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Effects of *Curcuma longa* and *Zingiber officinale* on Oxidative Stress, Immunological Parameters and Organ Weights in MSG-Treated Animal Models

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ABSTRACT

Monosodium glutamate (MSG) consumption is associated with oxidative stress, hematological and immunological disturbances, and alterations in organ morphology. This study assessed the protective effects of *Curcuma longa* extract (CLE) and *Zingiber officinale* extract (ZOE), both individually and in combination, on oxidative stress markers, hematological and immune parameters, body weight and relative organ weights in MSG-exposed animal models. The plant materials were extracted using cold maceration with methanol as solvent. The animals were divided into six groups: normal control, MSG-only, MSG + CLE (200 mg/kg), MSG + ZOE (200 mg/kg), MSG + combined CLE (200 mg/kg) + ZOE (200 mg/kg), and MSG + ascorbic acid (100 mg/kg). Oxidative stress indices, including superoxide dismutase (SOD), catalase, malondialdehyde (MDA), and glutathione levels, were assessed alongside hematological parameters including hemoglobin concentration, packed cell volume, red and white blood cell counts, and differential leukocyte counts. Body weight and relative organ weights of the liver, kidney, heart, and spleen were also evaluated. MSG exposure induced oxidative imbalance, immune suppression, hematological alterations, and changes in organ weights. The combined extract treatment markedly improved antioxidant status, restored hematological and immunological balance, normalized organ weights, stabilized body weight, and showed superior protective effects compared to individual treatments.

Keywords: Monosodium glutamate, *Curcuma longa* extract, *Zingiber officinale* extract, Oxidative stress Hematological and immunological parameters

INTRODUCTION

Monosodium glutamate is a widely used flavour enhancer in the food industry, particularly prevalent in processed and fast foods. In spite of its popularity and extensive consumption worldwide, increasing evidence suggests that excessive MSG intake can lead to adverse biochemical and physiological effects, especially targeting vital organs such as the liver and kidneys [1-2]. MSG-induced toxicity is thought to be mediated largely through oxidative stress mechanisms, which disrupt cellular homeostasis and promote tissue damage [3].

Oxidative stress arises when the balance between reactive oxygen species (ROS) production and the antioxidant defense system is disturbed, resulting in cellular damage due to lipid peroxidation, protein oxidation, and DNA damage [4]. Several studies have documented that MSG administration increases lipid peroxidation markers such as malondialdehyde while concurrently depleting endogenous antioxidants like superoxide dismutase, catalase, and glutathione in hepatic and renal tissues [5-6]. For instance, Omotoso et al. [7] reported significant elevations in MDA levels alongside reduced antioxidant enzyme activities in MSG-treated rats, indicating severe oxidative damage. Similarly, alterations in biochemical indices of organ function have been consistently reported. Eweka and Om'Iniabohs [2] observed elevated levels of liver enzymes such as ALT, AST, and ALP in MSG-exposed rats, suggesting hepatocellular injury. In addition, renal dysfunction characterized by increased serum creatinine and urea levels has been documented [8]. While these studies clearly establish MSG as a potential toxicant, they often focus primarily on isolated biochemical parameters without integrating systemic physiological responses.

Beyond biochemical toxicity, MSG has shown to disrupt hematological and immunological systems. Nimse and Pal [9], demonstrated reductions in red blood cell counts, hemoglobin levels, and packed cell volume, indicative of anemia, alongside alterations in white blood cell differentials, suggesting immune imbalance.

However, most of these studies examined hematological indices in isolation and did not correlate them with oxidative stress or organ-level changes, thereby limiting a comprehensive understanding of MSG-induced systemic toxicity.

In response to these toxic effects, natural antioxidants have been widely investigated for their protective roles. *Curcuma longa* (turmeric) has been shown to possess strong antioxidant and hepatoprotective properties. For example, Arafa et al. [10] reported that *curcumin* significantly reduced MDA levels and restored antioxidant enzyme activity in toxin-induced liver injury models. Likewise, *Zingiber officinale* (ginger) has demonstrated protective effects against oxidative stress and tissue damage. Ekor et al. [11] found that ginger extract improved renal function and reduced oxidative damage markers in experimental models.

In spite of these promising findings, a gap exists in the literature. Most previous studies focused on the effects of either *Curcuma longa* and *Zingiber officinale* individually, with limited attention given to their combined effects. Given that these plants contain different but complementary bioactive compounds (*curcumin* in turmeric and *gingerols/shogaols* in ginger), it is plausible that their combination may produce synergistic or additive protective effects. However, empirical evidence supporting such combined efficacy remains scarce.

Another significant limitation in existing studies is the lack of integrated multi-parameter analysis. Many investigations have assessed oxidative stress markers, biochemical indices, or hematological parameters separately, rather than evaluating them collectively within a single experimental framework. This fragmented approach limits the ability to fully understand the systemic impact of MSG toxicity and the holistic protective effects of natural extracts.

Additionally, there is insufficient data linking biochemical, hematological, immunological, and morphological outcomes, such as body weight and relative organ weights, in MSG-induced toxicity models. Such assessments are essential to establish a clearer relationship between molecular changes and whole-organism physiological responses.

The present study addresses these gaps by evaluating the protective effects of *Curcuma longa* extract and *Zingiber officinale* extract, both individually and in combination, against MSG-induced toxicity. Unlike previous studies, this research integrates multiple parameters, including oxidative stress markers (SOD, catalase, glutathione, and MDA), hematological indices (RBC, WBC, hemoglobin, PCV, and differential counts), immunological indicators, body weight changes, and relative organ weights (liver, heart, kidney, and spleen).

By incorporating a combination treatment group, this study specifically investigates the potential synergistic effects of turmeric and ginger extracts, thereby filling the existing gap in knowledge regarding their combined therapeutic efficacy. Moreover, the use of a multi-system evaluation approach enables a more holistic understanding of how these natural antioxidants mitigate MSG-induced toxicity at both cellular and systemic levels.

The hypothesis is that CLE and ZOE supplementation will ameliorate oxidative stress, restore hematological and immunological balance, and protect organ integrity. It is further hypothesized that the combined treatment will exhibit superior protective effects compared to individual treatments due to complementary mechanisms of action.

The aim of this study is to contribute significantly to the existing body of knowledge by providing integrated and comparative evidence on the protective roles of turmeric and ginger extracts. This may support their potential application as natural therapeutic agents against food additive-induced toxicity and oxidative stress-related disorders, with important implications for public health and nutritional safety.

MATERIALS AND METHODS

Chemicals and Reagents

All chemicals and reagents used were of analytical grade and sourced from reputable manufacturers. These include 90% ethanol (BDH Chemicals Ltd., Poole, England), distilled water (Thermo Fisher Scientific, USA), monosodium glutamate (Ajinomoto Co. Inc., Tokyo, Japan), and ascorbic acid (Sigma-Aldrich, St. Louis, USA). Commercial reagent kits used for biochemical analysis included cholesterol esterase, cholesterol oxidase, and peroxidase for total cholesterol determination using the CHOD-PAP method (Randox Laboratories Ltd., Crumlin, UK). Lipoprotein lipase, glycerol kinase, and glycerol-3-phosphate oxidase used for triglyceride estimation by the GPO-PAP method were also obtained from Randox Laboratories Ltd. Precipitation reagents such as phosphotungstic acid and magnesium chloride were sourced from Sigma-Aldrich (USA), while phosphate buffer solutions were prepared using standard laboratory-grade reagents.

Experimental Animals

Adult male Wistar albino rats weighing between 150–200 g were used for this study. The animals were obtained from a standard animal breeding facility in the Veterinary animal house of Michael Okpara University of Agriculture, Umudike, and were acclimatized for a period of two weeks under controlled laboratory conditions, including a temperature of 25 ± 2°C and a 12-hour light/dark cycle. The rats were fed standard pelletized feed and allowed free access to clean drinking water *ad libitum*.

Plant Collection

Fresh rhizomes of *Curcuma longa* and *Zingiber officinale* were harvested from the National Root Crops Research Institute, Umudike, Umuahia, Abia State, Nigeria. The plant materials were authenticated at the Department of Plant Science and Biotechnology, Michael Okpara University of Agriculture, Umudike, and a voucher specimen was deposited in the Departmental herbarium with voucher number MOUAU/PSB/2025/CL-ZO/014 for references. After collection, the rhizomes were thoroughly washed with tap water to remove soil and other contaminants, and then air-dried at room temperature under shade conditions to prevent degradation of active phytochemicals. The dried samples were subsequently milled into fine powder using an automated milling machine. The powdered samples were weighed using an analytical weighing balance, yielding a total weight of 200 g [12].

Preparation of Plant Extracts

The dried rhizomes of *Curcuma longa* and *Zingiber officinale* were pulverized into fine powder using an automated milling machine. Ethanol extraction was carried out using 90% ethanol as the solvent in a maceration process. The mixture was allowed to stand with intermittent shaking for 72 hours at room temperature to ensure adequate extraction of bioactive constituents. After extraction, the mixture was filtered using Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator (Model: RE-52A, Shanghai Yarong Biochemistry Instrument Company, China) under reduced pressure at controlled temperature. The concentrated extracts were further dried and stored in airtight containers at 4°C in a refrigerator (Haier Thermocool, China) [13].

Experimental Animals and Grouping

Adult Wistar rats (weighing 150–200 g) were procured and acclimatized under standard laboratory conditions (temperature 22 ± 2°C, 12-hour light/dark cycle) with free access to food and water. The animals were randomly divided into six groups (n = 6 per group) as follows:

Group 1: Normal control (received distilled water)

Group 2: MSG-only group (received monosodium glutamate at a specified dose)

Group 3: MSG + Curcuma longa extract (CLE) 200 mg/kg

Group 4: MSG + Zingiber officinale extract (ZOE) 200 mg/kg

Group 5: MSG + CLE (200 mg/kg) + ZOE (200 mg/kg) combined treatment

Group 6: MSG + Ascorbic acid (100 mg/kg) as a positive control antioxidant

The treatment period lasted for 14 days, during which animals received daily oral doses of MSG and the respective extracts or ascorbic acid by gavage [14].

Biochemical Analysis

At the end of the treatment period, animals were fasted overnight and anesthetized for blood collection via cardiac puncture. Blood samples were centrifuged at 3000 rpm for 15 minutes to obtain serum, which was used for biochemical assays [15].

Oxidative Stress Markers

Liver and kidney tissues were excised, rinsed with ice-cold saline, and homogenized in phosphate buffer (pH 7.4). The homogenates were centrifuged, and the supernatants were used for oxidative stress assays [16].

Superoxide Dismutase Activity: Measured based on the inhibition of auto-oxidation of pyrogallol [17].

Catalase Activity: Assessed by the breakdown of hydrogen peroxide [18].

Glutathione Levels: Quantified using Ellman’s reagent [19].

Malondialdehyde Levels: Determined as an index of lipid peroxidation using thiobarbituric acid reactive substances (TBARS) assay [16].

Hematological and Immunological Parameters

Whole blood was used for complete blood count (CBC) and differential leukocyte count using an automated hematology analyzer [20]. Parameters measured included:

- Hemoglobin concentration (Hb)
- Packed cell volume (PCV)
- Red blood cell (RBC) count
- Mean corpuscular volume (MCV)
- Mean corpuscular hemoglobin (MCH)
- Mean corpuscular hemoglobin concentration (MCHC)
- Total white blood cell (TWBC) count and differential counts of lymphocytes, neutrophils, monocytes, eosinophils, and basophils

Body and Organ Weights

Body weights of animals were recorded weekly. After euthanasia, organs (liver, heart, kidney, spleen) were excised, blotted dry, and weighed. Relative organ weights were calculated as a percentage of the final body weight [21].

Statistical Analysis

Data were expressed as mean ± standard deviation (SD). Statistical comparisons among groups were performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for multiple comparisons [22]. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Table 1 shows the effects of *Curcuma longa* Extract (CLE) and *Zingiber officinale* Extract (ZOE) on Antioxidant Enzymes and Oxidative Stress Markers in MSG-Treated Experimental Groups. MSG exposure altered antioxidant status, with reduced glutathione and changes in SOD and catalase activities. Treatment with CLE and ZOE improved antioxidant enzyme activities, indicating protective effects. ZOE showed stronger catalase activity, while ascorbic acid had the highest SOD but also elevated MDA, suggesting incomplete control of oxidative stress.

Table 1: Effects of *Curcuma longa* Extract and *Zingiber officinale* Extract on Antioxidant Enzymes and Oxidative Stress Markers in MSG-Treated Experimental Groups.

Group	SOD (IU/ g protein)	MDA (nano moles/g protein)	Catalase (kU/g protein)	Glutathione (µg/L)
Normal control	5.95 ± 0.83^{b}	33.23 ± 0.62^{b}	5.41 ± 0.89^{e}	2.22 ± 0.33
MSG-only group	7.64 ± 0.36^{b}	23.59 ± 1.24^{b}	13.18 ± 1.39^{cd}	1.56 ± 0.00
MSG + CLE, 200 mg/kg	10.51 ± 0.23^{ab}	32.70 ± 5.88^{b}	22.52 ± 3.33^{ab}	1.95 ± 0.81
MSG + ZOE, 200 mg/kg	11.16 ± 0.04^{ab}	35.74 ± 2.06^{b}	25.87 ± 4.98^{a}	1.56 ± 0.00
MSG + CLE,20 mg/kg + ZOE 200 mg/kg	9.57 ± 1.77^{ab}	37.52 ± 3.09^{b}	11.50 ± 0.13^{de}	1.91 ± 0.20
MSG + Ascorbic Acid, 100 mg/kg	18.18 ± 5.85^{a}	76.58 ± 17.68^{a}	13.06 ± 1.17^{cd}	2.04 ± 0.00

The different superscript (^{a,b,c,d}) are statistically significant at $p < 0.05$

Table 2 presents the effects of *Curcuma longa* Extract and *Zingiber officinale* Extract on Hematological Parameters in MSG-Treated Experimental Groups. MSG caused slight alterations in red blood cell indices. ZOE maintained near-normal hematological values, while

CLE (200 mg/kg) reduced Hb, PCV, and RBC, indicating possible adverse effects at higher dose. Combined treatment showed moderate improvement.

Table 2: Effects of *Curcuma longa* Extract and *Zingiber officinale* Extract on Hematological Parameters in MSG-Treated Experimental Groups.

Group	HB (g/dL)	PCV (%)	RBC (×10⁶mm³)	MCV (fL)	MCH (pg)	MCHC (dL/g)
Normal control	18.80±0.12[a]	50.00±0.58[a]	7.97 ± 0.10[a]	62.77±0.03[bc]	23.6±0.14[c]	37.61±0.20[bc]
MSG-only group	18.50±0.40[ac]	49.00±1.73[ab]	7.70±0.17[abc]	63.58±0.82[ab]	24.03±0.02[c]	37.81±0.51[bc]
MSG + CLE, 200 mg/kg	16.3 ±0.06[f]	38.50±0.29[c]	6.14 ± 0.02[e]	62.70±0.23[bc]	26.55±0.01[a]	42.34±0.17[a]
MSG + ZOE, 200 mg/kg	17.80±0.12[bd]	48.50±0.86[b]	7.70±0.12[abc]	62.98±0.18[abc]	23.13±0.20[c]	36.72± 0.42[c]
MSG + CLE, 200 mg/kg + ZOE 200 mg/kg	17.70±0.75[bd]	45.50±3.75[b]	7.09± 0.48[cd]	64.03± 0.94[a]	25.11±0.65[b]	39.29± 1.59[b]
MSG + Ascorbic Acid, 100 mg/kg	17.30 ±0.40[de]	45.00±2.31[b]	7.25± 0.38[bc]	62.07± 0.03[c]	23.97±0.68[c]	38.61±1.08[bc]

The different superscript ([a,b,c,d]) are statistically significant at $p < 0.05$

Table 3 shows the effects of *Curcuma longa* Extract (CLE) and *Zingiber officinale* Extract (ZOE) on Total and Differential White Blood Cell Counts in MSG-Treated Experimental Groups. MSG slightly stimulated immune response. CLE significantly increased WBC and eosinophils, suggesting immune activation, while ZOE maintained more stable immune parameters. Combination treatment showed balanced effects.

Table 3: Effects of *Curcuma longa* Extract and *Zingiber officinale* Extract on Total and Differential White Blood Cell Counts in MSG-Treated Experimental Groups.

Group	TWBC (×10³mm³)	RE lymphocyte (%)	RE neutrophil (%)	RE monocyte (%)	RE eosinophil (%)	RE basophil (%)
Normal control	9.98 ± 0.07[d]	59.00± 0.00[b]	33.50±0.29[bc]	5.50±0.29[ab]	2.00 ± 0.00[bc]	0.00 ± 0.00[ab]
MSG-only group	10.23±0.13[cd]	60.50± 0.29[a]	32.50± 0.29[c]	5.00±0.58[ab]	2.00 ± 0.00[c]	0.00 ± 0.00[b]
MSG+CLE, 200 mg/kg	13.15± 0.20[a]	53.50± 0.29[d]	35.00± 0.58[a]	4.50± 0.29[b]	6.50 ± 0.29[a]	0.50 ± 0.29[ab]
MSG+ ZOE, 200 mg/kg	10.43±0.33[cd]	58.50± 0.29[b]	33.50±0.29[bc]	5.00±0.00[ab]	3.00 ± 0.00[bc]	0.00 ± 0.00[b]

MSG+CLE, 200 mg/kg + ZOE 200 mg/kg	10.80±0.23^{bcd}	56.50± 0.29^{c}	34.50±0.29^{ab}	5.50±0.29^{ab}	2.50 ± 0.29^{bc}	1.00 ± 0.00^{a}
MSG+ Ascorbic Acid,100 mg/kg	10.08± 0.04^{bc}	57.00± 0.58^{c}	34.00±0.58^{ab}	6.00±0.00^{a}	2.50 ± 0.29^{bc}	0.50 ± 0.29^{ab}

The different superscript (^{a,b,c,d}) are statistically significant at $p < 0.05$

Table 4 reveals the absolute Counts of Lymphocytes, Neutrophils, Monocytes, Eosinophils, and Basophils in MSG-Treated Groups Administered with *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid. CLE increased lymphocytes, neutrophils, and eosinophils, confirming strong immune stimulation. ZOE had minimal effect, while the combination moderated these changes.

Table 4: Absolute Counts of Lymphocytes, Neutrophils, Monocytes, Eosinophils, and Basophils in MSG-Treated Groups Administered with *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid.

Group	AB lymphocyte ($\times 10^3 mm^3$)	AB neutrophil ($\times 10^3 mm^3$)	AB monocyte ($\times 10^3 mm^3$)	AB eosinophil ($\times 10^3 mm^3$)	AB basophil ($\times 10^3 mm^3$)
Normal control	5.89 ± 0.04^{c}	3.34 ± 0.00^{c}	0.55 ± 0.03^{b}	0.20 ± 0.00^{b}	0.00 ± 0.00^{b}
MSG-only group	6.19± 0.05^{bc}	3.32 ± 0.01^{c}	0.51 ± 0.07^{b}	0.20 ± 0.00^{b}	0.00 ± 0.00^{b}
MSG+CLE, 200 mg/kg	7.04 ± 0.15^{a}	4.60 ± 0.01^{a}	0.59 ± 0.03^{ab}	0.86 ± 0.05^{a}	0.07 ± 0.04^{ab}
MSG+ZOE, 200 mg/kg	6.10± 0.22^{bc}	3.49 ± 0.08^{c}	0.52 ± 0.02^{b}	0.31 ± 0.01^{b}	0.00 ± 0.00^{b}
MSG + CLE, 200 mg/kg + ZOE 200 mg/kg	6.10± 0.16^{bc}	3.72 ± 0.05^{b}	0.60 ± 0.04^{ab}	0.27 ± 0.03^{b}	0.11 ± 0.00^{a}
MSG + Ascorbic Acid, 100 mg/kg	5.74 ± 0.03^{c}	3.43 ± 0.07^{c}	0.60 ± 0.00^{ab}	0.25 ± 0.03^{b}	0.05 ± 0.03^{ab}

The different superscript (^{a,b,c,d}) are statistically significant at $p < 0.05$

Table 5 shows the effects of *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid on Body Weight Changes in MSG-Treated Experimental Groups over Two Weeks. MSG increased body weight. ZOE reduced weight gain, indicating metabolic regulation, while CLE had moderate effects. Ascorbic acid group showed the highest weight gain.

Table 5: Effects of *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid on Body Weight Changes in MSG-Treated Experimental Groups over Two Weeks.

Group	Week 1 (g)	Week 2 (g)
Normal control	74.68 ± 8.49[b]	86.00 ± 4.50[b]
MSG-only group	97.00 ± 3.18[a]	100.55 ± 3.67[ab]
MSG + CLE, 200 mg/kg	93.85 ± 6.90[a]	94.73 ± 7.73[ab]
MSG + ZOE, 200 mg/kg	87.13 ± 3.81[ab]	87.47 ± 5.83[b]
MSG + CLE,20 mg/kg + ZOE 200 mg/kg	97.63 ± 4.98[a]	94.95 ± 1.01[ab]
MSG + Ascorbic Acid, 100 mg/kg	101.18 ± 6.10[a]	107.65 ± 5.60[a]

The different superscript ([a,b,c,d]) are statistically significant at $p < 0.05$

Table 6 shows the effects of *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid on Relative Organ Weights in MSG-Treated Experimental Groups. MSG reduced some organ weights, suggesting toxicity. CLE increased liver, kidney, and spleen weights, indicating possible hypertrophy or stress, while ZOE maintained values closer to normal, suggesting better safety.

Table 6: Effects of *Curcuma longa* Extract, *Zingiber officinale* Extract, and Ascorbic Acid on Relative Organ Weights in MSG-Treated Experimental Groups.

Group	Liver (%)	Heart (%)	Kidney (%)	Spleen (%)
Normal control	4.60 ± 0.11[ab]	1.14 ± 0.03[a]	0.61 ± 0.04[c]	0.50 ± 0.03[b]
MSG-only group	3.74 ± 0.02[c]	0.62 ± 0.05[b]	0.82 ± 0.01[b]	0.53 ± 0.01[b]
MSG + CLE, 200 mg/kg	4.94 ± 0.18[a]	0.48 ± 0.01[cd]	0.96 ± 0.03[a]	0.99 ± 0.02[a]
MSG + ZOE, 200 mg/kg	3.80 ± 0.05[c]	0.50 ± 0.02[cd]	0.76 ± 0.01[b]	0.63 ± 0.04[b]
MSG + CLE,20 mg/kg + ZOE 200 mg/kg	4.21 ± 0.19[bc]	0.56 ± 0.02[bc]	0.85 ± 0.02[b]	0.70 ± 0.14[b]
MSG + Ascorbic Acid, 100 mg/kg	3.92 ± 0.24[c]	0.46 ± 0.03[d]	0.84 ± 0.04[b]	0.66 ± 0.07[b]

The different superscript ([a,b,c,d]) are statistically significant at $p < 0.05$

The oxidative stress data show a complex pattern. Superoxide dismutase activity increased in the MSG-only group (7.64 IU/g protein) relative to the normal control (5.95), indicating a possible adaptive response to enhanced reactive oxygen species generation induced by MSG toxicity [23]. However, MDA, a marker of lipid peroxidation, was paradoxically lower in the MSG-only group (23.59 nmol/g) than in controls (33.23 nmol/g), which may suggest early depletion of lipid substrates or interference in assay sensitivity [24].

Administration of *Curcuma longa* extract and *Zingiber officinale* extract, alone or combined, significantly increased SOD activity beyond MSG-only levels, with ZOE showing the highest SOD (11.16 IU/g). Catalase activity was markedly elevated in the MSG group (13.18 kU/g) compared to normal controls (5.41), indicating increased hydrogen peroxide breakdown to counteract oxidative stress [25]. Treatment groups, particularly MSG + CLE and MSG + ZOE, showed even higher catalase activities (22.52 and 25.87 kU/g, respectively), suggesting enhanced antioxidant enzyme induction. Glutathione levels showed a slight decrease in MSG groups, with partial restoration upon treatment, highlighting the antioxidant replenishment potential of the extracts [26]. The MSG + ascorbic acid group exhibited the highest SOD and MDA levels, reflecting a distinct antioxidant profile, possibly due to ascorbic acid's role as a pro-oxidant at high concentrations [27].

Hemoglobin, packed cell volume, and red blood cell counts were reduced in the MSG + CLE group compared to controls and other treatment groups, suggesting a mild anemia possibly related to high-dose CLE or its interaction with erythropoiesis [28]. Conversely, MSG + ZOE maintained values closer to normal, indicating better hematological protection. Mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) showed significant variations, with the CLE-treated group showing elevated MCH and MCHC, possibly reflecting macrocytic changes or increased hemoglobin loading per cell [29].

Total white blood cell counts were elevated in the MSG + CLE group ($13.15 \times 10^3/mm^3$), indicating an immunostimulatory effect, possibly due to CLE's known immunomodulatory properties [30]. Relative and absolute lymphocyte percentages decreased in this group but eosinophil counts rose significantly, consistent with an allergic or inflammatory response [31]. MSG alone did not significantly alter TWBC but showed slight shifts in differential counts, consistent with mild immune modulation reported in MSG toxicity [32].

MSG administration caused a significant increase in body weight at week 1 and a non-significant increase at week 2 compared to controls, confirming MSG's known obesogenic effect [33]. Treatment with ZOE normalized body weight, while CLE groups maintained elevated weights, possibly indicating differential metabolic effects of these extracts [34]. Ascorbic acid treatment showed the highest body weights, reflecting potential growth-promoting effects or fluid retention.

MSG caused a reduction in relative liver and heart weights, consistent with organ toxicity and tissue atrophy [2]. The liver weight was restored in the MSG + CLE group but remained low in other treated groups, suggesting that CLE may better protect hepatic tissue mass. Kidney weights increased with MSG and CLE treatments, possibly due to compensatory hypertrophy or inflammation [35]. Spleen weight was significantly elevated in the CLE group, indicating immune activation, while it remained near control values in other groups.

The elevation of antioxidant enzymes (SOD and catalase) in MSG groups aligns with previous findings that MSG induces oxidative stress, triggering compensatory antioxidant responses [36]. The further enhancement by CLE and ZOE supports their role as potent antioxidants, with ginger and turmeric extracts known to induce Nrf2 pathways and elevate antioxidant defenses [37-38].

The slight anaemia observed with CLE treatment may relate to high doses causing oxidative stress or affecting iron metabolism, as reported by Oladele *et al.* [28]. The immunomodulatory changes, particularly increased eosinophils and lymphocytes, underscore the immune-enhancing properties of CLE and ZOE, consistent with prior studies demonstrating their effects on cytokine profiles and immune cell proliferation [30-31].

MSG-induced weight gain confirms its obesogenic potential mediated through hypothalamic damage and altered appetite regulation [33]. The normalization of body weight by ZOE suggests metabolic benefits, likely via ginger's anti-inflammatory and lipid-lowering effects [34].

Organ weight alterations corroborate tissue-specific toxicity and protection. Restoration of liver weight by CLE indicates hepatoprotection, possibly through membrane stabilization and antioxidant effects [39]. The increased spleen weight with CLE reflects immune system stimulation [40].

CONCLUSION

MSG administration induces oxidative stress, mild anaemia, immunomodulation and changes in body and organ weights, reflecting systemic toxicity. Treatment with *Curcuma longa* and *Zingiber officinale* extracts modulates these effects variably, with both showing antioxidant and immunostimulatory benefits. CLE demonstrates stronger hepatic and immune protective effects but may cause mild anemia at higher doses, whereas ZOE effectively normalizes body weight and hematological parameters. These findings highlight the potential therapeutic role of these extracts against MSG-induced toxicity, warranting further investigation into their mechanisms and optimal dosing.

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