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Research Article
Nanoparticles Effects on Zinc Oxide/green Tea Complex on the Lipid Profile and Liver Functions of Rats after Monosodium Glutamate Treatment

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Abstract

Background and Objective: The potential benefit of green synthesis zinc oxide nanoparticles (ZnO NPs) is still a deprecatory issue. The aim of the present research was to elucidate the anti-hyperlipidemia of green tea leaves extract (GTE)/ZnO NPs complex against monosodium glutamate (MSG). **Materials and Methods:** Eight different groups of male rats were used: Group I was the control, group II received GTE (1 mg mL^{-1}), group III was treated with ZnO NPs (10 mg kg^{-1}), groups IV and V received MSG in two different doses (6.0 and 17.5 mg kg^{-1}), group VI treated with ZnO NPs/GTE complex, groups VII and VIII were given ZnO NPs/GTE complex plus MSG in different doses. The effect of ZnO NPs/GTE complex against MSG toxicity through studying the alteration of enzyme activity of liver functions [alanine aminotransferase (ALT), aspartate aminotransferase (AST), lactate dehydrogenase (LDH), alkaline phosphatase (ALK) and γ-glutamyl transferase (γ-GT)] and lipid profile alternation have been described. The rats that were given MSG only had a highly significant elevation in liver enzymes and severe lipid metabolism changes. **Results:** The findings for group VII and VIII clarify the efficacy of ZnO NPs/GTE complex as a hepato-protectant on MSG alone through improving the liver enzyme activity along with the lipid profile. The activities of ALT, AST, LDH, ALP and γ-GT in the serum were significantly reduced. **Conclusion:** ZnO NPs/GTE complex was proved to be a potential hepatoprotective as it significantly ameliorates the hepatotoxicity induced by MSG through hyperlipidemia reducing effect.

Key words: ZnO NPs/Green tea complex, lipid profile, liver biomarker enzymes

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Zinc oxide nanoparticles (ZnO NPs) consider one of the excellent metals that used in different areas as an antimicrobial and optical properties[1]. *Aloe barbadensis* has been used to form green ZnO NPs and revealed appreciable antibacterial and antibiofilm properties, therefore it has potential as nano antibiotic or drug carriers for drug delivery to the target cancer cell[2].

Camellia sinensis was adequately benefited to form green ZnO NPs as a common ligature agent. The role of *Camellia* extract on the synthesis of ZnO NPs was confirmed using TEM that revealed the crystallinity of NPs. The size of the particles was determined to be 200 nm as confirmed from TEM analysis[3]. The synthesis of ZnO NPs has generous interest because of having antibacterial properties and biomedical applications[4,5].

Moreover, the ZnO NPs with green tea extract has been studied by many investigators[5,6]. They found that polyphenolic and catechin compounds exist in green tea had intrigued a lot of interest due to their benefits to human health and their antioxidant capacity. The complex can be used against several pathophysiological conditions as hypertension, cardiovascular disease, dementia and even cancer[7,8]. The advantages that mentioned previously for green tea extract (GTE) because it has powerful phenolic antioxidants for innovative biomedical applications[5,9,10].

ZnO NPs/GTE complex acts as partial hepatic protection against monosodium glutamate by reducing the oxidative stress, anti-inflammatory biomarkers (C-reactive protein, α-tumor necrosis and interleukin-6) as well as increasing the antioxidants as superoxide dismutase, catalase, glutathione peroxidase and glutathione[5]. They found that GTE/ZnO NPs complex improved the histological analysis and transmission view of hepatic parenchyma in rats treated with monosodium glutamate (MSG). ZnO NPs/GTE showed amelioration of hepatic tissues with the restoration of most hepatic structures as normal nuclei without pyknosis and normal mitochondria as well as an improvement in the ultrastructural changes in the form of normal nuclei with little irregular boundaries of nuclei and mid-size mitochondria.

MSG is used to improve the taste whoever, the long-term using MSG-induced oxidative stress[11]. MSG intake has many side effects on the brain, obesity, sex organs and metabolism[12]. Cerebellar cortex showed degenerative changes as pyknotic Purkinje and granule cells with areas of degeneration surrounded by inflammatory cells in granular layer. Higher adipocyte lipid content and fat content/body weight ratio have been observed in 30 days old rats injected with 4 g kg^{-1} of MSG within the first 10 days of experiment. The MSG caused disturbances in metabolism with the increase in the insulin, fatty acids and triglycerides in serum. It affected the liver function resulting in elevation of transaminases' levels and bile synthesis, it also led to oxidative stress in liver and to the pathological changes in ovaries and fallopian tube.

To evaluate the hepatic status, many enzymes can be determined such as alanine aminotransferase (ALT), aspartate aminotransferase (AST), lactic dehydrogenase (LDH), gamma-glutamyl transpeptidase (γ-GT) and alkaline[13]. Moreover, there is no data available in the literatures concern about using GTE/ZnO NP complex against the toxicity of MSG. Therefore, the purpose of the current study was to discover the possible anti-hyperlipidemia effects of the GTE/ZnO NP complex in rats treated with MSG as well as the biomarkers enzymes activity of the liver.

MATERIALS AND METHODS

The green tea plant with high purity was obtained from the local market of Al-Taif city, Saudi Arabia. The ZnO NPs with a diameter of 200 nm, length up to 150 nm and size range 40-150 nm were obtained from Sigma-Aldrich Company. The purities of ZnO NPs were 99.5% Sigma Aldrich. Monosodium glutamate (MSG) with purity 99% was obtained from markets (Ajinomoto Co. Inc., Tokyo, Japan).

Preparation of green tea extracts (GTE): The whole plant was thoroughly washed with double distilled water and dried. A quantity of 10 g dry and powder of green tea was mixed with 100 mL ethanol 95° in 35°C. The mixed solution was left on persistent magnetic stirring for 24 h at 27°C[14]. The extract was filtered and stored at 4°C for further experiments.

Preparation of MSG: A stock solution of MSG was processed by dissolving 60 g in 1000 mL of double distilled water.

Characterization of ZnO NPs and preparation of GTE/ZnO NPs complex: The specific surface areas of ZnO NPs were 50 m^2 g^{-1}. About 0.001 M aqueous solutions of ZnO NPs were prepared by dispersing using ultrasonic vibration (130 W, 20 kHz) for 30 min and used for the synthesis of ZnO NPs/green tea complex[5].

The process of the green tea conjugation with ZnO NPs was comprised by addition of 5 mL of GTE to 120 mL aqueous solution of 0.001 M ZnO NPs to form GTE/ZnO NPs solution and kept at room temperature for an hour for the reduction process of Zn ions. Finally, the green tea extract/ZnO NPs complex was formed (GTE/ZnO NPs complex, 1 mg mL^{-1}).

Experimental animals design and ethical considerations: The Wistar rats were purchased from the animal house of the Faculty of Pharmacy-Zagazig University. Sixty-four adult male rats were weight 200-250 g and kept under laboratory conditions of aeration and room temperature (25±2°C) for two weeks before being experimented. The animals were allowed to food and water throughout the experimental period which had been started in March, 2018 for 30 days.

The rats were chosen as the most appropriate animal species. The sample size of animals was estimated using the less number of animals to obtain authentic results. All procedures were performed under anesthesia to evade any pain that could be exact on the animals. The Research Animal Ethics Committee in Taif University approved the standards of animal care (39-31-0034).

The rats were divided into eight groups (n = 8). Control group was given the physiological saline solution. Rats in the two treatment groups were administrated with two different doses of MSG (MSG-LD, MSG-HD, 6 and 17.5 mg kg^{-1}, respectively). Another three groups of rats treated with GTE alone (1 mg mL^{-1}), ZnO NPs (10 mg kg^{-1}) alone and GTE/ZnO NPs complex. The selective doses of MSG and Zn O NPs were chosen according to Hamza and Al-Harbi[15] and Ben-Slama *et al.*[16], respectively. However, the last two groups were treated with MSG-LD+GTE/ZnO NPs complex and MSG-HD+GTE/ZnO NPs complex. All the rats have administrated the materials orally for 30 successive days.

Blood sample collection: All rats were fasted overnight before collecting the blood from the retro-orbital plexus vein using capillary tubes (Micro Hematocrit Capillaries, Mucaps) under mild ether anesthesia. Blood samples were transferred to centrifuge tubes and allowed to stand for 30 min to clot before being centrifuged at 3,000 rpm for 15 min. Serum was separated and frozen at -20°C until the biochemical estimation.

Liver functions assessment: Serum enzymes activities of alanine aminotransferase (ALT), a separate aminotransferase (AST) and lactate dehydrogenase (LDH) were estimated using UV kinetics methodology of the commercial diagnostic kit (Stanbio Co., Spain). The γ-glutamyl transferase (γ-GT) activity was examined using Human Diagnostic worldwide, Germany. The data were expressed as international units per gram (IU g^{-1}). The proteins levels were estimated as described by the Bio-rad protein assay reagent (Bio-rad Laboratories, Hercules, CA, USA) using bovine serum albumin as the standard.

Lipid profile assessment: The serum total cholesterol (TC) and triglycerides (TG) were preserved by the method of Carr *et al.*[17]. The high-density lipoprotein-cholesterol (HDL-C) was evaluated according to the methods of Warnick *et al.*[18]. Serum low-density lipoprotein-cholesterol (LDL-C) level was calculated according to the formula of Friedewald *et al.*[19]. LDL-C = ¼ Total cholesterol levels-(Triglyceride concentration/5)-HDL-C concentration. Very low-density lipoprotein cholesterol (VLDL-c) was determined according to the method described by Friedewald *et al.*[19].

Statistical analysis: Data are presented as Mean±SE (n = 8/group). Statistical analysis was performed using one-way analysis of variance (ANOVA) to assess significant differences among treatment groups, the *post hoc* Tukey's test was used for comparisons. The statistical significance was set at $p<0.05$. All analyses were performed using SPSS version 18 (SPSS Inc., USA).

RESULTS

The serum lipid profile of rats was performed showing significant increments in TC, TG, LDL-C and VLDL-C in MSG-LD and MSG-HD treated groups as compared to the control, GTE and ZnO NPs animals in a dose-dependent manner (Table 1). However, the content of HDL-C showed a significant ($p<0.05$) decrease in MSG groups as compared to control, GTE and ZnO NPs. Treated the animals with GTE/ZnO NPs complex in combination with MSG-LD or MSG-HD decreased significantly all the lipid profile parameters except the HDL-C that elevated as compared to its relative of MSG alone.

There are significant differences in the activities of AST, ALT, ALP and LDH in the sera of MSG-LD and MSG-HD groups as compared to control rats (Table 2). Data showed that there were significant elevations in AST, ALT, ALP and LDH activities in the sera of animals treated with MSG-HD more than those administrated MSG-LD. However, treated the rats with GTE/ZnO NPs and MSG showed a significant decrease in the all the enzymes activity in comparison with animals of MSG alone. The changing in enzyme leakage percentage of all enzymes occurred in a dose-dependent manner.

After 30 days of MSG treatment, the levels of total proteins in serum were decreased in the rats by 29.1% and 46.5% for MSG-LD and MSG-HD, respectively (Table 2). Total proteins did not affect by MSG-LD and GTE/ZnO NPs treatment as compared to the animals of MSG-LD alone. However, total proteins level significantly increased after the combination of MSG-HD and GTE/ZnO NPs treatment by 1.5-fold as compared to MSG-HD alone.

Table 1: Changes of serum lipid profile in male rats treated with green ZnO NPs and monosodium glutamate

Parameters (mg dL^{-1})	Control	GTE	ZnO NPs	MSG-LD	MSG-HD	ZnO NPs/GTE	ZnO Nps/ GTE+MSG-LD	ZnO NPs/ GTE+MSG-HD
TC	78.6±1.9	73.3±3.8[a]	76.3±3.7	124.9±5.2[a]	204.0±15.7[a]	74.4±3.7	84.1±3.5[b]	103.1±4.9[b]
TG	67.8±1.6	72.2±2.9	73.4±3.1	132.6±6.8[a]	186.3±4.2[a]	68.1±3.0	88.3±3.0[b]	98.6±3.4[b]
HDL-C	40.6±0.6	38.6±0.6[a]	39.2±0.8	32.7±1.6[a]	28.6±1.4[a]	41.2±0.5	36.1±1.8	37.7±0.9[b]
LDL-C	20.3±1.4	21.6±1.6	20.3±2.0	30.4±2.6[a]	36.8±1.2[a]	19.5±0.9	21.1±3.3[b]	22.5±2.0[b]
VLDL-C	4.1±0.3	4.3±0.3	4.1±0.4	6.1±0.5[a]	7.4±0.3[a]	3.9±0.2	4.2±0.7[b]	4.5±0.4[b]

Values represent means±SE, n = 10 for each treatment group. GTE: Green tea extract, ZNO NPs: Zinc oxide nanoparticles, MSG-LD: A lower dose of monosodium glutamate, MSG-HD: A higher dose of monosodium glutamate, TC: Total cholesterol, TG: Triglyceride, HDL-C: High density lipoprotein cholesterol, LDL-C: Low density lipoprotein cholesterol, VLDL-C: Very low density lipoprotein cholesterol. [a]Significant difference as compared to control and [b]Significant difference as compared to the corresponding group treated with MSG alone

Table 2: Changes of liver enzymes activity and total proteins in male rats treated with green ZnO NPs and monosodium glutamate

Parameters (mg dL^{-1})	Control	GTE	ZnO NPs	MSG-LD	MSG-HD	ZnO NPs/GTE	ZnO Nps/ GTE+MSG-LD	ZnO NPs/ GTE+MSG-HD
ALT	20.9±1.0	20.3±0.7	20.9±1.1	144.5±27.6[a]	234.3±19.7[a]	16.2±0.9[a]	62.9±5.6[b]	57.5±6.1[b]
AST	18.1±1.3	21.5±1.1	20.6±1.2[a]	167.2±27.1[a]	228.9±20.6[a]	14.3±0.9[a]	61.9±3.3[b]	87.7±9.4[b]
ALP	33.3±1.4	42.5±3.1[a]	36.3±3.0	119.6±9.0[a]	179.3±7.4[a]	26.3±2.3	103.7±5.2	124.2±6.7[b]
LDH	111.4±4.4	116.8±2.4	114.8±4.3	250.9±11.2[a]	413.3±12.6[a]	101.5±4.2	183.6±14.2[b]	202.4±5.6[b]
γ-GT	5.0±0.3	4.9±0.1	5.2±0.3	4.6±0.3	6.5±0.3[a]	7.6±0.2	4.5±0.3[b]	4.7±0.4[b]
Total proteins	8.6±0.4	8.1±0.3	8.5±0.2	6.1±0.3[a]	4.6±0.3[a]	8.8±0.2	6.1±0.2	6.8±0.2[b]

Values represent means±SE, n = 10 for each treatment group. GTE: Green tea extract, ZNO NPs: Zinc oxide nanoparticles, MSG-LD: A lower dose of monosodium glutamate, MSG-HD: A higher dose of monosodium glutamate. [a]Significant difference as compared to control and [b]Significant difference as compared to the corresponding group treated with MSG alone

DISCUSSION

All the data available in the literature concern on the protective effect of vitamin C, vitamin E, quercetin and diltiazem on MSG-induced toxic changes. Treatment with vitamin C before the MSG repaired the efficiency of the antioxidant and it shows a defensive role against MSG-induced oxidative stress[20]. It is the first time to use the GTE/ZnO NPs complex to protect against MSG that induced the lipid metabolism disorder and enzymes leakage.

Hyperlipidemia could be treated with therapeutic drugs or by natural materials. Data of the current research found that hyperlipidemia, induced by MSG-treatment caused the marked elevation in all parameters of the lipid profile except HDL-C which was declined. Moreover, the disturbance of lipid profile was auxiliary with elevated markers of liver function as in the present study and histological alternation. In the liver injury, the hepatocytes are disturbed and resulting in the elevation of the serum liver enzymes.

Table 1 demonstrated a significant rise in the TC level of rats treated with MSG, for the month, as compared with the control animals that received the physiological solution saline. Inuwa *et al.*[21] stated that the potential evidence for MSG-obesity depends on its effect on lipid metabolism. The effect of MSG-HD on HDL-C was greater than MSG-LD of the rats. In the current investigation, elevation of serum TC and declining the HDL-C suggested that MSG could be a danger factor for coronary heart disease[22]. The comparison between the control group and animals treated with GTE indicate the anti-hyperlipidemia character of the GTE.

Elevation of serum LDL-C and VLDL-C in MSG groups as compared with those of control rats were reported in the current investigation. In addition, the rise in TC could be allocated to the reduction of TC-catabolic rate or inhibition the activity of hepatic cholesterol-7-alpha-hydroxylase that synthesis from cholesterol in bile acid[23]. Moreover, the amelioration of TC observed in this study could be related to increment HMG-CoA reductase activity in the hepatocytes of animals treated with MSG and the decline rate of LDL-clearance from the circulatory system due to deficient LDL-C receptors associated with the accumulation of TC level[24].

Moreover, the rise of TG level may be associated to the reduction of lipase activity that is an insulin-dependent enzyme participating in TG clearance from plasma by umpiring TG lipolysis into glycerol and free fatty acids[25].

Recently, many different drugs are used to control the levels of lipid in blood and decline the heart damage and blood vessel disability. Based on the present study, using GTE/ZnO NPs had a significant role in decline the risk of preventing diseases with high levels of blood lipid in MSG-treated animals.

Increasing the leakage of hepatocytes enzymes in serum were in concurrence with the observation of Egbuonu *et al.*[26] who stated that MSG administration caused the elevation in the enzyme activities (ALT and AST) and atrophic of liver

tissues which indicated that there were hepatocellular injuries. The same results have been reported by Akanya *et al.*[27] and Al Salmi *et al.*[3] These obviously could affect the most functions of the liver.

The oral administration of GTE/ZnO NPs prior to the treatment with MSG showed an enhancement in enzymes activities as compared with MSG groups alone. GTE/ZnO NPs complex has the ability to protect against the cytotoxicity of MSG.

The markers enzymes activities of hepatocellular injury as ALT, AST, ALP, LDH and γ-GT were shown a decreased in the combination of GTE/ZnO NPs and MSG. The ALT and AST are also increased in the occurrence of injury to kidney, heart and muscle[28]. LDH leakage is an indicator of plasmatic membrane damage and/or necrosis of hepatocytes[29]. Treatment with MSG-HD has the effect on serum total proteins. Therefore, the increased activities of ALT, AST, ALP, LDH and γ-GT in the sera with decreasing the total proteins of MSG-treated animals could be resulted from the liver injury by the MSG-induced oxidative stress as stated before by Al Salmi *et al.*[3].

Serum ALP is a marker of cholestasis[30]. Cholestasis progress from a deficiency in bile synthesis, deterioration in bile secretion or interference to bile flow and is characterized by increasing serum ALP[31]. The data obtained from the present study indicate that GTE/ZnO NPs complex improved ALP levels better than normal green tea. The GTE/ZnO NPs complex at a dose of 10 mg kg^{-1} can regulate bile acid metabolism by decreasing the levels of ALP. The regulatory function of GTE/ZnO NPs complex was found also in the rats that treated with MSG. These observations could be largely explained by its organic zinc and phenolic content of the GTE.

GTE/ZnO NPs complex has been settled biochemically as an antioxidant which ability to scavenge the free radicals (superoxide, hydrogen peroxide and hydroxyl) and decline the oxidative stress[3]. Moreover, it protects the architecture of the liver against different doses of MSG[3]. Hence, the rats in the group treated with GTE/ZnO NPs complex and MSO showed the decrease in the enzymes activity and lipid profile as compared to MSG alone.

CONCLUSION

Based on the results of the current investigation, the anti-hyperlipidemia effect of GTE/ZnO NPs was enhanced by the decline in the levels of TC, TG, LDL-C and increasing the HDL-C. Moreover, the integrity of hepatocytes was improved as indicated by decreasing the activity of the enzymes. The present study shows that GTE conjugated with ZnO NPs can be used as a promising anti-hyperlipidemic agent against hyperlipidemia disorders induced by MSG.

SIGNIFICANCE STATEMENT

This study discovers the GTE/ZnO NP complex that can be beneficial for liver function.

This study proved that ZnO NPs/GTE complex can be act as a potential hepatoprotective against MSG and it has the anti-hyperlipidemia effect.

This study will help the researcher to uncover the critical areas of GTE/ZnO NP complex that many researchers were not able to explore.

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