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Immunomodulatory and Histopathological Effects of Dietary Coriander Seed Powder on Liver and Kidney Tissues in Diabetic Rats

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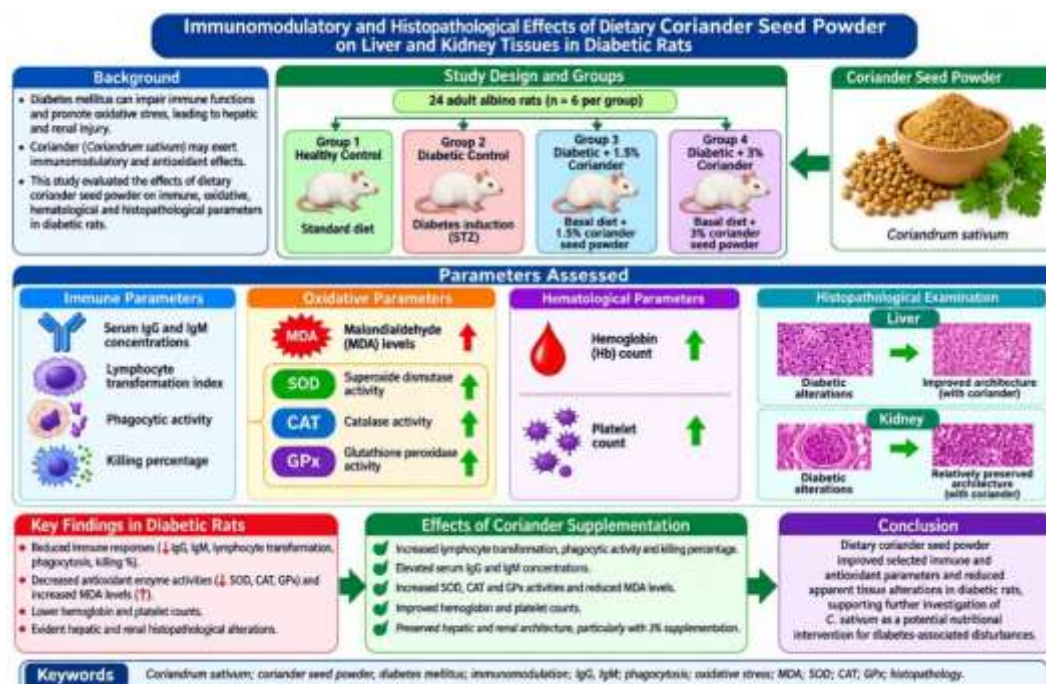
ABSTRACT:

Background: The immune system plays a central role in maintaining physiological homeostasis, and immune dysregulation is increasingly recognized as an important component of diabetes-associated metabolic and tissue abnormalities. Diabetes mellitus can impair innate and adaptive immune functions and promote oxidative stress, potentially contributing to hepatic and renal injury. This study evaluated the effects of dietary coriander seed powder on selected immune, oxidative, hematological, and histopathological parameters in diabetic rats.

Methods: Twenty-four adult albino rats were randomly allocated into four groups (n = 6): healthy control, diabetic control, and diabetic rats receiving basal diets supplemented with 1.5% or 3% coriander seed powder for 28 days. Immune status was assessed using serum IgG and IgM concentrations, lymphocyte transformation index, phagocytic activity, and killing percentage. Oxidative status was evaluated by measuring malondialdehyde (MDA) and the activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). Hemoglobin and platelet counts were also determined, and liver and kidney tissues were examined histopathologically.

Results: Diabetic rats showed reduced immune responses and antioxidant enzyme activities, increased MDA levels, lower hemoglobin and platelet counts, and evident hepatic and renal histopathological alterations compared with healthy controls. Coriander supplementation was associated with improvements in lymphocyte transformation, phagocytic activity, killing percentage, and serum IgG and IgM concentrations. It also increased SOD, CAT, and GPx activities and reduced MDA levels. Hemoglobin and platelet counts improved, while hepatic and renal tissues showed relatively preserved architecture, particularly following 3% supplementation.

Conclusion: Dietary coriander seed powder was associated with improved selected immune and antioxidant parameters and reduced apparent tissue alterations in diabetic rats. These findings support further investigation of *C. sativum* as a potential nutritional intervention for diabetes-associated disturbances



Graphical Abstract: Immunomodulatory and Histopathological Effects of Dietary Coriander Seed Powder on Liver and Kidney Tissues in Diabetic Rats.

1. INTRODUCTION

The immune system plays a central role in maintaining physiological homeostasis and protecting the body against infectious and endogenous challenges. Increasing evidence indicates a close interaction between metabolic status and immune function, with diabetes mellitus representing an important example of this relationship. Diabetes is now recognized as a systemic metabolic disorder associated with immune dysfunction, chronic low-grade inflammation, and oxidative stress, which collectively contribute to disease progression and the development of diabetes-related complications (Alexander et al., 2024; Weinberg Sibony et al., 2024). Persistent hyperglycemia can impair both innate and adaptive immune responses by altering the functions of lymphocytes, macrophages, neutrophils, natural killer cells, and other immune-cell populations. These alterations may affect immune-cell proliferation, differentiation, inflammatory signaling, cytokine production, phagocytic function, and antimicrobial responses, thereby increasing susceptibility to infections while contributing to persistent inflammatory activation (Adam et al., 2026; Lee et al., 2024; Zhou et al., 2024). Recent evidence indicates that hyperglycemia can affect multiple immune-cell populations, including T cells, macrophages, natural killer cells, and neutrophils, although the magnitude and nature of these effects may vary according to the type and duration of diabetes and the metabolic environment (Lee et al., 2024). Assessment of humoral immunity through immunoglobulins such as IgG and IgM, together with evaluation of lymphocyte proliferation and other cellular immune responses, may provide complementary information regarding adaptive immune function. Similarly, phagocytic activity and antimicrobial or killing capacity represent important functional components of innate immunity. Therefore, the combined assessment of humoral and cellular immune parameters may provide a broader characterization of diabetes-associated immune alterations (Aljehani et al., 2026; Zhou et al., 2024). Oxidative stress is another important feature of diabetes. Chronic hyperglycemia can enhance the generation of reactive oxygen species (ROS) through several interconnected mechanisms, including mitochondrial dysfunction, glucose auto-oxidation, advanced glycation end-product formation, and metabolic stress (Luna-Marco et al., 2024; Weinberg Sibony et al., 2024). Excessive ROS production can cause oxidative damage to lipids, proteins, and nucleic acids and can activate inflammatory signaling pathways, thereby contributing to cellular dysfunction and the progression of diabetes-related complications (Weinberg Sibony et al., 2024). Mitochondrial dysfunction and excessive ROS generation are considered important components of the pathophysiological relationship between metabolic disturbances and oxidative stress in diabetes.

(Luna-Marco et al., 2024). Malondialdehyde (MDA) is widely used as an indicator of lipid peroxidation and oxidative damage, whereas antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) represent important components of endogenous antioxidant defense systems. Recent systematic evidence has identified MDA, SOD, and related antioxidant parameters among the commonly investigated biomarkers of oxidative stress in patients with type 2 diabetes mellitus (Sabitha et al., 2024). Accordingly, simultaneous measurement of lipid-peroxidation products and antioxidant enzymes may provide a more comprehensive assessment of the balance between oxidative damage and antioxidant defense. Diabetes-associated metabolic, inflammatory, and oxidative disturbances may also contribute to injury and dysfunction in major organs, including the liver and kidneys. Diabetes, particularly type 2 diabetes, is strongly associated with metabolic dysfunction-associated steatotic liver disease (MASLD), and the relationship between the two conditions is considered bidirectional, with shared mechanisms involving insulin resistance, metabolic dysfunction, inflammation, and lipotoxicity (Huang et al., 2024; Wongtrakul et al., 2024). Recent evidence also indicates that MASLD is highly prevalent among individuals with type 2 diabetes and may increase the risk of progressive liver disease and other adverse outcomes (Huang et al., 2024). Chronic kidney disease (CKD) is another major complication associated with diabetes. According to the American Diabetes Association's current Standards of Care, CKD attributed to diabetes occurs in approximately 20–40% of people with diabetes and represents a major cause of morbidity and progression to kidney failure (American Diabetes Association Professional Practice Committee for Diabetes, 2026). Thus, the assessment of immune function and oxidative stress, together with metabolic and organ-specific parameters, may provide a more integrated understanding of the systemic effects of diabetes.

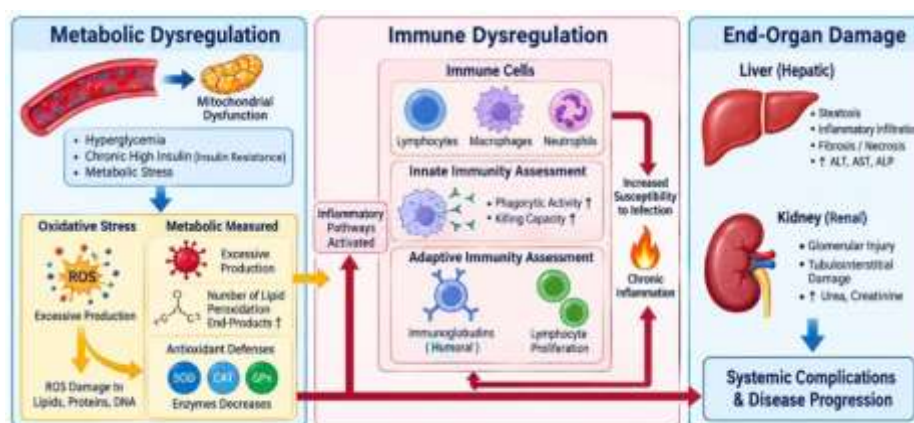


Figure 1: Pathophysiology of Diabetes Mellitus: Systemic Impact on Metabolic, Immune, and Organ Systems.

Histopathological examination can complement biochemical and immunological measurements by providing direct evidence of tissue-level alterations and structural injury. Natural products containing bioactive compounds have attracted considerable interest because they may influence multiple metabolic, inflammatory, and oxidative pathways simultaneously. Coriander (*Coriandrum sativum* L.) seeds contain a variety of phytochemicals, including polyphenols, flavonoids, essential-oil constituents, and other bioactive compounds, and several studies have reported antioxidant, anti-inflammatory, and antidiabetic activities associated with coriander-derived preparations (Mechchate et al., 2021; Scandar et al., 2023). Experimental evidence indicates that coriander seed preparations can improve glucose homeostasis and antioxidant status and reduce oxidative damage in experimental models of diabetes. For example, administration of coriander seed powder to streptozotocin-induced diabetic rats was associated with reduced lipid peroxidation and improvement of antioxidant defenses, including restoration of antioxidant enzyme activity (Deepa & Anuradha, 2011). More recent experimental work has also demonstrated antioxidant, anti-inflammatory, and antidiabetic effects of polyphenol-rich fractions obtained from *C. sativum* seeds (Mahzari et al., 2026). In addition, a recent study of *C. sativum* polysaccharides reported antioxidant, hypoglycemic, and immunomodulatory activities, including enhanced macrophage phagocytic activity in vitro (Jin et al., 2025). These findings provide experimental support for the potential interaction of coriander-derived phytochemicals with oxidative, metabolic, and immune pathways, although the effects of isolated extracts or fractions cannot necessarily be extrapolated directly to whole coriander seed powder. Evidence also suggests that coriander may exert protective effects on renal and metabolic parameters in diabetes. In an experimental model of diabetic nephropathy, *C. sativum* seed extract attenuated pathological progression and was

associated with inhibition of advanced glycation end-product-related mechanisms (Kajal & Singh, 2019). Furthermore, a recent randomized, double-blind, placebo-controlled clinical trial in patients with type 2 diabetes mellitus reported that dietary supplementation with coriander seed powder was associated with changes in glycemic indices and oxidative-stress-related biomarkers, including malondialdehyde and total antioxidant capacity (Zamany et al., 2025). However, because the latter study was conducted in humans and primarily evaluated metabolic and biochemical outcomes, its findings should not be interpreted as direct evidence of histopathological protection.

Despite these findings, relatively limited research has investigated the effects of whole coriander seed powder incorporated into the diet at different concentrations on multiple immune, oxidative, hematological, and histopathological outcomes simultaneously. In particular, the combined assessment of humoral immune parameters such as IgG and IgM, cellular immune responsiveness assessed by the lymphocyte transformation index, innate immune functions such as phagocytic activity and killing percentage, oxidative-stress markers including MDA, antioxidant enzymes such as SOD, CAT, and GPx, hematological parameters, and liver and kidney histopathology may provide a more comprehensive characterization of the effects of coriander supplementation in diabetes. Therefore, the present study investigated the immunomodulatory, antioxidant, hematological, and histopathological effects of dietary coriander seed powder in diabetic albino rats. Twenty-four rats were divided into four groups: a healthy negative control group, a diabetic positive control group, and two diabetic groups receiving diets supplemented with 1.5% or 3% coriander seed powder for 28 days. The study evaluated humoral and cellular immune responses, innate immune functions, oxidative-stress markers, antioxidant enzyme activities, hematological parameters, and histopathological changes in the liver and kidneys. This integrated experimental approach was designed to investigate the potential effects of dietary coriander seed powder on interconnected immune, oxidative, metabolic, and tissue-level alterations associated with diabetes (Mashnafi et al., 2026).

2. MATERIALS AND METHODS

2.1. Plant Material and Preparation of Coriander Seed Powder

Coriander seeds (*Coriandrum sativum* L.) were used as the experimental plant material in the present study. The seeds were carefully inspected to remove foreign materials, damaged seeds, and visible contaminants. The selected seeds were thoroughly cleaned and dried under suitable conditions away from direct sunlight to minimize potential degradation of light- and heat-sensitive bioactive constituents. After complete drying, the seeds were mechanically ground into a fine and homogeneous powder using an electric grinder. The resulting coriander seed powder was transferred into clean, airtight containers, protected from light, and stored under appropriate conditions until incorporation into the experimental diets. Coriander seeds contain various biologically active phytochemicals, including phenolic compounds, which have been investigated for their antioxidant and potential metabolic activities (Scandar et al., 2023).

2.2. Experimental Animals and Housing Conditions

Twenty-four adult white albino rats, weighing approximately 150 ± 10 g, were used in the present study. The animals were housed under suitable laboratory conditions throughout the experimental period. Before initiation of the experimental procedures, the rats were allowed to acclimatize to the laboratory environment for two weeks. The animals were maintained under controlled environmental conditions, including a 12-h light/12-h dark cycle and suitable room temperature and relative humidity. The rats had free access to drinking water and the basal diet throughout the acclimatization and experimental periods, except where otherwise specified by the experimental protocol. The animals were monitored regularly throughout the study for general health condition, body weight, food intake, and any observable clinical changes.

2.3. Induction of Experimental Diabetes

After the two-week acclimatization period, experimental type 1 diabetes mellitus (T1DM) was induced in the rats assigned to the diabetic groups using streptozotocin (STZ). Streptozotocin was administered by intraperitoneal injection at a dose of 75 mg/kg body weight according to the established experimental protocol. Following STZ administration, the animals were monitored for the development of hyperglycemia. After an appropriate fasting period, blood samples were collected for determination of blood glucose concentrations. Blood glucose levels were measured using a standard glucose determination procedure. Rats exhibiting blood glucose concentrations greater than 250 mg/dL were considered diabetic and were included in the diabetic experimental groups. Animals that did not reach the predefined hyperglycemic criterion were excluded from the diabetic groups. The diabetic state was confirmed before the commencement of the dietary intervention. Following

confirmation of diabetes, the diabetic rats were allocated to the positive control group or to the experimental groups receiving coriander seed powder supplementation. The healthy non-diabetic rats were maintained as the negative control group.

2.4. Basal Diet

The animals were provided with a nutritionally adequate basal diet throughout the experimental period. The basal diet was provided consistently to all experimental groups, except for the incorporation of coriander seed powder into the diets of the designated treatment groups. The basal diet was prepared and provided under appropriate hygienic conditions throughout the experimental period.

2.5. Experimental Design and Dietary Treatments

Following confirmation of diabetes, the animals were randomly allocated into four experimental groups, with six rats in each group ($n = 6$), as follows:

Group 1: Negative Control (NC): Six healthy non-diabetic rats were fed the basal diet throughout the 28-day experimental period. This group served as the normal control group.

Group 2: Positive Control (PC): Six diabetic rats were fed the basal diet without coriander seed powder throughout the 28-day experimental period. This group served as the untreated diabetic control group.

Group 3: Diabetic + 1.5% Coriander Seed Powder (DC + CSP 1.5%): Six diabetic rats were fed the basal diet supplemented with 1.5% powdered coriander seeds throughout the 28-day experimental period.

Group 4: Diabetic + 3% Coriander Seed Powder (DC + CSP 3%): Six diabetic rats were fed the basal diet supplemented with 3% powdered coriander seeds throughout the 28-day experimental period.

The graded dietary concentrations of coriander seed powder were used to investigate the potential concentration-dependent effects of *C. sativum* seed supplementation on immune function, oxidative status, hematological parameters, and tissue integrity in diabetic rats.

2.6. Preparation of Experimental Diets

The required quantities of coriander seed powder were thoroughly mixed with the basal diet to obtain final dietary concentrations of 1.5% and 3%. The ingredients were mixed carefully under appropriate hygienic conditions to ensure relatively uniform distribution of the plant material throughout each dietary formulation. The prepared diets were stored under suitable conditions and provided to the animals according to the experimental schedule.

2.7. Experimental Period

The experimental dietary intervention was continued for 28 consecutive days. During this period, the animals were maintained under the same housing and husbandry conditions, while the designated experimental groups received their respective dietary treatments.

2.8. Assessment of Body Weight and Food Intake

Body weights were recorded at the beginning of the experimental period and at regular intervals throughout the study. Food intake was also monitored throughout the experimental period to evaluate dietary consumption and changes in body weight among the experimental groups. Where applicable, body weight gain (BWG), body weight gain percentage (BWG%), and feed efficiency ratio (FER) were calculated using the following equations:

$$\text{BWG (g)} = \text{Final body weight (g)} - \text{Initial body weight (g)}$$

$$\text{BWG (\%)} = [(\text{Final body weight} - \text{Initial body weight}) / \text{Initial body weight}] \times 100$$

$$\text{FER} = \text{Body weight gain (g)} / \text{Food intake (g)}$$

2.9. Immunologic Analysis

2.9.1. Determination of Serum Immunoglobulins: Serum immunoglobulin G (IgG) and immunoglobulin M (IgM) concentrations were determined to assess humoral immune status. Blood samples were collected at the end of the experimental period, and serum was separated according to standard laboratory procedures and stored under appropriate conditions until analysis. IgG and IgM concentrations were determined according to the procedure described by Zilva and Pannall (1984). These immunoglobulins were evaluated as indicators of humoral immune status and antibody-associated immune responses.

2.9.2. Lymphocyte Transformation Test: The lymphocyte transformation test was performed to evaluate cellular immune responsiveness. Heparinized blood samples were used for lymphocyte isolation under sterile conditions. Lymphocytes were separated using a Ficoll-based lymphocyte separation medium according to the density-gradient separation procedure described by Böyum (1968). Briefly, heparinized blood was carefully layered over the lymphocyte separation medium and subjected to centrifugation under the appropriate conditions. The lymphocyte-containing interface was carefully collected, washed, and prepared for subsequent assessment of lymphocyte proliferative activity. The lymphocyte transformation response was expressed as a lymphocyte transformation index according to the calculation procedure used in the experimental protocol.

2.9.3. Phagocytosis and Killing Assay: Phagocytic activity and killing percentage were determined to evaluate innate immune function. Heparinized blood samples were used for the preparation of leukocytes for the assessment of phagocytic and microbicidal activities. The leukocyte preparation and subsequent phagocytosis and killing procedures were performed according to the method described by Woldehiwet and Rowan (1990). Phagocytic activity was assessed based on the ability of the prepared leukocytes to engulf the test microorganism, whereas killing percentage was used to assess the microbicidal capacity of the phagocytic cells. The results were expressed according to the calculation procedures specified in the experimental protocol.

2.10. Determination of Oxidative Stress and Antioxidant Biomarkers

Oxidative status was assessed by measuring malondialdehyde (MDA) concentration and the activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx).

2.10.1. Determination of Malondialdehyde: Malondialdehyde (MDA) concentration was determined as an indicator of lipid peroxidation according to the method described by Draper and Hadley (1990).

2.10.2. Determination of Superoxide Dismutase Activity: Superoxide dismutase (SOD) activity was determined according to the method described by Spitz and Oberley (1989). The assay was used to evaluate SOD activity as a component of the endogenous enzymatic antioxidant defense system.

2.10.3. Determination of Catalase Activity: Catalase (CAT) activity was determined according to the method described by Aebi (1984), based on the measurement of hydrogen peroxide decomposition by catalase.

2.10.4. Determination of Glutathione Peroxidase Activity: Glutathione peroxidase (GPx) activity was determined according to the method described by Moin (1986). GPx activity was evaluated as an additional component of the endogenous antioxidant defense system. The combined determination of MDA concentration and antioxidant enzyme activities was used to provide an integrated assessment of oxidative status and endogenous antioxidant defense in the experimental groups.

2.11. Hematological Analysis

At the end of the experimental period, blood samples were collected for hematological evaluation. The hematological parameters assessed included red blood cell (RBC) count, white blood cell (WBC) count, hemoglobin (Hb) concentration, and platelet count. These hematological parameters were determined using standard laboratory procedures and were used to evaluate the effects of diabetes and dietary coriander seed powder supplementation on the hematological status of the experimental animals.

2.12. Histopathological Examination

At the end of the 28-day experimental period, the animals were sacrificed according to the approved experimental protocol. Liver and kidney specimens were collected immediately after sacrifice for histopathological examination. The tissue specimens were fixed in 10% neutral buffered formalin, dehydrated through graded concentrations of ethyl alcohol, cleared in xylene, and embedded in paraffin wax. Paraffin-embedded tissues were sectioned, mounted on glass slides, and stained with hematoxylin and eosin (H&E). The stained sections were examined microscopically to evaluate the general histological architecture and identify pathological alterations in the liver and kidney tissues.

2.13. Statistical Analysis

The obtained data were statistically analyzed using one-way analysis of variance (ANOVA) to determine the significance of differences among the four experimental groups. When significant differences were detected, the least significant difference (LSD) test was used for post hoc comparisons among group means. Differences were considered statistically significant at $p < 0.05$ (Duncan, 1955).

2.14. Ethical Approval

All experimental procedures involving laboratory animals were conducted in accordance with the applicable institutional guidelines for the care and use of experimental animals. The experimental protocol was reviewed and approved by the Institutional Research Ethics Committee of Al-Baha University, Saudi Arabia (Approval No. 47119677, dated 17 May 2026).

3. RESULTS

3.1. Chemical composition of dried coriander seed powder

Table 1 presents the proximate nutritional composition and phytochemical profile of raw coriander seeds (*Coriandrum sativum* L.) expressed on a dry-weight basis. The analyzed seeds contained $12.37 \pm 1.12\%$ crude protein and $17.80 \pm 1.45\%$ fat, while crude fiber represented the predominant nutritional component, accounting for $42.00 \pm 3.10\%$ of the dry matter. The ash content was $5.50 \pm 0.65\%$, whereas total carbohydrates constituted $22.33 \pm 2.15\%$. Regarding the phytochemical constituents, the total phenolic content was 2.10 ± 0.15 , while the total flavonoid content was 1.40 ± 0.08 . These results indicate that raw coriander seeds contain appreciable levels of both nutritional components and bioactive phytochemical constituents. The relatively high crude fiber content, together with the presence of phenolic and flavonoid compounds, characterizes coriander seeds as a raw material with a diverse nutritional and phytochemical composition. All values are reported as mean $\pm$ standard deviation based on three independent determinations ($n = 3$).

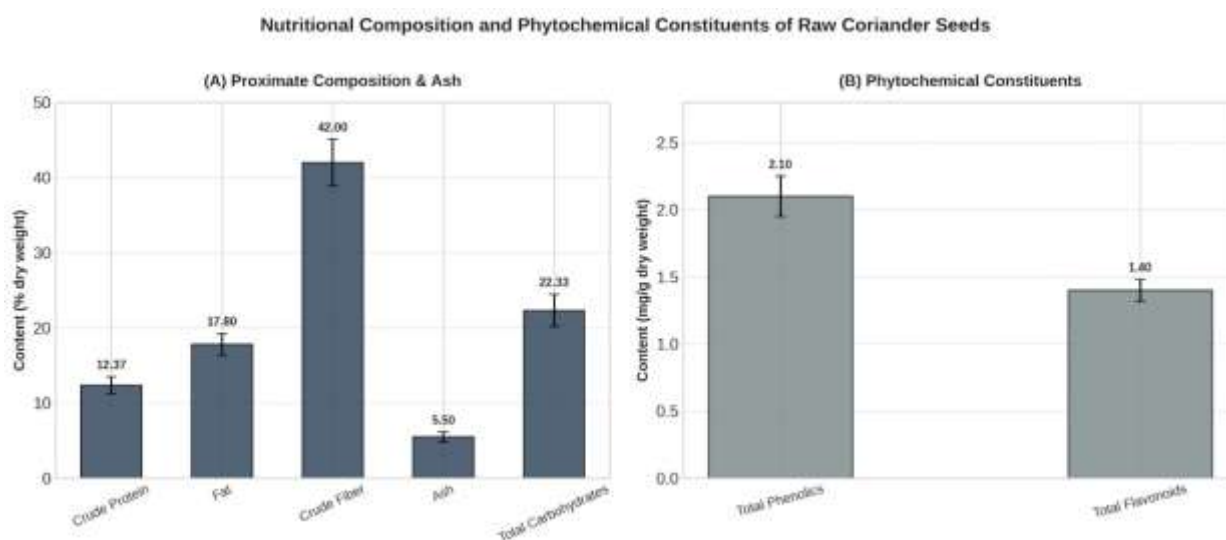


Figure 1. Nutritional composition (% dry weight) and phytochemical constituents (mg/g dry weight) of raw coriander seeds (*Coriandrum sativum* L.). Values are presented as mean $\pm$ standard deviation. $n=3$

3.2. Biological evaluation

Figure 3 shows the effects of dietary coriander seed powder supplementation on body weight and feed utilization in diabetic rats. No significant differences were observed in initial body weight among the experimental groups, indicating that the animals had comparable body weights at the beginning of the experimental period. At the end of the study, the negative control group showed a significant increase in final body weight, body weight gain (BWG), BWG percentage, and feed efficiency ratio (FER), with values of 222.4 ± 2.05 g, 33.9 ± 1.05 g, $17.98 \pm 0.55\%$, and 0.062 ± 0.002 , respectively. In contrast, the diabetic control group exhibited a significant reduction in final body weight compared with the negative control group. This group showed a negative BWG (-6.9 ± 1.15 g), BWG percentage ($-3.65 \pm 0.61\%$), and FER (-0.013 ± 0.002), indicating a marked decline in body weight and feed utilization during the experimental period.

Coriander seed powder supplementation was associated with an improvement in body weight-related parameters in diabetic rats. The group receiving 1.5% coriander seed powder had a significantly higher final body weight, BWG, BWG percentage, and FER than the diabetic control group ($P < 0.05$). The corresponding values were 196.5 ± 1.95 g, 7.7 ± 1.10 g, $4.08 \pm 0.58\%$, and 0.015 ± 0.002 , respectively. Supplementation with 3% coriander seed powder resulted in further numerical increases in these parameters, with final body weight, BWG, BWG percentage, and FER reaching 206.3 ± 2.10 g, 18.1 ± 1.20 g, $9.62 \pm 0.64\%$, and 0.034 ± 0.002 , respectively. Based on the statistical grouping, the 3% coriander seed powder group was statistically comparable with the negative control group for BWG, BWG percentage, and FER, as indicated by the shared superscript letters. However, its final body weight remained significantly lower than that of the negative control group. Taken together, coriander seed powder supplementation was associated with improved body weight gain and feed efficiency in diabetic rats compared with the untreated diabetic control, although the magnitude of the response varied according to the supplementation level.

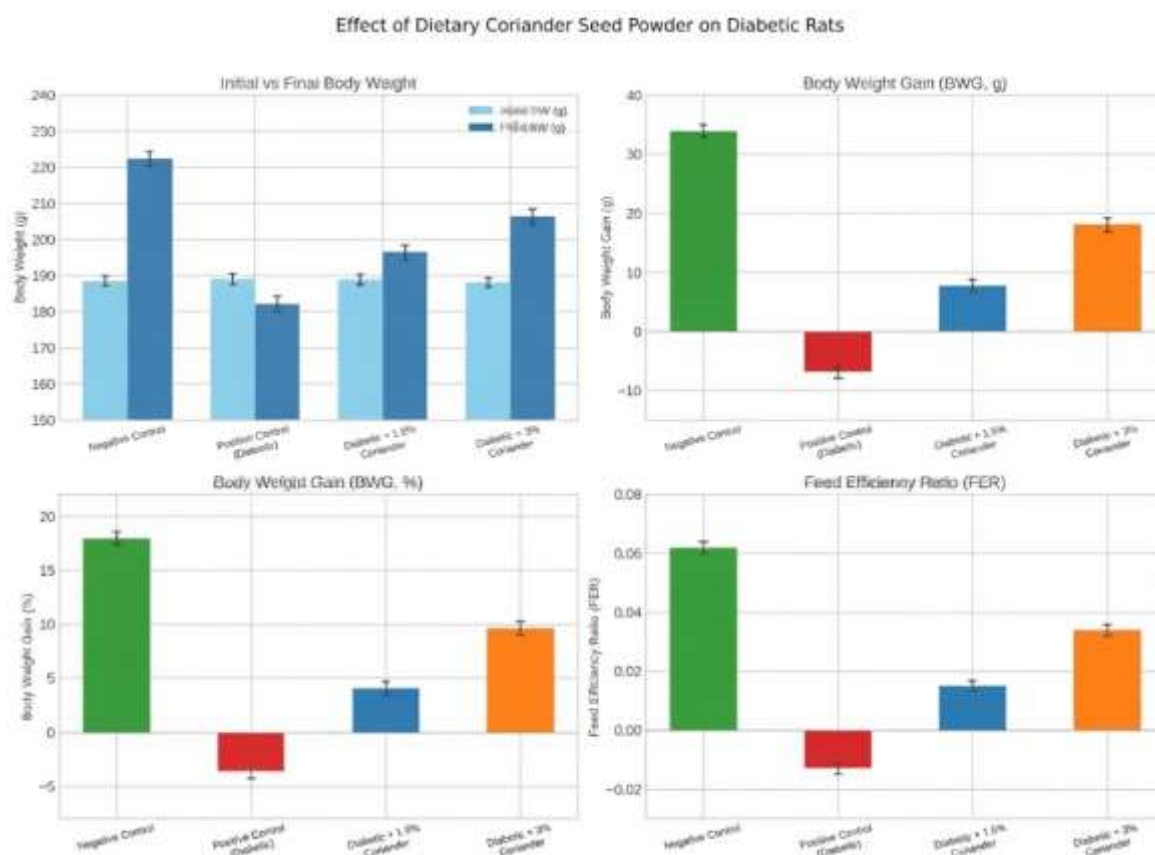


Figure 3. Effect of dietary coriander seed powder supplementation on final body weight and body weight gain in diabetic rats. Values are presented as mean $\pm$ SE ($n = 3$). Different superscript letters indicate significant differences among groups within the respective parameter at $P < 0.05$.

3.2. Immunological evaluation

Figure 4 illustrates the effects of dietary coriander seed powder supplementation on the lymphocyte transformation index, phagocytic activity, and killing percentage in diabetic rats. The diabetic control group showed significantly lower values for all three evaluated immune parameters than the negative control group ($P \leq 0.05$). The lymphocyte transformation index decreased from $3.25 \pm 0.10\%$ in the negative control group to $2.15 \pm 0.15\%$ in the diabetic control group. Likewise, phagocytic activity and killing percentage declined from $88.50 \pm 1.20\%$ and $84.50 \pm 1.10\%$, respectively, in the negative control group to $74.20 \pm 2.00\%$ and $70.80 \pm 1.30\%$ in the diabetic control group. Coriander seed powder supplementation was associated with an improvement in the assessed immune parameters in diabetic rats. Supplementation with 1.5% coriander seed powder increased the lymphocyte transformation index, phagocytic activity, and killing percentage to $2.50 \pm 0.08\%$, $81.10 \pm 1.10\%$, and $77.20 \pm 0.95\%$, respectively. These changes corresponded to improvement rates of 16.28%, 9.30%, and 9.04%, respectively, relative to the diabetic control group. At the 3% supplementation level, the corresponding values increased to $2.90 \pm 0.09\%$, $85.40 \pm 1.00\%$, and $81.00 \pm 0.90\%$, with improvement rates of 34.88%, 15.09%, and 14.41%, respectively. The statistical analysis revealed significant differences among the experimental groups for the evaluated parameters ($P \leq 0.05$). The 1.5% coriander supplementation group differed significantly from the diabetic control group, whereas the 3% supplementation group showed values statistically comparable to those of the negative control group, as indicated by the shared superscript letters. Overall, the findings indicate that dietary coriander seed powder supplementation was associated with improved lymphocyte transformation, phagocytic activity, and killing capacity in diabetic rats, with the responses at the 3% supplementation level approaching those observed in the negative control group.

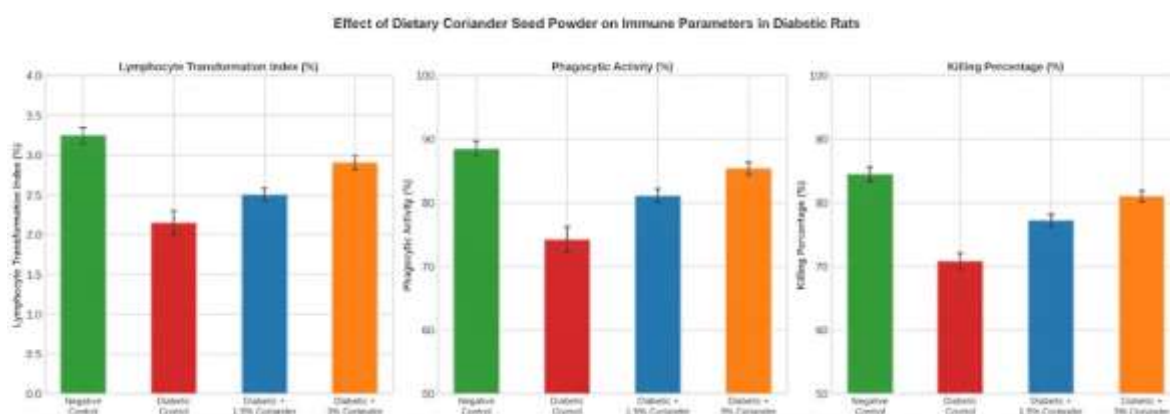


Figure 4. Effects of dietary coriander seed powder supplementation on lymphocyte transformation, phagocytic activity, and killing capacity in diabetic rats.

Figure 5 illustrates the effects of dietary coriander seed powder supplementation on serum immunoglobulin M (IgM) and immunoglobulin G (IgG) levels in diabetic rats. The diabetic control group exhibited significantly lower serum IgM and IgG concentrations than the negative control group ($P \leq 0.05$). Serum IgM decreased from 11.84 ± 0.28 g/L in the negative control group to 5.82 ± 0.09 g/L in the diabetic control group. Similarly, serum IgG decreased from 254.3 ± 2.45 g/L to 141.2 ± 1.15 g/L, respectively. Dietary supplementation with coriander seed powder was associated with increased serum immunoglobulin levels in diabetic rats. The administration of 1.5% coriander seed powder increased serum IgM and IgG concentrations to 7.91 ± 0.16 and 218.6 ± 2.10 g/L, respectively. Both parameters were significantly higher than those observed in the diabetic control group ($P \leq 0.05$), although they remained lower than the corresponding values in the negative control group. At the 3% supplementation level, serum IgM and IgG concentrations increased further to 9.45 ± 0.21 and 241.5 ± 2.30 g/L, respectively. For IgM, the 3% supplementation group was statistically comparable with the 1.5% supplementation group, as indicated by the shared superscript letter. In contrast, the IgG level in the 3% supplementation group was statistically comparable with the negative control group, as indicated by the shared superscript letters, and was significantly higher than that of the diabetic control group.

Overall, dietary coriander seed powder supplementation was associated with improved serum IgM and IgG levels in diabetic rats compared with the untreated diabetic control group. The values observed at the 3% supplementation level were closer to those of the negative control group, particularly for serum IgG.

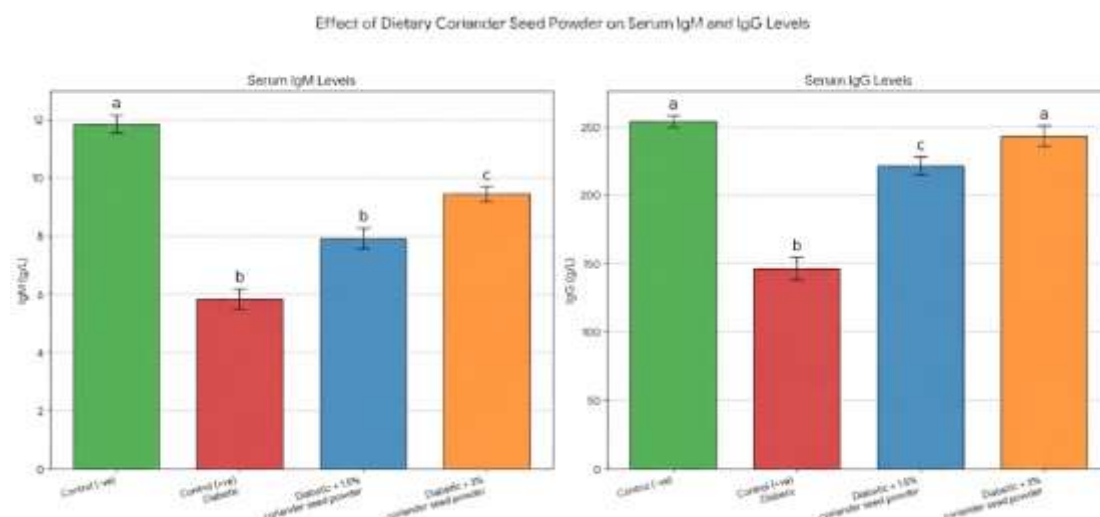


Figure 5. Effects of dietary coriander seed powder supplementation on serum IgM and IgG levels in diabetic rats.

3.3 Oxidative Stress and Antioxidant Biomarkers

Figure 6 illustrates the effects of dietary coriander seed powder supplementation on antioxidant enzyme activities and the oxidative stress marker malondialdehyde (MDA) in diabetic rats. The diabetic control group exhibited significantly lower GPx, CAT, and SOD activities than the negative control group ($P \leq 0.05$), with values of 19.2 ± 0.40 ng/mL, 58.9 ± 0.60 mmol/L, and 20.5 ± 0.48 U/L, respectively, compared with 45.5 ± 0.85 ng/mL, 82.4 ± 0.45 mmol/L, and 42.1 ± 0.52 U/L in the negative control group. In contrast, MDA concentration was markedly higher in the diabetic control group (8.12 ± 0.25 nmol/mL) than in the negative control group (2.95 ± 0.12 nmol/mL).

Dietary supplementation with coriander seed powder was associated with increased antioxidant enzyme activities and reduced MDA concentration in diabetic rats. At the 1.5% supplementation level, GPx, CAT, and SOD activities increased to 34.8 ± 0.50 ng/mL, 68.2 ± 0.50 mmol/L, and 31.4 ± 0.60 U/L, respectively, and were significantly higher than the corresponding values in the diabetic control group ($P \leq 0.05$). Meanwhile, MDA concentration decreased to 5.20 ± 0.15 nmol/mL, indicating a significant reduction compared with the diabetic control group. At the 3% supplementation level, GPx, CAT, and SOD activities reached 41.5 ± 0.60 ng/mL, 74.6 ± 0.42 mmol/L, and 37.8 ± 0.55 U/L, respectively. These values were statistically comparable with those of the negative control group, as indicated by the shared superscript letters. The MDA concentration also decreased to 4.05 ± 0.14 nmol/mL in the 3% supplementation group. This value was significantly lower than that of the diabetic control group but was statistically comparable with the values observed in both the negative control and 1.5% supplementation groups.

Overall, Figure 6 demonstrates that dietary coriander seed powder supplementation was associated with a more favorable oxidative stress profile in diabetic rats, characterized by higher antioxidant enzyme activities and lower MDA concentrations. The numerical changes were more pronounced at the 3% supplementation level, with the measured values approaching those of the negative control group..

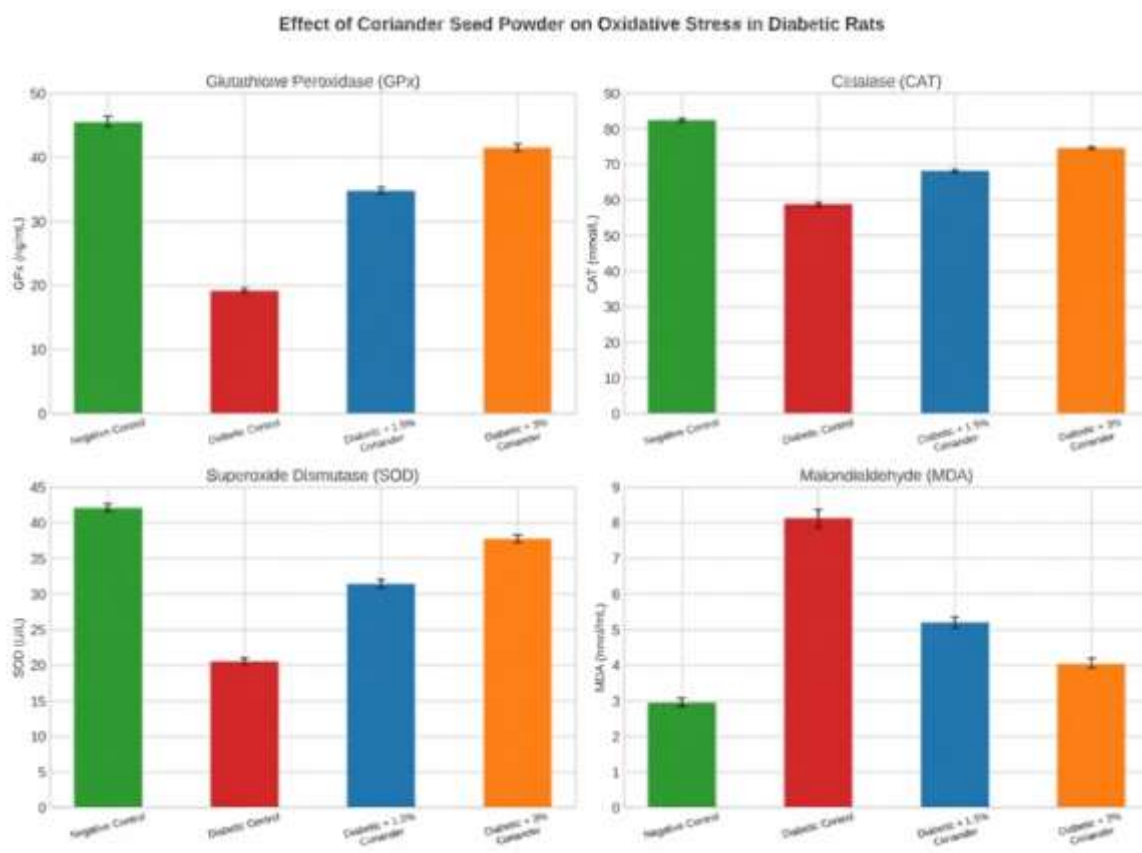


Figure 6. Effects of dietary coriander seed powder supplementation on antioxidant enzyme activities and oxidative stress in diabetic rats.

3.5. Hematological Analysis

Figure 7 illustrates the effects of dietary coriander seed powder supplementation on hemoglobin concentration and platelet count in diabetic rats. The diabetic control group showed significantly lower hemoglobin and platelet counts than the negative control group ($P \leq 0.05$). Hemoglobin concentration decreased from 13.42 ± 0.21 g/dL in the negative control group to 10.86 ± 0.18 g/dL in the diabetic control group. Similarly, the platelet count decreased from $782.3 \pm 18.45 \times 10^3/\mu\text{L}$ to $624.7 \pm 15.32 \times 10^3/\mu\text{L}$, respectively.

Dietary supplementation with coriander seed powder was associated with an increase in both hemoglobin concentration and platelet count compared with the diabetic control group. In rats receiving 1.5% coriander seed powder, hemoglobin concentration increased to 12.15 ± 0.19 g/dL, while the platelet count increased to $697.5 \pm 16.27 \times 10^3/\mu\text{L}$. Both parameters were significantly higher than those observed in the diabetic control group ($P \leq 0.05$), although they remained significantly lower than the corresponding values in the negative control group.

At the 3% supplementation level, hemoglobin concentration and platelet count increased further to 12.84 ± 0.22 g/dL and $748.6 \pm 17.14 \times 10^3/\mu\text{L}$, respectively. Based on the superscript notation, both parameters in the 3% supplementation group were statistically comparable with the negative control group and the 1.5% supplementation group. In contrast, they were significantly higher than the corresponding values in the diabetic control group.

Overall, dietary coriander seed powder supplementation was associated with improved hematological parameters in diabetic rats, as reflected by higher hemoglobin concentrations and platelet counts compared with the untreated diabetic control group. The values observed at the 3% supplementation level approached those of the negative control group.

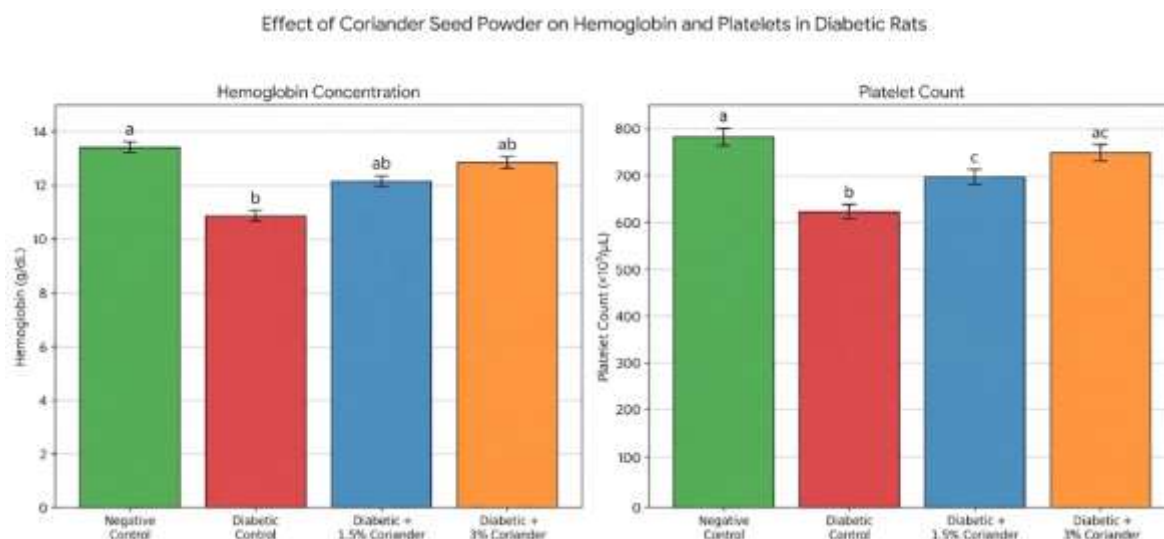


Figure 7. Effects of dietary coriander seed powder supplementation on hemoglobin concentration and platelet count in diabetic rats.

3.6. Histopathological Examination

• Renal Tissues

Figure 8. Representative photomicrographs of renal tissue sections stained with hematoxylin and eosin (H&E) from the different experimental groups.

- Negative control group: The renal section shows preserved renal architecture, with structurally intact renal corpuscles, well-defined glomeruli, and clearly identifiable Bowman's spaces. The proximal and distal convoluted tubules exhibit regular epithelial linings, with no apparent degenerative changes, vascular congestion, or inflammatory cell infiltration.
- (B) Diabetic control group: The renal section exhibits histopathological alterations characterized by vascular congestion and dilatation, accompanied by erythrocyte accumulation within glomerular capillaries and peritubular blood vessels. Focal tubular epithelial degeneration and mild interstitial edema are also observed, indicating renal tissue alterations associated with the diabetic condition.
- (C) Diabetic rats treated with 1.5% coriander seed powder: The renal tissue shows relatively preserved histological architecture, with recognizable glomerular structures and tubular organization. The apparent extent of structural alterations is reduced compared with that described in the diabetic control group. The degree of preservation should be interpreted in relation to the histological features observed in the examined sections.
- (D) Diabetic rats treated with 3% coriander seed powder: The renal section displays largely preserved renal architecture, with relatively well-maintained glomeruli and tubular structures. Fewer apparent histopathological alterations are observed compared with the diabetic control group, suggesting an association between coriander seed powder supplementation and improved preservation of renal tissue morphology.

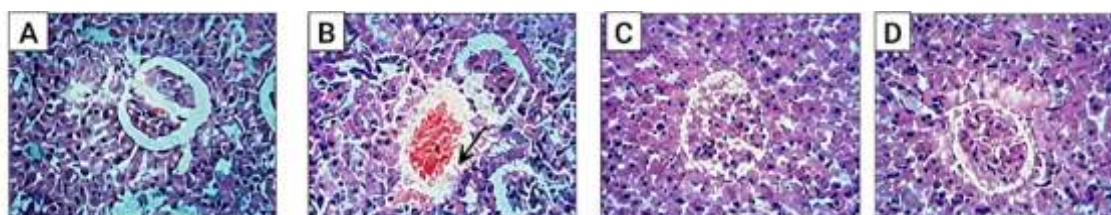


Figure 8. Histopathological examination of renal tissues in diabetic rats supplemented with coriander seed powder.

• Hepatic Tissues

Figure 9. Representative photomicrographs of H&E-stained liver sections from the different experimental groups.

- Negative control group: The liver section exhibits a well-preserved hepatic architecture with clearly organized hepatic cords radiating from a distinct central vein. Hepatocytes display the expected polygonal morphology, with centrally located nuclei and eosinophilic cytoplasm. The hepatic sinusoids appear narrow and regularly arranged, with no apparent evidence of vascular congestion, hepatocellular necrosis, or inflammatory cell infiltration.
- (B) Diabetic control group: The liver section shows evident histopathological alterations, including increased Kupffer cell activity along the hepatic sinusoids, as indicated by the arrows, together with the presence of a small number of leukocytes within the sinusoidal spaces. Mild hepatocellular swelling and focal degenerative changes are also observed. These findings indicate morphological alterations in the hepatic parenchyma associated with the diabetic condition.
- (C) Diabetic rats supplemented with 1.5% coriander seed powder: The hepatic tissue shows a relatively well-preserved overall architecture, with regularly arranged hepatic cords and recognizable hepatocellular morphology. The central vein and sinusoidal spaces appear relatively well maintained, with fewer apparent pathological alterations compared with the diabetic control group. These findings indicate partial preservation of hepatic tissue morphology following dietary supplementation.
- (D) Diabetic rats supplemented with 3% coriander seed powder: The liver section demonstrates largely preserved hepatic architecture, with well-organized hepatic cords and relatively intact hepatocytes. Mild Kupffer cell activation and a small number of scattered leukocytes are observed within the hepatic sinusoids. Overall, the extent of the observed histopathological alterations appears limited, with the hepatic tissue showing a relatively preserved morphology compared with the diabetic control group.

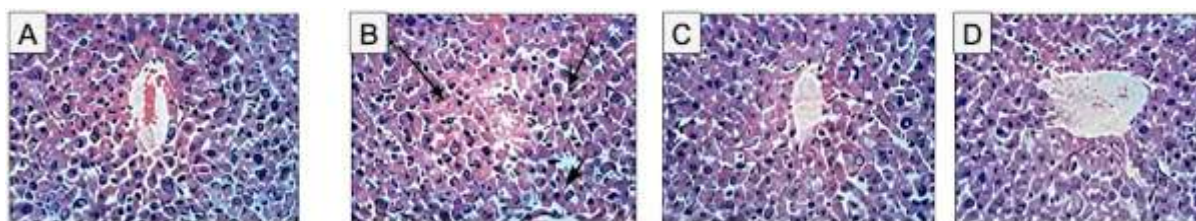


Figure 9. Histopathological examination of hepatic tissues in diabetic rats supplemented with coriander seed powder

4. DISCUSSION

The present study demonstrated that dietary supplementation with coriander seed powder was associated with improvements in immune function, oxidative balance, selected hematological parameters, and the histological appearance of hepatic and renal tissues in streptozotocin (STZ)-induced diabetic rats. The overall pattern of findings suggests that coriander seed powder may partially attenuate several of the metabolic and tissue alterations associated with experimental diabetes. Importantly, the effects were generally more pronounced in rats receiving 3% coriander seed powder, suggesting a possible concentration-related response. However, because only two supplementation levels were investigated, a formal dose-response relationship cannot be established. Furthermore, the present study did not directly measure inflammatory cytokines, insulin signaling, or specific molecular pathways; therefore, the mechanisms underlying the observed effects should be interpreted cautiously.

The reduction in body weight, body weight gain, and feed efficiency observed in the diabetic control group is consistent with the metabolic disturbances commonly associated with severe experimental diabetes. STZ induces pancreatic β -cell injury and consequently reduces insulin availability, resulting in impaired glucose utilization and altered metabolism of carbohydrates, lipids, and proteins. These metabolic abnormalities may increase the mobilization of endogenous fat and protein stores and contribute to loss of body weight in experimental diabetic animals. The magnitude of these changes, however, depends on factors such as STZ dose, experimental model, duration of diabetes, and animal characteristics (Furman, 2021). The improvement in final body weight, body weight gain, and feed efficiency following coriander supplementation may therefore indicate partial improvement in overall metabolic utilization or nutritional status. Nevertheless, because blood glucose and

insulin concentrations were not among the outcomes measured in the present study, these changes cannot be attributed specifically to improved glycemic control. Previous experimental research supports the potential metabolic effects of *Coriandrum sativum*. Deepa and Anuradha (2011) reported that dietary administration of coriander seed powder in STZ-induced diabetic rats was associated with improvements in oxidative status and antioxidant defense. However, the interpretation of the metabolic effects of coriander should take into account differences in experimental design, including the plant preparation, dose, route of administration, and duration of treatment. Other experimental studies have also demonstrated antihyperglycemic and antihyperlipidemic effects of *C. sativum* preparations in chemically induced diabetic animals, although some of these studies used leaf and stem extracts rather than whole seed powder (Sreelatha & Inbavalli, 2012). Thus, the present findings are broadly consistent with the previously reported biological activity of *C. sativum*, while the specific contribution of coriander seed powder to glycemic regulation cannot be established without direct measurements of glucose and insulin. The immunological findings are particularly relevant because diabetes is associated with alterations in both innate and adaptive immune responses. In the present study, untreated diabetic rats exhibited lower lymphocyte transformation, phagocytic activity, killing percentage, and serum IgM and IgG concentrations than the healthy control group. These findings are broadly compatible with evidence indicating that persistent hyperglycemia and the associated metabolic environment can interfere with leukocyte function, inflammatory signaling, cellular immune responses, and host defense mechanisms (Alexander et al., 2024; Mjery et al., 2026; Zhou et al., 2024). Hyperglycemia may affect several immune-cell populations, including lymphocytes, macrophages, neutrophils, and natural killer cells, although the nature and magnitude of these alterations may vary according to the severity and duration of diabetes (Lee et al., 2024). The improvement in lymphocyte transformation, phagocytic activity, killing percentage, and serum immunoglobulin concentrations following coriander supplementation suggests that coriander seed powder may influence several components of immune responsiveness. The more pronounced response observed in the 3% supplementation group, particularly for lymphocyte transformation and phagocytic activity, is compatible with a concentration-related biological effect. However, because inflammatory cytokines, immune-cell phenotypes, and specific signaling pathways were not measured, the present findings cannot establish a specific immunological mechanism. Rather, the results indicate an association between coriander supplementation and improved functional immune parameters under the conditions of the present experimental model. The immunological findings are further supported by experimental evidence concerning bioactive constituents derived from coriander. Jin et al. (2025) reported antioxidant, hypoglycemic, and immunomodulatory activities of polysaccharides isolated from *C. sativum*, including enhancement of macrophage phagocytic activity in vitro. Although this study used an isolated polysaccharide preparation and macrophage cell cultures rather than whole coriander seed powder administered to diabetic animals, it provides experimental evidence that coriander contains constituents capable of modulating innate immune activity. Similarly, Omar et al. (2024) reported antioxidant, anti-inflammatory, and immunostimulatory effects of coriander seed essential oil in RAW 264.7 murine macrophages, including effects on macrophage functional activity. These findings provide mechanistic support for the possibility that coriander-derived constituents contribute to the immunological effects observed in the present study. Nevertheless, direct extrapolation from isolated compounds, essential oils, or in vitro cellular models to whole coriander seed powder in diabetic animals should be made cautiously. The phytochemical composition of coriander may provide a plausible basis for these biological effects. Coriander seeds contain phenolic compounds, flavonoids, and volatile constituents, including linalool, together with other phytochemicals that have demonstrated antioxidant and anti-inflammatory activities in experimental studies (Chaurasia & Bharati, 2025; Alkhudhayri et al., 2026). Mechchate et al. 2021; Abbas & Abd Elmeged, , 2025) specifically identified several polyphenolic constituents in coriander seeds and reported antioxidant, anti-inflammatory, and antidiabetic activities. Therefore, the improvement in phagocytic and lymphocyte responses observed in the present experiment may reflect the combined activity of multiple phytochemical constituents rather than the action of a single compound.

The changes in oxidative biomarkers provide additional evidence of an association between coriander supplementation and improved antioxidant status. Diabetes is characterized by increased oxidative stress resulting from excessive reactive oxygen species generation and disruption of endogenous antioxidant defenses (Weinberg Sibony et al., 2024; Mohammed Nour et al., 2025). In the present study, diabetic rats exhibited increased MDA concentrations accompanied by reduced SOD, CAT, and GPx activities, indicating increased lipid peroxidation together with reduced activity of important enzymatic antioxidant defenses. Coriander supplementation partially reversed these changes, and the 3% group generally showed values closer to those of the healthy control group. These findings are consistent with previous experimental evidence involving coriander. Deepa and Anuradha (2011) reported that coriander seed powder improved antioxidant defenses and reduced oxidative stress

in the kidneys of STZ-induced diabetic rats. This study is particularly relevant to the present investigation because it involved coriander seed powder and a chemically induced diabetic rat model. In addition, Mechchate et al. (2021) demonstrated antioxidant activity associated with polyphenols identified in coriander seeds. More recent evidence has also demonstrated antioxidant activity in coriander-derived polysaccharides (Jin et al., 2025). Collectively, these studies support the antioxidant potential of coriander-derived preparations, although differences in preparation and experimental models must be considered when comparing results. The antioxidant effects of coriander may be related to its phenolic, flavonoid, and volatile constituents, which may contribute to radical-scavenging activity and modulation of endogenous antioxidant systems (Chaurasia & Bharati, 2025; Alzahrani et al., 2026). However, the precise mechanism cannot be established from the present biochemical measurements alone. The reduction in MDA and increase in antioxidant enzyme activities may result from direct antioxidant activity, preservation or enhancement of endogenous antioxidant defenses, reduced oxidative generation secondary to improved metabolic conditions, or a combination of these mechanisms. Accordingly, molecular studies assessing oxidative signaling pathways and specific redox-regulatory proteins would be required to establish the underlying mechanism. The hematological findings further indicated that diabetes was associated with alterations in selected blood parameters. In the present study, diabetic control rats exhibited lower hemoglobin concentration and platelet count than healthy control animals, whereas coriander supplementation was associated with an increase in these parameters. These changes may reflect the systemic metabolic and oxidative disturbances associated with diabetes. Oxidative stress and metabolic abnormalities can influence erythrocyte integrity and hematological homeostasis, although the specific mechanisms responsible for the changes observed in the present study cannot be determined from the measured parameters alone. The improvement following coriander administration may therefore reflect an indirect association with improved systemic metabolic or oxidative status rather than a direct hematopoietic effect. The hematological findings should nevertheless be interpreted cautiously because only selected hematological parameters were evaluated. Additional measurements, including hematocrit, mean corpuscular volume, mean corpuscular hemoglobin, mean corpuscular hemoglobin concentration, differential leukocyte counts, and reticulocyte indices, would provide a more comprehensive assessment of erythropoietic and immune-cell changes. Such measurements would also help determine whether the observed changes represent a specific effect of coriander supplementation or a broader improvement in the physiological consequences of experimental diabetes. The histopathological findings provide morphological support for the biochemical and immunological observations. The kidneys of untreated diabetic rats exhibited vascular congestion and dilatation, erythrocyte accumulation, focal tubular epithelial degeneration, and mild interstitial edema. In contrast, the coriander-treated groups showed relatively preserved glomerular and tubular architecture and fewer apparent pathological alterations. These observations are consistent with previous experimental evidence indicating potential renal protective effects of coriander-derived preparations under diabetic conditions.

Kajal and Singh (2019) reported that *C. sativum* seed extract attenuated pathological changes associated with experimental diabetic nephropathy and was associated with inhibition of advanced glycation end-product-related mechanisms. Their study also reported improvements in glomerular morphology and reductions in diabetic renal alterations. Although the extract preparation, dose, and experimental conditions differed from those used in the present study, the similarity in the direction of the histopathological findings provides supportive evidence for the potential nephroprotective activity of coriander-derived preparations. Importantly, the present study used whole coriander seed powder incorporated into the diet, whereas Kajal and Singh (2019) used a seed extract; therefore, the findings should be considered complementary rather than directly equivalent.

The hepatic observations showed a similar pattern. The diabetic control group exhibited increased Kupffer cell activity, scattered leukocytes, hepatocellular swelling, and focal degenerative alterations, whereas coriander-treated animals showed relatively preserved hepatic cords and hepatocellular morphology. These findings are compatible with the recognized relationship between diabetes, oxidative stress, inflammation, and hepatic injury. Previous experimental work has demonstrated antioxidant and antihyperglycemic effects of *C. sativum* preparations in chemically induced diabetic animals (Labban et al., 2026; Sreelatha & Inbavalli, 2012; Alzahrani et al., 2025). However, Sreelatha and Inbavalli (2012) investigated leaf and stem extracts in alloxan-induced diabetic rats rather than whole coriander seed powder in an STZ model. Therefore, their findings provide general support for the biological activity of *C. sativum* but should not be interpreted as direct evidence for the specific hepatic effects of whole coriander seed powder observed in the present study. The relationship between diabetes and hepatic metabolic dysfunction is also well established. Current diabetes standards recognize diabetes as an important risk factor for metabolic dysfunction-associated steatotic liver disease (MASLD), with shared mechanisms

involving insulin resistance, metabolic dysfunction, inflammation, and altered lipid metabolism (American Diabetes Association Professional Practice Committee for Diabetes, 2026). Nevertheless, because the present study did not quantify hepatic steatosis, liver enzymes, hepatic lipid accumulation, or molecular markers of MASLD, the histological findings should be interpreted as evidence of general hepatic structural alterations rather than as evidence of a specific effect on MASLD. Taken together, the present results suggest that dietary coriander seed powder may exert a multifaceted protective effect in experimental diabetes, involving improved immune responsiveness, enhancement of antioxidant defenses, attenuation of lipid peroxidation, improvement of selected hematological parameters, and preservation of hepatic and renal tissue architecture. The apparently greater response observed at the 3% supplementation level is compatible with a concentration-related biological effect; however, a formal dose-response relationship cannot be established because only two supplementation concentrations were examined. The findings should also be interpreted in light of several limitations. The study involved a relatively small number of animals and a short intervention period. In addition, histopathological evaluation was descriptive rather than based on a validated semiquantitative scoring system, and the study did not include direct measurements of blood glucose, insulin, inflammatory cytokines, immune-cell phenotypes, or molecular markers of oxidative and inflammatory signaling. Consequently, the observed improvements cannot be assigned to a single molecular mechanism or interpreted as evidence of therapeutic efficacy. Future studies should incorporate larger sample sizes, longer intervention periods, quantitative histopathological scoring, serum biochemical indices of hepatic and renal function, glucose and insulin measurements, inflammatory cytokines, and molecular markers of oxidative stress and immune signaling. Studies comparing different doses and standardized coriander preparations would also be useful for determining whether the apparent concentration-related effects observed in the present experiment represent a reproducible dose-response relationship. Overall, the findings are consistent with previous experimental evidence indicating that *C. sativum* contains bioactive constituents with antioxidant, metabolic, immunomodulatory, and potentially tissue-protective activities (Chaurasia & Bharati, 2025; Ali et al., 2026; Mechchate et al., 2021). The present study adds to this literature by evaluating whole coriander seed powder as a dietary intervention and by examining immune, oxidative, hematological, and histopathological outcomes within the same experimental model. Further controlled experimental studies are warranted to establish the reproducibility, dose dependence, safety, and molecular basis of these effects.

5. CONCLUSION

The present study demonstrated that dietary supplementation with *Coriandrum sativum* L. seed powder was associated with favorable changes in several immune, oxidative, hematological, and histopathological parameters in streptozotocin-induced diabetic rats. Diabetes was associated with impaired immune responsiveness, increased oxidative stress, alterations in selected hematological parameters, and pathological changes in hepatic and renal tissues. Supplementation with coriander seed powder, particularly at the 3% dietary level, was associated with improved lymphocyte transformation, phagocytic activity, killing capacity, and serum IgM and IgG concentrations, together with increased SOD, CAT, and GPx activities and reduced MDA concentrations. Improvements in hemoglobin concentration and platelet count were also observed. Histopathological examination further showed relatively better preservation of hepatic and renal architecture in coriander-supplemented diabetic rats compared with the untreated diabetic group.

The observed effects may be related to the diverse bioactive constituents of coriander seeds, including phenolic compounds, flavonoids, and other phytochemicals with reported antioxidant and immunomodulatory properties. The concurrent improvement in antioxidant defenses and selected immune parameters suggests that attenuation of oxidative disturbances may contribute to the observed biological effects. However, the present findings do not establish a specific molecular mechanism, and the histological observations should be interpreted as evidence of tissue preservation rather than definitive proof of therapeutic hepatoprotective or nephroprotective activity.

Overall, the findings support the potential of dietary coriander seed powder as a promising plant-based nutritional intervention for attenuating selected diabetes-associated immune, oxidative, hematological, hepatic, and renal alterations in an experimental animal model. Further studies with larger sample sizes, longer intervention periods, quantitative histopathological scoring, comprehensive biochemical assessment of hepatic and renal function, and molecular investigations are warranted to confirm these effects, clarify the underlying mechanisms, and establish the optimal and safe dietary dose before any potential translation to human studies.

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