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Therapeutic effects of zinc and maple syrup on zinc deficiency in male albino rats

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ABSTRACT

This study was conducted to investigate the therapeutic effects of zinc (Zn) and maple syrup on zinc deficiency in male albino rats. Thirty adult male Albino rats were randomly divided into 5 groups (6 each). The first group served as a control, the second group was fed a zinc-deficient diet (3 ppm Zn/kg). The remaining three groups were initially fed a zinc-deficient diet for 4 weeks, subsequently, the third group received 84 ppm Zn/kg diet. The fourth group then received 84 ppm Zn/kg diet and maple syrup (100 mg/kg body weight/intraperitoneally/day), while the fifth group received 84 ppm Zn/kg diet and maple syrup (200 mg/kg body weight/intraperitoneally/day) for 2 consecutive weeks. Rats body weight and food intake were measured and blood samples were gathered to assays the levels of Zn, lipid profile, total thyroxine (T4), triiodothyronine (T3), and testosterone. While, liver tissue samples were gathered to assays the levels of Zn, glutathione (GSH), glutathione peroxidase (GPX), and malondialdehyde (MDA). Zinc deficiency significantly impaired growth, nutrient utilization, lipid metabolism, T3, testosterone, GSH and GPX. While, Co-administration of maple syrup with zinc improved nutritive effects, lipid profiles, and significantly boosted testosterone levels and antioxidant defense mechanisms. It can be recommended that the incorporating of combining zinc and maple syrup in diet may enhance zinc bioavailability and provide additional health-promoting effects.

Keywords: Maple syrup, Zinc deficiency, Antioxidant, Testosterone, Rats.

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INTRODUCTION

Zinc deficiency is a physiological state where the body lacks adequate zinc to support essential metabolic functions, including growth, immune response, and tissue healing. A major consequence of zinc deficiency is impaired immune function, where innate and adaptive responses are weakened, leading to increased susceptibility to infections, especially in the respiratory and gastrointestinal systems **(Maares & Haase, 2020)**. Zinc supplementation effectively reverses symptoms of zinc deficiency in rats, including extreme growth retardation, abnormal hair/alopecia, dermal lesions and delayed sexual maturation **(Padoan *et al.*, 2024)**. Cognitive and emotional disturbances, including memory impairment and depression, are linked

to low zinc levels **(Azargoonjahromi, 2024)**. Dermatological symptoms such as dermatitis, poor wound healing, and alopecia are also common. Zinc levels are depleted during diarrhea and gastrointestinal conditions. In males, a deficiency in zinc leads to impairs in testosterone production and sperm quality **(Zečević *et al.*, 2025)**.

Maple syrup is a natural sweetener extracted from the sap of maple trees (*Acer saccharum*), and recognized for its unique taste as well as nutritional and health benefits. This syrup is abundant in vital minerals such as zinc, manganese, potassium, magnesium and calcium **(Nimalaratne *et al.*, 2020)**. It also features a variety of polyphenolic compounds, including the distinctive quebecol, which has been noted for its health-enhancing properties. Furthermore, the presence of phenolic content in maple syrup could help lower the risks of oxidative stress and inflammation, which lead to cardiovascular disease and certain types of cancer **(Bhatta *et al.*, 2018)**. Additionally, maple syrup has a lower glycemic index than sugar, which means that it has a milder effect on blood glucose. Studies involving animal models have demonstrated that maple syrup might be a preferable sweetening agent for metabolic health and substituting sucrose with maple syrup can lead to improvements in insulin resistance and reductions in liver fat accumulation **(Valle *et al.*, 2020)**. It is important to consume maple syrup in balanced diet mindful of overall sugar consumption due to its sugar content **(Morissette *et al.*, 2024)**. Zinc sulfate (ZnSO4) is a compound given in the treatment of conditions associated with zinc-deficiency such as acrodermatitis enteropathica, also used as an astringent in eye drops and lotions **(Scott *et al.*, 2024)**. This study aimed to assess the potential therapeutic effects of supplemented zinc and maple syrup on zinc deficiency in experimental rats.

MATERIALS AND METHODS

Materials:

Maple syrup was obtained from local market in Cairo, Egypt. The basal diet and zinc-deficient diet components are shown in table (1) according to **NRC (1995) and Dura-Trave *et al.*, (1986)** respectively. The diets components and zinc sulfate (ZnSO4) were obtained as the following: ZnSO4, casein (containing >85% protein), minerals, vitamins, and sucrose were obtained from El-Gomhoriya Pharmaceutical and Chemical Industries Co., Cairo, Egypt. Cellulose and DL-methionine were purchased from Morgan Company, Cairo, Egypt. Corn oil and corn starch was acquired from the local market, Cairo, Egypt.

Table 1: Components of Basal diet and Zinc- deficient:

Ingredients	Basal diet g/kg	Zinc- deficient diet g/kg
Casein	200	200
Corn starch	497	497
Sucrose	100	100
Cellulose	30	30
Corn oil	50	50
Mineral admixtures	100	47
Vitamin admixtures	20	20
DL-methionine	3	3

Experimental animals:

Thirty male adult albino rats of Sprague–Dawley strain weighing 110±10g were obtained from Laboratory of Animal Colony, Helwan, Egypt.

Methods:

Chemical and Phytochemical analysis of maple syrup:

Maple syrup were analyzed for the moisture, protein, fat, ash and fiber substances according to **AOAC (2005**). Nitrogen-free extract (NFE) were calculated by difference 100 - (moisture% +protein% +fat % +ash %+ fiber %) according to **(Cosoroaba & Constantin, 1979)**. While, the phytochemical analysis of polyphenols and flavonoids contents of maple syrup were established using HPLC analysis (Hewlett Packard series 1100) according to **(Merfort, *et al.*, 1997)**. These evaluates were achieved at the Agricultural Research Center, Mansoura city branch, Egypt.

Experimental animal management:

Thirty adult male albino rats of the Sprague-Dawley strain (weighing 110±10 g) were kept in standard polypropylene cages at the research laboratory in the Faculty of Specific Education, Mansoura University. Approval for the experiment was got from the Animal Care and Use Committee, Mansoura University, under animal protocol code No (MU-ACUC\ OTH.R.25.04.4). Rats were subdividing randomly into five groups (six each) as the following:
Group 1: Control group: rats were fed on a basal diet containing 79 mg ZnSO4/kg diet (equivalent to 35 ppm Zn/kg diet) according to **NRC (1995)**.

Group 2: Zinc-deficient (ZD) group: rats were fed on a zinc-deficient diet (3 ppm Zn/kg diet) according to **Dura-Trave *et al.*, (1986)**.

Group 3: ZD + Zn group: rats were maintained on a zinc-deficient diet for four weeks. Subsequently, their diet was supplemented with 200 mg ZnSO4 (equivalent to 84 ppm Zn/kg diet) for 2 consecutive weeks according to **Mehiry and Deen, (2015)**.

Group 4: ZD + Zn + of maple syrup group: rats were maintained on a zinc-deficient diet for 4 weeks, followed by supplementation with ZnSO4 (84 ppm) and maple syrup (100 mg/kg/b. wt/intraperitoneally/day) for 2 consecutive weeks.

Group 5: ZD + Zn + of maple syrup group: rats were kept on a zinc-deficient diet for 4 weeks, followed by supplementation with 84 ppm ZnSO4 and maple syrup (200 mg/kg/b. wt/intraperitoneally/day) for 2 consecutive weeks.

The experiment continued for six weeks. At the end of the experiment, rats were euthanized by decapitation after an overnight fast. Blood samples were collected from each rat into clean, dry tubes, free of anticoagulants, and stored at -20°C until subsequent analysis. Immediately after blood collection, liver and testicular samples were carefully removed, immersed in cold saline (0.9% sodium chloride), rapidly frozen in liquid nitrogen, and stored at -40°C. To prevent contamination, all cages and equipment used in the experiment were thoroughly immersed in 1% EDTA and rinsed with deionized water before use.

Nutritional Parameters:

During the experimental period, food intake was recorded daily, and body weight was measured weekly to determine weight gain. At the conclusion of the experiment, body weight gains and feed efficiency ratio (FER) were calculated using the equations described by **Chapman *et al*., (1959)**: Body weight gain = Final weight (g) - Initial weight (g)

Feed efficiency ratio (FER) = Body weight gain (g) / Food intake (g)

Biochemical analysis:

All biological evaluates were performed in a private laboratory in Mansoura city, Egypt, using kits bought from Diamond Bio diagnostic (Egypt). Serum samples were diluted (1:3) with deionized water to measure zinc levels. Freeze-dried organ sections were weighed and then cured in Muffled oven at 450°C. The ash residue was dissolved in concentrated hydrochloric acid (HCL) and then diluted with deionized water as needed to determine zinc content. Zinc concentrations in serum and tissue were analyzed using a Perkin-Elmer 305B atomic absorption spectrometer. Serum lipid levels were determined as follows: total triglycerides (TG), total cholesterol (T. Chol), high density lipoprotein (HDL-c) and low density lipoprotein (LDL-c) were determined using the methods illustrated by **Roeschlau *et al*., (1974) and Fossati & Principe (1982)**, respectively. Serum levels of total thyroxine (T4), triodothyronine (T3), and testosterone were measured using the methods illustrated by **Larsen (1972); Schuurs and Van Weeman (1977) and Maruyama *et al*., (1987)**, respectively. Also, serum and portions of the liver were quickly excised on ice-cold plates for the assessment of Malondialdehyde (MDA), Glutathione (GSH), and Glutathione peroxidase (GPX) levels using the methods illustrated by **Beauchamp & Fridovich (1971); Ursini *et al*., (1985) and Burnett & Felder (1978)**, respectively.

Statistical analysis:

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 26 (2019; SPSS Inc., Chicago, IL, USA). Statistics were presented as means ± standard deviations (SD) and were evaluated using a one-way analysis of variance (ANOVA), followed by the least significant difference (LSD) test, as described by **Abu-Bader (2011)**.

RESULTS AND DISCUSSION

Chemical analysis of maple syrup:

The data in Table 2 show the chemical composition of maple syrup, which refers to its potential to be a functional food ingredient beyond its role as a natural sweetener. Carbohydrates represent the major component of maple syrup, represented by the nitrogen-free extract (59.19%), with sucrose being the predominant sugar. While the presence of other components includes moisture, fat, protein, ash, and fiber, indicates a more complex nutritional profile than carbohydrates.

The ash content indicates that it contains several essential minerals such as manganese, zinc, potassium, and calcium **(Nimalaratne *et al*., 2020)**. These minerals are essential for the body to perform many physiological processes, especially bone health, nerve function, and enhance the immune response **(Saraiva *et al*., 2022)**.

Table 2: Chemical analysis of maple syrup:

Parameter (%)	Maple syrup
Moisture	15.80
fat	11.46
Protein	10.46
Ash	1.55
Fiber	1.09
Nitrogen-free extract (NFE)	59.19

Values are expressed as means ± SD

Phytochemical analysis of maple syrup:

The phytochemical analysis presented in Table 3 identified significant concentrations of various bioactive compounds such as Pyrogallol, Protocatechuic, Benzoic acid, e-vanillic, Salicylic, Ellagic, Quercetin, Kaempferol and Caffeic acid.

Pyrogallol and protocatechuic acid are recognized for their strong free-radical scavenging activities, which can help mitigate oxidative stress in the body **(Mohammed *et al.*, 2022)**. Quercetin and kaempferol are the most common flavonoid extensively studied to a demonstrating their significant anti-inflammatory, anticancer, and antiviral effects **(Amin *et al.*, 2024)**. This is consistent with recent findings that proved the role of polyphenols in maple syrup contribute to reducing oxidative damage and inflammation, which the key factors in mitigating oxidative stress and inflammation associated with various chronic diseases **(Mohammed *et al.*, 2023)**.

Table 3: Phytochemical analysis of maple syrup:

Compounds	Maple syrup (ppm)
Gallic acid	4.06
Fedic acid	15.58
Pyrogallol	51.47
Chlorogenic acid	5.80
Protocatechuic	35.66
Caffeine	4.21
Quercetin	8.61
Hesperidin	7.59
Coumarin	15.28
Caffeic acid	2.10
Vanillin	9.03
Hesperetin	9.78
Salycilic	24.41
Cinnamic	1.99
Ellagic	21.29
e-vanillic	28.16
Ferulic	3.56
Kaempferol	3.17
Benzoic	29.19

Values are expressed as means ± SD

Nutritive effects in the experimental groups:

The nutritional outcomes presented in Table 4 showed non-significant differences in feed intake across all experimental groups. The zinc-deficient (ZD) group displayed a significantly lower body weight and Feed efficiency ratio (FER) compared to the control group. A significantly recovery was observed in Zn-deficient (ZD)+Zn group in body weight and FER compared to the control group. The groups receiving 100 or 200 mg/kg body weight of maple syrup alongside 84 ppm/kg zinc successfully restored body weight compared to the control group.

The zinc deficiency is known to impair appetite and growth in various animal models, leading to reduced feed intake and subsequent weight loss **(Jin *et al.*, 2023)**. Also, maple syrup might play a role in enhancing nutrient absorption or metabolic efficiency, thereby synergistically supporting growth. Although the presence of various bioactive compounds in maple syrup could contribute to improved intestines health and nutrient bioavailability which in turn can impact nutrient absorption and overall metabolic health **(Rech *et al.*, 2024)**.

Table 4: Nutritive effects in the experimental groups:

Groups / Parameters	Control	Zn-deficient (ZD)	Zn-deficient (ZD)+Zn		
	Zn=35ppm/kg diet	Zn=3ppm/kg diet	Zn=84ppm/kg diet	Zn=84ppm/kg diet +100 maple syrup	Zn=84ppm/kg diet +200 maple syrup
Feed intake (g/d)	15.32± 2.14[a]	13.55± 2.55[a]	15.45± 2.42[a]	15.40± 2.33[a]	15.85± 2.33[a]
Body weight (g)	114.77± 8.11[a]	72.89± 6.11[b]	105.14± 9.13[a]	117.33± 8.03[a]	119.28± 8.03[a]
Feed efficiency ratio (FER)	0.135± 0.01[a]	0.082± 0.03[b]	0.111± 0.02[a]	0.115± 0.04[a]	0.125± 0.04[a]

Data are expressed as means ± SD within each row having superscript letters (a, b, c, d...) which indicate significant differences at $p \leq 0.05$.

Biochemical analysis:

Concentrations of zinc (Zn) in serum and tissues in the experimental groups:

Table 5 provide critical data on the concentrations of zinc (Zn) in serum and tissues in the experimental groups. The zinc-deficient (ZD) group exhibited significantly reduced in zinc levels in serum and tissue compared to the control group. Zinc supplementation (ZD + Zn group) led to a significant improvement in both serum and tissue zinc levels compared to ZD group, although these levels remained significantly lower than those observed in the control group. The groups receiving 100 or 200 mg/kg body weight of maple syrup alongside 84 ppm/kg zinc demonstrated a pronounced enhancement in zinc status in serum and tissue, which both showed substantial improvement, approaching or reaching control group levels.

The components within maple syrup may actively enhance the bioavailability of dietary zinc or improve its systemic utilization and retention. While maple syrup contains zinc, the magnitude of the observed increase, particularly in serum, points towards a more complex

interaction, potentially involving the modulation of gut microbiota or intestinal zinc transporters by maple syrup's rich phytochemical profile **(Wang *et al.*, 2025)**. Also, the presence of certain organic acids or phenolic compounds in maple syrup might chelate zinc in a manner that makes it more bioavailable or reduce the impact of other inhibitors **(Decabooter *et al.*, 2024)**.

Table 5: Concentrations of zinc (Zn) in serum and tissues in the experimental groups:

Groups / Parameters	Control	Zn-deficient (ZD)	Zn-deficient (ZD)+Zn		
	Zn=35ppm/kg diet	Zn=3ppm/kg diet	Zn=84ppm/kg diet	Zn=84ppm/kg diet +100 maple syrup	Zn=84ppm/kg diet +200 maple syrup
Zn (µmol/L)	11.24± 0.12[a]	5.79± 0.08[b]	10.10± 0.09[c]	11.93± 0.11[d]	12.13± 0.11[d]
Zn (µmol/100 g tissue)	0.92± 0.02[a]	0.66± 0.03[b]	0.78± 0.02[c]	0.80± 0.04[c]	0.85± 0.04[c]

Data are expressed as means ± SD within each row having superscript letters (a, b, c, d...) which indicate significant differences at $p \leq 0.05$.

Serum lipid profile levels: total cholesterol (T. Chol), total triglycerides (TG), high density lipoprotein (HDL-c) and low density lipoprotein (LDL-c) in the experimental rat groups:

Table 6 provide critical data serum lipid profile levels in the experimental groups. The zinc-deficient (ZD) group displayed significant dyslipidemia, characterized by markedly elevated in T. Chol, TG, and LDL-c levels, while HDL-c level were significantly lower compared to the control group, which confirms that zinc-deficiency induces an atherogenic. Zinc supplementation (ZD + Zn group) demonstrated an improvement in T. Chol, TG, and LDL-c levels, where it decreased, and HDL-c level increased when compared with the ZD group. Moreover, the groups receiving 100 or 200 mg/kg body weight of maple syrup alongside 84 ppm/kg zinc showed higher levels in HDL-c and lower levels in T. Chol, TG, and LDL-c which were considered superior lipid levels when compared with the ZD group. These parameters have not completely stabilized to control group levels.

The zinc-deficiency status can influence various enzymes involved in lipids metabolism and modulate adipokine secretion, like zinc-alpha2-glycoprotein, which plays a role in lipids degradation **(Martínez-Navarro *et al.*, 2024)**. This effect can be attributed to the polyphenols content of maple syrup, these compounds have been proven to possess a hypolipidemic effect by fatty acid metabolism, modulating cholesterol synthesis and normal bile acid excretion Also, some types of polyphenols can restrain HMG-CoA reductase, the main enzyme in cholesterol synthesis, and activate AMP-activated protein kinase, which causes fatty acid oxidation **(Seyedmahalleh *et al.*, 2023 and Kapper *et al.*, 2024)**.

Table 6: Serum lipids profile: Total Cholesterol (T. Chol), Total Triglycerides (TG), High Density Lipoprotein (HDL-c) and Low Density Lipoprotein (LDL-c) levels in the experimental rat groups:

Groups / Parameters	Control	Zn-deficient (ZD)	Zn-deficient (ZD)+Zn		
	Zn=35ppm/kg diet	Zn=3ppm/kg diet	Zn=84ppm/kg diet	Zn=84ppm/kg diet +100 maple syrup	Zn=84ppm/kg diet +200 maple syrup
T. Chol (mg/dl)	55.38± 0.28[a]	71.54± 0.89[b]	68.06± 0.63[c]	64.46± 0.39[d]	65.96± 0.39[d]
TG (mg/dl)	60.78± 0.38[a]	75.83± 0.87[b]	70.14± 0.64[c]	65.52± 0.50[d]	66.52± 0.50[d]
HDL-c (mg/dl)	16.95± 0.13[a]	16.03± 0.11[b]	17.11± 0.14[b]	17.52± 0.15[d]	18. 32± 0.15[d]
LDL-c (mg/dl)	27.42± 0.18[a]	41.38± 0.36[b]	34.78± 0.29[c]	36. 74± 0.24[d]	38. 06± 0.24[d]

Data are expressed as means ± SD within each row having superscript letters (a, b, c, d...) which indicate significant differences at $p \leq 0.05$.

Serum level of Total Thyroxine (T4), Triiodothyronine (T3), and Testosterone hormones in the experimental rat groups:

Data in Table 7 provide the serum levels of T4, T3 and testosterone in the experimental groups. The zinc-deficient (ZD) group exhibited significantly lower levels of T3 and testosterone when compared to the control group. Zinc supplementation (ZD + Zn group) improved T3 and testosterone levels compared to the ZD group, though both remained significantly lower than the control group. The T3 and testosterone levels significantly approached control group levels in the groups receiving 100 or 200 mg/kg body weight of maple syrup alongside 84 ppm/kg zinc. While T4 levels remained consistently stable and similar to control group across all groups.

Zinc acts as an essential co-factor for many enzymes involved in stimulating thyroid hormone secretion, including deiodinases, which catalyze the conversion of thyroxine to the biologically active triiodothyronine **(Severo *et al.*, 2019)**. Therefore, zinc-deficiency can impair this conversion, which leads to reduced T3 levels. As well, zinc directly influences testosterone synthesis and spermatogenesis. for that reason, it's vital for male reproductive health **(Bonaventura *et al.*, 2015)**. Polyphenols, found in maple syrup may contribute to improved hormonal balance through different mechanisms, such as modulating the activities of enzymes involved in hormone synthesis, reducing oxidative stress on endocrine glands, and enhancing receptor sensitivity **(Prasad & Bao, 2019)**.

Table 7: Serum level of Total Thyroxine (T4), Triiodothyronine (T3), and Testosterone in the experimental rat groups:

Groups / Parameters	Control	Zn-deficient (ZD)	Zn-deficient (ZD)+Zn		
	Zn=35ppm/kg diet	Zn=3ppm/kg diet	Zn=84ppm/kg diet	Zn=84ppm/kg diet +100 maple syrup	Zn=84ppm/kg diet +200 maple syrup
T4 (µg/dl)	4.28± 0.016[a]	4.11± 0.05[a]	4.35± 0.06[a]	4.38± 0.07[a]	4.38± 0.07[a]
T3 (ng/dl)	83. 89± 0.66[a]	62.25± 0.56[b]	76.33± 0.63[c]	79.94± 0.61[d]	80.04± 0.61[d]
Testosterone (ng/dl)	1.43± 0.027[a]	0.83± 0.02[b]	1.24± 0.02[c]	1.40± 0.03[d]	1.81± 0.03[d]

Data are expressed as means ± SD within each row having superscript letters (a, b, c, d...) which indicate significant differences at $p \leq 0.05$.

Serum and tissues concentrations of glutathione (GSH), glutathione peroxidase (GPX) and malondialdehyde (MDA) in the experimental rat groups:

Data in Table 8 provide the concentrations of GSH, GPX and MDA in serum and tissues of the experimental groups. The zinc-deficient (ZD) group showed clear signs of severe oxidative stress, marked by significantly reduced in GSH and GPX levels, coupled with significantly elevated MDA when compared to the control group. Zinc supplementation (ZD + Zn group) clearly shows significantly improvement and increased in GSH and GPX levels, while MDA levels decreased when compared to the ZD group. The groups treated with zinc and maple syrup (ZD + Zn + 100 maple syrup and ZD + Zn + 200 maple syrup) showed significantly higher levels of GSH and GPX, and significantly lower levels of MDA levels when compared with Zn-deficient (ZD) group, which both showed substantial improvement approaching the control group levels.

This proves that zinc-deficiency induces a state of compromised antioxidant defense system and increased oxidative damage. The zinc multifaceted antioxidant mechanisms can act as a structural component and co-factor for enzymes such as glutathione peroxidase (GPX) and superoxide dismutase (SOD), stimulates the synthesis of free radical scavenger (metallothionein), affects the rate of glutathione synthesis and inhibits oxidative enzymes such as NADPH oxidase **(Olechnowicz *et al.*, 2018 and Woźniak *et al.*, 2025)**. The polyphenols in maple syrup are known for their direct free-radical scavenging capability and their capacity to modulate the endogenous antioxidant enzyme activities **(Liu *et al.*, 2020 and Missier *et al.*, 2023)**.

Table 8: Serum and tissues concentrations of glutathione (GSH), glutathione peroxidase (GPX) and malondialdehyde (MDA) in the experimental rat groups:

Groups / Parameters	Control	Zn-deficient (ZD)	Zn-deficient (ZD)+Zn		
	Zn=35ppm/kg diet	Zn=3ppm/kg diet	Zn=84ppm/kg diet	Zn=84ppm/kg diet +100 maple syrup	Zn=84ppm/kg diet +200 maple syrup
GSH (µmol/L)	3. 97± 0.06a	1.94± 0.03b	2.41± 0.03c	3.15± 0.04d	3.85± 0.04d
GSH (mg/g tissue)	20. 56± 0.17a	14.62± 0.09b	17.38± 0.13c	18.02± 0.14d	19.58± 0.14d
GPX (mU/ml)	10.02± 0.09a	6.92± 0.06b	8.27± 0.07c	9.36± 0.08d	9.98± 0.08d
GPX (µmol/min /g protein)	94.96± 0.82a	69.51± 0.56b	80.01± 0.67c	86.24± 0.77d	91.24± 0.77d
MDA (nmol/ml)	36.91± 0.23a	53.43± 0.41b	47.28 ± 0.37c	37.89± 0.28d	35.09± 0.28d
MDA (nmol/NADH oxidized/min/ mg/protein)	6.59± 0.06a	12.08± 0.09b	9.39 ± 0.08c	8.62± 0.07d	8.00± 0.07d

Data are expressed as means ± SD within each row having superscript letters (a, b, c, d...) which indicate significant differences at $p \leq 0.05$.

CONCLUSION

This study assessed the possible therapeutic effects of zinc supplementation and maple syrup on zinc-deficiency in male albino rats. The results confirm that the co-administration of zinc with maple syrup promotes therapeutic benefits for the body. Maple syrup is rich in polyphenolic compounds which contribute to improved nutritive effects and lipids levels, significantly improving testosterone levels and an antioxidant defense mechanism. Also, maple syrup is the healthier alternative for honey because it contains less sugar as a whole, and essentially, it has less fructose. These results indicated the potential effect of maple syrup as a valuable dietary supplement in mitigating the harmful effects of zinc-deficiency and improving overall health, especially in relation to hormonal and metabolic functions. We recommend conducting future studies on maple syrup to learn about specific mechanisms that exert beneficial effects and its possible application on human health.

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