RESEARCH PAPER

Antidiabetic Effects of Hydroalcoholic Extract of *Woodfordia fruticosa* Flowers in Experimental Model of Diabetes

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ABSTRACT

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia, impaired insulin secretion, dyslipidemia, oxidative stress, and inflammatory responses that contribute to the development of various complications. The present study was undertaken to evaluate the antidiabetic and protective effects of the hydroalcoholic extract of *Woodfordia fruticosa* flowers (HAWF) in an experimental diabetic animal model. Animals were divided into six groups comprising normal control, diseased control, metformin-treated (150 mg/kg), and HAWF-treated groups at doses of 100, 200, and 400 mg/kg. Various physiological, biochemical, oxidative stress and inflammatory parameters were assessed during the experimental period.

The diseased control group exhibited significant metabolic disturbances, including reduced body weight and elevated food intake, water consumption, and urine output, indicating the development of classical diabetic symptoms. A marked increase in fasting serum glucose, glycated hemoglobin (HbA1c), total cholesterol, triglycerides, low-density lipoprotein (LDL), very low-density lipoprotein (VLDL), lipid peroxidation, tumor necrosis factor-alpha (TNF-α), and interleukin-1 beta (IL-1β) levels was observed. Conversely, serum insulin, high-density lipoprotein (HDL), superoxide dismutase (SOD), catalase, and reduced glutathione (GSH) levels were significantly decreased.

Treatment with HAWF significantly ameliorated diabetes-induced alterations in a dose-dependent manner. The extract improved body weight and reduced polyphagia, polydipsia, and polyuria. Significant reductions in fasting blood glucose and HbA1c levels were accompanied by restoration of serum insulin concentrations, suggesting improved glycemic control and pancreatic function. HAWF also corrected lipid abnormalities by decreasing total cholesterol, triglycerides, LDL, and VLDL levels while increasing HDL concentrations. Furthermore, treatment enhanced antioxidant defenses through elevation of SOD, catalase, and GSH levels and suppression of lipid peroxidation. Inflammatory cytokines TNF-α and IL-1β were markedly reduced following HAWF administration.

In conclusion, HAWF demonstrated significant antidiabetic, antihyperlipidemic, antioxidant, anti-inflammatory, and pancreatic protective activities. The beneficial effects were most pronounced at the 400 mg/kg dose, indicating its potential as a promising natural therapeutic agent for the management of diabetes and its associated complications.

Keywords: *Woodfordia fruticosa*; Hydroalcoholic flower extract; HAWF; Diabetes mellitus; Hyperglycemia; Serum insulin; HbA1c; Dyslipidemia; Oxidative stress; Inflammatory cytokines; Antidiabetic activity

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1. Introduction

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. The disease is associated with disturbances in carbohydrate, lipid, and protein metabolism and remains one of the leading causes of morbidity and mortality worldwide (1, 2). Chronic hyperglycemia

contributes to the development of several complications, including cardiovascular diseases, nephropathy, neuropathy, and retinopathy. In addition, diabetes is frequently accompanied by dyslipidemia, oxidative stress, and inflammatory responses that further exacerbate tissue damage and disease progression (3, 4).

Oxidative stress plays a crucial role in the pathogenesis of diabetes by promoting the excessive generation of reactive oxygen species (ROS), which impair cellular functions and damage pancreatic β-cells (5). Furthermore, inflammatory mediators such as tumor necrosis factor-alpha (TNF-α) and interleukin-1 beta (IL-1β) contribute to insulin resistance and β-cell dysfunction, thereby aggravating diabetic complications (6). Although conventional antidiabetic drugs are effective in controlling blood glucose levels, their long-term use may be associated with adverse effects, creating a need for safer and more effective therapeutic alternatives (7, 8). Medicinal plants have gained considerable attention as potential sources of antidiabetic agents due to their diverse phytochemical constituents and favorable safety profiles. *Woodfordia fruticosa* (L.) Kurz, belonging to the family Lythraceae, is an important medicinal plant widely used in traditional systems of medicine. The flowers of *W. fruticosa* are reported to contain flavonoids, tannins, polyphenols, and other bioactive compounds possessing antioxidant and anti-inflammatory properties. Therefore, the present study was undertaken to evaluate the antidiabetic, antihyperlipidemic, antioxidant, anti-inflammatory, and pancreatic protective effects of the hydroalcoholic extract of *Woodfordia fruticosa* flowers (HAWF) in an experimental model of diabetes.

2. Materials and Methods

2.1 Plant Material Collection and Authentication

Fresh flowers of *Woodfordia fruticosa* (L.) Kurz were collected from the local region during the flowering season and authenticated by a qualified taxonomist. The collected flowers were washed thoroughly with distilled water to remove adhering dust and foreign materials, shade-dried at room temperature, and pulverized using a mechanical grinder. The dried powder was stored in an airtight container until further use.

2.2 Preparation of Hydroalcoholic Extract

The powdered flower material was subjected to extraction using a hydroalcoholic solvent system consisting of ethanol and water (70:30 v/v) by the maceration method. The extraction process was continued for 72 h with intermittent shaking. The resulting extract was filtered through Whatman No. 1 filter paper and concentrated under reduced pressure using a rotary vacuum evaporator. The concentrated extract was further dried to obtain a semisolid mass designated as Hydroalcoholic Extract of *Woodfordia fruticosa* Flowers (HAWF). The percentage yield of the extract was calculated and the extract was stored at 4°C until further experimentation.

2.3 Experimental Animals

Healthy adult Wistar albino rats of either sex weighing 180–250 g were procured from a registered animal facility. Animals were housed in polypropylene cages under standard laboratory conditions of temperature (25 ± 2°C), relative humidity (55 ± 5%), and a 12 h light/dark cycle. Standard pellet diet and water were provided ad libitum throughout the study. The animals were acclimatized to laboratory conditions for one week before the commencement of the experiment.

2.4 Induction of Experimental Diabetes

Experimental diabetes was induced by administration of streptozotocin (STZ) and nicotinamide. Nicotinamide (110 mg/kg, i.p.) was administered 15 min before streptozotocin (55 mg/kg, i.p.). Hyperglycemia was confirmed after 72 h of induction by measuring fasting blood glucose levels. Animals exhibiting fasting blood glucose levels greater than 250 mg/dL were considered diabetic and selected for the study (9, 10).

Table 1: Experimental Design

Group	Treatment
Group I	Normal Control
Group II	Diabetic Control
Group III	Metformin (150 mg/kg, p.o.)
Group IV	HAWF (100 mg/kg, p.o.)
Group V	HAWF (200 mg/kg, p.o.)
Group VI	HAWF (400 mg/kg, p.o.)

The treatments were administered orally once daily for 75 consecutive days.

2.5 Assessment of Physiological Parameters

Body weight, food intake, water intake, and 24-hour urine volume were recorded periodically during the experimental period. Body weight was measured using a digital balance. Food consumption was determined by calculating the difference between the amount of food supplied and food remaining after 24 h. Water intake was recorded daily, while urine volume was measured using metabolic cages (11, 12).

2.6 Estimation of Fasting Blood Glucose

Fasting blood glucose levels were measured on Days 7, 30, and 75 using blood collected from the tail vein. Glucose concentration was determined using a standard glucometer and expressed as mg/dL (13).

2.7 Estimation of Serum Insulin

At the end of the experimental period, blood samples were collected by retro-orbital puncture under light anesthesia. Serum was separated by centrifugation at 3000 rpm for 15 min. Serum insulin levels were quantified using a commercially available enzyme-linked immunosorbent assay (ELISA) kit according to the manufacturer's instructions (14).

2.8 Estimation of Glycated Hemoglobin (HbA1c)

Glycated hemoglobin levels were determined using a standard HbA1c assay kit based on the manufacturer's protocol. Results were expressed as percentage HbA1c (15).

2.9 Estimation of Lipid Profile

Serum lipid parameters including total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and very low-density lipoprotein cholesterol (VLDL-C) were estimated using standard commercial diagnostic kits. All estimations were performed according to the manufacturer's instructions using a semi-auto biochemical analyzer (16, 17).

2.10 Assessment of Oxidative Stress Biomarkers

At the completion of treatment, pancreatic tissue homogenates were prepared in ice-cold phosphate buffer. The homogenates were centrifuged and the supernatant was used for biochemical estimations. SOD activity was determined based on its ability to inhibit the auto-oxidation of pyrogallol and was expressed as U/mg protein. Catalase activity was estimated by measuring the rate of decomposition of hydrogen peroxide and was expressed as U/g tissue. Reduced glutathione content was measured using Ellman's reagent (DTNB) and expressed as µM/mg protein. Lipid peroxidation was assessed by estimating malondialdehyde (MDA) formation through the thiobarbituric acid reactive substances (TBARS) method and expressed as nmol/mg protein (18, 19).

2.11 Estimation of Inflammatory Cytokines

Serum levels of tumor necrosis factor-alpha (TNF-α) and interleukin-1 beta (IL-1β) were quantified using commercially available ELISA kits according to the manufacturer's protocols. The cytokine concentrations were expressed as pg/mL (20, 21).

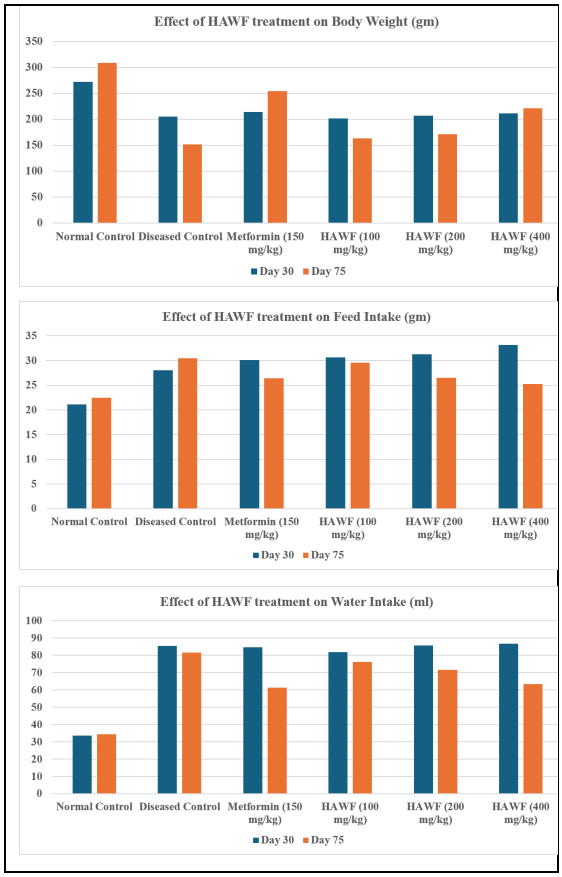
2.13 Statistical Analysis

All experimental data were expressed as mean ± SEM (n = 6). Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test using GraphPad Prism software. Differences were considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1 Effect of HAWF on Body Weight, Food Intake, Water Intake, and Urine Volume

The diabetic control group exhibited marked physiological alterations compared with the normal control group, including a significant reduction in body weight and substantial increases in food intake, water intake, and 24-hour urine volume. At the end of the experimental period, diabetic animals showed a body weight of 151.92 g, whereas food intake, water consumption, and urine output increased to 30.46 g/day, 81.74 mL/day, and 66.94 mL/day, respectively. Treatment with HAWF attenuated these diabetes-associated changes in a dose-dependent manner. Animals receiving HAWF at 100, 200, and 400 mg/kg demonstrated progressive improvement in body weight and reductions in excessive food consumption, water intake, and urine volume. The HAWF 400 mg/kg group exhibited the greatest improvement, with body weight increasing to 221.14 g and significant reductions in food intake (25.21 g/day), water intake (63.47 mL/day), and urine volume (44.18 mL/day). The effect observed at the highest dose was comparable to that of metformin-treated animals, indicating substantial amelioration of diabetic symptoms. The most pronounced effect was observed in the HAWF 400 mg/kg group, which showed substantial restoration of body weight and marked decreases in excessive feed consumption, water intake, and urinary output. The effects of the highest dose were comparable to those observed with metformin treatment. These findings indicate that HAWF effectively ameliorates diabetes-induced physiological disturbances and contributes to the restoration of metabolic homeostasis, possibly through improved glycemic control and enhanced utilization of nutrients.



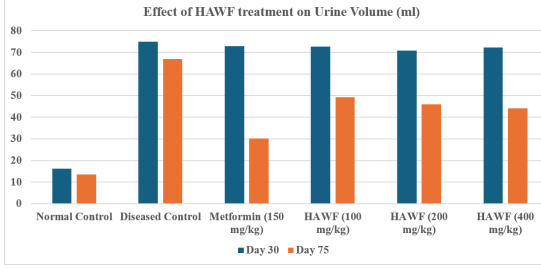


Figure 1: Effect of HAWF on Body Weight, Food Intake, Water Intake, and Urine Volume

3.2 Effect of HAWF on Fasting Blood Glucose, Serum Insulin and HbA1c

The diabetic control group exhibited progressive deterioration in glycemic status between Day 30 and Day 75. Fasting blood glucose levels increased significantly from 347.18 ± 3.72 mg/dL on Day 30 to 406.37 ± 4.08 mg/dL on Day 75, while serum insulin levels remained markedly reduced (6.15 ± 0.32 to 6.49 ± 0.35 µIU/mL). Similarly, HbA1c levels increased from 7.61 ± 0.31% on Day 30 to 10.18 ± 0.24% on Day 75, indicating persistent hyperglycemia and poor glycemic control. In contrast, treatment with HAWF produced significant improvements in these parameters over the study period. HAWF at 100 mg/kg reduced fasting blood glucose from 343.57 ± 4.53 mg/dL on Day 30 to 225.84 ± 5.18 mg/dL on Day 75, accompanied by an increase in serum insulin from 5.88 ± 0.28 µIU/mL to 7.35 ± 0.19 µIU/mL and a reduction in HbA1c from 7.82 ± 0.32% to 8.82 ± 0.29%. Animals treated with HAWF at 200 mg/kg showed a decline in fasting glucose from 352.76 ± 3.24 mg/dL to 211.65 ± 4.55 mg/dL, while insulin levels increased from 5.21 ± 0.27 µIU/mL to 8.76 ± 0.24 µIU/mL and HbA1c levels decreased from 7.68 ± 0.35% to 8.02 ± 0.31%. The most pronounced effect was observed with HAWF at 400 mg/kg, where fasting blood glucose decreased from 356.21 ± 3.54 mg/dL to 179.34 ± 2.26 mg/dL, serum insulin increased from 5.37 ± 0.25 µIU/mL to 11.57 ± 0.29 µIU/mL, and HbA1c levels decreased from 7.85 ± 0.41% to 7.94 ± 0.34%. These effects were comparable to those observed with metformin, which reduced glucose levels from 348.42 ± 4.85 mg/dL to 123.18 ± 3.42 mg/dL, increased insulin from 6.02 ± 0.24 µIU/mL to 13.18 ± 0.35 µIU/mL, and decreased HbA1c from 7.54 ± 0.42% to 6.85 ± 0.36% by Day 75. The findings indicate that HAWF effectively improved glycemic control and pancreatic function in a dose-dependent manner.

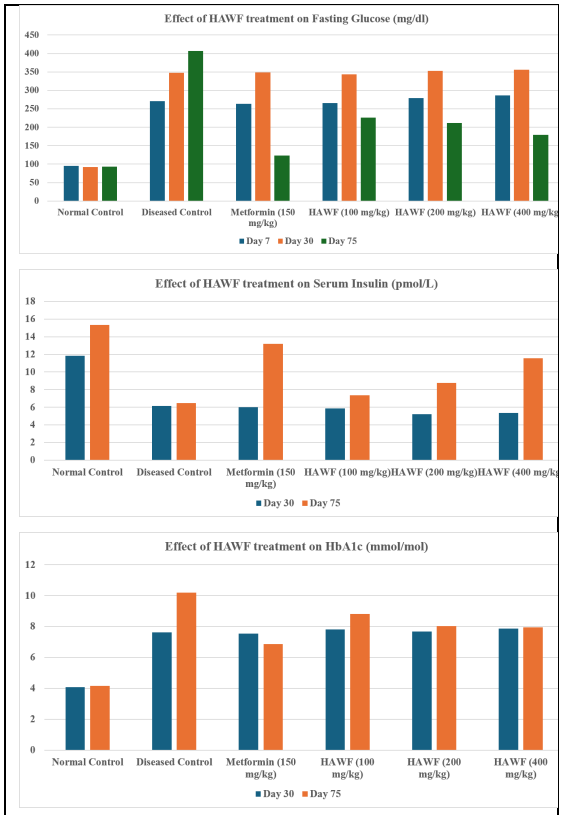


Figure 2: Effect of HAWF on Fasting Blood Glucose, Serum Insulin and HbA1c

3.3 Effect of HAWF on Lipid Profile

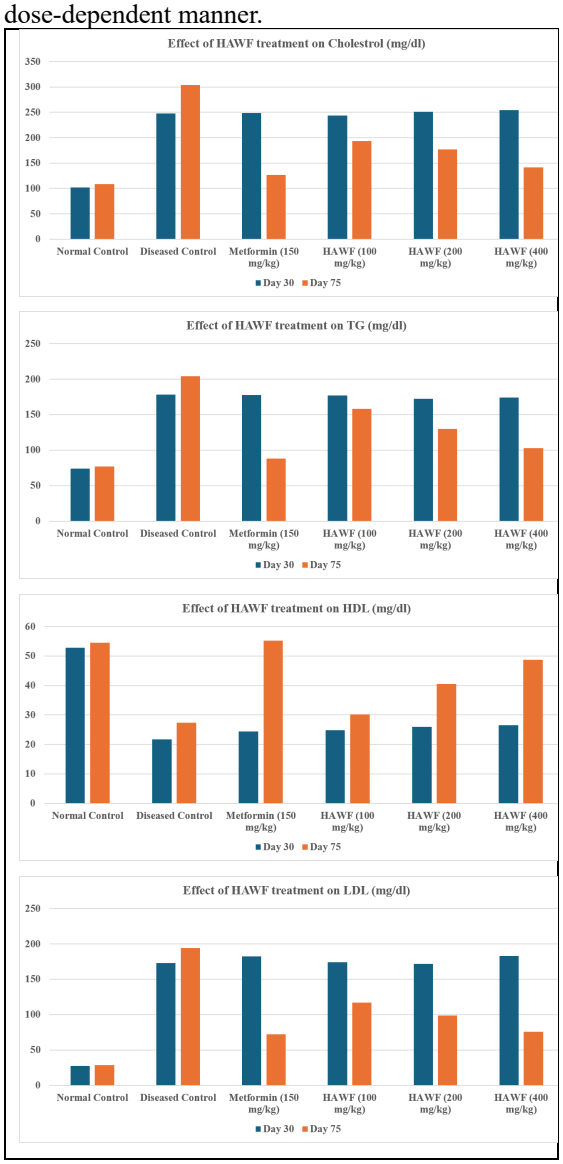
The diabetic control group exhibited progressive dyslipidemia between Day 30 and Day 75, characterized by significant elevations in total cholesterol, triglycerides, LDL, and VLDL levels along with a reduction in HDL concentration compared to the normal control group. Total cholesterol increased from 247.82 ± 2.68 mg/dL on Day 30 to 304.18 ± 3.12 mg/dL on Day 75, while triglyceride levels increased from 178.24 ± 2.15 mg/dL to 204.37 ± 1.92 mg/dL. Similarly, LDL and VLDL levels increased from 172.84 ± 3.42 mg/dL and 34.27 ± 0.48 mg/dL to 194.16 ± 1.83 mg/dL and 40.84 ± 0.39 mg/dL, respectively. HDL levels remained markedly reduced (21.76 ± 1.19 to 27.35 ± 2.28 mg/dL).

Treatment with HAWF significantly improved lipid abnormalities in a dose-dependent manner. In the HAWF 100 mg/kg group, total cholesterol decreased from 243.56 ± 2.79 mg/dL on Day 30 to 193.22 ± 1.26 mg/dL on Day 75, while triglycerides decreased from 176.84 ± 2.88 mg/dL to 158.46 ± 1.63 mg/dL. LDL and VLDL concentrations decreased from 174.28 ± 2.56 mg/dL and 32.84 ± 0.63 mg/dL to 117.26 ± 1.75 mg/dL and 31.68 ± 0.34 mg/dL, respectively, whereas HDL increased from 24.89 ± 1.58 mg/dL to 30.15 ± 1.28 mg/dL.

Animals treated with HAWF 200 mg/kg exhibited further improvement, with total cholesterol declining from 251.34 ± 3.41 mg/dL to 176.91 ±

2.75 mg/dL, triglycerides from 172.46 ± 2.57 mg/dL to 129.78 ± 2.44 mg/dL, LDL from 171.74 ± 2.47 mg/dL to 98.83 ± 1.64 mg/dL, and VLDL from 33.18 ± 0.49 mg/dL to 26.14 ± 0.48 mg/dL. Concurrently, HDL levels increased from 25.94 ± 1.41 mg/dL to 40.52 ± 2.44 mg/dL.

The most pronounced effect was observed in animals treated with HAWF 400 mg/kg, where total cholesterol was reduced from 254.08 ± 2.95 mg/dL on Day 30 to 141.36 ± 1.94 mg/dL on Day 75. Triglycerides, LDL, and VLDL levels decreased from 174.18 ± 2.46 mg/dL, 183.15 ± 2.45 mg/dL, and 33.86 ± 0.51 mg/dL to 102.84 ± 1.52 mg/dL, 75.54 ± 3.05 mg/dL, and 20.46 ± 0.31 mg/dL, respectively. In contrast, HDL levels increased substantially from 26.57 ± 1.49 mg/dL to 48.73 ± 2.59 mg/dL. These effects were comparable to those observed with metformin treatment, which significantly normalized all lipid parameters by Day 75. Overall, the findings indicate that HAWF effectively ameliorates diabetes-induced dyslipidemia and improves lipid metabolism in a dose-dependent manner.



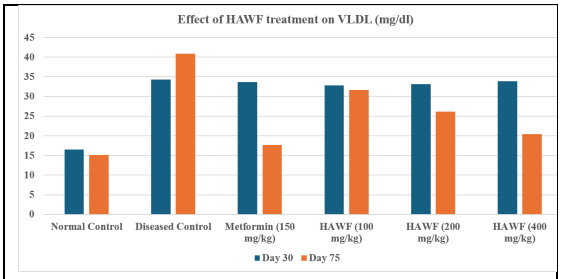


Figure 3: Effect of HAWF on Lipid Profile

3.4 Effect of HAWF on Oxidative Stress Parameters

The diabetic control group exhibited marked oxidative stress as evidenced by a significant reduction in endogenous antioxidant enzymes and increased lipid peroxidation compared with the normal control group. SOD activity decreased from 4.12 ± 0.18 U/mg protein in the normal control group to 1.42 ± 0.08 U/mg protein in diabetic animals. Similarly, catalase and GSH levels declined from 76.24 ± 0.91 U/g and 72.35 ± 0.59 µM/mg protein to 35.28 ± 0.56 U/g and 36.18 ± 0.42 µM/mg protein, respectively. In contrast, lipid peroxidation increased markedly from 0.61 ± 0.09 nmol/mg protein in normal animals to 3.82 ± 0.12 nmol/mg protein in the diabetic control group.

Treatment with HAWF significantly ameliorated oxidative stress in a dose-dependent manner. Animals treated with HAWF at 100 mg/kg exhibited improvements in antioxidant parameters, with SOD, catalase, and GSH levels increasing to 1.84 ± 0.24 U/mg protein, 39.16 ± 0.59 U/g, and 41.25 ± 0.61 µM/mg protein, respectively. Concurrently, lipid peroxidation decreased to 2.65 ± 0.08 nmol/mg protein. Further improvement was observed in the HAWF 200 mg/kg group, where SOD, catalase, and GSH values increased to 2.61 ± 0.26 U/mg protein, 43.08 ± 0.51 U/g, and 45.16 ± 0.34 µM/mg protein, respectively, while lipid peroxidation decreased to 2.02 ± 0.10 nmol/mg protein.

The most pronounced antioxidant effect was observed in animals treated with HAWF 400 mg/kg. In this group, SOD activity increased to 2.95 ± 0.39 U/mg protein, catalase activity increased to 55.27 ± 0.47 U/g, and GSH levels increased to 48.41 ± 0.23 µM/mg protein. Simultaneously, lipid peroxidation was significantly reduced to 1.76 ± 0.05 nmol/mg protein. These effects were comparable to those observed with metformin treatment, which restored SOD, catalase, and GSH levels to 3.74 ± 0.15 U/mg protein, 66.15 ± 0.62 U/g, and 65.42 ± 0.38 µM/mg protein, respectively, while reducing lipid peroxidation to 1.08 ± 0.04 nmol/mg protein.

Overall, HAWF treatment effectively restored antioxidant defense mechanisms and attenuated lipid peroxidation in diabetic animals, demonstrating significant antioxidant activity and protection against diabetes-induced oxidative stress.

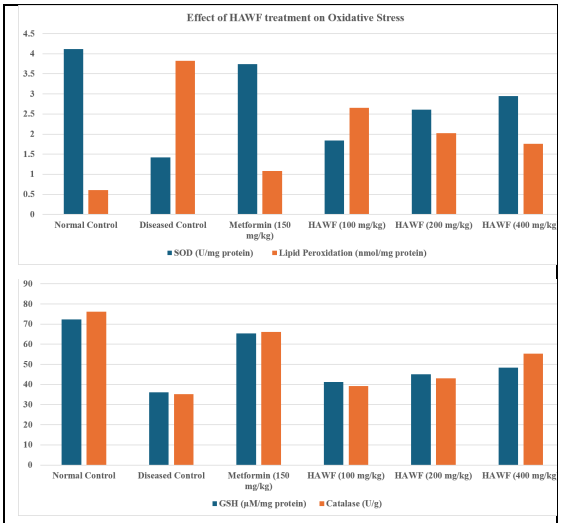


Figure 4: Effect of HAWF on Oxidative Stress Parameters

3.5 Effect of HAWF on Inflammatory Cytokines

The diabetic control group exhibited a marked elevation in the levels of pro-inflammatory cytokines compared with the normal control group, indicating the development of systemic inflammation associated with hyperglycemia. TNF-α levels increased significantly from 40.15 ± 1.68 pg/mL in the normal control group to 116.42 ± 1.95 pg/mL in diabetic animals, while IL-1β concentrations increased from 66.74 ± 1.53 pg/mL to 176.08 ± 2.18 pg/mL. These findings confirm the activation of inflammatory pathways in the diabetic state.

Treatment with HAWF significantly attenuated the elevated inflammatory cytokine levels in a dose-dependent manner. Animals treated with HAWF at 100 mg/kg exhibited a reduction in TNF-α levels to 96.38 ± 2.24 pg/mL, while IL-1β levels decreased slightly to 172.86 ± 2.07 pg/mL. Further improvement was observed in the HAWF 200 mg/kg group, where TNF-α and IL-1β concentrations were reduced to 92.85 ± 1.42 pg/mL and 165.72 ± 2.76 pg/mL, respectively.

The most pronounced anti-inflammatory effect was observed in the HAWF 400 mg/kg-treated group. In this group, TNF-α levels declined to 79.36 ± 0.73 pg/mL, while IL-1β concentrations decreased to 156.42 ± 2.58 pg/mL, demonstrating significant suppression of inflammatory mediators. Comparable effects were observed in the metformin-treated group, where TNF-α and IL-1β levels were reduced to 71.24 ± 1.02 pg/mL and 127.85 ± 2.26 pg/mL, respectively.

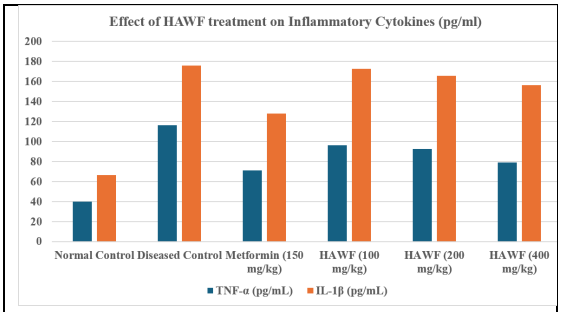


Figure 5: Effect of HAWF on Pro-Inflammatory Cytokines

Overall, HAWF treatment effectively reduced diabetes-induced inflammatory responses as evidenced by the significant decrease in TNF-α and IL-1β levels. The reduction was dose dependent, with the 400 mg/kg dose producing the greatest improvement. These findings suggest that HAWF possesses significant anti-inflammatory activity, which may contribute to its overall protective effect against diabetic complications.

4. Conclusion

The present study demonstrated that the hydroalcoholic extract of *Woodfordia fruticosa* flowers (HAWF) possesses significant antidiabetic activity and effectively ameliorates diabetes-induced metabolic, biochemical, oxidative and inflammatory alterations. Experimental diabetes resulted in marked hyperglycemia, reduced serum insulin levels, elevated glycated hemoglobin, dyslipidemia, oxidative stress, and increased production of pro-inflammatory cytokines, accompanied by severe pancreatic tissue damage. These pathological changes were associated with characteristic diabetic manifestations, including loss of body weight, increased food and water intake, and excessive urine output.

Administration of HAWF significantly improved glycemic control as evidenced by reductions in fasting blood glucose and HbA1c levels along with restoration of serum insulin concentrations. The extract also effectively corrected diabetes-associated dyslipidemia by lowering total cholesterol, triglycerides, LDL and VLDL levels while increasing HDL concentrations. Furthermore, HAWF enhanced endogenous antioxidant defense mechanisms through the restoration of superoxide dismutase, catalase, and reduced glutathione levels and simultaneously reduced lipid peroxidation, indicating attenuation of oxidative stress. The extract also suppressed inflammatory responses by decreasing TNF-α and IL-1β levels, suggesting a protective role against cytokine-mediated tissue damage.

Overall, the findings indicate that HAWF exerts antidiabetic effects through multiple mechanisms, including improvement of glucose metabolism, modulation of lipid abnormalities, enhancement of antioxidant defenses, suppression of inflammatory

mediators, and protection of pancreatic tissue. These results suggest that *Woodfordia fruticosa* flowers represent a promising natural source of bioactive compounds for the management of diabetes mellitus and its associated complications. Further studies are warranted to elucidate the underlying molecular mechanisms and to establish its clinical applicability as a safe and effective antidiabetic therapeutic agent.

5. Conflict of Interest

None

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