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Original Research Article

Evaluation of Antidiabetic Potential and Biochemical Parameters of Aqueous Pod Extract of *Moringa oleifera* in Alloxan Diabetic Rats

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ABSTRACT

Moringa oleifera leaves and seeds are sold in Nigeria as nutraceutical for the treatment of various diseases including diabetes mellitus. It may also be possible that the pod of *M. oleifera* could have antidiabetic effect and lower plasma lipid in which diabetic patients are predisposed to. Hence there is the need to evaluate the potential of the aqueous pod extract of *M. oleifera* as an antidiabetic and lipid lowering agent. Acute blood glucose lowering effect of varying doses (100, 200 and 400 mg/kg) of the aqueous pod extract of *M. oleifera* and glibenclamide (10 mg/kg) on normal and alloxan-induced diabetic rats was investigated. The rats were treated daily for 21 days with the most effective dose (200 mg/kg, orally) and its effects on blood glucose, oral glucose tolerance, body weight, biochemical parameters and lipid indices were evaluated. Results of the study showed significant ($p<0.05$) reduction in blood glucose level. Daily administration of the extract significantly ($p<0.05$) improved glucose tolerance, attenuated plasma lipids levels, alanine transaminase and aspartate transaminase in the diabetic group. There was positive improvement in the body weight of the diabetic rats after treatment. The aqueous pod extract of *M. oleifera* exhibited significant antidiabetic and lipid lowering effects, which may be due to the presence of flavonoids, which are known antioxidants or possible regeneration of the pancreatic β-cells.

Keywords: *Moringa oleifera* pod, diabetes, oral glucose tolerance, lipids, transaminases.

Introduction

Diabetes mellitus is a complex metabolic disorder characterized by impairment of carbohydrate, protein and lipid metabolism[1] as a result of defect in insulin secretion or action.[2] The major goal in the treatment and management of diabetes mellitus is to achieve blood glucose concentration as close to normal as possible. The challenge in attaining this goal has continued to encourage researches into drugs that are affordable for its management, more so that WHO has emphasized on the rational use of safer and affordable traditional and natural indigenous medicines for treating diabetes mellitus.[3,4] In addition, the use of traditional medicine among the rural population in the treatment and management of diseases is likely to continue due to socio-cultural and socio-economic heritage as well as lack of basic healthcare and support for the rural population.[5] Thus it is pertinent that continuous studies be carried out in the search for indigenous medicines for the teaming rural population.

In non-diabetic individuals, blood glucose level peaks at about an hour after a meal, rarely exceeding 150 mg/dL, and returns to pre-prandial level within 2–3 hours.[6] This value is usually very high in diabetic conditions and would be a risk in the development of metabolic and vascular complications. In diabetes mellitus, post-prandial blood glucose plays an important role in the overall glycaemic control; some epidemiological studies suggest that post-prandial hyperglycaemia is linked with long-term indices of diabetic control, such as glycosylated haemoglobin, lipid abnormalities and is a risk factor for the development of vascular complications.[7] Thus there is a great need to stabilize post-prandial blood glucose and prevent lipid abnormalities in an effort to control impending health risk.

The liver plays an important role in the maintenance of normal blood glucose levels during fasting as well as in the post-prandial state.[7, 8] In insulin-resistant state, excess free fatty acid is produced which is known to be directly toxic to hepatocytes [9, 10] and may lead to marker enzymes leakage into the blood. Therefore, drugs that will stabilize post-prandial glucose as well as control lipid abnormalities will be of great importance.

Moringa oleifera, has long been used as folklore to treat various diseases and as nutritional supplement.[11, 12] It has been demonstrated that methanol pod extract of *M. oleifera* has antioxidant and antidiabetic properties and caused a reversal in the damage to the β-cells of the pancreas,[13] its leaves and seeds are good as antioxidant, antidiabetic,[14,15] hypocholesterolaemic,[16,17] anti-inflammatory, diuretic, antibacterial, antifungal, antinociceptive and in wound healing.[18-21] The leaves, seed and flowers have been shown to have antisickling properties.[22] However, none of these studies have reported the activity of the aqueous pod extract of this plant as a potential antidiabetic agent. Thus, this study investigated the possible hypoglycaemic and antidiabetic potentials of the aqueous pod extract of *M. oleifera* in normal and alloxan-induced diabetic rats and also the effects of the pod extract on their liver enzymes and lipid profile.

Materials and Methods

Plant Extraction

Moringa oleifera was harvested from a farm in Ilorin, Kwara State, Nigeria and was identified by Mr. O. O. Oyebanji of the Department of Botany of the University of Lagos, Nigeria. The voucher specimen (LUH 5905) was deposited in the University of Lagos herbarium. The pods were separated; dried and 585 g of pulverized pod was

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exhaustively extracted with water for 24 h using soxhlet extractor. The aqueous extract was lyophilized using freeze dryer to yield 210.71 g (36.02% w/w). The extract residue was stored at -20°C in an impervious amber bottle until used.

Animals

One hundred and twenty (120) adult Sprague Dawley rats of both sexes (130 - 150 g) and 50 mice of both sexes (19-26 g) were used for the diabetic and acute toxicity studies, respectively. The animals were cared for in accordance with Institute of Laboratory Animal Research (ILAR) guidelines.[23] The animals were housed in a properly ventilated animal centre of the College of Medicine of the University of Lagos, Nigeria. They were allowed to acclimatize for 4 weeks prior to experimentation under standard laboratory condition (12:12 h dark/light cycle) with access to commercial pellet diet and water *ad libitum*.

Chemicals and Instrument

The chemicals were of analytical reagent grade, products of Sigma Chemical Company (St. Louis, MO), tablets of glibenclamide® were locally purchased. The absorbances were recorded by UV-Visible spectrophotometer (Agilent 8453 t technologies, Hewlett-Packard, Germany) with Agilent ChemStation software (Agilent, Palo Alto, USA) running on a Compaq compatible personal computer (Hewlett-Packard, Obregon, Mexico). The ChemStation also consists of an interface bus for data acquisition and a pinwriter HP DeskJet 5652 printer.

Phytochemical screening

Qualitative test indicating the presence or absence of phytochemical constituents was carried out using standard methods of Talukdar *et al*.,[24] and Harborne.[25]

Acute Toxicity Study

Acute toxicity of the aqueous pod extract of *M. oleifera* was studied following standard procedures and guidelines.[26] Fifty mice evenly shared into 5 groups were fasted for 10 h prior to the experiment. The mice were administered orally by gavage with doses of the extract (0.5, 1.0, 2.0, 4.0 and 5.0 g/kg body weight); the control group was given distilled water. The animals were continuously observed for over a period of 24 h for behavioural, neurological and autonomic changes. Mortality was determined 24 h post administration and the LD_{50} was calculated according to the method of Litchfield and Wilcoxon.[27] A further 14 days continuous observation was allowed on the animals for elimination of possible delayed toxicity which usually occur in some drugs.

Induction of experimental diabetes

Diabetes was induced in 10 h fasted rats by a single intraperitoneal injection of freshly prepared alloxan monohydrate at a dose of 100 mg/kg body weight in 0.9% NaCl solution. Control rats received similar volume of 0.9% NaCl solution. Two days after injection of alloxan, fasting blood glucose was determined. Rats that were diabetic as indicated in their fasting blood glucose level of above 200 mg/dL as well as polydipsia, polyuria, glycosuria (indicated by Benedict's test for urine) were included in the study.

Effect of aqueous pod extract of Moringa oleifera on blood glucose of normal and diabetic rats

The hypoglycemic effect of the aqueous pod extract of *M. oleifera* was investigated in normal and diabetic rats after a single oral administration of the pod extract by measuring blood glucose level before (0 h) and at 1, 2, 3, 4 and 6 h after dosing. The animals were well matched for weight and were grouped (Table 1).

Evaluation of oral glucose tolerance test in normal and diabetic rats

A different group of fifty (50) rats, well matched for weights and shared equally into 10 groups were fasted for 10 h prior to the study. Fasting blood glucose was determined, in order to measure baseline blood glucose level; thereafter the rats were fed with the pod extract. Group I (normal control) was given distilled water; groups II, III, IV and V were normal rats and administered with 100, 200 and 400 mg/kg of the pod extract and glibenclamide (10 mg/kg) as the standard drug respectively. Group VI (diabetic control) was given distilled water; groups VII, VIII, IX and X were diabetic rats and administered with 100, 200 and 400 mg/kg of the pod extract and glibenclamide (10 mg/kg) respectively. Blood glucose was determined after 90 min of extract administration and was considered as zero hour (0 h). Then the rats were orally fed with 2 g/kg of standard glucose after which blood was withdrawn and glucose levels were estimated at 1, 2, 3, 4 and 6 h following the method of Jaiswal *et al*.,[15] Throughout the experimentation, the rats were only allowed water *ad libitum*.

Blood collection and estimation of blood glucose

Prior to blood collections, animals were fasted for 10 h. Blood samples, 1 mL were withdrawn from the retro orbital plexus of each rat using sterile capillary tube[28, 29] into potassium oxalate and sodium fluoride bottles. The blood samples were centrifuged immediately at 3000 g for 15 min; plasma of each blood sample was carefully collected using Pasteur pipette and blood glucose was estimated with Randox-assay kit (Bayer Diagnostics India, Limited). The principle is based on the formation of a stable red purple product (quinoneimine dye), produced by oxidative condensation of phenol with 4-aminoantipyrine in the presence of hydrogen peroxide catalysed by peroxidase.[30] Briefly, glucose is enzymatically oxidized by glucose oxidase to gluconic acid and hydrogen peroxide. The hydrogen peroxide generated oxidatively couple phenol with 4-aminoantipyrine to form a red purple quinoneimine dye which is measured spectrophotometrically at 500 nm. The intensity of the red-purple quinoneimine dye is directly related to the concentration of glucose in the sample. The reaction equation is shown in scheme 1 below.[31]

Table 1: Classification of rats for acute hypoglycemic experiment with aqueous pod extract of *Moringa oleifera*

Group Classification	Normal Control	Diabetic Control	Normal + pod of *M. oleifera*			Diabetic + pod of *M. oleifera*			Normal + glibenclamide	Diabetic + glibenclamide
No. of groups	A	B	C	D	E	F	G	H	I	J
Doses mg/kg	DW	DW	100	200	400	100	200	400	10	10
No. of rats	5	5	5	5	5	5	5	5	5	5

DW = Distilled water (5 mL/kg)

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Effect of prolong administration of Moringa oleifera pod extract to diabetic rats

In this study, twenty (20) diabetic rats were shared equally into 4 groups and treated daily with aqueous pod extract of *M. oleifera* by oral gavage for 21 days. Groups I and II were normal and diabetic controls, respectively and were given distilled water; while groups III and IV were administered 200 mg/kg of the pod extract (most effective dose) and glibenclamide (10 mg/kg), respectively. Blood glucose levels were estimated before the first extract administration (0 h) and at weekly interval for 21 days in overnight (10 h) fasted diabetic rats and 2 hours after meal (postprandial blood glucose). The weights of the rats were noted each week.

Estimation of biochemical and organ function parameters after prolong administration of Moringa oleifera pod extract to diabetic rats

After a 3 week treatment, blood samples (2 mL) were withdrawn from the retro orbital plexus of each rat using sterile capillary tube into EDTA bottles. Blood samples collected were centrifuged at 3000 g for 15 min. The plasma samples obtained were tested for total cholesterol (TC) and triglyceride [32] high density lipoprotein (HDL-cholesterol) [33] using diagnostic kit (BIOLABO 02160 MAIZYFRANCE); Low density lipoprotein (LDL-cholesterol) was calculated using the formula of Friedewald *et al*., [34] Atherogenic index was calculated as a ratio of total cholesterol to HDL-cholesterol; creatinine, Alanine Transaminase (ALT) and Aspartate Transaminase (AST) were estimated using an automated chemistry analyzer (Hitachi 904, Roche Diagnostics GmbH, Germany) following the approved method of IFCC (International Federation of Clinical Chemistry).[35,36] Protein concentration in the plasma was determined by Biuret method.[37]

Statistical Analysis

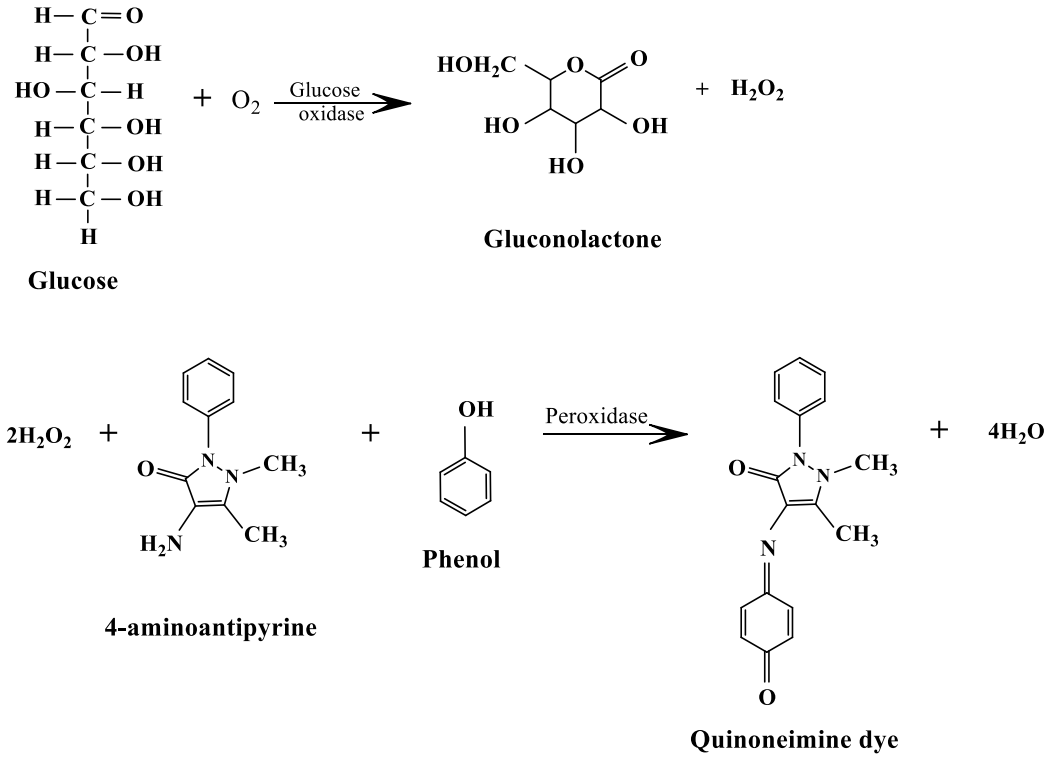
Results were expressed as mean ± SEM. The data were statistically analyzed to assess difference between means using graphpad Prism version 5.00 for windows (Graphpad SoftWare, San Diego, CA, USA) and the values of $p<0.05$ were taken as significant.

Results and Discussion

Increased blood glucose level production and its decreased utilization by the tissues form the fundamental basis of hyperglycaemia in diabetes mellitus. Complications associated with diabetes mellitus and its high incidence rate has encouraged the quest for drugs for its treatment. Thus this study evaluated the antidiabetic and biochemical effects of the aqueous pod extract of *Moringa oliefera* in alloxan diabetic rats.

The acute toxicity study of the aqueous pod extract of *Moringa oliefera* did not show any lethality or toxic reaction even at the highest dose of 5 g/kg b.wt., indicating that the extract is safe and has a large margin of safety at the doses studied. However, the study of Gupta *et al.*,[13] reported an LD_{50} of 1300 mg/kg b.wt with the methanol pod extract of *M. oleifera*. Induction of diabetes resulted in significant ($p<0.05$) loss of body weight (Table 2), probably due to increased muscle wasting and loss of tissue proteins and excessive fluid loss.[38, 39] The loss in body weight of the diabetic rats was attenuated following treatment with the pod extract of *M. oleifera* extract and glibenclamide (Table 2) when compared to the diabetic control. It is therefore assumed that the pod extract may have effect in controlling muscle wasting probably by correcting the impairment of carbohydrate metabolism. The aqueous pod extract of *M. oleifera* revealed the presence of tannins, saponins, flavonoids, terpenoids, anthraquinones, steroids, alkaloids and cardiac glycosides (Table 3). Flavonoids are good in scavenging reactive oxygen specie and help to speed up natural healing process which may invariably reverse free radical mediated ailments. Thus the presence of flavonoids and tannins in the aqueous pod extract may be the reason for the observed activities in this study.

Alloxan induces diabetes mellitus by destroying the β-cells of pancreas through generation of reactive oxygen species which would lead to alterations in carbohydrate metabolism due to insulin deficiency.[40-42] Graded doses of the aqueous pod extract of *M. oleifera* or glibenclamide (10 mg/kg) did not exhibit significant ($p>0.05$) hypoglycemic effect on fasting blood glucose level in normal rats (Figures 1); however, the hyperglycemic effect observed in the



Scheme 1: Reactions involved in the quantification of glucose blood using enzymatic methods

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diabetic rats was significantly ($p<0.05$) ameliorated with the administration of *M. oleifera* bringing hypoglycemic effects to near normal and comparable to the results obtained with the antidiabetic drug, glibenclamide (Figure 2b). In the oral glucose tolerance test, normal rats treated with the pod extract exhibited significant ($p<0.05$) reduction in the blood glucose level following 2 g/kg glucose load (Table 4). The blood glucose level in these groups returned to near normal within 6 h of glucose loading. This reduction was most significant within 4 h in the rats that received 200 mg/kg extract and was comparable to the glibenclamide group. The fact that glucose tolerance did not change in the normal rats was because the β-cells were intact, so had the ability to secrete insulin. There was impaired glucose tolerance in the diabetic rats; load of glucose, 2 g/kg in the diabetic rats further caused a greater impairment evident by the sustainable rise in blood glucose within the study period (Table 5). However, administration of the pod extract of *M. oleifera* significantly ($p<0.05$) ameliorated this impairment and hypoglycemia was observed with more pronounced effect in the 200 mg/kg treated group. This may indicate that aqueous pod extract of *M. oleifera* is efficient in the control of blood glucose in diabetic state, probably by enhancing insulin secretion and ultimate increase in glucose utilization.

The management of diabetes is usually challenging; treatments of fasting plasma glucose and postprandial plasma glucose have to be considered when determining an appropriate treatment [43] for a diabetic patient, normalizing postprandial blood glucose levels is more difficult than normalizing fasting blood glucose. Several herbal drugs have been found sufficient in lowering fasting blood glucose with no effect on postprandial blood glucose. From this study, rats in the diabetic control group showed consistent elevated fasting plasma glucose (FBG) with two deaths at the third week; treatment of this group with the most effective dose (200 mg/kg b.wt.) significantly ($p<0.05$) reduced the blood glucose level from 289.9 ± 9.4 mg/dL to 113.8 ± 8.9 mg/dL in the third week and was comparable to the glibenclamide group (Figure 2). The aqueous pod extract of *M. oleifera* lowered postprandial glucose level to near the pre-prandial value (Figure 2).

This may be explained from the fact that the extract may suppress postprandial glucagons by enhancing the release of insulin through repair of the pancreas or may be an α-glucosidase inhibitor, slowing intestinal carbohydrate digestion and absorption [13, 44-46] thus improving post-prandial glucose levels.

The diabetic rats showed no significance ($p>0.05$) change in creatinine value and were comparable to the control group, indicating that the kidneys were still in its optimal function (Table 6). Impaired lipid metabolism resulting from uncontrolled hyperglycaemia has been implicated in cardiovascular complications in diabetes patients.[43] Low level insulin stimulates fatty acid and cholesterol synthesis as well as inhibits the activities of the protein-lipoprotein lipase enzyme needed to break up triglycerides in very low-density lipoprotein cholesterol[47] thus a diabetic patient may have a high triglyceride level. Researches have reported a high LDL-C level and a low HDL-C level in diabetics and that elevated LDL-C has been found to be a risk factor for the development of cardiovascular disease. [48, 49] Therefore prevention and treatment of complications of diabetes would include monitoring and treating elevated lipid levels. The result of this study showed a high level of total cholesterol (TC), triglyceride (TG) and low density lipoprotein-cholesterol (LDL-C) in diabetic rats (Table 6) which is in keeping with the fact that these parameters increase in diabetic conditions. These increases were significantly ($p<0.05$) ameliorated with subsequent increase in high density lipoprotein-cholesterol (HDL-C) when treated with the aqueous pod extract of *M. oleifera* and were comparable to the control group (Table 6). This effect may probably be attributed to the plant's ability to repair the pancreas thus causing insulin release, which would eventually cause increase in lipoprotein lipase and scavenging of reactive oxygen species in the rats. The findings in this study is supported by the work of Gupta *et al.*,[13] who reported on the regeneration of the β-cells of pancreas after

Table 2: Effects of aqueous pod extract of *Moringa oleifera* on the body weight of the normal and diabetic rats.

No. of groups	Classification of groups	Doses (mg/kg)	Initial weight (g)	Weeks of treatment (Body weight in g)		
				1	2	3
I	ND control	DW	141 ± 4.07	142 ± 2.45	145 ± 1.95	148 ± 2.60
II	D control	DW	140 ± 3.91	136 ± 6.30	118 ± 4.11	101 ± 8.59
III	D + extract	200	146 ± 6.11	143 ± 8.32	141 ± 9.89	144 ± 10.41
V	D + glibenclamide	10	147 ± 6.46	141 ± 7.35	143 ± 10.57	143 ± 11.72

DW = Distilled water (5 mL/kg), D= diabetic rats. ND = non-diabetic rats

Table 3: Phytochemical screening of aqueous pod extract of *Moringa oleifera*

Solvent of extraction	Phytochemical tests								
	Anthraquinones	Tannins	Flavonoids	Terpenoids/steroids	Cardiac glycosides	Saponins	Reducing sugar	Volatile oil	Alkaloids
Water	+	+	+	+	+	+	-	-	-

(+): Indicates presence; (-): Indicates absence

Table 4: Effects of aqueous pod extract of *Moringa oleifera* on oral glucose tolerance test in normal rats.

Doses	Blood glucose level (mg/dL)						
	FBG	after 90 min	after 2 g/kg glucose administration				
			1	2	3	4	6
NC	101.56 ± 7.5	101.45 ± 7.9	135.71 ± 8.3	132.05 ± 7.9	128.61 ± 8.5	125.66 ± 6.7	111.77 ± 7.7
N (100)	102.41 ± 7.1	98.33 ± 6.5	143.03 ± 7.2	136.14 ± 8.1	130.45 ± 9.4	121.14 ± 7.1	118.03 ± 8.3
N (200)	98.71 ± 6.4	94.07 ± 6.0	137.16 ± 7.5	129.18 ± 7.7	114.17 ± 8.3	103.08 ± 7.2	99.48 ± 7.0
N (400)	96.11 ± 4.1	98.10 ± 7.3	151.08 ± 8.1	136.02 ± 6.2	121.10 ± 8.3	113.31 ± 8.0	105.33 ± 7.3
Gli (10)	101.07 ± 7.0	89.13 ± 7.2	130.46 ± 6.2	116.06 ± 8.0	108.21 ± 8.7	97.40 ± 7.3*	86.61 ± 6.9*

Values are expressed as mean ± SEM, n=5; *p< 0.05, compared with normal control; NC: normal control; 100, 200 400 are mg/kg extract; Gli = glibenclamide 10 mg/kg

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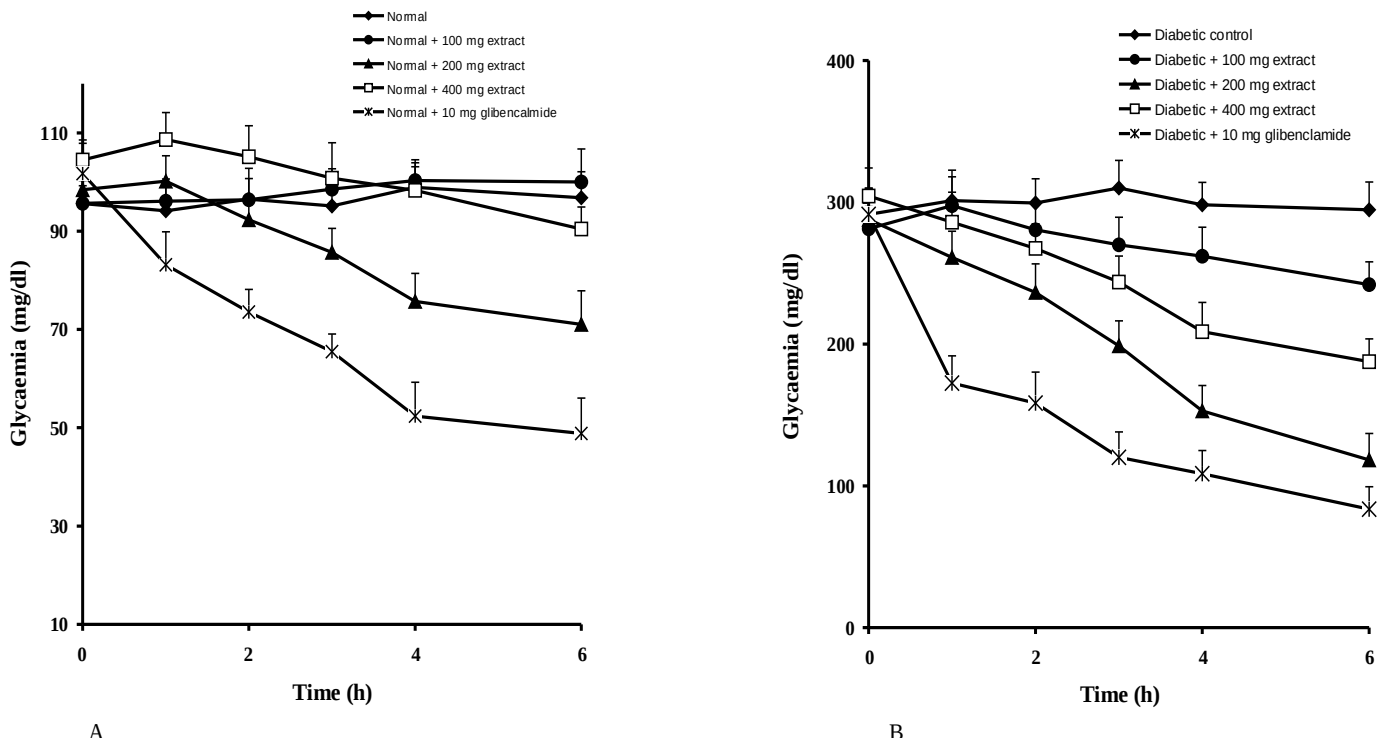

Figure 1: Mean blood glucose level of normal (A) and alloxan-induced diabetic (B) rats after treatment with aqueous pod extract of *Moringa oleifera*. Values are expressed as mean ± SEM, n=5; *P< 0.05, compared with diabetic control.

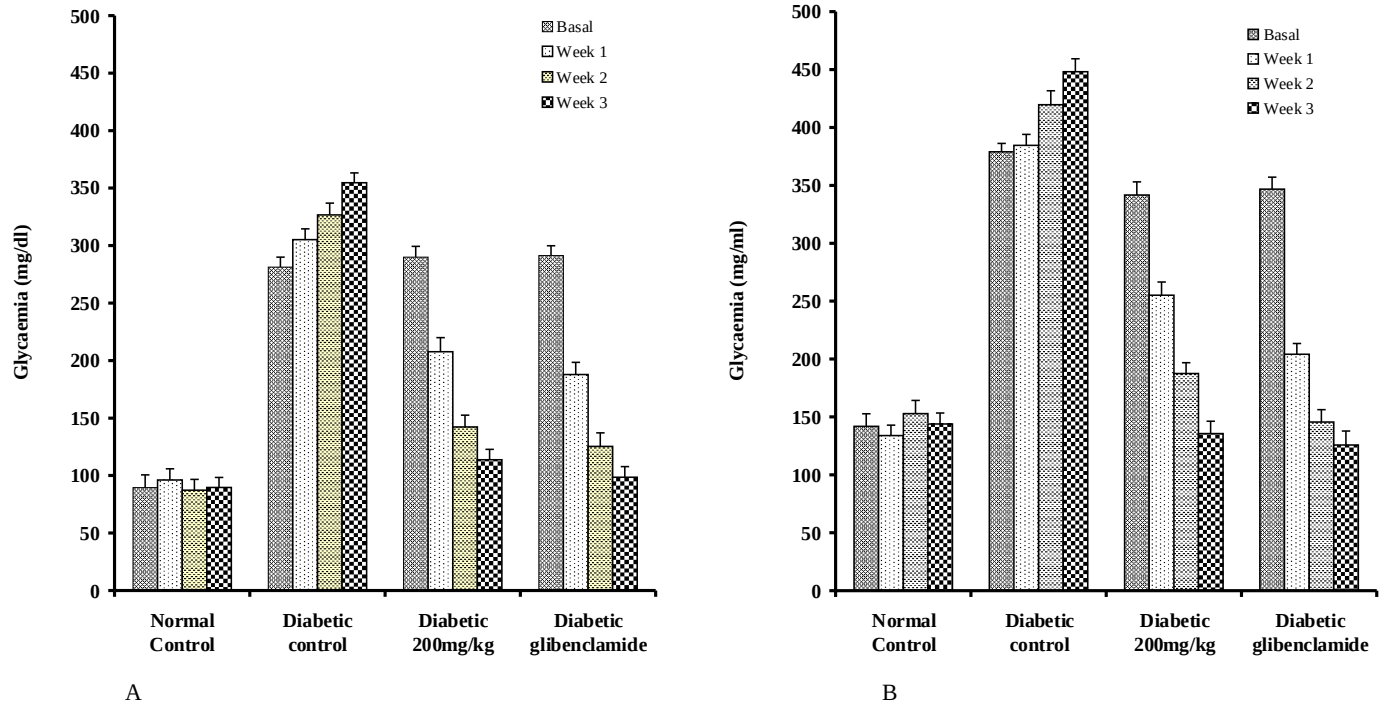

Figure 2: Effects of 21 days administration of aqueous pod extract of *Moringa oleifera* on fasting and postprandial blood glucose levels of normal (A) and diabetic (B) rats. Values are expressed as mean±SEM, n=5; *P< 0.05 significantly compared with control.

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Table 5: Effects of aqueous pod extract of *Moringa oleifera* on oral glucose tolerance test in alloxan-diabetic rats.

Doses	Blood glucose level (mg/dL)						
	FBG	after 90 min	after 2 g/kg glucose administration				
			1	2	3	4	6
DC	278.23 ± 6.1	298.11 ± 8.1	354.15 ± 6.3	331.55 ± 5.9	325.41 ± 7.1	315.60 ± 8.1	305.51 ± 6.1
D (100)	286.15 ± 3.9	271.43 ± 8.3	335.61 ± 6.2	318.34 ± 5.1	291.30 ± 7.9	271.35 ± 8.5	253.33 ± 6.5
D (200)	298.08 ± 4.6	244.21 ± 6.8	276.23 ± 8.2	229.00 ± 8.0	201.33 ± 6.1	183.11 ± 7.2*	123.84 ± 7.6*
D (400)	295.10 ± 4.7	241.00 ± 5.9	271.61 ± 7.7	243.52 ± 6.6	226.27 ± 5.5	255.21 ± 5.8	211.31 ± 8.1
Gli (10)	288.13 ± 6.1	225.05 ± 7.1	253.41 ± 7.5	210.01 ± 6.3	195.23 ± 6.4	182.70 ± 6.3*	117.60 ± 8.5*

Values are expressed as mean ± SEM, n=5; *P< 0.05, compared with diabetic control; DC: diabetic control; 100, 200 400 are mg/kg extract; Gli = glibenclamide 10 mg/kg

Table 6: Biochemical parameters after 21 days oral administration of the aqueous pod extract of *Moringa oleifera* in normal and alloxan-diabetic rats**.**

Biochemical Parameters	Group (Rats)			
	Normal	Diabetic	200 mg/kg	Glibenclamide
AST (U/L)	74.13 ± 17.48	191.33 ± 21.78	111.67 ± 15.60*	87.83 ± 27.26*
ALT (U/L)	32.20 ± 13.14	88.25 ± 9.14	38.08 ± 9.19*	29.03 ± 3.15
TP (g/dL)	71.00 ± 13.05	121.25 ± 19.73	98.25 ± 9.44	76.65 ± 9.14
ALP (U/L)	28.23 ± 11.75	51.16 ± 13.03	35.22 ± 11.13	31.53 ± 11.81
Creatinine (mg/dL)	0.73 ± 7.23	0.92 ± 4.70	0.67 ± 5.12	0.65 ± 4.14
Total Cholesterol (mg/dL)	118.73 ± 6.52	176.70 ± 6.03	128.81 ± 4.32*a	112.74 ± 9.59*a
Triglyceride mg/dL	77.03 ± 12.79	223.13 ± 9.93	117.09 ± 8.17	92.88 ± 6.52
(HDL-cholesterol) mg/dL	58.84 ± 6.24	38.38 ± 9.08	61.17 ± 8.91	64.45 ± 9.78
(LDL-cholesterol) mg/dL	45.78 ± 7.51	91.72 ± 11.09	45.34 ± 9.95	32.17 ± 9.06
Atherogenic index	1.97 ± 7.98	4.47 ± 8.01	2.16 ± 5.16*a	1.87 ± 9.37

Values are expressed as Mean ± SEM, n=5, Aspartate transaminase (AST), Alanine transaminase (ALT), Alkaline phosphatase (ALP) and total protein (TP). Statistical analysis was done using one-way ANOVA with *P < 0.05 significantly different from diabetic control group. *P < 0.05 comparable to normal control.

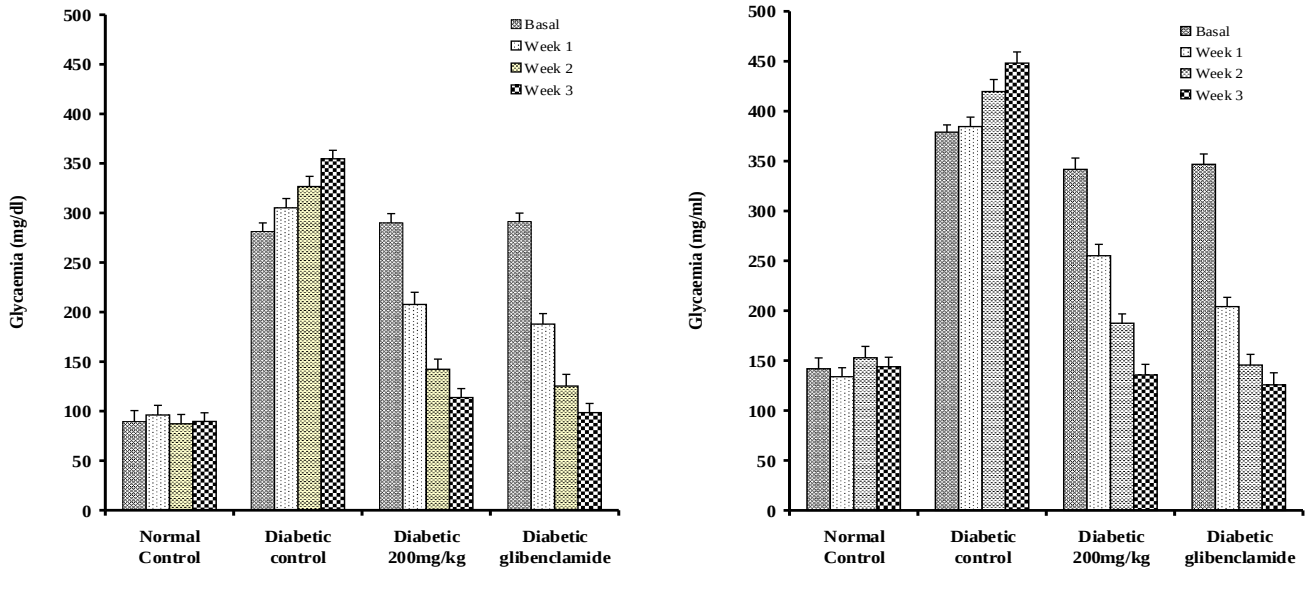

Figure 2: Effects of 21 days administration of aqueous pod extract of *Moringa oleifera* on fasting and postprandial blood glucose levels of normal (A) and diabetic (B) rats. Values are expressed as mean ± SEM, n=5; *P< 0.05 significantly compared with control.

strong marker to predict cardiovascular risk.[50] Treatment with *M. oleifera* significantly ($p<0.05$) reduced the atherogenic index (Table 6) which again indicates the protective nature of *M. oleifera* against CVDs. Low level or absence of insulin increases the activities of liver marker enzymes alanine transaminase (ALT) and aspartate transaminase (AST).[51,52] This may be attributed to glycogenic hepatopathy which develops due to excess and irreversible accumulation of glycogen in the hepatocytes thus causing liver function disorders and hepatomegaly.[53, 54] Administration of the pod extract of *M. oleifera* was effective in reducing the plasma level of ALT and AST, which may probably be due to the depletion of glycogen in the liver thus preventing destruction of the liver and discouraging gluconeogenesis.

Conclusion

The findings from this study showed that the aqueous pod extract of *Moringa oleifera* has significant antidiabetic activity and improved metabolic impairment in the diabetic rats as well as lowered elevated lipid and some biochemical parameters in the diabetic rats. This study has evaluated for the first time the effect of the aqueous pod extract of *Moringa oleifera* on blood glucose and biochemical parameters of the normal and diabetic rats.

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.

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