ± 3.14^{b}	53.40 ± 2.94^{c}	66.00 ± 3.01^{a}	62.30 ± 2.09^{ab}	0.01
Albumin (g/dL)	15.02 ± 1.91^{b}	10.79 ± 1.03^{c}	16.60 ± 2.08^{a}	15.70 ± 1.13^{ab}	0.01
Globulin (g/dL)	44.58 ± 2.55^{b}	42.61 ± 1.98^{c}	59.40 ± 3.05^{a}	46.60 ± 1.81^{b}	0.03
Creatinine (µmol/L)	22.30 ± 0.05^{b}	33.90 ± 0.03^{a}	22.50 ± 0.04^{b}	17.20 ± 0.02^{c}	0.02
Cholesterol (µmol/L)	3.02 ± 0.41^{c}	4.90 ± 0.34^{a}	4.36 ± 0.15^{b}	2.14 ± 0.28^{d}	0.01
AST (IU/L)	121.00 ± 10.24^{b}	146.00 ± 9.94^{a}	116.00 ± 11.01^{b}	80.90 ± 10.00^{c}	0.02
ALT (IU/L)	78.70 ± 4.10	76.30 ± 5.11	72.60 ± 3.99	78.20 ± 4.48	0.11

Note: Values are means ± standard deviation. Means in a row without a common superscript letter differ significantly (P < 0.05). MSG = monosodium glutamate, GRM = ginger rhizome meal, Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg, AST = aspartate aminotransferase, ALT = alanine aminotransferase.

Antioxidant Enzymes and Electrolyte Balance of Broilers Fed with MSG and GRM

The results of the activities of serum antioxidant enzymes and electrolyte balance among the birds on different diets are shown in Table 4. The birds fed diets containing 1.25 g MSG/kg diet (diet B) displayed significant (P < 0.05) reductions in all the serum antioxidant enzymes studied when compared with the broilers on the control diets. However, the inclusions of 1.25 and 2.50 g/kg GRM significantly (P < 0.05) improved the serum concentrations of these antioxidant enzymes when compared with birds on diet B. The serum concentrations of GSH-Px and SOD enzymes among the broilers fed 2.50 g/kg GRM were significantly (P < 0.05) higher than what was recorded among those fed 1.25 g/kg GRM. However, doubling the inclusion of GRM in the diet significantly (P < 0.05) enhanced the serum concentration of these enzymes among the birds on diet D.

Furthermore, the inclusion of 1.25 g/kg MSG alone or in combination with varied inclusion of GRM did not significantly (P > 0.05) influence the

serum concentrations of Na^+ and K^+. However, the inclusion of 1.25 g/kg MSG in the diet statistically ($P < 0.05$) elevated the serum concentrations of Cl^- when compared with broilers on the control diet. Inclusion of 1.25 and 2.50 g/kg GRM, thus, significantly ($P < 0.05$) reduced this electrolyte concentration in the serum when compared with birds on diet B. The values recorded were comparable ($P > 0.05$) with the values of the birds on the control diet.

Table 4 Antioxidant enzymes and electrolyte balance of broilers fed monosodium glutamate and ginger rhizome meal

Parameters	Diet A	Diet B	Diet C	Diet D	P-value
Serum antioxidant enzymes					
Catalase (mM/mL/min)	12.30 ± 0.01^{b}	7.24 ± 0.00^{c}	20.60 ± 0.04^{a}	19.40 ± 0.02^{a}	0.01
Glutathione peroxidase (µg/g)	220.00 ± 0.29^{ab}	125.00 ± 0.32^{c}	198.00 ± 0.20^{b}	242.00 ± 0.37^{a}	0.01
Superoxide dismutase (%)	67.51 ± 0.03^{b}	50.50 ± 0.04^{c}	65.86 ± 0.08^{b}	76.79 ± 0.05^{a}	0.01
Serum electrolyte balance					
Potassium (K^+) (mmol/L)	4.59 ± 0.06	4.71 ± 0.04	4.86 ± 0.02	4.43 ± 0.03	0.09
Chloride (Cl^-) (mmol/L)	97.20 ± 0.22^{bc}	116.00 ± 0.32^{a}	99.00 ± 0.18^{b}	89.40 ± 0.30^{c}	0.02
Sodium (Na^+) (mmol/L)	128.00 ± 0.30	129.00 ± 0.38	133.00 ± 0.61	121.00 ± 0.30	0.15

Note: Values are means ± standard deviation. Means in a row without a common superscript letter differ significantly ($P < 0.05$). MSG = monosodium glutamate, GRM = ginger rhizome meal, Diet A = Basal (control), Diet B = Basal + 1.25 g MSG/kg, Diet C = Diet B + 1.25 g GRM/kg, Diet D = Diet B + 2.50 g GRM/kg.

From the result of this study, the significant increase observed in the level of serum CAT among the broilers fed diets C and D, as well as GSH-Px and SOD among birds on diet D, indicated the serum antioxidant enzymes enhancing the ability of ginger powder at inclusion rates of 1.25 to 2.50 g/kg diet while the significant decrease in serum antioxidant enzymes among birds in diet B indicated that high inclusion of MSG in broiler diets could predispose them to oxidative stress. We can, therefore, opine that ginger meal has antioxidant and ameliorative effects on the perceived cellular damage that may be occasioned by the high inclusion of MSG. This result agreed with Moreki and Gabanakgosi (2014), who recorded a similar trend in the dietary inclusion of moringa at 5 to 20% in broiler feeding. This is pointing toward the ability of phyto-additives to enhance the antioxidant enzymes of chickens, thereby protecting them against the possibility of oxidative stress. From this study, it was clear that higher inclusion of ginger powder, as observed among birds on diet D, proved to better enhance the serum antioxidant enzymes of the birds against oxidative stress occasioned by the high inclusion of MSG. The body of animals, including poultry, contains a large variety of ions or electrolytes that perform a variety of functions. The ions in the blood plasma play important roles in the osmotic balance that regulates the movement of water between cells and their environment (Olarotimi, 2020). In the present study, the elevated serum Cl^- level observed among the broilers on diet B was an indication that a high dose of MSG in broiler diets could result in hyperchloremia. The results of this finding agreed with the report of Olarotimi (2020), who reported an elevation in serum Na^+, K^+, and Cl^- levels of broiler chickens fed with diets containing varying levels of MSG. The present study differed from his report in that the inclusion

of MSG in this study did not significantly affect the serum Na^+ and K^+ concentrations. This might be due to the variation in nutritional compositions of the diet used in this study.

CONCLUSION

It could, therefore, be concluded from the results of this study that the dietary inclusion of ginger meals could enhance the growth and health status of broiler chickens fed high dietary monosodium glutamate. It was revealed that the inclusion of 1.25 to 2.50 g GRM/kg was capable of providing better growth and viability rate when fed to broiler chickens. The abundant bioactive components of ginger meal played specific immunomodulatory roles by improving the hematological and serum biochemical indices of the chickens, thereby protecting them against oxidative stress. The antioxidative status and the electrolyte balance of the broiler chickens were also maintained against the possible oxidative stress that high inclusion of MSG might cause. It is therefore recommended that the inclusion of 1.25 to 2.50 g GRM/kg in the diets of broiler chickens fed high MSG for taste enhancement would bring about optimal utilization of the feeds without any detrimental effects on the health status of the birds.

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