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Antidiabetic Potential of *Moringa oleifera* Bark and Leaf in Streptozotocin-Induced Diabetic Rats

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ABSTRACT

Studies have documented the antioxidant and therapeutic potentials of *Moringa oleifera*, which has been harnessed in the management of diabetes and its complications. This study aimed to evaluate the anti-diabetic effect of *Moringa oleifera* bark methanol extract (MOBE), leaf methanol extract (MOLE), ordinary leaf (MOOL), and ordinary bark (MOOB) on streptozotocin (STZ)-induced diabetic rats. Thirty-five Wistar rats were randomly allocated into seven groups (I – VII), each containing five rats. To Group I was administered distilled water to serve as the normal control. Groups II-VII received an intraperitoneal injection of 60 mg/kg streptozotocin (STZ) to induce diabetes. Group II rats were not treated, and served as the diabetic control. Following STZ-induction, the rats in groups III-VI received treatments of 150 mg/kg or 300 mg/kg of MOBE, MOLE, MOOL, and MOOB, respectively, while group VII rats received metformin (21.4 mg/kg). The treatments were given orally once daily for 14 days. The results indicated a substantial alteration of blood glucose levels, lipid profiles, and biomarker enzymes in untreated STZ-induced rats. All treatments resulted in statistically significant ($p < 0.05$) modifications of all regulated parameters. The histological analysis of both the pancreas and liver corroborated the biochemical data. The modulatory impact of MOBE was most pronounced when compared to metformin. Further investigation into the synergistic effects of these extracts could yield improved results.

Keywords: Diabetes, *Moringa oleifera*, Streptozotocin (STZ), Lipid profile, Blood Glucose.

Introduction

Diabetes mellitus (DM) is characterized as a collection of metabolic illnesses, including disruptions in the metabolism of lipids, carbohydrates, and proteins.[1] Diabetes mellitus is a prevalent chronic condition in many countries.[2] The International Diabetes Federation (IDF) estimates that diabetes affects over 500 million individuals worldwide. Given the prevalence, projections indicate that this figure will rise to over 780 million by 2045.[3–5] Diabetes ranks among the three non-communicable diseases responsible for approximately 80% of fatalities. It ranks among the top ten causes of mortality globally.[6] Three factors contribute to the increased prevalence of diabetes among adult individuals: altered lifestyles, heightened obesity rates, and reduced physical activity.[7,8] While the genesis of diabetes mellitus remains unclear, researchers have implicated variables such as viral infection, environmental influences, and autoimmune disorders.[9] Primary participants identified in the genesis, progression, and consequences of diabetes mellitus include lipid peroxidation, elevated oxidative stress, and compromised antioxidant defense mechanisms.[10,11] The effective management of diabetes mellitus with minimal adverse consequences remains a challenge.

Medicinal herbs are viewed as a viable alternative therapy for diabetes. Interest in these plants is growing due to their perceived lower risk of toxicity, cost-effectiveness, and reduced side effects.[12]

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Research into novel pharmaceuticals that are highly effective, cost-effective, and non-toxic for the treatment of diabetes mellitus and its related complications is on the increase. This is due to WHO recommendations on the use of herbal remedies for diabetes treatment.[13,14] Naturally occurring compounds exhibit a variety of bioactivities, structural diversity, and low toxicity, which enhance their therapeutic potential.[15] Moreover, studies indicate that medicinal plants play a substantial role in the management of various chronic diseases, including diabetes mellitus.[16]

Moringa oleifera Lam (*M. oleifera*) possesses remarkable therapeutic attributes and is rich in vital nutrients. Due to its abundant array of anti-ageing chemicals, amino acids, minerals, antioxidants, and anti-inflammatory agents, the plant has been extensively used in addressing diverse health issues in South Asia and India.[15,17] The World Health Organization has endorsed these remarkable attributes, and has recommended the plant for the treatment of malnutrition as a substitute for imported food since 1998. Apart from the nutritional and therapeutic benefits of its roots, leaves, immature pods, bark, seeds, flowers, and fruits,[18] *Moringa oleifera* tree is used for fencing, and as food and fodder. Its therapeutic applications encompass arthritis, fever, diabetes, and hypertension.[19,20] The seed and bark are used for water treatment. They function as a natural anticoagulant that eliminates pollutants and turbidity in water. It also removes colors, heavy metals, and microorganisms.[21,22]

Numerous studies have examined the antidiabetic properties of *Moringa oleifera* leaves,[23–25] and seed extracts,[26] but limited research has focused on the bark extract. This study aimed to comprehensively evaluate the antidiabetic effect of both the methanol extract and the unextracted leaves and bark of *Moringa oleifera* in streptozotocin-induced diabetic rats.

Materials and Methods

Chemicals and equipment

Absolute methanol, normal saline, distilled water, Streptozotocin (STZ), and metformin (Merck S. L. Polingo Merck). All the chemicals

and reagents used were of high (analytical) grade and were products of Sigma Chem., Co. (London, UK). The equipment used were glucometer (Accu-Check), and Visible spectrophotometer, model 721 (TBT Scietech, China).

Plant collection and identification
Fresh leaves and barks of *Moringa oleifera* were collected in July 2023 from a mature *Moringa oleifera* tree behind the Department of Food Technology and CEDVS aquaculture unit buildings, Federal Polytechnic Ado-Ekiti, Ekiti State, Nigeria (Longitude 7º36'42.065" N, and Latitude 5º16'5.088" E). The plant material was authenticated by Mr Felix O. Omotayo, a botanist at Ekiti State University (EKSU), Ado-Ekiti, where a voucher number UHAE: 2023074 was assigned.

Extraction of Moringa oleifera (MO) leaves
Moringa oleifera Leaves were dried for twenty-five days at 27ºC. The dried leaves were ground into powder. *Moringa oleifera* leaf powder (500 g) was macerated in 2 L of methanol for three days. The extract was filtered, and the filtrate was allowed to dry at 27°C. The dried methanol leaf extract was kept in a refrigerator at 4°C until further analysis.

Extraction of Moringa oleifera (MO) barks
Fresh barks of *Moringa oleifera* were dried in the oven at 30°C. The dried barks were ground into powder. The powdered barks (500 g) was macerated in 2 L of methanol for three days. The extract was filtered, and the filtrate was allowed to dry at 27°C. The dried methanol bark extract was kept in a refrigerator at 4°C until further analysis.

Experimental animals
Thirty-five male Albino rats (Wistar strain) of average weight 150 g were obtained from Ladoke Akintola University, Ogbomoso, Oyo State, Nigeria. The rats were acclimatized in the animal house of the Department of Science Technology, The Federal Polytechnic, Ado Ekiti for 2 weeks. They were housed in clean wire meshed cages under standard conditions of temperature (24 ± 1oC), relative humidity, and 12/12-hour light and dark cycle. They were allowed to have access to food (commercial pelletized diet from Vital Feed Mill) and drinking water *ad libitum*. The rat beddings were changed and replaced every day throughout the experimental period.

Ethical approval
Ethical approval with reference number: FPA/EC/23/0089 was obtained from the Ethics Committee, Directorate of Research, Federal Polytechnic, Ado-Ekiti. The experiment was carried out following appropriate international guidelines and regulations for the use of animals in experiments.

Experimental design
Thirty-five male rats were grouped into seven groups of 5 animals each. Group I served as the normal control and received only distilled water throughout the experiment. Group II was considered the diabetic control and was administered a single intraperitoneal dose of 60 mg/kg body weight of streptozotocin (STZ). Groups III, IV, V, VI, and VII were the treatment groups, and received a single intraperitoneal dose of 60 mg/kg STZ, and after high blood glucose was established, groups III-VII received a daily dose of 150 mg/kg of methanol leaf extract of *Moringa oleifera*, 150 mg/kg of methanol bark extract of *Moringa oleifera*, 300 mg/kg of ordinary (unextracted) leaf of *Moringa oleifera*, 300 mg/kg of ordinary (unextracted) bark of *Moringa oleifera*, and 21.4 mg/kg of metformin, respectively for fourteen consecutive days.[27]

Determination of blood glucose level
The blood glucose level of each experimental rat was measured using a glucometer. This was carried out by placing the blood samples from the sharply cut tail vein on the test strip, which had been previously inserted into the glucometer. The reading on the glucometer was then noted.[28]

Collection of blood and target organs
Twenty-four hours after the last administration of the extracts, the rats were sacrificed after being anaesthetized with an intraperitoneal injection of multichris ketamine (1 mL/kg body weight). Blood samples were collected by cardiac puncture into EDTA bottles. The blood samples were used for the determination of various biochemical parameters. Thereafter, the rats were dissected, and the liver and pancreas were harvested and used for histopathological analysis.

Preparation of plasma
Blood collected into the EDTA bottles was centrifuged at 3000 rpm for 15 min at 25ºC, and the separated plasma was collected.

Preparation of organ homogenates
The liver and pancreas were homogenized in 10 mL of phosphate buffer with the aid of a homogenizer (Teflon). The homogenate obtained was centrifuged at 6000 g for 30 min at 4ºC.

Evaluation of enzyme biomarkers
Aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) were evaluated as shown below.

Evaluation of AST activity
The assay for AST activity was conducted following the method established by Reitman and Frankel (1957).[29] Phosphate buffer (0.5 mL of 100 mmol/L, pH 7.4) was added to the plasma sample (100 µL) and incubated at 37°C for 30 minutes. Thereafter, 0.5 mL of 2,4-dinitrophenylhydrazine (2 mmol/L) was added at ambient temperature (27°C). After 20 minutes, 5 mL of sodium hydroxide (0.4 mol/L) was introduced and allowed to equilibrate at room temperature for 5 minutes before measuring the absorbance at 546 nm, using a spectrophotometer against a reagent blank. A standard curve included in the kit package was used to determine the AST activity.

Evaluation of ALT activity
The procedure outlined by Reitman and Frankel (1957)[29] was used to analyse the ALT activity. Reagent 1 (0.5 mL) comprising phosphate buffer (100 mmol/L, pH 7.4), L-aspartate (100 mmol/L), and α-oxoglutarate (2 mmol/L) was introduced to the plasma sample (100 µL). After a 30-minute incubation at 37°C, the mixture was incorporated into reagent 2 and maintained at 20°C for 20 minutes. Thereafter, 5 mL of sodium hydroxide (0.4 mol/L) was introduced, and the absorbance was measured at 546 nm using a spectrophotometer. A standard curve from the kit was used to determine the ALT activity in plasma.

Evaluation of ALP activity
The plasma alkaline phosphatase activity was assessed using a commercial ALP assay kit from Randox Laboratories, UK. Absorbance was measured at one-minute intervals for three minutes.[30]

UI = 2760 * A405 nm/min.

Assay of total bilirubin (BIL)
The assessment of total bilirubin (BIL) was conducted using the method established by Jendrassik and Grof (1938).[31] The plasma sample (100 µL) was thoroughly mixed with the three reagents provided in the assay kit. After a 10-minute incubation at 25°C, reagent 4 was introduced, and the absorbance was measured at 578 nm after 30 minutes. Total bilirubin was estimated using the formula below:
Total Bilirubin (mg/dL) = 10.8 * absorbance.

Assay of plasma albumin (ALB)
Plasma albumin (ALB) concentration was determined using a commercial kit from Randox Laboratories, UK. The plasma sample (100 µL) was mixed with 0.5 mL of the reagent (R1) provided, and the absorbance was measured at 578 nm against the reagent blank within 60 minutes.[32]

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Determination of uric acid (UA) concentration
The plasma uric acid concentration was measured using the Fawcett and Scott method.[33] Reagent 1 and plasma (100 µL) were combined in a tube, incubated at 20 - 25°C, and the absorbance was measured at 546 nm within 30 minutes. Plasma uric acid concentration was estimated using the formula:
UA concentration (g/dL) = A.S1/A.S2 * concentration of the standard.
Where;
A.S1 denotes the sample absorbance, and A.S2 signifies the absorbance of the standard.

Determination of urea concentration
Plasma urea concentration was determined following the method described by Fawcett and Scott (1960).[33] Plasma sample (100 µL) were mixed with reagent 1 and incubated at 37°C for 10 minutes. Into the mixture were introduced reagents 2 and 3, and further incubated at 37°C for 15 minutes. The absorbance was measured at 546 nm within 30 minutes. The urea concentration (mg/dL) was calculated using the formula below:
A.S1/A.S2 * concentration of the standard
Where;
A.S1 denotes the sample absorbance, and A.S2 is the absorbance of the standard.

Determination of lipid profile
Determination of total cholesterol concentration
A commercially available kit (Randox Laboratories, UK) was used to determine the total plasma cholesterol level.[34] To an equal amount of standard and samples in a test tube, the working reagent was added. After thorough mixing, the mixture was incubated at room temperature (27°C) for 10 minutes. The absorbance was measured at 500 nm using a spectrophotometer. Cholesterol concentration was calculated using the formula below:
Cholesterol concentration (mg/dL) = A.S1/A.S2 * concentration of the standard.
Where;
A.S1 is the absorbance of the sample, and A.S2 is the absorbance of the standard

Determination of triglyceride concentration
Triglyceride level in the plasma was determined using the Tietz technique,[35] using a commercially available kit from Randox Laboratories, UK. Plasma sample (100 µL) and reagent 1 were mixed and incubated at ambient temperature (27°C) for 10 minutes. The absorbance of the mixture was measured at 500 nm using a spectrophotometer. Triglyceride concentration was calculated using the formula below:
Triglyceride concentration (mg/dL) = A.S1/A.S2 * concentration of the standard.

Where;

A.S1 represents the absorbance of the sample, and A.S2 represents the absorbance of the standard.

Determination of high-density lipoprotein (HDL) cholesterol
The concentration of HDL-cholesterol in the plasma was estimated using the Grove method.[34] Precipitation was done by combining the cholesterol standard, serum, and diluted precipitant R1. After 10 minutes of incubation at room temperature, the mixture was centrifuged at 4,000 rpm for 10 min. The HDL-cholesterol concentration in the isolated, clear supernatant was estimated using the CHOD-PAP reaction technique.
HDL-cholesterol concentration (mg/dL) = A.S1/A.S2 * concentration of the standard

Where;
A.S1 represents the absorbance of the sample, and A.S2 represents the absorbance of the standard
Determination of low-density lipoprotein (LDL) cholesterol
The concentration of LDL cholesterol in the plasma was calculated using the formula of Friedewald *et al.* (1972).[36]

$$\text{LDL cholesterol} = \text{Total cholesterol} - \frac{\text{Triglycerides}}{5} - \text{HDL-cholesterol}$$

Determination of very low-density lipoprotein (VLDL) cholesterol
The concentration of very low-density lipoprotein (VLDL) in the plasma was calculated using the formula of Friedewald *et al.* (1972).[36]

$$\text{VLDL cholesterol} = \frac{\text{Triglycerides}}{5}$$

Estimation of coronary risk index
The coronary risk index (CRI) was calculated using the formula of Friedewald *et al.* (1972).[36]

$$\text{CRI} = \frac{\text{Total Cholesterol}}{\text{High-Density Lipoprotein Cholesterol}}$$

Histopathological examination of the liver and pancreas
The histopathological examination of the liver and pancreas was carried out according to standard histopathological examination procedure.[37] A tissue processor (Leica TP1020) was used for the processing. Stations one and two contained normal saline, while stations three to seven contained 70%, 80%, 90%, 95%, and absolute ethanol, respectively. Stations eight and nine, containing xylene, were used to dehydrate the tissues. Infiltration and impregnation were done by transferring to 3 wax baths. These were stained with Hematoxylin and Eosin techniques. Leica SCN software was used for the evaluation.

Statistical analysis
Data were presented as mean ± standard deviation (SD), (n = 5). Data were analyzed using one way analysis of variance (ANOVA), with a significance threshold set at $p < 0.05$. Statistical analysis was conducted using IBM SPSS 25.0 for Windows.[38]

Results and Discussion

Effect of Moringa oleifera leaf and bark extracts on blood glucose level
This study examined the antidiabetic effects of methanol leaf and bark extracts as well as unextracted leaf and bark of *Moringa oleifera* (MO) in rats. A single intraperitoneal injection of streptozotocin (STZ) at 60 mg/kg body weight has been shown to induce hyperglycaemia in rats.[39] The administration of STZ partially damages the pancreatic β-cells, leading to hyperglycemia.[40] In this study, STZ-induction resulted in weight loss, frequent urination, and elevated fasting blood glucose, which were consistent with diabetes. By the fourteenth day, the blood glucose levels of the STZ-induced but untreated rats remained elevated, whereas treatment with MOBE, MOLE, MOOL, and MOOB significantly ($P < 0.05$) reduced the elevated blood glucose levels in STZ-induced diabetic rats to levels comparable to normal range (Table 1). The hypoglycaemic effect of *Moringa oleifera* may be attributed to the presence of bioactive phytochemicals such as flavonoids, alkaloids, saponins, and tannins, which are believed to contribute to the reduction of blood glucose by reducing intestinal glucose absorption, and enhancing insulin action.[41,42]

Effect of Moringa oleifera leaf and bark extracts on serum biochemical parameters
The effect of *Moringa oleifera* leaf and bark on liver function biomarkers in STZ-induced diabetic rats are presented in Tables 2 and 3. The concentrations of liver function enzymes (ALT, AST, and ALP), ALB, TP, and BIL in the plasma and liver were measured to assess hepatocellular damage. Clinical assessment of liver function typically employs these enzymes. The liver function enzymes, and BIL were markedly elevated in the untreated diabetic rats, while ALB and TP

levels were significantly ($P < 0.05$) reduced. However, treatment of the diabetic rats with MOBE, MOLE, MOOL, and MOOB significantly ($P < 0.05$) reduced the elevated liver enzymes, and BIL, and restored ALB and TP to levels comparable to normal values (Tables 2 and 3). Gupta *et al.*[41] have also demonstrated this pattern. Hepatocellular injury, likely resulting from stress that triggers the release of ALT, AST, and other enzymes from liver cells, may account for the heightened enzymatic activity in diabetic rats. The marked reduction in the levels of AST, ALT, and ALP in treated animals in comparison to the untreated animals indicates decreased hepatic oxidative stress in the treated animals. It is hypothesized that the MO extract enhanced the regenerative capacity of *β*-cells, aiding the rats in recovering from STZ-induced injury. The findings indicated that the STZ-induced but untreated rats had significant ($P < 0.05$) hypoalbuminemia relative to the control group. This indicates hepatic damage associated with hyperglycemia. Treatment with MOLE, MOBE, MOOL, and MOOB significantly elevated plasma albumin levels. When compared to other treatments, the bark extract (MOBE) demonstrates superior efficacy compared to conventional medicine. Hypoalbuminemia is a reliable clinical indicator for hepatic damage and inflammation.[43,44]

Table 1: Effect of *Moringa oleifera* leaf and bark on blood glucose level in streptozotocin-induced diabetic rats

Group	Blood Glucose Level (mg/dL)			
	Before induction	**After 48 h of induction**	**After 7 days of treatment**	**After 14 days of treatment**
NDC	94.75 ± 2.20^{a}	94.00 ± 2.03^{a}	91.25 ± 3.08^{a}	87.00 ± 1.52^{f}
DC	102.75 ± 3.51^{e}	278.50 ± 5.19^{d}	267.25 ± 2.01^{g}	262.25 ± 3.11^{g}
STZ + MOBE	96.0 ± 2.34^{c}	298.00 ± 3.55^{f}	206.50 ± 1.15^{f}	71.25 ± 1.84^{e}
STZ + MOLE	97.75 ± 1.09^{d}	298.75 ± 2.81^{f}	161.00 ± 2.41^{d}	59.75 ± 1.50^{b}
STZ + MOOB	106.5 ± 2.56^{f}	290.00 ± 4.06^{e}	133.00 ± 2.91^{b}	66.25 ± 2.33^{d}
STZ + MOOL	107.50 ± 4.31^{g}	229.75 ± 3.62^{b}	162.75 ± 3.73^{e}	55.75 ± 1.07^{a}
STZ + MET	95.75 ± 1.50^{b}	255.75 ± 2.19^{c}	155.75 ± 2.00^{c}	62.00 ± 2.16^{c}

Values are expressed as mean ± standard deviation (SD), n = 5. Values with different superscript letters are significantly different at $P < 0.05$.
Key: STZ = **s**treptozotocin**,** MOBE = *Moringa oleifera* bark extract, MOLE = *Moringa oleifera* leaf extract, MOOB = *Moringa oleifera* ordinary bark, MOOL = *Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control

Table 2: Effect of *Moringa oleifera* leaf and bark on liver biomarker of oxidative stress in streptozotocin-induced diabetic rats

Group	Levels of Liver Biomarker of Oxidative Stress (mg/dL)					
	AST	**ALT**	**ALP**	**ALB**	**BIL**	**TP**
NDC	77.50 ± 6.78^{a}	24.64 ± 5.13^{b}	85.82 ± 0.93^{b}	52.50 ± 1.06^{g}	22.04 ± 2.19^{a}	13.38 ± 0.56^{f}
DC	130.66 ± 2.86^{g}	44.83 ± 8.94^{g}	111.50 ± 3.98^{g}	32.87 ± 3.40^{a}	42.09 ± 1.73^{g}	7.23 ± 0.72^{a}
STZ + MOBE	$98.42+1.55^{c}$	28.90 ± 1.06^{c}	96.39 ± 2.63^{e}	50.87 ± 2.05^{f}	27.81 ± 0.86^{c}	10.87 ± 0.43^{d}
STZ + MOLE	102.89 ± 2.04^{d}	18.65 ± 1.06^{a}	79.23 ± 2.90^{a}	46.83 ± 2.05^{d}	31.44 ± 0.88^{d}	9.75 ± 0.56^{c}
STZ + MOOB	104.88 ± 2.52^{e}	32.41 ± 1.06^{e}	104.65 ± 2.17^{f}	37.75 ± 2.05^{b}	33.45 ± 0.27^{e}	8.73 ± 0.24^{b}
STZ + MOOL	118.94 ± 2.39^{f}	35.52 ± 1.06^{f}	94.31 ± 0.79^{d}	38.59 ± 2.05^{c}	37.22 ± 0.74^{f}	7.74 ± 0.39^{a}
STZ + MET	87.50 ± 2.80^{b}	29.74 ± 2.80^{d}	88.19 ± 3.24^{c}	49.51 ± 2.05^{e}	24.88 ± 1.51^{b}	11.95 ± 1.50^{e}

Values are expressed as mean ± standard deviation (SD), n = 5. values with different superscript letters are significantly different at $P < 0.05$.
Key: ALP = Alkaline phosphatase, ALT = Alanine aminotransferase, AST = Aspartate aminotransferase, ALB = Albumin, TP = Total Protein, STZ = **s**treptozotocin**,** MOBE = *Moringa oleifera* bark extract, MOLE = *Moringa oleifera* leaf extract, MOOB = *Moringa oleifera* ordinary bark, MOOL=*Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control

Table 3: Effect of *Moringa oleifera* leaf and bark on serum biomarker of oxidative stress in streptozotocin-induced diabetic rats.

Group	Levels of Serum Biomarker of Oxidative Stress (mg/dL)							
	AST	**ALT**	**ALP**	**ALB**	**BIL**	**TP**	**UREA**	**UA**
NDC	76.84 ± 1.54^{d}	19.71 ± 1.86^{a}	44.06 ± 4.50^{a}	44.77 ± 1.06^{g}	34.02 ± 2.61^{b}	9.92 ± 0.32^{e}	38.43 ± 1.52^{c}	22.50 ± 1.72^{b}
DC	92.24 ± 1.69^{g}	52.47 ± 6.42^{g}	84.69 ± 4.13^{g}	26.84 ± 3.40^{a}	61.48 ± 2.18^{g}	4.90 ± 1.17^{a}	67.49 ± 1.77^{g}	41.56 ± 1.11^{f}
STZ + MOBE	71.45 ± 3.19^{a}	31.53 ± 1.17^{c}	52.33 ± 5.03^{c}	42.17 ± 1.42^{f}	36.41 ± 0.64^{c}	8.61 ± 0.32^{d}	34.24 ± 1.74^{b}	22.36 ± 1.63^{b}
STZ + MOLE	74.26 ± 1.14^{c}	27.31 ± 1.55^{b}	63.34 ± 4.50^{d}	36.92 ± 2.05^{d}	40.76 ± 1.36^{d}	7.98 ± 0.13^{c}	41.92 ± 1.17^{d}	30.74 ± 0.07^{c}
STZ + MOOB	78.42 ± 3.80^{e}	37.82 ± 1.43^{f}	71.61 ± 4.50^{e}	30.58 ± 2.05^{b}	43.66 ± 2.19^{e}	6.84 ± 0.43^{bc}	48.69 ± 1.66^{e}	32.53 ± 0.07^{d}
STZ + MOOL	85.53 ± 2.18^{f}	34.08 ± 1.54^{d}	72.29 ± 1.38^{f}	32.95 ± 2.05^{c}	49.79 ± 0.77^{f}	6.03 ± 0.07^{b}	55.72 ± 1.887^{f}	34.64 ± 1.61^{e}
STZ + MET	72.11 ± 1.55^{b}	35.61 ± 1.06^{e}	50.26 ± 5.21^{b}	39.97 ± 2.05^{e}	23.81 ± 3.59^{a}	9.57 ± 0.68^{e}	33.19 ± 1.874^{a}	16.72 ± 0.67^{a}

Values are expressed as mean ± standard deviation (SD), n = 5. Values with different superscript letters are significantly different at $P < 0.05$.
Key: ALP = Alkaline phosphatase, ALT = Alanine aminotransferase, AST = Aspartate aminotransferase, ALB = Albumin, TP = Total Protein, UA = Uric Acid, STZ = **s**treptozotocin**,** MOBE = *Moringa oleifera* bark extract, MOLE = *Moringa oleifera* leaf extract, MOOB = *Moringa oleifera* ordinary bark, MOOL = *Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control

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There were significant elevations of serum total cholesterol, TG, LDL, VLDL, and CRI, while the HDL levels were decreased in the untreated diabetic rats compared to the normal non-diabetic rats (Table 4). In contrast, treatment of the STZ-induced diabetic rats with *Moringa oleifera* leaf and bark extracts significantly ($P < 0.05$) reduced elevated serum total cholesterol, TG, LDL, VLDL, and CRI to levels comparable to that of the normal non-diabetic rats. In addition, HDL levels were noticeably higher in diabetic rats that were given MOBE, MOLE, MOOL, and MOBE compared to rats that were not treated. *Moringa oleifera* extracts showed a favorable comparison with the conventional medication, particularly the MOBE (Table 4). This suggests that the extracts are rich in antidiabetic phytochemicals.

Table 4: Effect of *Moringa oleifera* leaf and bark on serum lipid profile in streptozotocin-induced diabetic rats.

Group	Serum Lipid Profile (mg/dL)					CRI
	CHOL	TRIG	HDL	LDL	VLDL	
NDC	42.09 ± 1.29^{b}	58.82 ± 2.01^{a}	15.82 ± 0.25^{f}	14.51 ± 1.00^{b}	11.76 ± 0.39^{a}	2.66 ± 0.02^{a}
DC	75.12 ± 2.07^{g}	114.60 ± 2.09^{g}	10.07 ± 0.88^{a}	42.87 ± 1.19^{g}	22.92 ± 1.06^{f}	7.46 ± 0.30^{f}
STZ + MOBE	45.26 ± 1.43^{c}	71.68 ± 1.14^{c}	15.08 ± 1.01^{e}	15.84 ± 0.73^{c}	14.34 ± 0.70^{c}	3.00 ± 0.08^{b}
STZ + MOLE	49.16 ± 1.18^{d}	79.10 ± 1.20^{e}	13.62 ± 0.78^{d}	19.72 ± 0.87^{d}	15.82 ± 0.82^{d}	3.61 ± 0.06^{c}
STZ + MOOB	54.35 ± 2.02^{e}	78.11 ± 1.16^{d}	12.85 ± 1.07^{c}	25.88 ± 0.96^{e}	15.62 ± 0.17^{d}	4.23 ± 0.44^{d}
STZ + MOOL	58.62 ± 2.39^{f}	97.00 ± 1.38^{f}	11.24 ± 0.59^{b}	27.98 ± 1.15^{f}	19.40 ± 0.54^{e}	5.22 ± 0.16^{e}
STZ + MET	39.69 ± 1.10^{a}	63.95 ± 2.15^{b}	15.34 ± 0.81^{ef}	11.56 ± 1.02^{a}	12.79 ± 0.66^{b}	2.59 ± 0.47^{a}

Values are expressed as mean ± standard deviation (n=5) values with different superscripts that are significantly different at $P<0.05$.
Key: CHOL = Cholesterol, LDL = Low-density lipoprotein, TG = Triglyceride, VLDL = Very low-density lipoprotein, HDL = High density lipoprotein, CRI = Coronary risk index. STZ = **s**treptozotocin**,** MOBE = *Moringa oleifera* bark extract, MOLE=*Moringa oleifera* leaf extract, MOOB = *Moringa oleifera* ordinary bark, MOOL = *Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control.

Diabetes has an impact on fat metabolism.[45] The elevation of LDL, total cholesterol, and triglycerides, along with a reduction in HDL values in STZ-induced diabetic rats demonstrates this. Some studies show that the abnormal signal that causes the liver to make too much glucose in people with diabetes mellitus also helps fatty acids to be burned, since both signals mean that the body needs fuel.[20,46,] Studies showed that the liver uses fatty acids to make triglycerides instead of burning them, which causes them to build up in the livers of diabetics.[47] In type 1 diabetes mellitus, a lack of insulin increases hormone-sensitive lipase in adipose tissues. This leads to higher circulation of fatty acids and better lipolysis, which in turn causes fatty acids to build up in the liver. This makes it easier for the liver to absorb VLDL and make triglycerides. High levels of glucagon change how fatty acids are absorbed, made, exported, and burned, while also stopping the liver from making triglycerides. This is believed to be responsible for the accumulation of fat often observed in the liver.[48] Another potential cause for the accumulation of lipids in hepatocytes, aside from abnormalities in lipoprotein metabolism, may be the activation of the transcription factor induced by hyperglycemia, specifically sterol regulatory element-binding protein 1c, carbohydrate-responsive element-binding protein, and the enhanced regulation of glucose transporter 2 protein, leading to subsequent intrahepatic lipid synthesis or a combination of these mechanisms.[49,50]

Dyslipidemia is a common manifestation of diabetes.[51] Increased cholesterol levels are its hallmark. In diabetics, elevated glucose levels, dyslipidemia, and other metabolic disturbances lead to atherosclerosis [52]

Insulin stimulates the hydrolysis of triglycerides and the enzyme lipoprotein lipase. Phytochemicals that enhance insulin sensitivity may contribute to the capacity of MOBE, MOLE, MOOB, and MOLE to reduce triglycerides. Consequently, hypertriglyceridemia results from an insulin shortage.[53] This elucidates the heightened levels in untreated rats and the opposite in treated animals. The complete suppression of fatty acid production may account for the hypocholesterolemic effect demonstrated by the plant.[53]

Histopathological findings

Hepatocellular damage has been linked to high blood sugar.[54] This study examined the histopathological effect of STZ-induced diabetes on the liver and pancreas. Figures 1 and 2 present the histopathological findings of the liver and pancreas. The results showed compromised liver architecture, with numerous inflammatory cells lining the periportal vein, moderate to severe congestion of the periportal vein, severe portal triaditis, and swollen hepatocytes with spongy cytoplasm (Figure 1). However, treatment with MOBE, MOLE, MOOB, and MOOL mitigated the majority of the STZ-induced hepatocellular damage, and the liver architecture was restored to normal, with the rats receiving MOOB and MOLE showing full restoration, the effect of which was comparable to that of metformin (Figure 1). This observation suggests that *Moringa oleifera* have a preventive role in hepatic damage linked to hyperglycemia. Furthermore, the liver histopathological analysis indicated that all treated rats had normal liver restoration, except for the group administered bark extract, which still displayed minor portal congestion. Nonetheless, some architectural elements appeared standard (Figure 1). Research has shown that *Moringa oleifera* leaves reduce proinflammatory mediators, which indicates the prevention of inflammatory responses.[11,55] This indicates the possible general anti-inflammatory ability of *Moringa oleifera.* Previous studies have documented the protective effect of *Moringa oleifera* on the hearts of diabetic rats.[56] Other studies have also found that *Moringa oleifera* leaf extract alleviates hyperglycemia in the testis. [24] Resistance or deficiency of insulin, as occurs in diabetes, also affects the gonads, perigonads, pituitary glands, and hypothalamus.[57] Insulin deficiency and resistance in diabetes can damage the hypothalamus, pituitary gland, gonads, and perigonads.[58]

Similarly, there were compromised pancreatic architecture in the untreated diabetic rats, with regions of degraded serous acinar cells, significant fibrotic interlobular connective tissue, considerable vascular congestion, and mild atrophy of the Langerhans islets (Figure 2). On the other hand, the treated groups appeared to have rehabilitated pancreases, with groups treated with MOBE and MOOL exhibiting full recovery. The histopathological findings of the liver and pancreas corroborate the reported antidiabetic effect of *Moringa oleifera*, and demonstrate the protective role of the plant on the liver and pancreatic cells. These findings have demonstrated the promising therapeutic effect of *Moringa oleifera* in the management of diabetes mellitus, and therefore necessitate additional investigation.

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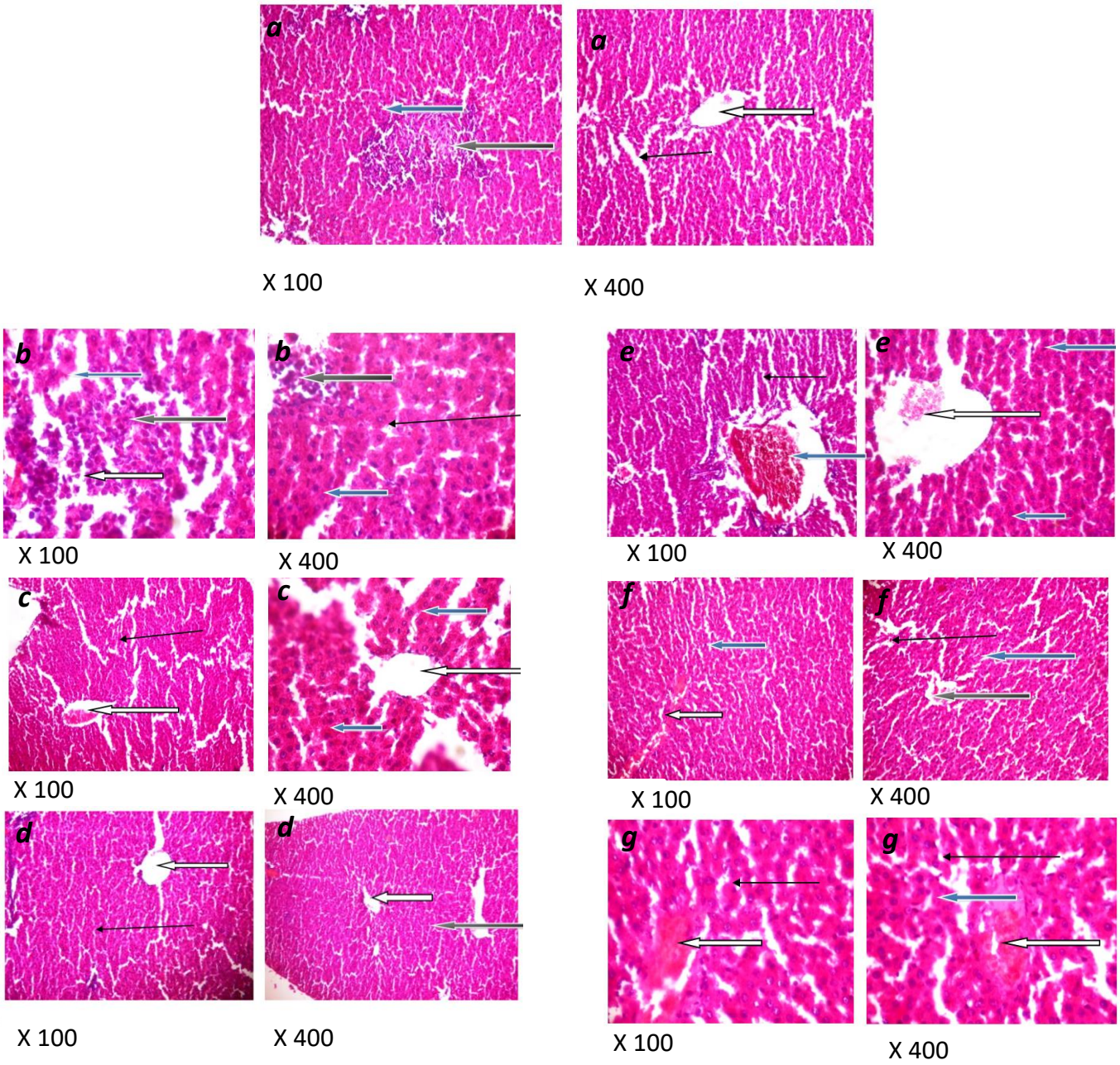

Figure 1: Photomicrograph of rat liver section stained with hematoxylin and eosin and viewed at X100 and X400 magnifications.
a = NDC: Normal central venules without congestion (white arrow), the parenchyma of the liver show focal areas of moderate inflammatory cells aggregate (black arrow), the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow). **b = DC:** Poor architecture. There is moderate to severe congestion of the portal vein (white arrow) as well as severe peri portal infiltration of inflammatory cells - severe portal triaditis (black arrow), some of the morphology of the hepatocytes show ballooned hepatocytes with spongy cytoplasms (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow). **c = MOBE:** Normal central venules without congestion (white arrow), mild portal congestion, the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow), no pathological lesion seen. **d = MOLE:** Normal central venules without congestion (white arrow), the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow). **e = MOOB:** Normal central venules without congestion (white arrow), normal venules are seen (white arrow), the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated **f = MOOL:** Normal central venules without congestion (white arrow), the parenchyma of the liver show focal areas of moderate inflammatory cells aggregate (black arrow), the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow). **g = MET:** Normal central venules without congestion (white arrow), the morphology of the hepatocytes appear normal (blue arrow), the sinusoids appear normal and not infiltrated (slender arrow), no pathological lesion seen.
MOOB = *Moringa oleifera* ordinary bark, MOOL = *Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control.

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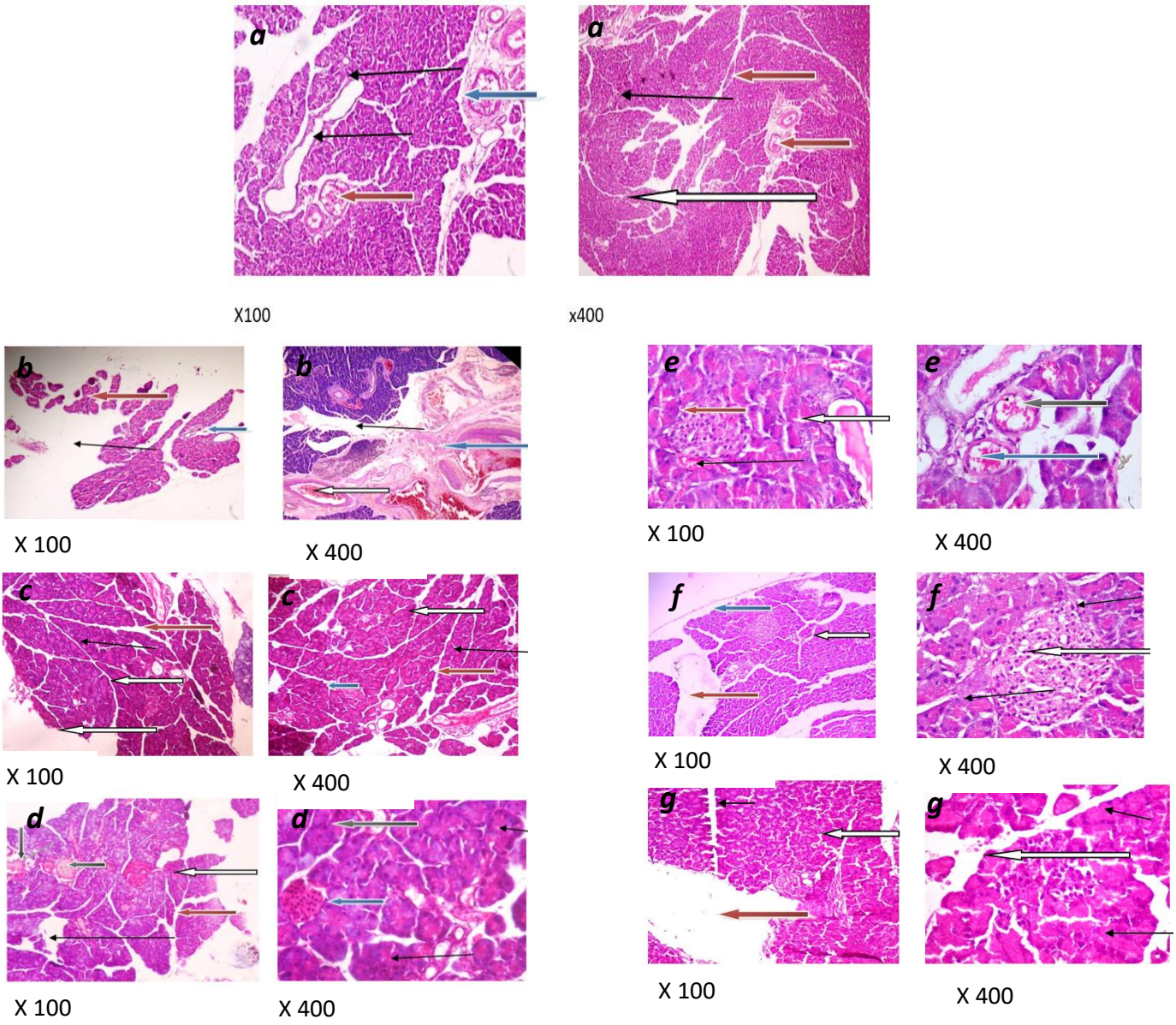

Figure 2: Photomicrograph of rat pancreas section stained with hematoxylin and eosin and viewed at X100 and X400 magnifications. **a = NDC:** Normal architecture. The parenchyma of the pancreas shows normal serous acinar and zymogenic cells (slender arrow) containing abundant granular eosinophilic cytoplasm, there is normal interlobular connective tissues (blue arrow) and normal septa seen (red arrow) are seen. There are normal islets of Langerhans (white arrow) consisting of round to oval collections of endocrine cells. **b = DC:** Poor architecture. The parenchyma of the pancreas shows the area of degenerated serous acinar cells (slender arrow) there is severe fibrotic interlobular connective tissues (blue arrow) and moderate vascular congestion (red arrow) are seen. The islets of Langerhans show moderate atrophy white arrow). **c = MOBE:** Normal architecture. The parenchyma of the pancreas shows normal serous acinar and zymogenic cells (slender arrow) containing abundant granular eosinophilic cytoplasm, there is normal interlobular connective tissues (blue arrow) and normal septa seen (red arrow) are seen. There are normal islets of Langerhans (white arrow) consisting of round to oval collections of endocrine cells. **d = MOLE:** Moderate architecture. The parenchyma of the pancreas shows normal serous acinar and zymogenic cells (slender arrow) containing abundant granular eosinophilic cytoplasm, normal interlobular connective tissues (blue arrow) and septa (red arrow) are seen. Moderate vascular congestion is seen (black arrow), and the islets of Langerhans (white arrow) consist of round to oval collections of normal endocrine cells. **e = MOOB:** Pancreas with normal serous acinar and zymogenic cells (slender arrow) containing abundant granular eosinophilic cytoplasm, normal interlobular connective tissues (blue arrow) and septa (red arrow) are seen. There are normal islets of Langerhans (white arrow) consisting of round to oval collections of endocrine cells. There is mild vascular and ductal congestion (black arrow). **f = MOOL:** Normal architecture. The parenchyma of the pancreas shows normal serous acinar and zymogenic cells (slender arrow) containing abundant granular eosinophilic cytoplasm, there are normal interlobular connective tissues (blue arrow) and normal septa seen (red arrow) are seen. The islets of Langerhans appear normal (white arrow). **g = MET:** Moderately normal architecture, the parenchyma of the pancreas shows normal acinar cells (slender arrow) containing abundant granular eosinophilic cytoplasm, normal interlobular connective tissues and septa (red arrow) are seen. There are normal islets of Langerhans (white arrow) consisting of round to oval collections of endocrine cells.
MOOB = *Moringa oleifera* ordinary bark, MOOL = *Moringa oleifera* ordinary leaf, MET = Metformin, NDC = Non-Diabetic Control, DC = Diabetic Control.

Conclusion

In conclusion, the bark and leaves of *Moringa oleifera* exhibit antidiabetic properties that regulate blood glucose levels, biomarker enzymes, lipid profiles, and the structural integrity of the pancreas and liver. Additional research on the optimization of these treatments is essential for improving their medicinal application.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

References

1. Sapra A and Bhandari P. Diabetes. [Updated 2023 Jun 21]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551501/
2. Institute for Health Metrics and Evaluation. Global Burden of Disease Study 2019. Results. Global Burden of Disease Collaborative Network.
3. Sun H, Saeedi P, Karuranga S, Pinkepank M, Ogurtsova K, Duncan BB, Stein C, Basit A, Chan JCN, Mbanya JC, Pavkov ME, Ramachandaran A, Wild SH, James S, Herman WH, Zhang P, Bommer C, Kuo S, Boyko EJ, Magliano DJ. IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. Diab Res Clin Pract. 2022; 183:109119. doi:10.1016/j.diabres.2021.109119
4. Hossain MJ, Al-Mamun M, Islam MR. Diabetes mellitus, the fastest growing global public health concern: Early detection should be focused. Health Sci Rep. 2024; 7(3):e2004. doi:10.1002/hsr2.2004
5. Cho NH, Shaw JE, Karuranga S, Shaw J, Karuranga S, Huang Y, da Rocha Fernandes J, Ohlrogge A, Malanda B. IDF Diabetes Atlas: Global estimates of diabetes prevalence for 2017 and projections for 2045. Diab Res Clin Pract. 2018; 138:271-281. doi:10.1016/j.diabres.2018.02.023
6. GBD 2013 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990-2013: A systematic analysis for the Global Burden of Disease Study 2013. The Lan. 2015; 386(10010):2287-2323. doi:10.1016/S0140-6736(15)00128-2
7. Shaw JE, Sicree RA, Zimmet PZ. Global estimates of the prevalence of diabetes for 2010 and 2030. Diab Res Clin Pract. 2010; 87(1):4-14. doi:10.1016/j.diabres.2009.10.007
8. Tella EE, Yunusa I, Hassan JH, Chindo IA, Oti VB. Prevalence, Contributing Factors and Management Strategies (Self-Management Education) of Type 2 Diabetes Patients in Nigeria: A Review. Int J Diab Clin Res. 2021; 8(3):1-10. doi:10.23937/2377-3634/1410148
9. Shewade Y, Tirth S, Bhonde RR. Pancreatic Islet-Cell Viability, Functionality and Oxidative Status Remain Unaffected at Pharmacological Concentrations of Commonly Used Antibiotics *In Vitro*. J Biosci. 2001: 26(3):349-355.
10. Rudge M V, DamAsceno DC, Volpato GT, Almeida FC, Calderon IM, Lemonica IP. Effect of *Ginkgo biloba* on the reproductive outcome and oxidative stress biomarkers of streptozotocin-induced diabetic rats. Braz J Med Biol Res. 2007; 40(8):1095-1099.
11. Antar SA, Ashour NA, Sharaky M, Khattab M, Ashour NA, Zaid RT, Roh EJ, Elkamhawy A, Al-Karmalawy AA. Diabetes mellitus: Classification, mediators, and complications; A gate to identify potential targets for the development of new effective treatments. Biomed Pharm. 2023; 168:115734. doi:10.1016/j.biopha.2023.115734
12. Nissen SE and Wolski K. Effect of Rosiglitazone on the Risk of Myocardial Infarction and Death from Cardiovascular Causes. N Engl J Med. 2007; 356(24):2457-2471. doi:10.1056/NEJMoa072761
13. Roglic G. WHO global report on diabetes – a summary. Int J Noncommun Dis. 2016; 1:3-8.
14. Kumar S, Mittal A, Babu D, Mittal A. Herbal Medicines for Diabetes Management and its Secondary Complications. Curr Diab Rev. 2021; 17(4):437-456. doi:10.2174/1573399816666201103143225
15. Islam Z, Islam SMR, Hossen F, Mahtab-Ul-Islam K, Hasan MR, Karim R. *Moringa oleifera* is a Prominent Source of Nutrients with Potential Health Benefits. Int J Food Sci. 2021; 2021:6627265. doi:10.1155/2021/6627265
16. Kaur N, Kumar V, Nayak SK, Wadhwa P, Kaur P, Sahu SK. Alpha-amylase as molecular target for treatment of diabetes mellitus: A comprehensive review. Chem Biol Drug Des. 2021; 98(4):539-560. doi:10.1111/CBDD.13909
17. Farooq F, Rai M, Tiwari A, Khan AA, Farooq S. Medicinal properties of *Moringa oleifera*: An overview of promising healer. J Med Plant Res. 2012; 6(27):4368-4374. doi:10.5897/JMPR12.279
18. Anwar F, Latif S, Ashraf M, Gilani AH. *Moringa oleifera*: a food plant with multiple medicinal uses. Phytother Res. 2007; 21(1):17-25. doi:10.1002/ptr.2023
19. Meireless D, Gomes J, Lopes L, Hinzmann M, Machado J. A review of properties and pharmaceutical applications of *Moringa oleifera*: integrative approach on conventional and traditional Asian medicine. Adv Trad Med. 2020; 20:495-515. doi:https://doi.org/10.1007/s13596-020-00468-0
20. Mthiyane FT, Dludla PV, Ziqubu K, Mthembu S, Muvhulawa N, Hlengwa N, Nkambule B, Mazibuko-Mbeje S. A Review on the Antidiabetic Properties of *Moringa oleifera* Extracts: Focusing on Oxidative Stress and Inflammation as Main Therapeutic Targets. Front Pharmacol. 2022; 13:940572. doi:10.3389/fphar.2022.940572
21. Azad S and Hassan MS. Importance of *Moringa oleifera* for Wastewater Treatment: A Review. Int J Sustainab Energy Dev. 2020; 8(1):415-420. doi:10.20533/ijsed.2046.3707.2020.0049
22. Thapa K and Chitwan R. *Moringa oleifera*: A Review Article on Nutritional Properties and its Prospect in the Context of Nepal. Acta Sci Agric. 2019; 3(11):47-54. doi:10.31080/ASAG.2019.03.0683
23. Novia J, Juvi D, Riskianto R, Sugata M, Rosa D. Anti-Hyperglycemic and Anti-Inflammatory Activities of *Moringa oleifera* Lam Leaves Extract. Trop J Nat Prod Res. 2022; 6(6):884-888.
24. Nasution MHF, Kalanjati VP, Abdurachman A, Aditya DMN, Pamungkas DBB, Syamhadi MR. The Effects of Methotrexate, *Moringa oleifera* Leaf Extract, and *Andrographis paniculata* Leaf Extract on the Testes of Hyperglycemic Wistar Rats. Trop J Nat Prod Res. 2023; 7(6):3140-3146. doi:10.26538/tjnpr/v7i6.12
25. Kamar Bashan N and Mat Noor M. Antihyperglycemic and androgenic properties of *Moringa oleifera* leaves aqueous extract attenuate sexual dysfunction in diabetes-induced male rats. Mal Appl Bio. 2021; 50(2):99-105. doi:10.55230/mabjournal.v50i2.1977
26. Sailaja BS, Aita R, Maledatu S, Ribnicky D, Verzi MP, Raskin I. Moringa isothiocyanate-1 regulates Nrf2 and NF-κB pathway in response to LPS-driven sepsis and inflammation. PLoS One. 2021; 16(4):e0248691. doi:10.1371/journal.pone.0248691
27. Toama FN, Ibrahim MN, Mostafa EM. Study of the Histological Changes Caused by the Intake of Metformin, Carnitine and Omega-3 in Some Organs of Male Diabetic Rabbits. Trop J Nat Prod Res. 2022; 6(9):1464-1468. doi:10.26538/tjnpr/v6i9.21
28. Sepici-Dincel A, Açikgöz S, Cevik C, Sengelen M, Yeşilada E. Effects of *In vivo* antioxidant enzyme activities of myrtle oil in normoglycaemic and alloxan diabetic rabbits. J Ethnopharm. 2007; 110(3):498-503. doi:10.1016/j.jep.2006.10.015

29. Reitman S and Frankel S. A Colorimetric Method for the Determination of Serum Glutamic Oxalacetic and Glutamic Pyruvic Transaminases. Am J Clin Pathol. 1957; 28(1):56-63.
30. Englehardt A. Measurement of Alkaline Phosphatase. Aerzti Labor. 1970; 16(20):42-43.
31. Jendrassik L and Grof P. Simplified Photometric Methods for the Determination of Bilirubin. Biochem J. 1938; 297:81-89.
32. Grant GH. Amino Acids and Proteins; Fundamentals of Clinical Chemistry. 3rd ed. (Tietz N, ed.). WB Saunders Company; 1987.
33. Fawcett JK and Scott JE. A rapid and precise method for the determination of urea. 1960; 13(2):156-159
34. Grove TH. Effect of reagent pH on determination of high-density lipoprotein cholesterol by precipitation with sodium phosphotungstate-magnesium. Clin Chem. 1979; 25(4):560-564. doi:10.1093/clinchem/25.4.560
35. Tietz NW. Clinical Guide to Laboratory Tests. 2nd ed. W.B. Saunders Company; 1990.
36. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clin Chem. 1972; 18(6):499-502.
37. Avwioro OG. Textbook of Histochemistry and Tissue Pathology. 2nd ed. Claverianun Press; 2010.
38. Armonk NY. IBM SPSS Statistics for Windows. Published online 2017.
39. Ghasemi A and Jeddi S. Streptozotocin as a tool for induction of rat models of diabetes: a practical guide. excli J. 2023; 22:274-294. doi:10.17179/excli2022-5720.
40. Szlachetka K, Kut P, Stępień A. Cytotoxic and anticancer activity of *Moringa oleifera*. Eur J Clin Exp Med. 2020; 18(3):214-220. doi:10.15584/ejcem.2020.3.9
41. Gupta R, Mathur M, Bajaj VK, Katariya P, Yadav S, Kamal R, Gupta R. Evaluation of antidiabetic and antioxidant activity of *Moringa oleifera* in experimental diabetes. J Diab. 2012; 4(2):164-171. doi:10.1111/j.1753-0407.2011.00173.x
42. Bacanli M, Dilsiz SA, Başaran N, Başaran AA. Effects of phytochemicals against diabetes. Adv Food Nutr Res. 2019; 89:209-238. doi:10.1016/bs.afnr.2019.02.006
43. Sheinenzon A, Shehadeh M, Michelis R, Shaoul E, Ronen O. Serum albumin levels and inflammation. Int J Biol Macromol. 2021; 184:857-862. doi:10.1016/j.ijbiomac.2021.06.140
44. Levitt D and Levitt M. Human serum albumin homeostasis: a new look at the roles of synthesis, catabolism, renal and gastrointestinal excretion, and the clinical value of serum albumin measurements. Int J Gen Med. 2016; 9:229-255. doi:10.2147/IJGM.S102819
45. Romani P, Valcarcel-Jimenez L, Frezza C, Dupont S. Crosstalk between mechanotransduction and metabolism. Nat Rev Mol Cell Biol. 2021; 22(1):22-38. doi:10.1038/s41580-020-00306-w
46. Ito F, Sono Y, Ito T. Measurement and clinical significance of lipid peroxidation as a biomarker of oxidative stress: Oxidative stress in diabetes, atherosclerosis, and chronic inflammation. Antioxidants. 2019; 8(3):72. doi:10.3390/antiox8030072
47. Gar C, Haschka SJ, Kern-Matschilles S, Rauch B, Sacco V, Prehn C, Adamski J, Seissler J, Wewer Albrechtsen NJ, Holst JJ, Lechner A. The liver-alpha cell axis associates with liver fat and insulin resistance: a validation study in women with non-steatotic liver fat levels. Diabetologia. 2021; 64(3):512-520. doi:10.1007/s00125-020-05334-x
48. Smith K, Dennis KMJH, Hodson L. The ins and outs of liver fat metabolism: The effect of phenotype and diet on risk of intrahepatic triglyceride accumulation. Exp Physiol. 2025; 110(7):936-948. doi:10.1113/EP092001
49. Jamaludin J, Nazratun Nafizah AH, Zariyantey AH, Budin SB. Mechanisms of Diabetes-Induced Liver Damage: The role of oxidative stress and inflammation. Sultan Qaboos Univ Med J. 2016; 16(2):e132-141. doi:10.18295/squmj.2016.16.02.002
50. Jiang S, Young JL, Wang K, Qian Y, Cai L. Diabetic-induced alterations in hepatic glucose and lipid metabolism: The role of type 1 and type 2 diabetes mellitus (Review). Mol Med Rep. 2020; 22(2):603-611. doi:10.3892/mmr.2020.11175
51. Jialal I and Singh G. Management of diabetic dyslipidemia: An update. World J Diab. 2019; 10(5):280-290. doi:10.4239/wjd.v10.i5.280
52. Poznyak A, Grechko A V., Poggio P, Myasoedova VA, Alfieri V, Orekhov AN. The diabetes mellitus–atherosclerosis connection: The role of lipid and glucose metabolism and chronic inflammation. Int J Mol Sci. 2020; 21(5):1835. doi:10.3390/ijms21051835
53. Kaur G, Invally M, Sanzagiri R, Buttar HS. Evaluation of the antidepressant activity of Moringa oleifera alone and in combination with fluoxetine. J Ayurveda Integr Med. 2015; 6(4):273. doi:10.4103/0975-9476.172384
54. Muzumbukilwa WT, Nlooto M, Owira PMO. Hepatoprotective effects of *Moringa oleifera* Lam (Moringaceae) leaf extracts in streptozotocin-induced diabetes in rats. J Funct Foods. 2019; 57:75-82. doi:10.1016/j.jff.2019.03.050
55. Cuellar-Núñez ML, Gonzalez de Mejia E, Loarca-Piña G. *Moringa oleifera* leaves alleviated inflammation through downregulation of IL-2, IL-6, and TNF-α in a colitis-associated colorectal cancer model. Food Res Int. 2021; 144:110318. doi:10.1016/j.foodres.2021.110318
56. Aju BY, Rajalakshmi R, Mini S. Protective role of *Moringa oleifera* leaf extract on cardiac antioxidant status and lipid peroxidation in streptozotocin induced diabetic rats. Heliyon. 2019; 5(12):e02935. doi:10.1016/j.heliyon.2019.e02935
57. He Z, Yin G, Li QQ, Zeng Q, Duan J. Diabetes Mellitus Causes Male Reproductive Dysfunction: A Review of the Evidence and Mechanisms. In Vivo. 2021; 35(5):2503-2511. doi:10.21873/invivo.12531
58. Andlib N, Sajad M, Kumar R, Thakur SC. Abnormalities in sex hormones and sexual dysfunction in males with diabetes mellitus: A mechanistic insight. Acta Histochem. 2023; 125(1):151974. doi:10.1016/j.acthis.2022.151974