Green Algae as a Natural Therapeutic Strategy for Obesity and Metabolic Disorders in Experimental Rats

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Received: 31st May, 2026; **Revised:** 8th June, 2026; **Accepted:** 10th June, 2026; **Available Online:** 13th June, 2026

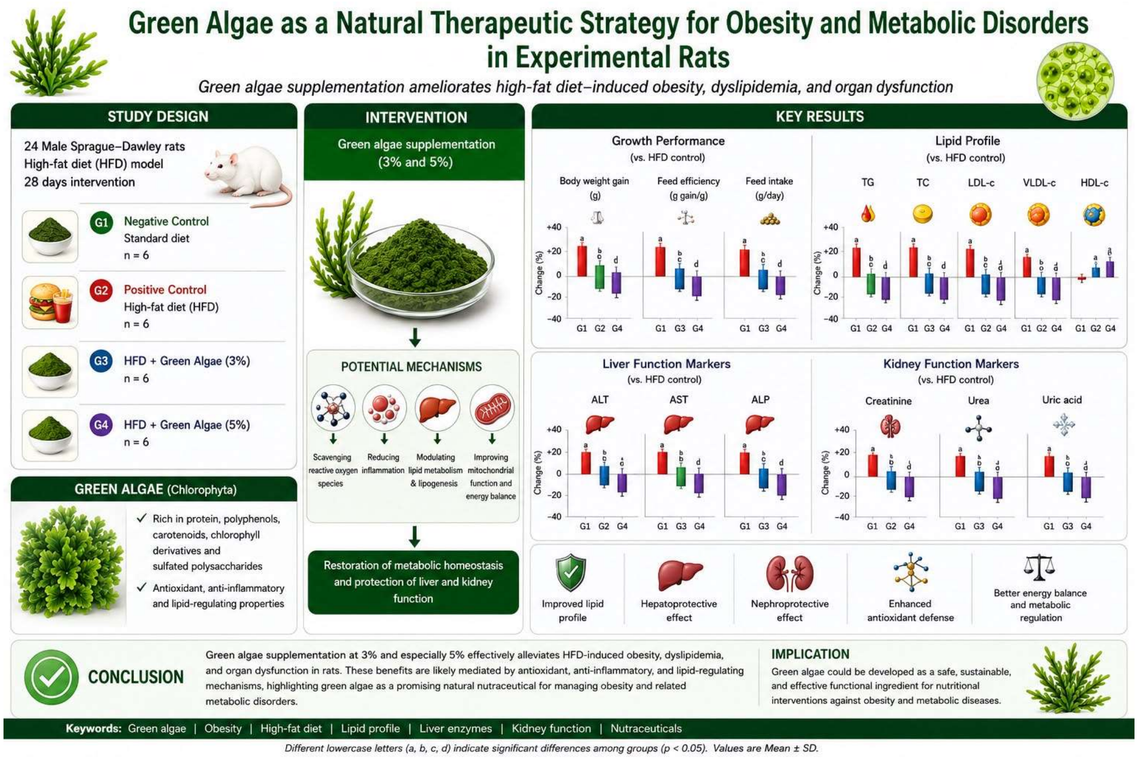
ABSTRACT

Obesity is a major global health concern closely associated with metabolic dysregulation, oxidative stress, and organ dysfunction. The present study investigated the potential therapeutic effects of green algae supplementation on obesity-related metabolic disturbances in a high-fat diet (HFD)-induced rat model. Twenty-four male Sprague-Dawley rats were randomly divided into four groups: a negative control group fed a standard diet, a positive control group fed HFD without treatment, and two treated groups receiving HFD supplemented with green algae at 3% and 5%, respectively, for 28 days. The results demonstrated that HFD feeding significantly increased body weight gain, feed efficiency ratio, and feed intake, along with marked dyslipidemia characterized by elevated triglycerides, total cholesterol, LDL-c, and VLDL-c, and reduced HDL-c levels. In addition, significant elevations in liver enzymes (ALT, AST, ALP) and renal function markers (creatinine, urea, uric acid) were observed, indicating hepatic and renal impairment. Conversely, green algae supplementation improved growth performance parameters and significantly ameliorated lipid profile alterations. It also restored liver and kidney function biomarkers toward normal levels in a dose-dependent manner, with the 5% supplementation showing superior efficacy compared to the 3% dose. In conclusion, green algae exhibit promising anti-obesity, hepatoprotective, and nephroprotective effects, likely mediated through antioxidant and lipid-regulating mechanisms. These findings support their potential application as a functional nutraceutical for the management of obesity and related metabolic disorders, although further mechanistic and clinical investigations are warranted.

Keywords: Green algae, Obesity, High-fat diet, Lipid profile, Liver enzymes, Kidney function.
How to cite this article: Aljehani AA, Elmeged LSMA, Labban RSM, Mjery YA, Baity A. Green Algae as a Natural Therapeutic Strategy for Obesity and Metabolic Disorders in Experimental Rats. Int J Drug Deliv Technol. 2026;16(59s): 1124-1139. DOI: 10.25258/ijddt.16.59s.130

Source of support: Nil

Conflict of interest: None



CONCLUSION Green algae supplementation at 3% and especially 5% effectively alleviates HFD-induced obesity, dyslipidemia, and organ dysfunction in rats. These benefits are likely mediated by antioxidant, anti-inflammatory, and lipid-regulating mechanisms, highlighting green algae as a promising natural nutraceutical for managing obesity and related metabolic disorders.

IMPLICATION Green algae could be developed as a safe, sustainable, and effective functional ingredient for nutritional interventions against obesity and metabolic diseases.

Keywords: Green algae | Obesity | High-fat diet | Lipid profile | Liver enzymes | Kidney function | Nutraceuticals

Different lowercase letters (a, b, c, d) indicate significant differences among groups ($p < 0.05$). Values are Mean ± SD.

Graphical Abstract: Green Algae Mitigate High-Fat Diet–Induced Obesity and Metabolic Dysfunction in Experimental Rats

.Introduction

The dramatic global shift toward energy-dense, ultra-processed dietary patterns has propelled obesity to the forefront of contemporary public health crises . Beyond the simple accumulation of white adipose tissue, obesity acts as a pathophysiological epicenter for a constellation of metabolic disturbances, including systemic hypertension, insulin resistance, and severe dyslipidemia (World Health Organization, 2024). In experimental models, prolonged exposure to a high-fat diet (HFD) does not merely distort body composition; it initiates a cascade of "metabolic inflammation" (metainflammation). This persistent, low-grade inflammatory state is fundamentally driven by the excessive generation of reactive oxygen species (ROS), sulfated polysaccharides (such as ulvans), specialized chlorophyll derivatives, and which incapacitate the endogenous antioxidant defense systems such as superoxide dismutase (SOD) and glutathione peroxidase (GPx) leading to oxidative lipotoxicity in vital metabolic hubs like the liver and kidneys (Jomova et al., 2023**;**Abd Elmeged et al., 2026). As illustrated in **Figure 1**, the integration of marine-derived bioactives represents a strategic shift toward "nutraceuticals functional agents that provide therapeutic benefits beyond basal nutrition. Marine ecosystems, particularly the diverse Chlorophyta (green algae) taxa, serve as an expansive, yet largely untapped, reservoir of these bioactive molecules . Unlike their terrestrial counterparts, green algae thrive under fluctuating osmotic pressures and high UV

exposure, necessitating the synthesis of unique secondary metabolites. These include

Ali et al., 2026). Simultaneously, the renal system is susceptible to hemodynamic alterations and tubular oxidative stress, often resulting in glomerular filtration impairment (Kidgell et al., 2019). The unique polyphenolic and flavonoid profiles of green algae have demonstrated a profound capacity to stabilize mitochondrial membranes and restore physiological enzyme kinetics. However, despite the burgeoning literature supporting marine-derived interventions, a significant knowledge gap persists regarding the optimal dose-response dynamics of these extracts in reversing established metabolic damage.

complex carotenoids like astaxanthin and lutein (Xu et al., 2023). These metabolites function as molecular rheostats, capable of directly neutralizing free radicals and downregulating key lipogenic transcription factors, thereby mitigating hepatic steatosis and renal hypertrophy (Magwaza et al., 2023).

The hepatoprotective and renoprotective potential of Chlorophyta is of paramount importance in the field of nutritional science. Obesity-induced metabolic stress often leads to ectopic lipid deposition in the liver, manifesting clinically through elevated transaminase levels (ALT and AST), which are hallmark indicators of hepatocellular integrity loss (Xu et al.,2023 ;

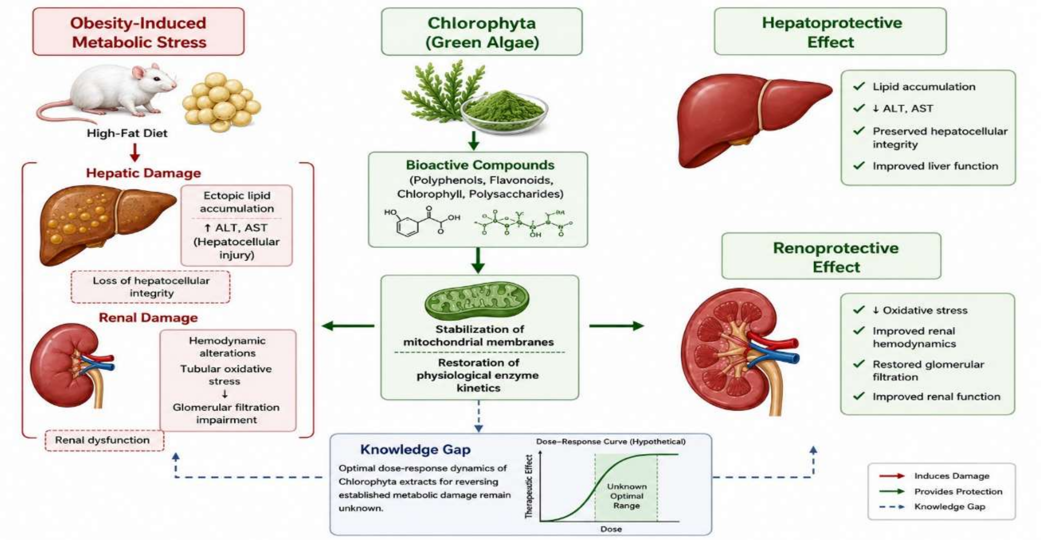


Figure 1: Hepatoprotective and Renoprotective Mechanisms of Green Alge (Chlorophyta) Against Obesity-Induced Metabolic Stress

assessment we aim to construct a high-resolution metabolic profile of its biological efficacy. This research transcends simple weight management, seeking to elucidate the mechanisms by which these natural extracts restore glycaemic homeostasis and safeguard organ-specific biomarkers. Ultimately, these findings aim to establish a robust scientific foundation for validating green algae as a

Consequently, this study was meticulously engineered to examine the synergistic therapeutic impacts of green algae extract at two distinctive dietary concentrations (3% and 5%) utilizing an HFD-induced obesity rat model. By implementing a dual-phased investigative approach first, an in vitro characterization of the extract's phytochemical potency, followed by an in vivo physiological functional food technology (Plaza et al.,2009; Alzahrani et al., 2026).

sustainable and potent alternative to synthetic anti-obesity pharmacotherapy, facilitating its future application in clinical nutrition and

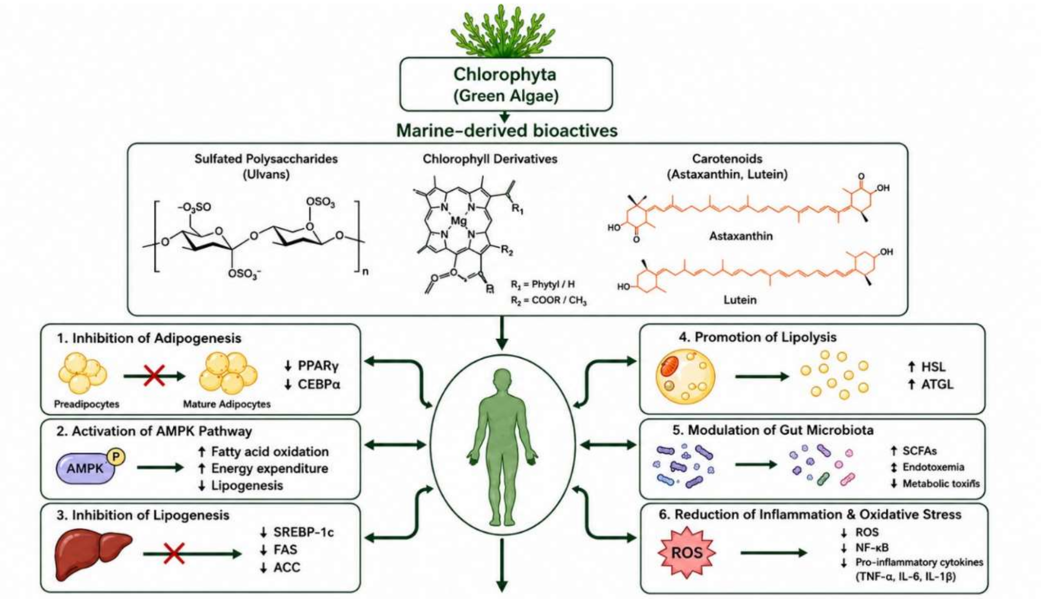


Figure 2. Original schematic illustration of the anti-obesity mechanisms mediated by marine-derived Chlorophyta bioactives through modulation of adipogenesis, lipogenesis, lipolysis, oxidative stress, and metabolic homeostasis.

Green algae (Chlorophyta) were processed following standardized marine botanical protocols. The material was thoroughly washed, air-dried (25 ± 2 °C), and pulverized into a 40-mesh powder (Holdt & Kraan, 2011).

- Proximate Composition: Moisture, ash, crude protein, and total lipids were quantified according to AOAC official methods (AOAC International, 2019).

- HPLC-DAD Phenolic Profiling: Phytochemical fingerprinting was performed using an Agilent 1260 Infinity II HPLC system following validated chromatographic principles for polyphenol analysis in algae .

2.3. Induction of Experimental Obesity

2. Materials and Method.

2.1. Biological Materials and Ethical Approval

A total of 24 adult male Sprague-Dawley albino rats (150 ± 10 g) were obtained from the animal house facility of the Institute of Nutrition (Cairo, Egypt). The animals were selected based on uniform age and optimal health status to ensure metabolic reliability (National Research Council, 2011). All experimental procedures were reviewed and approved by the Institutional Research Ethics Committee of Al-Baha University, Saudi Arabia (Approval No. 46123022), adhering to the "Guide for the Care and Use of Laboratory Animals" (National Research Council, 2011).

2.2. Preparation and Characterization of Green Algae Extract

- Group 2 (Positive Control): Obese rats fed HFD without treatment.
- Group 3 (Green Algae 3%): Obese rats fed basal diet supplemented with 3% green algae.
- Group 4 (Green Algae 5%): Obese rats fed basal diet supplemented with 5% green algae.

(Randomization and group allocation follow standard preclinical experimental design guidelines: Festing & Altman, 2002**).**

2.5. Dietary Formulation

Experimental diets were prepared freshly on a weekly basis and stored at 4 °C to preserve bioactive stability .The detailed composition is presented in Table 1.

Metabolic disorder was induced by feeding the rats a High-Fat Diet (HFD). The diet formulation followed widely used obesity-induction protocols in rodent models based on modified AIN-93 guidelines (Reeves et al., 1993; Buettner et al., 2007). DL-methionine (0.3%) and bile acids (0.2%) were incorporated to enhance metabolic stress induction (Buettner et al., 2007).

2.4. Experimental Design and Grouping

After a 7-day acclimatization period, the 24 rats were randomly allocated into four equal groups (n = 6 per group) and maintained for 28 consecutive days as follows:

- Group 1 (Negative Control): Healthy rats fed a standard basal diet.

Table (1): The basic and experimental diets' compositions.

Component (g)	Control (-)	Control (+)	3% Green Algae	5% Green Algae
Test ingredients	---	---	3	5
Casein	20	20	20	20
Corn oil	4.7	4.7	4.7	4.7
Mineral mix	3.5	3.5	3.5	3.5
Vitamin mix	1	1	1	1
Cellulose	5	5	5	5
Cholin chloride	2	2	2	2
Sucrose	10	10	10	10
Corn starch	**Up to 100**	**Up to 100**	**Up to 100**	**Up to 100**

Serum biochemical parameters were quantified using validated commercial diagnostic kits and standardized spectrophotometric techniques, ensuring high analytical reliability and reproducibility (Tietz, 2015).

• Liver Function Parameters

2.6. Growth Performance

Body Weight Gain (BWG%) and Feed Efficiency Ratio (FER) were calculated using standard experimental animal nutrition formulas widely adopted in rodent studies (Reeves et al., 1993).

2.7. Biochemical Analysis

Atherogenic Index was calculated as TC/HDL-C ratio, a widely accepted cardiovascular risk marker (Dobiasova & Frohlich, 2001).

2.8. Statistical Analysis

Data were expressed as Mean ± SD. Statistical analysis was performed using one-way ANOVA followed by appropriate post hoc tests for multiple comparisons using SPSS software (Field, 2018).

4. RESULTS

- **Chemical Composition of dried green alga *(Chlorophyta*)**

The proximate chemical composition of the dried green alga *(Chlorophyta*) was evaluated on a wet weight basis (wwb). The obtained results demonstrated that the algal biomass possessed a nutritionally valuable biochemical composition characterized by a remarkably high protein content together with moderate concentrations of lipids and carbohydrates. The moisture content was determined to be 10.50 ± 0.12%, indicating that the dried biomass retained only a limited amount of residual water after processing. Such a relatively low moisture level is considered advantageous for enhancing storage stability and reducing the risk of microbial contamination during preservation and handling. Protein was identified as the predominant biochemical component of the dried algal biomass, accounting for 55.40 ± 0.45% of the total composition. This high protein concentration reflects the nutritional importance of green algae belonging to the division *Chlorophyta* and highlights their growing significance as sustainable alternative sources of protein for food, feed, and industrial applications. The elevated protein percentage observed in the present analysis is in agreement with the biochemical characteristics commonly

Aminotransferase Activities (ALT and AST) were determined using IFCC-recommended kinetic methods, which are globally standardized for liver injury assessment (Schumann et al., 2002; Burtis & Bruns, 2019).

Alkaline Phosphatase (ALP) activity was measured using IFCC standardized procedures for cholestatic and biliary function assessment (Burtis & Bruns, 2019).

Total bilirubin and total protein were quantified using standard clinical chemistry methods including the Jendrassik–Grof method and Biuret assay respectively (Tietz, 2015).

• Renal Function Markers

Serum urea was determined using the urease–GLDH method, a standard enzymatic approach for renal function assessment (Fawcett & Scott, 1960; Tietz, 2015).

Uric acid was quantified using the uricase–POD enzymatic colorimetric method, widely used in metabolic and renal studies (Tietz, 2015).

Creatinine was measured using the Jaffe reaction or enzymatic methods recommended for routine renal function testing (Burtis & Bruns, 2019).

• Lipid Profile Assessment

Total cholesterol and triglycerides were measured using enzymatic CHOD-PAP and GPO-PAP methods respectively, which are reference methods in lipid metabolism studies (Allain et al., 1974; Fossati & Prencipe, 1982).

HDL-cholesterol was determined using precipitation-based methods or direct enzymatic assays (Tietz, 2015).

LDL and VLDL were calculated using the Friedewald equation, validated for use in metabolic research under standard triglyceride conditions (Friedewald et al., 1972).

industrial and biotechnological value of the biomass, particularly in applications involving bioactive compounds, nutraceutical products, and renewable biological resources. In addition, the ash content was found to be 4.70 ± 0.09%, reflecting the presence of mineral elements and inorganic constituents naturally accumulated during algal growth and metabolism.

Overall, the proximate analysis demonstrated that the dried green algal biomass belonging to the division *Chlorophyta* possesses a balanced and nutritionally rich biochemical profile characterized by substantial protein content along with appreciable levels of carbohydrates, lipids, fiber, and mineral matter. These findings support the potential utilization of green algae as valuable natural resources in nutritional, pharmaceutical, and biotechnological fields.

associated with many green microalgal species cultivated under suitable environmental and nutritional conditions.

The total carbohydrate content, excluding crude fiber, was recorded at 16.10 ± 0.28%, suggesting that carbohydrates represent an important reserve energy component within the algal cells. Crude fiber content was measured at 2.15 ± 0.05%, indicating the presence of structural polysaccharides that contribute to the rigidity and integrity of the algal cell wall. These fibrous compounds may also provide additional nutritional and functional benefits when the biomass is utilized in dietary or pharmaceutical formulations.

The lipid fraction constituted 11.15 ± 0.18% of the dried biomass, revealing a moderate accumulation of fatty substances within the algal cells. This lipid level may increase the

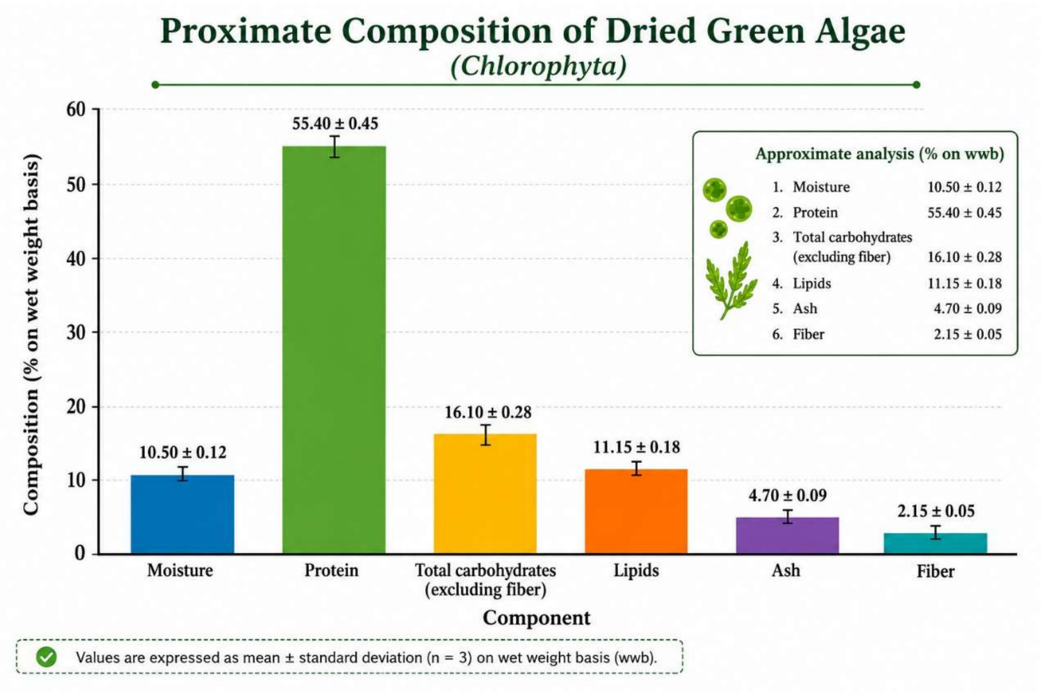


Figure 3. Proximate composition (% dry weight basis) of dried green algae (*Chlorophyta*).

Supplementation with green algae resulted in a noticeable improvement in all measured parameters. Group 3 (3% green algae) recorded BWG of 68.90 ± 1.95, FER of 0.119 ± 0.003, and FI of 21.80 ± 1.01, showing values slightly lower than the positive control group but still indicating limited improvement.

A more pronounced effect was observed in Group 4 (5% green algae), which showed reduced BWG (63.45 ± 2.87), FER (0.116 ± 0.004), and FI (20.15 ± 1.04) compared with Group 3. This suggests a dose-dependent improvement in metabolic performance with increasing levels of green algae supplementation.

Overall, the results demonstrate that green algae supplementation exerts a beneficial modulatory effect on growth performance parameters in obese rats induced by a high-fat diet, with the 5% supplementation level showing greater efficacy than the 3% level.

4.2. Biological evaluation

Effects of green algae supplementation on growth performance parameters (BWG, FER, and FI)

The effects of green algae supplementation on body weight gain (BWG), feed efficiency ratio (FER), and feed intake (FI) are presented in Figure 4. The experimental groups included Group 1 (Negative Control), Group 2 (Positive Control), Group 3 (3% green algae), and Group 4 (5% green algae).

The negative control group (G1) exhibited the lowest values for all measured parameters, recording BWG of 33.84 ± 1.05, FER of 0.082 ± 0.002, and FI of 13.75 ± 0.88. This reflects normal physiological conditions under a standard basal diet.

In contrast, the positive control group (G2), which was fed a high-fat diet without treatment, showed a marked increase in BWG (71.22 ± 1.48), FER (0.121 ± 0.001), and FI (22.36 ± 0.69), indicating a significant disturbance in metabolic regulation compared with the negative control group.

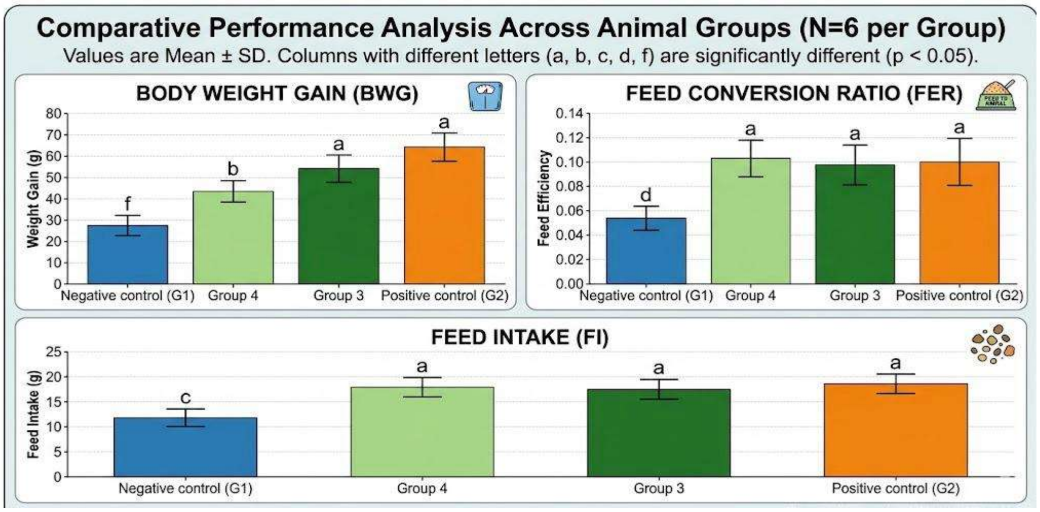


Figure 4: Influence of different experimental treatments on growth performance and nutritional indices in rats.

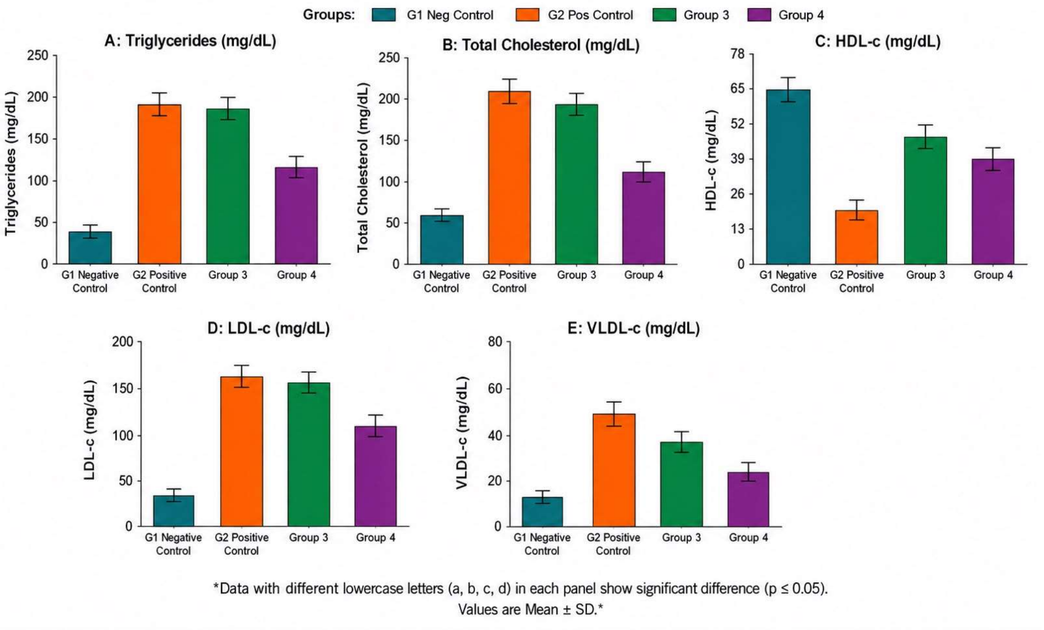
The effects of green algae supplementation on serum lipid profile, including triglycerides (TG), total cholesterol

4.3.Biochemical Analysis

Effects of green algae supplementation on lipid profile parameters

with green algae resulted in an improvement in lipid profile parameters. Group 3 exhibited reduced triglycerides (229.4 ± 5.9), total cholesterol (196.2 ± 4.8), LDL-c (121.3 ± 6.1), and VLDL (45.8 ± 0.8), along with a slight increase in HDL-c (32.1 ± 1.6) compared with the positive control group. Similarly, Group 4 showed a more pronounced improvement, with further reductions in triglycerides (214.7 ± 4.5), total cholesterol (187.9 ± 4.2), LDL-c (110.6 ± 4.7), and VLDL (42.9 ± 0.7), as well as an increase in HDL-c (36.4 ± 1.3), indicating a dose-dependent beneficial effect of green algae supplementation. Overall, the results suggest that green algae supplementation ameliorates high-fat diet–induced dyslipidemia, with the 5% supplementation level demonstrating a stronger lipid-lowering effect compared with the 3% level.

(TC), high-density lipoprotein cholesterol (HDL-c), low-density lipoprotein cholesterol (LDL-c), and very-low-density lipoprotein (VLDL), are presented in figure 5. The negative control group (G1) exhibited the most favorable lipid profile, recording the lowest levels of triglycerides (142.6 ± 4.8), total cholesterol (108.3 ± 5.1), LDL-c (42.1 ± 3.9), and VLDL (28.4 ± 0.6), along with the highest HDL-c value (55.8 ± 1.4), indicating a normal metabolic status under a standard diet. In contrast, the positive control group (G2), fed a high-fat diet without treatment, showed a significant dyslipidemic pattern characterized by elevated triglycerides (238.9 ± 6.2), total cholesterol (205.7 ± 6.0), LDL-c (128.4 ± 5.8), and VLDL (47.6 ± 0.9), together with a marked reduction in HDL-c (30.5 ± 1.9), compared with the negative control group. Supplementation



Data with different lowercase letters (a, b, c, d) in each panel show significant difference (p ≤ 0.05). Values are Mean ± SD.

Figure 5: Modulatory effects of different experimental treatments on serum lipid profiles in animal models. (A) Triglycerides, (B) Total Cholesterol, (C) High-Density Lipoprotein Cholesterol (HDL-c), (D) Low-Density Lipoprotein Cholesterol (LDL-c), and (E) Very Low-Density Lipoprotein Cholesterol (VLDL-c).

Effects of green algae supplementation on liver function enzymes (ALT, AST, and ALP)

The effects of green algae supplementation on liver function markers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP), are presented in Figure 6. The negative control group (G1) showed the lowest enzyme activities, with ALT (31.84 ± 1.92), AST (33.10 ± 2.11), and ALP (112.40 ± 3.05), reflecting normal hepatic function under physiological conditions. In contrast, the positive control group (G2), fed a high-fat diet without treatment, exhibited a marked elevation in liver enzymes, with ALT (66.25 ± 2.88), AST (64.70 ± 0.62), and ALP (155.80 ± 3.40), indicating hepatic stress and possible liver dysfunction induced by the high-fat diet. Supplementation with green algae improved liver function parameters in a dose-dependent manner. Group 3 (3% green algae) showed reduced ALT (61.90 ± 1.15), AST (60.55 ± 0.28), and ALP (149.60 ± 0.90) compared with the positive control group, indicating partial hepatoprotective effects. Similarly, Group 4 (5% green algae) demonstrated a more pronounced improvement, with further reductions in ALT (56.30 ± 2.40), AST (56.10 ± 2.10), and ALP (143.85 ± 3.20), suggesting stronger protective effects against high-fat diet–induced hepatic injury.

Overall, these findings indicate that green algae supplementation exerts a hepatoprotective effect, with the higher dose (5%) showing greater efficacy in improving liver enzyme profiles compared with the lower dose (3%).

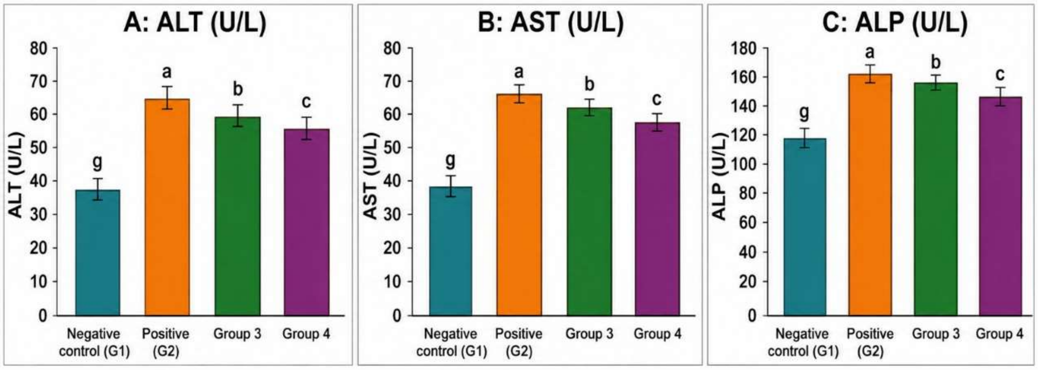


Figure 6: Protective effects of different experimental treatments on serum hepatic biomarkers in animal models. (A) Alanine Aminotransferase (ALT), (B) Aspartate Aminotransferase (AST), and (C) Alkaline Phosphatase (ALP).

Effects of green algae supplementation on kidney function parameters.

The effects of green algae supplementation on kidney function biomarkers, including creatinine, urea, and uric acid, are presented in Figure 7.

The negative control group (G1) exhibited the lowest values of all renal function parameters, with creatinine (0.58 ± 0.006), urea (12.40 ± 1.85), and uric acid (2.05 ± 0.06), indicating normal kidney function under physiological conditions.

In contrast, the positive control group (G2), which was fed a high-fat diet without treatment, showed a significant impairment in renal function, as evidenced by elevated creatinine (1.32 ± 0.05), urea (29.10 ± 1.70), and uric acid (4.35 ± 0.02), compared with the negative control group.

Supplementation with green algae resulted in an improvement in renal function markers. Group 3 (3% green algae) showed slightly reduced creatinine (1.28 ± 0.004), urea (27.85 ± 2.00), and uric acid (4.18 ± 0.09) compared with the positive control group, although the values remained relatively elevated.

A more pronounced improvement was observed in Group 4 (5% green algae), which demonstrated further reductions in creatinine (1.19 ± 0.06), urea (23.40 ± 1.90), and uric acid (3.78 ± 0.10), suggesting a dose-dependent ameliorative effect of green algae on high-fat diet–induced renal dysfunction.

Overall, these findings indicate that green algae supplementation exerts a protective effect on kidney function, with the higher dose (5%) showing greater efficacy than the lower dose (3%).

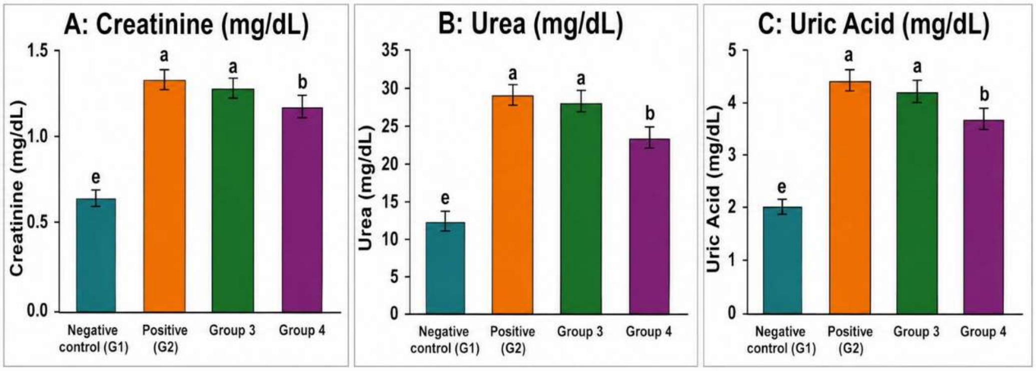


Figure 7: Influence of different experimental treatments on serum renal function biomarkers in animal models. (A) Creatinine, (B) Urea, and (C) Uric Acid.

The marked increase in BWG, FER, and FI observed in the positive control group reflects enhanced energy efficiency and altered appetite regulation commonly associated with high-fat feeding. Such metabolic alterations are often linked to leptin resistance and dysregulation of hypothalamic appetite control centers (Klok et al., 2007). Interestingly, green algae supplementation significantly attenuated these changes, particularly at the 5% inclusion level, suggesting an improvement in energy utilization and metabolic efficiency. This effect may be attributed to the high content of bioactive compounds in Chlorophyta, which have been reported to modulate digestive enzyme activity and lipid absorption in the gastrointestinal tract (Xu et al., 2023).

5- DISCUSSION

The present investigation provides strong experimental evidence that dietary supplementation with green algae exerts a multi-targeted protective effect against high-fat diet (HFD)-induced obesity and its associated metabolic complications in rats. Obesity is increasingly recognized as a chronic metabolic disease driven not only by excessive caloric intake but also by dysregulated endocrine signaling, oxidative stress, and chronic inflammation, collectively referred to as "metabolic inflammation" (World Health Organization, 2024; Bluher, 2019). The present findings confirm that prolonged exposure to HFD successfully induced a state of metabolic imbalance, as reflected by significant disturbances in growth performance, lipid metabolism, and organ function biomarkers.

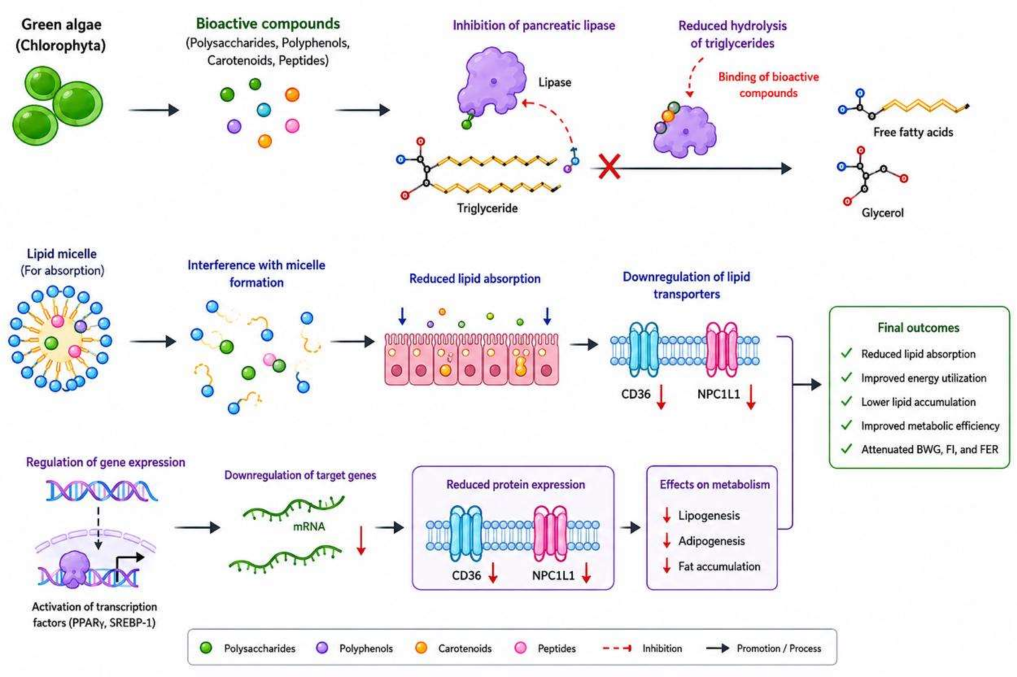


Figure 8. Proposed molecular mechanisms of *Chlorophyta bioactive compounds in improving metabolic efficiency and reducing lipid absorption under high-fat diet conditions.

Liver function analysis further supports the hepatoprotective potential of green algae. The elevated ALT, AST, and ALP levels in HFD-fed rats indicate hepatocellular injury and cholestatic stress, which are hallmarks of diet-induced non-alcoholic fatty liver disease (NAFLD) (Younossi et al., 2018). NAFLD is strongly associated with oxidative stress and mitochondrial dysfunction, leading to hepatocyte membrane instability and enzyme leakage into circulation. The significant reduction in these enzymes following green algae supplementation suggests stabilization of hepatic cellular integrity. This hepatoprotective effect may be linked to the antioxidant properties of algal polyphenols and carotenoids, which neutralize reactive oxygen species and prevent lipid peroxidation in hepatic tissues (Jomova et al., 2023**;** Mashnafi et al., 2025). In addition to hepatic protection, green algae demonstrated a clear renoprotective effect.

The lipid-lowering effects observed in the present study are particularly noteworthy. The significant reductions in triglycerides, total cholesterol, LDL-c, and VLDL-c, alongside increased HDL-c levels, indicate a strong hypolipidemic action of green algae supplementation. These effects are consistent with previous reports demonstrating that marine algae bioactives can inhibit intestinal lipid absorption and suppress hepatic de novo lipogenesis (Shimada et al., 2010). Mechanistically, these improvements may involve modulation of AMP-activated protein kinase (AMPK) signaling, which plays a central role in regulating lipid oxidation and energy balance (Hardie et al., 2012). Activation of AMPK leads to enhanced fatty acid oxidation and reduced lipid accumulation in hepatic tissues, thereby improving systemic lipid homeostasis.

mode of action provides a strong advantage over conventional pharmacological agents that typically target a single metabolic pathway.

The present findings also align with the growing body of evidence supporting marine algae as sustainable functional food ingredients with therapeutic potential. Unlike synthetic drugs, algal-derived compounds offer a natural, low-toxicity alternative with broad metabolic benefits. However, despite these promising results, further molecular investigations are necessary to clarify the precise signaling pathways involved, including gene expression analysis of lipid-regulating and inflammatory markers.

Green algae supplementation demonstrated significant protective effects against HFD-induced metabolic disorders, with improvements in body weight regulation, lipid metabolism, and organ function. The observed benefits appear to be mediated through antioxidant, anti-inflammatory, and lipid-modulating mechanisms, with a clear dose-dependent response favoring the higher supplementation level. These findings support the potential use of green algae as a functional dietary intervention for the prevention and management of obesity-related metabolic diseases.

6- Conclusion

In conclusion, the present study demonstrates that dietary supplementation with green algae exerts a significant protective and therapeutic effect against high-fat diet-induced obesity and its associated metabolic disturbances in experimental rats. The findings clearly indicate that HFD feeding induces marked dysregulation in body weight, lipid profile, and organ function biomarkers, reflecting a state of metabolic stress and systemic dysfunction. Green algae Elevated serum creatinine, urea, and uric acid levels in the positive control group indicate impaired renal clearance and increased protein catabolism, commonly observed in obesity-induced nephropathy (Kovesdy et al., 2017**;** Labban & Abd Elmeged, 2026). Chronic oxidative stress contributes to glomerular damage and tubular dysfunction, ultimately reducing filtration capacity. The improvement in renal biomarkers in algae-treated groups suggests enhanced antioxidant defense and improved glomerular integrity. Marine-derived polysaccharides have been shown to reduce renal inflammation by inhibiting pro-inflammatory cytokines such as TNF-α and IL-6, thereby preserving renal function (Kidgell et al., 2019**;** Elmeged & Albaggar, 2026).

A notable finding of the present study is the dose-dependent response observed across all measured parameters. The 5% green algae group consistently exhibited superior outcomes compared with the 3% group, indicating that higher concentrations of bioactive compounds produce stronger metabolic benefits. This dose-response relationship supports the hypothesis that the therapeutic efficacy of Chlorophyta is directly linked to its phytochemical density, particularly flavonoids, sulfated polysaccharides, and chlorophyll derivatives (Xu et al., 2023).

Furthermore, the systemic improvements observed across lipid, hepatic, and renal profiles suggest that green algae does not act through a single isolated pathway but rather exerts pleiotropic metabolic effects. Such multifunctionality is a key characteristic of nutraceutical interventions, which act through synergistic modulation of oxidative stress, inflammation, and lipid metabolism simultaneously (Plaza et al., 2009). This holistic supplementation effectively improved growth performance parameters, as evidenced by reduced body weight gain, feed efficiency ratio, and feed intake, particularly at the higher inclusion level (5%). Moreover, a clear amelioration of dyslipidemia was observed, characterized by decreased triglycerides, total cholesterol, LDL-c, and VLDL-c, alongside an improvement in HDL-c levels, indicating enhanced lipid metabolism and cardiovascular protection. In addition, green algae demonstrated notable hepatoprotective effects through the normalization of ALT, AST, and ALP levels, suggesting reduced hepatic injury and improved liver function. Similarly, renal function markers, including creatinine, urea, and uric acid, were significantly improved, reflecting a protective effect against obesity-induced kidney dysfunction.Overall, the study highlights that green algae act through multiple mechanisms, including antioxidant, anti-inflammatory, and lipid-regulating pathways, to restore metabolic homeostasis. The observed effects were dose-dependent, with the 5% supplementation showing superior efficacy compared to the 3% level.These results support the potential use of green algae as a promising natural nutraceutical intervention for the prevention and management of obesity and related metabolic disorders. However, further molecular and clinical studies are recommended to fully elucidate the underlying mechanisms and confirm its applicability in human health.

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