Research Functional Mayonnaise: A Therapeutic Approach for Management Obesity and Oxidative Stress in Rats

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Abstract

The global mayonnaise market witnesses a significant demand. The versatility of mayonnaise as a spread, dip, or salad dressing is contributing to its growing popularity among consumers worldwide. Innovation in formula profiles and the introduction of healthier variants can open new avenues for market expansion. Monosodium glutamate (MSG) and commercial mayonnaise promote oxidative stress, weight gain, organ dysfunction, and adverse lipid profiles, particularly when consumed in excess or prepared and stored improperly. This can lead to foodborne illnesses, especially in immunocompromised individuals like the elderly and pregnant women. This study supports the development of reformulated mayonnaise, MSG-free as food alternatives using natural ingredients to combat metabolic disorders and obesity. The results offer renal and kidney protection, potentially through the action of bioactive compounds (e.g., unsaturated fatty acids and antioxidants) present in ingredients such as flaxseed or fermented milk. The results demonstrate that MSG induces hematological suppression and oxidative stress in rats, increased MDA, and diminished antioxidant enzyme activities. In contrast, reformulated mayonnaise samples, particularly those enriched with functional ingredients such as flaxseed oil, fermented milk, and spices, exhibited protective effects by improving antioxidant status and maintaining normal hematological values. These findings highlight the potential of reformulated mayonnaise products as functional foods in obesity prevention, cardio-protective and metabolic health management.

Keywords: Commercial mayonnaise, functional foods, oxidative stress, Monosodium glutamate (MSG), obesity

INTRODUCTION

The global mayonnaise market is undergoing notable expansion, primarily driven by increasing consumer preference for rich and creamy condiments. This growth is supported by the rising demand for convenience foods and the resurgence of home cooking practices (**Mirzanajafi-Zanjani *et al.*, 2019**) Mayonnaise is widely utilized due to its multifunctional role as a spread, dip, and salad dressing, contributing to its widespread acceptance. Growing health awareness among consumers has prompted manufacturers to produce mayonnaise with low fat and caloric content (**Abd Rashed *et al.*, 2017**). In 2023, the global mayonnaise market was valued at USD 13.0 billion and is expected to reach USD 18.8 billion by 2032, with a compound annual growth rate (CAGR) of 4.2% during the period 2024–2032. This trajectory is largely attributed to the increasing global demand for convenient and adaptable food products (www.globalinforesearch.com **, 2025**).

Mayonnaise is calorie dense and high in fats, often avoided by consumers due to its oil content, typically ranging from 65% to 80% with calories (680–700 kcal/100g) so, it is linked to an elevated risk of cardiovascular diseases (CVD), diabetes, obesity, and various forms of cancer **Gomes *et al.* (2017)**. Commercial mayonnaise contains preservatives, emulsifiers, and monosodium glutamate (MSG) to enhance flavor and shelf-life. While considered safe in moderation, some studies suggest MSG and other additives may have adverse effects in sensitive individuals, potentially contributing to oxidative stress, headaches, or allergic reactions **Ahmed *et al.*, (2023)**. Also, homemade or improperly stored mayonnaise poses a risk of microbial contamination, particularly Salmonella from raw eggs. This can lead to foodborne illnesses, especially in immune compromised individuals elderly and pregnant women **Sinha *et al.* (2025).**

Functional foods enriched with bioactive ingredients such as essential fatty acids, antioxidants, and anti-inflammatory compounds offer a promising dietary approach to obesity management (**Zhang *et al.* 2020**).

Fermented milk is a nutrient-rich food, offering an excellent source of calcium, phosphorus, potassium, and vitamins. It also supplies high-quality proteins with a complete amino acid profile and essential fatty acids. Growing evidence supports the role of fermented milk products in delivering various health benefits, including the prevention of osteoporosis, diabetes, and cardiovascular diseases, along with enhancing gut health and supporting immune system function (**Mishra *et al*., 2017**).

Omega-3 fatty acids, particularly EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid), are essential polyunsaturated fats known for their wide range of health benefits. They play a crucial role in cardiovascular health, brain function , mental health, anti-inflammatory effects and prenatal and infant development (**Elagizi *et al*., 2021**).

The present work focuses on investigating the effective role of functional appetizers as a therapeutic approach for managing obesity and oxidative stress conditions in rats.

Materials and Methods

Materials:

- Fresh milk (full cream, skim and low fat) was obtained from the Animals Production Research Institute, Giza, Egypt.
- Spices like lemon, garlic, pepper and vegetable oils like sunflower and flaxseed oil samples were obtained from the Agricultural Research Center, Dokki, Egypt
- Monosodium glutamate used in the present study was purchased from LOBA Chemie Ltd., Mumbai, India.
- Chemicals and kits used for determination of catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GPx); total cholesterol, triacylglyceroles, high-density lipoprotein cholesterol (HDL-C) and kits used for estimation of activities of AST, ALT, urea, creatinine and concentration of glucose, were obtained from companies Spectrum and Biomed, respectively. Other ingredients like commercial mayonnaise, sucrose, cornstarch were purchased from the local market. Rats were obtained from the National Research Centre, Egypt.

Methods:

Preparation of appetizer:

- Functional appetizer samples were prepared similar to mayonnaise, according to **Odep *et al*., (2024)** with some modification using fermented milk, and vegetable oil (sunflower and flaxseed). All appetizer samples were stored at 5°C for analyzed for chemical and sensorial properties in comparison of commercial mayonnaise.

Chemical characterization:

- Chemical analysis of the resulting appetizer for total solids, protein, fat, and ash were analyzed according to the Association of Official Analytical Chemists **AOAC (2000)**. Also, all samples pH will be measured using a pH-meter (Hanna Instruments, Germany).
- Determination of fatty acids profile of the resulting products using Gas Chomatography (GC).

Sensory evaluation:

- Organoleptic evaluation of the resulting appetizer as described by **(Ghazizadeh and Raseghi, 1998)**.

Experimental animal plan and procedures:

- The experimental animal was done by using 36 healthy male rats (Sprague Dawley strain), with a body weight of 100 ±10 g. The rats were housed in plastic cages under hygienic conditions in a temperature-controlled room at 25°C. The food and water were allowed ad libitum. The diets were nutritionally adequate (AIN-93 M), the vitamins mixture and minerals mixture were prepared as described by **Reeves *et al*., 1993.** The animals were randomly divided into 6 rats in each group according to the following: Negative group: Fed a standard diet prepared according to **Reeves et al. (1993)**. MSG group: Fed on a diet prepared according to **Nnadozie *et al*.,**

(2019) which contained monosodium glutamate "MSG "(120 mg/kg). Group3: Fed a basal diet containing "MSG" referred to the positive group with commercial mayonnaise in addition (10%). Group4: Fed a basal diet containing "MSG" referred to the positive group with prepared appetizer full-fat milk in addition (10%). Group5: Fed a diet referred to as a positive group with prepared appetizer medium-fat milk in addition (10%). Group6: Fed a diet referred to as a positive group with prepared appetizer low fat milk in addition (10%). During the experiment, all diets maintained consistent levels of vitamins, minerals, and fiber throughout the 8-week experimental period. Body weight and feed intake were recorded weekly. Nutritional evaluation was conducted following the methodology outlined by **Chapman et al. (1959).** At the end of the experimental period, blood samples were centrifuged at 4000 ×g for 15 minutes, with serum and plasma separated and stored at −20°C. Homogenate liver tissues were analyzed for antioxidant enzyme activities, including superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and catalase (CAT), expressed as units per mg of protein. Biochemical parameters in blood and liver tissue were analyzed as follows: The activity of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), was measured in liver tissue homogenate following the methods of **Nishikimi et al. (1972)**, **Aebi (1984)**, and **Paglia and Valentine (1967)**, respectively. Malondialdehyde (MDA), an indicator of lipid peroxidation, was assessed using the Thiobarbituric Acid Assay (TBA) according to **Draper and Hadley (1990)**. For liver function assessment, the activities of AST and ALT were determined calorimetrically following the method of **Reitman and Frankel (1957)**. Kidney function was evaluated by estimating urea levels using **Fawcett and Scott (1960)** and creatinine levels according to **Bartels et al. (1972)**. Lipid profile analysis included the measurement of triacylglycerol following **Chowdhury et al. (1971)** and total cholesterol following **Lopes-Virella et al. (1977)**. LDL and VLDL cholesterol were determined according to **Warnick et al. (1990)**. Finally, the atherogenic index was calculated as described by **Goh et al. (2004)**.

- **Statistical Analysis:** Data were expressed as mean ± standard deviation (SD). Statistical evaluations were conducted using SPSS software (GraphPad Software Inc., San Diego, CA, USA). A one-way analysis of variance (ANOVA) was applied, followed by Duncan's multiple range test for post hoc comparisons. A P-value of $\leq$ 0.05 was considered statistically significant, following the methodology of **Sendecor and Cochran (1979)**.
- All experiments were conducted in accordance with standard ethical guidelines and were approved by the Institution Animal Care and Use Committee (ARC-IACUC) of the Agricultural Research Center Ethics Committee IACUC number (ARCFHE4024).

Results and discussion:

The current study investigated the protective effects of fermented milk on oxidative stress and metabolic disturbances induced by monosodium glutamate (MSG) in rats, with a particular focus on liver and kidney function, lipid metabolism, and antioxidant defense mechanisms.

Physicochemical properties results:

The physicochemical analysis of the formulated appetizer samples (low-fat, medium-fat, and full-fat) in comparison with a commercial mayonnaise sample is presented in Table (1). The results highlight significant differences in pH, titratable acidity (TA), total solids (TS), moisture, fat, and protein content among the samples.

pH and Titratable Acidity (TA):

The pH of the samples ranged from 5.11 in the low-fat sample to 6.10 in the full-fat sample, indicating a trend of increased alkalinity with higher fat content. Correspondingly, titratable acidity was inversely related to fat content, with the low-fat sample showing the highest acidity (1.54%) and the commercial sample the lowest (0.85%). This inverse relationship aligns with findings by **Gaikwad et al. (2017),** who reported that higher fat content tends to buffer acidity in emulsified systems, reducing total acidity. However, the fat content in the commercial sample is 52.98% and TA is 1.15. It could be due to the food additives, stabilizers, and buffering agents to prolong self-life.

Total Solids (TS) and Moisture Content:

A clear increase in TS was observed with increasing fat levels, from 66.58% in the full-fat sample to 32.98% in the low-fat samples. Moisture content decreased accordingly, as expected. These variations reflect the denser, more nutrient-concentrated nature of higher-fat formulations, as similarly reported by **Talens et al. (2024)** in mayonnaise-like emulsions.

Fat and Protein Content:

The commercial sample had the highest fat content (52.98%), followed by full-fat (40.86%), medium-fat (18.45%), and low-fat (12.87%) formulations. The high-fat sample showed the highest protein content (20.72%), likely due to the higher proportion of protein-rich ingredients used to stabilize the emulsion in the absence of excess oil. These trends are in agreement with the work of **Botti et al., (2022**) who noted that reduced-fat emulsions often require higher protein or carbohydrate content for functional stability.

Table.1. Chemical analysis of the resulting appetizer for pH, total acidity, total solids, mature, fat, protein in mayonnaise samples compared to commercial

Samples / Parameters	Appetizer samples			
	Commercial	**Low fat**	**Medium Fat**	**Full fat**
pH	5.80	5.11	5.74	6.10
TA	1.15	1.54	1.34	0.85
TS	62.61	32.98	40.58	66.58
Moisture %	35.40	65.02	61.80	33.42
Fat %	52.98	12.87	18.45	40.86
Protein %	7.63	13.72	17.13	20.72

***pH:** Potential of hydrogen**, TA;** Titratable acidity **, TS:** Total solids

Organoleptic Evaluation.

Total scores of the organoleptic attributes of flavor, body and texture, appearance, and overall acceptability were evaluated to determine consumer perception of the developed reformulated mayonnaise appetizers. The results are represented in table (2). The results indicate high acceptability across all samples, with some variation based on fat content and formulation. Flavor scores ranged from 46.5 to 49.25 out of 50. The full-fat sample recorded the highest score (49.25 ± 1.1), followed closely by the commercial and medium-fat samples (48.5 ± 2.81 and 48.5 ± 0.64, respectively). The low-fat sample scored slightly lower (46.5 ± 5.8), possibly due to the reduced fat content affecting flavor intensity and mouth feel. These results are consistent with **Hildebrand *et al.* (2019)**, who noted that reduced-fat emulsions may lack the full sensory experience provided by lipids, although improvements can be achieved through formulation techniques. In terms of body and texture, full-fat and commercial samples achieved the highest score (39 ± 0.58), indicating a desirable, creamy consistency. Medium-fat formulations performed comparably (38 ± 0.58), while the low-fat sample scored slightly lower (37 ± 1.15), suggesting that fat plays a critical role in emulsion stability and perceived creaminess. According to **Aganovic *et al.*, 2018)** texture is often compromised in low-fat spreads unless stabilizers or protein-based emulsifiers are optimized. Appearance scores were high across all samples, ranging from 8.2 to 9.5 out of 10. The full-fat sample received the highest rating (9.5 ± 0.29), followed by medium-fat (9.2 ± 0.01) and commercial samples (9.0 ± 0.01), indicating an appealing visual presentation across the board. These results align with findings from **Sun *et al.* (2018)**, which noted that emulsified products with balanced oil and protein ratios tend to have a glossier and more uniform appearance. The overall acceptability score was highest in the full-fat sample (97.75 ± 13.56), reflecting superior flavor, texture, and visual appeal. The commercial and medium-fat formulations also showed strong consumer preference (96.5 ± 11.2 and 95.7 ± 12.3, respectively). The low-fat sample, while still well-received, had a significantly lower overall score (91.7 ± 10.4), which is consistent with the common challenge of flavor and texture retention in reduced-fat products **(Drake, 2007)**. These findings collectively suggest that while full-fat formulations deliver the most favorable sensory attributes, medium-fat products offer a highly acceptable compromise between health benefits and consumer appeal. Moreover, proper formulation techniques such as the inclusion of fermented milk, stabilizers, and natural emulsifiers can significantly improve the sensory profile of low-fat mayonnaise-like products (**Anisa *et al.*, 2021).**

Table (2). Organoleptic properties of mayonnaise samples

Parameter	**Mayonnaise samples**			
	Commercial	**Low fat**	**Medium Fat**	**Full fat**
Flavor (50)	48.5 ± 2.81^a	46.5 ± 5.8^b	48.5 ± 0.64^a	49.25 ± 1.1^a
Body and texture (40)	39 ± 2.89^a	37 ± 1.15^b	38 ± 0.58^a	39 ± 0.58^a
Appearance (10)	9 ± 0.01^a	8.2 ± 0.01^a	9.2 ± 0.01^a	9.5 ± 0.29^a
Total score (100)	96.5 ± 11.2^a	91.7 ± 10.4^b	95.7 ± 12.3^a	97.75 ± 13.56^a

All parameters are represented as a means of replicates ± standard deviation. Means with different small superscript letters in the same row are significantly different at $p \leq .05$.

Fatty Acid Composition:

The fatty acid composition, oil content, and oxidative status (peroxide value) of sunflower and flaxseed oils are presented in Table (2). These parameters provide valuable insights into the nutritional and functional characteristics of each oil, particularly their suitability for incorporation into functional food formulations. Both sunflower and flaxseed oils exhibited distinct fatty acid profiles, reflective of their botanical origins. The predominant saturated fatty acids identified were palmitic acid (C16:0) and stearic acid (C18:0). Palmitic acid was found in comparable amounts in both oils (9.66% in sunflower and 10.08% in flaxseed), while stearic acid content was slightly higher in sunflower oil (7.4%) than in flaxseed (5.51%). These levels are consistent with previous studies highlighting the moderate saturated fatty acid content of both oils **(Ciftci et al., 2012).** In terms of monounsaturated fatty acids (MUFA), oleic acid (C18:1n9c) was dominant, comprising 36.55% in sunflower oil and 28.43% in flaxseed oil. Oleic acid is known for its cardioprotective properties due to its influence on lipid profiles and inflammation markers (**Perdomo et al., 2015**). Flaxseed oil distinguished itself by its high content of alpha-linolenic acid (ALA, C18:3n3) at 9.82%, compared to only 1.16% in sunflower oil. This omega-3 fatty acid is essential for brain function and reducing cardiovascular risk, and its high presence is a hallmark feature of flaxseed oil (**Goyal et al., 2014**). Additionally, γ-linolenic acid (C18:3n6), a biologically active omega-6 fatty acid, was detected only in flaxseed oil (0.4%). Both oils exhibited high levels of linoleic acid (C18:2n6c) an essential omega-6 fatty acid measured at 44.17% in sunflower oil and 45.17% in flaxseed oil. Although linoleic acid is necessary for maintaining cellular function and integrity, its excess over omega-3s can disrupt the omega-6: omega-3 ratio, which is often associated with pro-inflammatory states **(Mahesty et al., 2020).** Minor fatty acids such as arachidic (C20:0), behenic (C22:0), and palmitoleic acids were detected in low quantities, aligning with standard profiles of cold-pressed plant oils **(Codex Alimentarius, 2019).**

Oil Content:

The oil yield was slightly higher in flaxseed oil (52.10–52.51%) than in sunflower oil (48.45–48.84%), which is consistent with the findings of **Bayrak et al. (2010),** who noted that flaxseed contains a high lipid fraction, particularly when cold-pressed under optimized conditions. This higher oil content, along with its superior omega-3 profile, supports the use of flaxseed oil in functional and therapeutic food applications.

Peroxide Value (PV):

The peroxide value, a marker of primary lipid oxidation, was higher in flaxseed oil (20.58–20.67 meq/kg) than in sunflower oil (17.23–17.6 meq/kg). This is expected due to the higher polyunsaturated fatty acid (PUFA) content in flaxseed oil, especially ALA, which is more prone to oxidative degradation **(Visioli et al., 2020)**. Although flaxseed oil offers significant nutritional benefits, its susceptibility to oxidation necessitates careful handling, packaging, and potential use of natural antioxidants during processing and storage. Flaxseed oil, characterized by its higher ALA content, superior oil yield, and nutritionally favorable PUFA profile, demonstrates great potential as a functional ingredient in health-oriented food products. However, its higher susceptibility to oxidation compared to sunflower oil must be addressed to preserve its quality. Sunflower oil, on the other hand, provides a more stable alternative rich in oleic and linoleic acids. However, use spices like lemon and garlic in addition to flaxseed making it suitable for broader culinary and industrial applications. Obesity is closely linked with dyslipidemia, oxidative stress, and metabolic disturbances, making dietary fat composition a crucial factor. Omega-3-rich foods, like flaxseed oil and fermented milk, have demonstrated the ability to modulate lipid profiles, reduce inflammatory markers, and improve body composition. In our study, oils with a higher unsaturated fat content and antioxidant activity are better candidates for functional food development targeting obesity **(Ganesan and Xu, 2017).** Fermented milk products have also gained attention due to their probiotic content and potential anti-obesity effects. When combined with functional ingredients like flaxseed oil, they may synergistically enhance metabolic outcomes. Probiotics can influence gut microbiota composition, leading to improved fat metabolism and reduced adiposity, further supporting the role of functional mayonnaise and fermented dairy products in health-oriented diets **Pimentel et al., (2018)**. So, both sunflower and flaxseed oils have value in mayonnaise production, but their impacts differ. Sunflower oil offers oxidative stability and a good source of unsaturated fats, while flaxseed oil provides essential omega-3 fatty acids beneficial for obesity prevention and metabolic health. Coupled with the benefits of fermented milk, these ingredients may be incorporated into functional foods aimed at reducing obesity-related risks and improving overall health.

Table.3. Fatty acid composition of sunflower and flaxseed oil (g/100g).

Fatty acid	Sunflower	Flaxseed
Palmitic acid (C16:0)	9.66	10.08
Palmitoleic acid (C16:1)	0.29	--------
Stearic acid (C18:0)	7.4	5.51
Oleic acid (C18:1n9c)	36.55	28.43
Linoleic acid (C18:2n6c)	44.17	45.17
Linolenic acid (C18:3n3)	1.16	9.82
γ- Linolenic acid (C18:3n6)	---------	0.4
Arachidic acid (C20:0)	0.57	0.23
Cis-11- Eicosenoic acid (C20.1)	0.2	---------
Behenic acid (C22:0)	---------	0.36
Peroxide value (meq/kg)	17.6	20.58
Oil content in seeds (%)	48.84	52.10

Biological evaluation:

Food consumption and body weight:

The results of Initial Body Weight (IBW), Final Body Weight (FBW), Gain in Body weight (GBW), and Food Efficiency Ratio (FER) across all experimental groups are summarized in Table (4). These parameters collectively provide a comprehensive understanding of how a test mayonnaise samples affects on nutritional status, metabolic efficiency, energy balance, obesity or weight loss, growth and development.

Body Weight Gain

There were no significant differences in IBW among all groups, indicating homogeneity at baseline and allowing for valid comparisons post-treatment. However, significant differences were observed in FBW, GBW, and FER, reflecting the impact of dietary treatments. The MSG group demonstrated a marked increase in FBW (582.4±13.6), GBW (476.4±17.3), and FER (0.064±0.00), significantly higher than the control group. This aligns with previous findings that MSG promotes excessive weight gain by enhancing palatability and stimulating appetite, likely through hypothalamic damage and leptin resistance **(Nnadozie *et al.* (2019)**. Additionally, MSG can disrupt energy balance, causing increased fat deposition and impaired satiety signaling, contributing to rapid weight gain **(Ahmed *et al.* 2023).** The commercial mayonnaise group also showed elevated FBW (564.4±11.2) and GBW (459.0±11.3), with a high FER (0.06±0.02), closely like to MSG group. This could be attributed to the high fat and calorie content in commercial mayonnaise, which is typically rich in saturated fats and additives that promote adiposity **(Mozaffarian *et al.* (2010)**. Moreover, emulsified fat products have been shown to enhance lipid absorption and influence energy intake, potentially increasing FER (**Sharma, 2015).** Conversely, rats treated with reformulated mayonnaise, particularly medium- and low-fat versions, exhibited significantly lower FBW and GBW. The medium-fat group recorded a GBW of 318.8±7.0 and an FER of 0.041±0.00, similar to the control group, indicating improved metabolic balance. Likewise, the low-fat group showed moderate body weight gain (327.4±6.4) and FER (0.049±0.00). These findings suggest that reducing dietary fat content, while incorporating functional ingredients, can limit excessive weight gain and improve feed utilization. Interestingly, the full-fat mayonnaise group exhibited the lowest FBW and GBW among the mayonnaise groups, but with a moderate FER (0.049±0.00). This may indicate that fermented milk, garlic, and other bioactive components included in the formulation exert fat burner effects, potentially through modulation of gut microbiota, improved digestion, and lipid metabolism **(Peng *et a*l., 2018).** FER is a key indicator of how efficiently the body converts feed into body mass. A higher FER in the MSG and commercial mayonnaise groups indicates enhanced energy storage, often associated with excess adiposity, while lower FER values, as seen in the control, medium-fat, and low-fat groups, suggest leaner weight gain and better energy homeostasis. These findings emphasize that MSG and high-fat mayonnaise exacerbate weight gain and disrupt metabolic regulation, while functional, reformulated foods can mitigate these effects and support healthier growth trajectories.

Table (4): Effect of mayonnaise samples on Initial Body Weight (IBW), Final Body Weight (FBW), Gain in body weight (GBW), and Food efficiency ratio (FER).

Groups \ Parameter		IB W (g)	FBW (g)	GBW (g)	FER
Control Negative		104.8±2.4[a]	442.30±11.6[c]	337.5±10.8[c]	0.041±0.03[c]
MSG group		106.00±3.2[a]	582.40±13.6[a]	476.40±17.3[a]	0.064±0.00[a]
Mayonnaise samples	Commercial	105.40±4.2[a]	564.40±11.2[b]	459.00±11.3[b]	0.06±0.02[a]
	Full fat	105.60±2.2[a]	413.60±9.5[f]	308.00±8.90[f]	0.049±0.0[b]
	Medium Fat	106.00±1.5[a]	424.80±5.7[e]	318.80±7.0[e]	0.041±0.00[c]
	Low Fat	105.40±3.3[a]	432.80±4.7[d]	327.40±6.4[d]	0.049±0.00[b]

All parameters are represented as a means of replicates ± standard deviation. Means with different small superscript letters in the same column are significantly different at $p \leq .05$.

Liver and kidney function:

This study evaluated the impact of monosodium glutamate (MSG) and different mayonnaise formulations on kidney and liver function biomarkers in experimental rats. The assessed parameters include creatinine, urea, alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP) (Table 5).

Renal Function Markers (Creatinine and Urea)

The MSG-treated group showed a significant elevation in serum creatinine (0.97±0.16 mg/dl) and urea (46.60±2 mg/dl) compared to the negative control (0.68±0.18 mg/ dl and 35.00±2.3 mg/ dl, respectively). Elevated levels of these nitrogenous wastes suggest renal impairment, possibly linked to oxidative stress and nephrotoxicity induced by MSG **(Al-Malki, 2013).** Similar elevations were observed in the commercial mayonnaise group, indicating no protective effect. In contrast, all reformulated mayonnaise samples (full fat, medium fat, and low fat) demonstrated significantly lower creatinine and urea levels, particularly the low-fat group (0.65±0.12 mg/dl and 33.00±1.6 mg/ dl, respectively). These results suggest that these formulations may offer renal protection, potentially through the action of bioactive compounds (e.g., unsaturated fatty acids and antioxidants) present in ingredients such as flaxseed or fermented milk **(Hosseini et al., 2015)**

Liver Function Markers (ALT, AST, ALP)

Rats exposed to MSG exhibited markedly increased ALT (53.00±2.4 U/L) and AST (57.00±1.8 U/L) activities, as well as reduced ALP levels (3.54±0.5 IU/L), when compared to the control group (ALT: 34.60±3.3 U/L; AST: 45.00±1.7 U/L; ALP: 4.10±0.11 IU/L). These changes reflect hepatocellular damage and compromised liver function, aligning with previous studies indicating that MSG can cause hepatic oxidative damage and enzyme leakage into circulation **(Pokusaeva et al., 2015**). Interestingly, while the commercial mayonnaise group showed no improvement, the full-fat, medium-fat, and low-fat mayonnaise groups exhibited significantly lower levels of ALT and AST, approaching those of the control group. The low-fat mayonnaise group had the lowest AST (41.40±1.8 U/L) and ALT (35.00±2.9 U/L) levels among all treated groups, suggesting enhanced hepatoprotective effects. The preservation of ALP levels close to the control group across these samples further supports the protective potential of these formulations. This hepatoprotective effect may be attributed to the presence of unsaturated fatty acids (especially linolenic acid), antioxidants, and probiotics in the ingredients used, which help stabilize cell membranes and reduce oxidative stress in hepatic tissue **(Uneyama et al. 2017).**The data indicate that MSG induces significant renal and hepatic dysfunction, evident from elevated creatinine, urea, and liver enzyme levels. However, reformulated mayonnaise samples especially the low-fat variant exhibited marked improvements in renal and hepatic biomarkers, likely due to the inclusion of functional bioactives such as omega-3 fatty acids and probiotics. These findings support the development of functional food products capable of mitigating dietary toxin-induced organ damage.

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Table (5): Effect of mayonnaise samples on Liver and Kidney Functions in Obese Rats

Groups \ Parameter		Creatinine mg/dl	Urea mg/dl	ALT U/L	AST U/L	ALP IU/L
Control Negative		0.68±.18[b]	35.00±2.3[b]	34.60±3.3[c]	45.00±1.7[c]	4.10±0.11[a]
MSG group		0.97±0.16[a]	46.60±2[a]	53.00±2.4[a]	57.00±1.8[a]	3.54±0.5[b]
Mayonnaise samples	Commercial	0.97±0.4[a]	45.00±1.9[a]	54.60±3.4[a]	58.40±4.1[a]	3.72±0.18[b]
	Full fat	0.67±0.17[b]	36.60±2.7[b]	38.60±3.4[b]	48.60±2.5[b]	4.00±.03[a]
	Medium Fat	0.68±0.8[b]	34.00±1.9[c]	36.20±2.5[b]	45.60±3.2[c]	4.12±.04[a]
	Low Fat	0.65±.12[b]	33.00±1.6[c]	35.00±2.9[b]	41.40±1.8[d]	4.02±.13[a]

AST: Aspartate Aminotransferase **ALT:** Alanine Aminotransferase **ALP:** Alkaline Phosphatase

All parameters are represented as a means of replicates ± standard deviation. Means with different small superscript letters in the same column are significantly different at $p \leq .05$.

Lipid profile:

The current study assessed the impact of monosodium glutamate (MSG) and various mayonnaise formulations on the lipid profile of experimental rats, including serum total cholesterol (CHO), triglycerides (TG), high-density lipoprotein cholesterol (HDL-c), low-density lipoprotein cholesterol (LDL-c), and the atherogenic index of plasma (AIP). These markers provide essential insight into cardiovascular risk and metabolic health. The results of these markers are illustrated in table (6).

Effect on Serum Lipid Profile

The MSG group exhibited a significant elevation in total cholesterol (158.2±2.11 mg/dl), triglycerides (154.8±5.8 mg/ dl), and LDL-c (89.84±4 mg/ dl), with a marked reduction in HDL-c (37.4±1.5 mg/ dl), compared to the control group. These changes suggest that MSG promotes dyslipidemia, characterized by elevated atherogenic lipoproteins and reduced protective HDL. This is consistent with earlier reports that MSG consumption disrupts lipid metabolism through oxidative stress and impaired insulin sensitivity **(Filpa et al., 2016).** The commercial mayonnaise group showed a similarly adverse lipid profile, with high TG (166.8±4.1 mg/ dl) and low HDL-c (31.6±1.4 mg/ dl), possibly due to its high saturated fat and additive content. Additionally, the AIP was highest in this group (0.72±0.02), indicating an elevated risk for atherosclerosis. The AIP, calculated as log (TG/HDL), is a reliable predictor of cardiovascular risk; values above 0.24 suggest elevated atherogenic potential **(Dobiasova, 2004).** In contrast, reformulated mayonnaise samples showed significantly improved lipid parameters. The medium-fat and low-fat mayonnaise groups exhibited the lowest total cholesterol (131.8±5.2 and 132.2±3.1 mg/ dl, respectively), lower TG, and the highest HDL-c (66.6±3.7 and 68±2.8 mg/ dl), suggesting a cardioprotective effect. Their respective AIP values (0.22±0.04 and 0.26±0.03) were significantly lower than those of the MSG and commercial groups, reflecting a favorable lipid profile. Interestingly, even the full-fat mayonnaise group, although containing more fat overall, showed improved HDL-c (66.0±3.4 mg/ dl) and lower TG levels (111.80±4.7 mg/ dl) compared to the MSG group. This may be attributed to the inclusion of health-promoting ingredients such as fermented milk, garlic, flaxseed oil, or unsaturated fatty acids, which are known to enhance lipid metabolism and improve HDL function **(Rezaei et al. 2017).** The hypolipidemic effects observed in the reformulated groups can be attributed to several functional ingredients; Fermented milk contains probiotics and bioactive peptides that have been shown to reduce LDL and TG levels while increasing HDL **(Abd-El Monem et al., 2023**;**).** Flaxseed is rich in omega-3 fatty acids and lignans that improve lipid regulation and reduce AIP **(Jamilian et al., 2020).** Garlic has been widely studied for its lipid-lowering and antioxidant properties, particularly in reducing total cholesterol and LDL-c **(Yeh & Liu, (2001).** These ingredients may act synergistically to reduce lipid peroxidation, modulate hepatic lipid enzymes, and enhance reverse cholesterol transport, thus mitigating the dyslipidemic effects of MSG and promoting cardiovascular health.

Table (6): Effect of mayonnaise samples on on lipid fractions and glucose level.

Groups \ Parameter		CHO mg/dl	T.G mg/dl	HDL-c mg/dl	LDL-c mg/dl	AIP
Control Negative		142.80±2.5[c]	129.20±2.3[c]	66.40±1.9[a]	50.56±2.6[c]	0.29±0.01[c]
MSG group		158.2±2.11[a]	154.8±5.8[b]	37.4±1.5[c]	89.84±4[a]	0.62±0.03[b]
Mayonnaise samples	Commercial	157±4.2[a]	166.8±4.1[a]	31.6±1.4[b]	73.24±5.7[b]	0.72±0.02[a]
	Full fat	150.60±2.7[b]	111.80±4.7[e]	66.0±3.4[a]	92.04±2.5[a]	0.230±0.02[e]
	Medium Fat	131.8±5.2[d]	109.8±1.9[e]	66.6±3.7[a]	43.24±4.5[d]	0.22±0.04[e]
	Low Fat	132.2±3.1[d]	122.80±3.4[d]	68±2.8[a]	39.64±1.8[e]	0.26±0.03[d]

CHO: Cholesterol HDL-c: High density lipoprotein-cholesterol
LDL-c : Low density lipoprotein-cholesterol T.G. : Triglycerides AIP: Atherogenic Index in plasma
All parameters are represented as a means of replicates ± standard deviation. Means with different small superscript letters in the same row are significantly different at $p \leq .05$.

Oxidative Stress Markers:

The effect of monosodium glutamate (MSG) and mayonnaise-based formulations on hematological and oxidative stress biomarkers was evaluated, including hemoglobin (Hb), malondialdehyde (MDA), superoxide dismutase (SOD), catalase, and glutathione peroxidase (GPX) levels in experimental rats (Table 7).

Hemoglobin (Hb) Concentration

The MSG group exhibited a significant reduction in hemoglobin levels (12.96±0.4 mg/dl) compared to the negative control (13.8±0.38 mg/ dl), indicating potential hematotoxic effects of MSG, possibly due to oxidative damage to erythrocytes, as supported by previous studies **Ackroff et al., 2013).** However, rats fed full-fat, medium-fat, and low-fat mayonnaise showed significantly higher Hb levels (14.0–14.10 mg/ dl), suggesting a protective or restorative effect against MSG-induced anemia. These findings align with studies showing that diets rich in polyunsaturated fatty acids (PUFAs) and antioxidant components can improve hematological profiles **Zhang et al. (2020).**

Lipid Peroxidation (MDA)

MDA, a marker of lipid peroxidation and oxidative damage, was significantly elevated in the MSG group (3.78±0.1 U/mL), confirming the pro-oxidant effect of MSG **Eweka & Om'Iniabohs, (2007).** Similarly, commercial mayonnaise fed rats showed high MDA levels (3.6±0.1 U/mL), likely due to its formulation lacking protective bioactives. Conversely, the full-fat, medium-fat, and low-fat mayonnaise groups exhibited significantly lower MDA levels (2.44–2.72 U/mL), reflecting reduced oxidative stress. This suggests the inclusion of antioxidant-rich ingredients, such as flaxseed or fermented milk components, can mitigate lipid peroxidation **Wijesundera et al. (2013).** .

Antioxidant Enzyme Activities

SOD activity was markedly reduced in the MSG group (747.4±33.36 U/gT) compared to the control (977.0±7.6 U/gT), indicating oxidative stress-induced enzyme suppression. Commercial mayonnaise yielded similar values (747.0±34.8 U/gT). However, full-fat, medium-fat, and low-fat groups maintained significantly higher SOD activities (900.2–910.8 U/gT), implying the antioxidant potential of these formulations, likely due to bioactive fatty acids such as alpha-linolenic acid from flaxseed oil **Simopoulos, (2002).**

Catalase and **GPX** activities followed similar trends: the MSG group showed a significant decline (69.8 and 38.2 U/gT, respectively), while improved levels were observed in all tested mayonnaise formulations, with the low-fat group showing the highest catalase (85.2±3.5 U/gT) and GPX (54.8±3.5 U/gT) values. These enzymes play critical roles in neutralizing hydrogen peroxide and lipid hydroperoxides, suggesting that the functional ingredients in the tested samples support endogenous antioxidant defense mechanisms **Yilmaz et al. (2011); Al-Malki & Sayed, (2014).** The results demonstrate that MSG induces hematological suppression and oxidative stress in rats, as reflected by reduced Hb, increased MDA, and diminished antioxidant enzyme activities. In contrast, mayonnaise samples, particularly those enriched with functional ingredients such as flaxseed oil or fermented milk, exhibited protective effects by improving antioxidant status and maintaining normal hematological values. These findings highlight the potential of reformulated mayonnaise products as functional foods with antioxidant benefits.

Table (7): Antioxidant enzymes activities in liver tissues lipid peroxidation and hemoglobin level of mayonnaise samples.

Groups \ Parameter		Hb (mg/dl)	MDA (U/ml)	SOD (U/gT)	Catalase (U/gT)	GPX (U/gT)
Control Negative		13.8±0.38^{a}	2.08±0.26^{d}	977.00±7.6^{a}	95.40±3.3^{a}	55.00±3.0^{a}
MSG group		12.96±0.4^{b}	3.78±0.1^{a}	747.40±33.36^{c}	69.80±3.1^{c}	38.20±3.6^{b}
Mayonnaise samples	Commercial	12.9±0.3^{b}	3.6±0.1^{a}	747.0±34.8^{c}	63.4±3.3^{d}	37.6±4.6^{b}
	Full fat	14.0±0.3^{a}	2.72±0.13^{b}	907.40±17.98^{b}	83.80±4.4^{b}	51.20±3.3^{a}
	Medium Fat	14.10±0.2^{a}	2.44±0.1^{c}	900.20±9.5^{b}	84.20±4.0^{b}	51.60±3.2^{a}
	Low Fat	14.08±0.17^{a}	2.60 ±0.18^{bc}	910.80±35.3^{b}	85.20±3.5^{b}	54.80±3.5^{a}

Gpx: Glutathione Peroxidase **SOD:** Superoxide Dismutase **MDA:** Malondialdehyde

All parameters are represented as mean of replicates ± standard deviation. Means with different small superscript letters in the same row are significantly different at $p \leq .05$.

Conclusion

Overall, the data reveal that MSG induces significant dyslipidemia, while reformulated mayonnaise especially medium- and low-fat formulations markedly improves lipid parameters and reduces cardiovascular risk. The results strongly support the potential of functional ingredients in mayonnaise as a dietary strategy to manage lipid disorders and obesity

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الملخص العربي

يشهد سوق المايونيز طلباً كبيرا عالميا. ويساهم تنوع استخدامات المايونيز، سواءً كصوص قابل للفرد أو صلصة أو تتبيلة سلطة، في تزايد شعبيته بين المستهلكين حول العالم. ويمكن للابتكار في تركيبات المايونيز وإدخال أنواع صحية أخرى أن يفتح آفاقًا جديدة لتوسيع السوق. يُعزز أحادي الجلوتامات الصوديوم (MSG) والمايونيز التجاري الإجهاد التأكسدي، وزيادة الوزن، واختلال وظائف الأعضاء، وارتفاع مستويات الدهون، خاصة عند الإفراط في استهلاكه أو تحضيره وتخزينه بشكل غير صحيح. وقد يؤدي ذلك إلى أمراض منقولة بالغذاء، وخاصة لدى الأشخاص الذين يعانون من ضعف المناعة مثل كبار السن والنساء الحوامل. تدعم هذه الدراسة تطوير المايونيز المعاد تركيبه، والخالي من جلوتامات أحادي الصوديوم، كبدائل غذائية باستخدام مكونات طبيعية لمكافحة الاضطرابات الأيضية والسمنة. وتوفر النتائج حماية للكلى، ربما من خلال تأثير المركبات النشطة بيولوجيًا (مثل الأحماض الدهنية غير المشبعة ومضادات الأكسدة) الموجودة في مكونات مثل بذور الكتان أو الحليب المخمر. وأظهرت النتائج أن مركب MSG يُسبب تثبيطًا دمويًا وإجهادًا تأكسديًا لدى الفئران، ويزيد من مستوى MDA ، ويقلل من نشاط إنزيمات مضادات الأكسدة. في المقابل، أظهرت عينات المايونيز المعاد تركيبها، وخاصة تلك المدعمة بمكونات وظيفية مثل زيت بذور الكتان والحليب المخمر والتوابل، تأثيرات وقائية من خلال تحسين حالة مضادات الأكسدة والحفاظ على القيم الدموية الطبيعية. وتسلط هذه النتائج الضوء على إمكانات منتجات المايونيز المعاد تركيبها كأغذية وظيفية في الوقاية من السمنة، وحماية القلب، وإدارة الصحة الأيضية.

الكلمات المفتاحية: مايونيز تجاري، أغذية وظيفية، إجهاد تأكسدي، أحادي جلوتامات الصوديوم (MSG)، السمنة