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Antidiabetic Activity of *Abelmoschus esculentus* (Ex- Maradi Okra) Fruit in Alloxan-induced Diabetic Rats

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Abstract: Diabetes is a chronic disease that occurs either when the pancreas fails to produce enough insulin or when the body cannot effectively use the insulin it produces. The condition is characterized by persistent hyperglycaemia. Diabetes has become a pandemic with limited treatment options, hence the pressing need to explore better treatment. *Abelmoschus esculentus* fruit (Okra) is a well-known vegetable, fibrous and viscous in nature and has been reported to possess hypoglycaemic activity. This study investigated the antidiabetic effects of different parts [Whole Okra (WO), Okra Peel (OP) and Okra Seed (OS)] of one of the varieties of Okro Ex-Maradi in Alloxan-induced diabetic rats. Diabetes was induced by intra-peritoneal administration of a single dose (120 mg/kg) of Alloxan. Rats were randomly divided into four main groups: WO, OP, OS and Control group (C). The effects of the treatments with the various parts of the Okro were studied on blood glucose level, glycated haemoglobin and lipid profile. Glucose was estimated using glucose oxidase/peroxidase method and glycated haemoglobin by colourimetric method. The lipid profile parameters were analysed by enzymatic method. All parts of the Okra fruits (WO, OP and OS) showed significant ($P<0.05$) reduction in blood glucose level, glycated haemoglobin and improvement on lipid profile compared with the diabetic non-treated control and comparable with Metformin positive Control. This study demonstrates that various parts of Ex-Maradi Okra fruit variety is effective in controlling blood glucose level and improvement of lipid profile and have potentials in the development of Okra- based antidiabetic nutraceutical.

KEYWORDS: Diabetes Mellitus, *Abelmoschus esculentus*, Hyperglycemia, Okra fruit, Metformin

1.0 Introduction

Diabetes Mellitus (DM) is a group of metabolic disorders associated with disturbances in the metabolism of fuel molecules due to absolute deficiency of insulin, insufficient insulin secretion and /or its action (Saidu *et al;* 2011). It is caused by genetic or lifestyle factors and is characterized by hyperglycemia (Saidu *et al;* 2011). It is a widespread endocrine disorder that is associated with considerable morbidity and mortality and is found in all population throughout the world (Davis and Granner, 2001; WHO, 2016). The worldwide prevalence of diabetes mellitus in all age groups was estimated to be about 171 million people (2.8%) in the year 2000 and the number is projected to increase to at least 366 million (5.4%) by 2030. (WHO, 2016). The large increment will occur mostly in developing countries, especially in people aged between 45 and 64 years (Wild *et al.*, 2004; Chen, 2008; WHO, 2016).

The current management of diabetes involves mainly insulin therapy or oral hypoglycaemic drugs. Insulin therapy has several draw backs like insulin resistance, anorexia nervosa, hypoglycemia, brain atrophy, and fatty liver especially in chronic treatment (Piedrola *et al.*, 2001). Oral hypoglycemic drugs (e.g. Sulphonylureas and Biguanides) are also associated with side effects such as hepatotoxicity, abdominal pain, flatulence,

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diarrhoea and hypoglycaemia (Fujisawa *et al*; 2005). Drug resistance has also been reported after prolonged period of treatment. In view of these, there is urgent need to develop new medications or strategies to counter the huge increase in prevalence and incidence of diabetes mellitus as well as the problems associated with the present medications. It is a known fact that traditional medicines are used for primary health care by about 80 % of the world's population particularly in the developing countries where resources are meager and medical facilities are expensive. Phytochemicals identified from traditional medicinal plants are presenting an exciting opportunity for the development of new types of therapeutics (Ashok and Roa, 2002).

Abelmoschus esculentus fruit (Okra) is one of the classical examples of plant used not only as food but also for its unique therapeutic significance owing to its several beneficial effects like hypoglycaemic, hypocholesterolemic, antioxidant, antimicrobial, anti-inflammatory, anti-constipation, anti-cancer activities and host of other potentials (Viuda-Martos *et al.*, 2010). Okra fruits are readily available and affordable in Nigerian communities and are a good source of various vitamins and minerals in addition to its high dietary fiber content (Habtamu *et al.*, 2014). Hence, exploration of potential antidiabetic property of such plant is critical for future management of diabetes mellitus.

The aim of the present study was to evaluate the anti-diabetic effect of Ex-Maradi Okra fruit variety for possible development of Okra-based anti-diabetic nutraceutical formulation that is safe, effective and affordable for the management of diabetes.

2.0 Materials and Methods

2.1 Materials

2.1.1 Chemicals and Reagents

All chemicals and reagents used were of analytical grade and were obtained from May and Baker Ltd Degenham, England, BDH Chemicals Ltd., Poole England, Sigma Chemical, St Louis, USA, or Randox Laboratories, London, UK.

2.1.2 Okro Sample

Ex-Maradi, (a commercially available dry-Okra fruits variety from vegetable growers/ sellers at Maradi; Niger Republic) was obtained from Maggi Market at Sokoto State; Nigeria. The sample was botanically identified and authenticated by Mal. A Umar, a taxonomist in the Botany Unit of the Department of Biological Sciences, Usmanu Danfidiyo University, Sokoto (UDUS), Nigeria. A voucher specimen number (UDUH/ANS/0066) was assigned to the sample while the specimen sample was deposited in the Herbarium of the same Department.

2.1.3 Experimental Animals

Seventy two (72) apparently healthy young Wister albino rats of both sexes weighing between 100-200 g obtained from the Animal House of the Department of Biological Sciences, UDUS, Nigeria, were used for this study. The rats were kept under standard laboratory conditions in well ventilated cages. They were maintained on grower's mash (Vital Feeds Nigeria Ltd, Jos, Nigeria) and allowed access to water *ad libitum*. The animals were allowed to acclimatize for two weeks.

2.2 Methods

2.2.1 Preparation of Sample

The Okra sample was thoroughly sorted to remove any unwanted material. 500 g of the Okra sample were weighed and pulverized using pestle and mortar. Another 1000 g of the sample was also weighed and broken to separate the seeds from the pods. The two portions of the samples (Okra peels and the seeds) were separately pulverized. The powdered samples were sieved with a fine mesh placed in a labeled sealed container and stored at normal laboratory conditions until when required for reconstitution and administration.

2.2.2 Induction of Diabetes

Alloxan diabetic rat were prepared by adopting the method of Saidu *et al.*,(2011) All

rats, except the Normal Control Group were intraperitoneally injected with 120 mg/kg body weight of the prepared Alloxan. After 6 h of alloxan administration, rats in their cages were then allowed 10 % glucose solution for the next 24 hours in order to prevent alloxan- induced hypoglycaemia. The animals were observed for polydipsia, polyuria, polyphagia as well as general reduction of body weight. Seventy two hours after the alloxan administration, the animals were fasted overnight and diabetes was confirmed by measuring fasting blood glucose level with the aid of a single touch glucometer (Fine touch, USA). Only rats that have fasting blood glucose level >7.0 mmol/l (126 mg/dl) were considered and included in the study (Saidu, *et al.*, 2011).

2.2.3 Grouping of Experimental Rats and Treatment

Simple random sampling technique was used in grouping the rats for this study. The rats were randomly divided into four (4) large groups: [(WO, OP, OS and the Control group (C)]. Each group was further subdivided into 3 sub-groups: (WO_1, WO_2, WO_3; OP_1, OP_2, OP_3; OS_1, OS_2, and OS_3) based on the dosage to be given i.e. 100, 200, and 300 mg/kg/day. The sub-groups in the control group were: Metformin (MC), Diabetic (DC) and Normal (NC) Control groups. The MC group was treated with 500 mg/kg Metformin while the DC and NC groups were not given any treatment and were maintained on normal diet and water. The weights of the rats were monitored before the induction and throughout the duration of the experiment.

2.2.4 Collection of Blood Sample and Preparation of Serum

Twenty four hours after the last treatment, the rats were subjected to 12 hours fasting after which they were anaesthetized by dropping individual animal in a plastic jar saturated with chloroform vapour. The rat was then removed from the jar and blood samples collected through cardiac puncture into labeled plastic specimen sample bottles containing EDTA for glycated haemoglobin assay. The remaining blood was collected into plain plastic centrifuge tubes and were allowed to clot then centrifuged at 4000 g for ten minutes. The sera obtained were pipetted into labeled specimen test tubes for estimation of serum glucose and lipid profile.

2.2.5 Determination of Biochemical Parameters

Blood glucose level was determined by glucose oxidase/ peroxidase method using Randox kit (Trinder, 1969). Total hemoglobin (Hb) content of the blood samples were estimated by spectrophotometric method (Dacie and Lewis, 1991). HbA_{1c} was determined by colorimetric method (Jim and Phillip, 1983) while serum total cholesterol (TC) was estimated by enzymatic method using Randox kit (Allain *et al.*, 1974). The serum high density lipoprotein cholesterol (HDL-C) was done by enzymatic method using Randox Kit (Burstein *et al.*, 1970). The procedure outlined by Tietz (1990) was adopted in the assay of serum triglyceride (TG) while the expression described by Friedewald *et al* (1972) was used to compute the values of serum low density lipoprotein cholesterol (LDL-C) as shown:

$$\text{LDL-C (mg/dl)} = \text{TC} - (\text{HDL - C}) + \left(\frac{TG}{5}\right)$$

The serum very LDL-C was also computed as described by Friedewald *et al* (1972) using the expression:

$$\text{VLDL-C (mg/dl)} = \frac{TG}{5}$$

while the ratio of LDL-C to HDL-cholesterol was adopted in the computation of atherogenic index as described by Abbott *et al* (1988).

2.2.6 Data Analysis

The data obtained were presented as mean ± standard error of the mean. Results of the biochemical parameters were analyzed by one way analysis of variance (ANOVA) followed by postHoc, Duncan test using the SPSS Software, Version 20 (IBM Corporation, New York, USA) A P-value < 0.05 was considered statistically significant.

3.0 Results

The results of the effect of treatment with different parts (WO, OP and OS) of the Okra fruit on body weight changes are presented in Table 1. The result indicates that alloxan injection resulted in drastic decrease in body weight of the animals compared with that of the normal control. The results of the repeated treatment with the different parts (WO, OP and OS) of the Okra fruit and Metformin for three weeks resulted in increase in body weight of all the treated rats. During the weekly body weight observation of the treated and untreated diabetic rats, there was no improvement in the observed body weight changes in the entire treated groups in comparison with the normal control rats after the first week of treatment with the different parts (WO, OP, and OS) of the Okra fruit at doses of 100, 200 and 300 mg/kg. The same effect was observed for Metformin control group. (Table 1). However, the effect of repeated treatment for 14 days resulted in considerable increases in body weight in all the animals treated with the different parts (WO, OP, and OS) of the Okra fruit and Metformin. This progress continued up to the last day (day 21) of the experimental period where most of the individual animals were observed to regain their initial body weight. On the other hand, there was progressive decrease in body weight of the diabetic untreated rats as compared with that of the normal control and the entire treated groups (Table 1).

The results of the effect of treatment with the different parts of the Okra fruit on serum glucose, total haemoglobin and glycated haemoglobin are presented in Table 2. Generally, the results indicate significant increase (P<0.05) in the levels of serum glucose (14.50±1.21 mmol/l) and percentage glycated haemoglobin (10.58±0.68) in the diabetic untreated group (DC) as compared with the normal control group (NC). Results of the effect of treatments with the different parts of the Okra fruit for three weeks resulted in significant (P<0.05) decrease in serum glucose and % glycated hemoglobin levels in a dose dependant manner as compared to the diabetic untreated group (DC). Although OP_3 show the highest hypoglycaemic effect (4.5 to 8.78 mmol/l) when compared with the other treated groups (Table 2); it was observed that, the glucose levels of diabetic rats treated with WO_3, OP_3, and OS_3 are statistically similar (P>0.05) with that of the normal and Metformin control groups. All the treatments also show significant decrease in % HbA_{1c} as compared with the diabetic untreated group (DC). The results also show a significant (P>0.05) decrease in haemoglobin concentration in diabetic untreated group compared with the normal untreated, Metformin control and groups treated with various parts of the Okra fruit.

The results of the effect of treatment with the different parts of the Okra fruit on serum lipid profile are presented in Table 3. The result indicates significant (P<0.05) increase in the levels of serum total cholesterol (TC), triglyceride (TG), very low density lipoprotein (VLDL-C), low density lipoprotein (LDL-C) and atherogenic index (AIX) but significant decrease in HDL-C in the alloxan-induced diabetic untreated group (DC) as compared with that of the normal control group (NC). Results of the effect of treatments with the different parts of the Okra fruit for three weeks (Table 3) show significant (P<0.05) decrease in the levels of serum TC, TG, VLDL-C, LDL-C and AIX while the serum HDL-C level was observed to significantly (P<0.05) increase. The same effect was observed in the MC treated group. The serum TC, TG, VLDL-C, LDL-C levels and AIX in WO_3 treated group are statistically (P>0.05) the same when compared with the normal and Metformin control groups (NC & MC).

Discussion

Diabetes mellitus is a complex metabolic disorder characterized by high blood glucose levels due to the inability of the body cells to utilize glucose properly (King and Brownlee, 1996; Saidu *et al.*, 2011). In the present study, an attempt was made to elucidate the role of different parts of Ex-Maradi Okra fruit variety in controlling diabetes mellitus in alloxan- induced diabetic rats. Diabetes was induced after the intraperitoneal administration of 120 mg/kg b.w of alloxan to the albino rats. There is increasing The reduction in phosphorylation at Ser-2 of RNAPII CTD (the phosphorylation site of CDK 9) by the CDK 9 knockdown as well as the Ser-5 phosphorylation (the CDK 7 phosphorylation

site) which remained unchanged indicated that a superior level of selectivity was achieved with biological inhibition (shRNA). This contrast to chemical inhibition of CDK9 in which both CDKI-77 and flavopiridol reduced Ser-5 phosphorylation (Shao *et al.*, 2012). These findings formed the basis that some level of certainty observed were solely due to CDK 9 inhibition.

Table 1: Effect of Administration of Different Parts of Okra Fruit on Body Weight of Alloxan-induced diabetic Rats

GRP	Body Weight Before Alloxan Induction (g)	Body Weight After Alloxan Induction (g)			
		Initial day	7th Day	14th Day	21st Day
[NC]	151.25±14.03	154.50±13.58	158.00±12.81	161.00±13.45	162.25±12.57
[DC]	135.00±9.59	124.00±10.68	116.00±11.15	108.75±10.81	102.00±9.78
[MC]	143.25±15.01	132.00±14.67	133.50±15.13	137.00±15.07	140.25±14.13
[WO_1]	132.75±15.56	118.75±15.04	122.50±15.76	127.25±15.51	130.25±15.81
[WO_2]	138.25±11.43	121.75±12.15	125.00±11.48	131.25±10.31	131.75±11.71
[WO_3]	137.25±9.72	123.00±11.26	129.25±9.97	134.75±9.62	138.50±9.45
[OP_1]	134.75±15.47	122.75±12.65	124.75±13.11	128.50±12.97	130.50±13.61
[OP_2]	143.00±18.05	130.50±17.86	131.00±18.08	133.75±17.65	134.50±16.94
[OP_3]	144.25±12.25	130.50±12.14	132.50±11.12	135.75±11.39	136.75±12.24
[OS_1]	136.50±17.99	124.25±17.71	127.00±16.84	129.75±17.32	132.25±17.08
[OS_2]	141.75±14.84	128.25±15.62	130.50±15.50	132.75±15.57	133.75±14.72
[OS_3]	146.25±21.03	135.50±20.29	138.00±20.17	142.25±19.83	143.25±19.40

Values are expressed as mean ± S.E.M., Mean values having the same superscript letter in the same column or row are significantly the same at ($p<0.05$). GRP: Group; NC: Normal Control, DC: Diabetic Control, MC: Metformin Control (500 mg/kg body weight) of Metformin; WO_1, WO_2, WO_3: (100, 200 & 300 mg/kg body weight) of Whole Okra., OP_1, OP_2, & OP_3: (100, 200 & 300 mg/kg body weight) of Okra Peel and OS_1, OS_2, & OS_3: (100, 200 & 300 mg/kg body weight) of Okra Seed.

Table 2: Effect of Administration of Different Parts of Okra Fruit on Serum Glucose, Total Haemoglobin and Glycated Haemoglobin Levels in Alloxan-induced diabetic Rats

GROUP	Glucose (mmol/l)	Total Hb (g/dl)	HbA_{1c} (%)
[NC]	5.13 ± 0.18^{a}	12.95 ± 0.66^{c}	4.48 ± 0.37^{a}
[DC]	14.50 ± 1.21^{d}	8.69 ± 0.47^{a}	10.58 ± 0.68^{e}
[MC]	4.72 ± 0.35^{a}	12.30 ± 0.17^{c}	5.55 ± 0.10^{a}
[WO_1]	9.27 ± 0.38^{c}	9.60 ± 0.40^{a}	6.97 ± 0.75^{c}
[WO_2]	7.42 ± 0.31^{b}	12.26 ± 0.16^{c}	6.23 ± 0.38^{b}
[WO_3]	5.32 ± 0.40^{a}	12.78 ± 0.18^{c}	5.35 ± 0.23^{a}
[OP_1]	8.78 ± 0.23^{c}	11.31 ± 0.19^{b}	5.93 ± 0.20^{b}
[OP_2]	7.08 ± 0.18^{b}	11.97 ± 0.48^{c}	5.45 ± 0.25^{a}
[OP_3]	4.51 ± 0.20^{a}	12.09 ± 0.17^{c}	4.96 ± 0.47^{a}
[OS_1]	8.89 ± 0.17^{c}	9.44 ± 0.19^{a}	8.01 ± 0.91^{d}
[OS_2]	7.86 ± 0.60^{b}	9.31 ± 0.36^{a}	8.42 ± 0.43^{d}
[OS_3]	5.90 ± 0.55^{a}	10.31 ± 0.35^{b}	6.28 ± 0.30^{b}

Values are expressed as mean ± S.E.M., Mean values having different superscript letter in the same column are significantly different at ($p<0.05$). NC: Normal Control, DC: Diabetic Control, MC: Metformin Control, WO_1, WO_2, WO_3; OP_1, OP_2, OP_3; and OS_1, OS_2, OS_3 denotes Whole Okra, Okra peel and Okra Seed while the Subscripts 1, 2 and 3 denotes doses of 100,200 and 300 mg/kg body weight respectively.

Table 3: Effect of Administration of Different Parts of Okra Fruit on Serum Lipid Profile and Atherogenic Index in Alloxan-induced diabetic Rats

	Lipid Profile (mg/dl)					
GRP	TC	TG	HDL	VLDL	LDL	AIX
[NC]	72.35±1.37^{a}	77.25±1.67^{a}	48.05±1.31^{c}	15.44±0.33^{a}	8.85±1.30^{a}	0.18±.03^{a}
[DC]	104.59±2.88^{e}	94.10±2.30^{c}	22.67±1.24^{a}	18.82±0.46^{c}	63.09±3.25^{e}	2.81±0.22^{c}
[MC]	69.58±1.81^{a}	78.51±1.36^{a}	43.29±3.52^{c}	15.70±0.27^{a}	10.59±3.97^{a}	0.26±0.10^{a}
[WO_1]	85.91±4.48^{b}	86.89±3.37^{b}	38.84±1.91^{b}	17.37±0.67^{b}	29.67±2.95^{c}	0.76±0.054^{b}
[WO_2]	79.09±1.69^{ab}	80.19±1.65^{a}	42.58±1.52^{c}	16.03±0.32^{a}	20.47±1.15^{b}	0.48±0.039^{a}
[WO_3]	76.26±3.33^{a}	76.42±1.15^{a}	47.85±1.28^{c}	15.28±0.23^{a}	13.12±2.27^{a}	0.27±0.04^{a}
[OP_1]	88.04±0.84^{c}	90.69±4.44^{b}	37.54±1.09^{b}	18.13±0.88^{b}	32.36±0.97^{c}	0.86±0.03^{b}
[OP_2]	93.45±2.79^{d}	90.39±2.21^{b}	39.24±0.878^{b}	18.07±0.44^{b}	36.13±3.49^{d}	0.93±0.10^{b}
[OP_3]	84.51±2.53^{b}	82.42±5.20^{a}	42.68±1.75^{c}	16.48±1.04^{a}	25.34±3.81^{b}	0.92±0.41^{b}
[OS_1]	90.27±2.44^{dc}	106.83±3.83^{d}	38.88±0.68^{b}	21.36±0.76^{c}	30.03±1.62^{c}	0.77±0.03^{b}
[OS_2]	86.57±3.73^{b}	95.09±5.22^{c}	37.24±1.49^{b}	18.89±1.01^{c}	30.43±5.56^{c}	0.83±0.17^{b}
[OS_3]	89.81±2.48^{c}	90.82±1.44^{b}	39.32±.815^{b}	18.16±0.28^{b}	32.32±1.63^{c}	0.81±0.03^{b}

Values are expressed as mean ± S.E.M., Mean values having different superscript letter in the same column are significantly different at (p<0.05). TC: Total Cholesterol,TAG: Triacylglycerol, HDL: High Density Lipoprotein, VLDL : Very Low Density Lipoprotein, LDL: Low Density Lipoprotein, AIX: Atherogenic index, GRP: group, NC: Normal Control, DC: Diabetic Control, MC: Metformin Control (500 mg/kg) body weight of Metformin; WO_1, WO_2, WO_3: (100, 200 & 300 mg/kg) body weight of Whole Okra., OP_1, OP_2, & OP_3: (100, 200 & 300 mg/kg) body weight of Okra Peel and OS_1, OS_2, & OS_3: (100, 200 & 300 mg/kg) body weight of Okra Seed.

evidences showing that mechanism of Alloxan-induced diabetes involves the degeneration of islet β-cells by accumulation of cytotoxic free radicals (Halliwell and Gutteridge, 1989; Szkudelski, 2001). Following its administration, alloxan is concentrated in the islets and in the liver, where it is reduced to dialuric acid (Halliwell and Gutteridge, 1989; Szkudelski, 2001). This acid is unstable in aqueous solutions and undergoes oxidation back to alloxan, accompanied by generation of superoxide, hydrogen peroxide and hydroxyl radicals by Fenton type reaction (Halliwell and Gutteridge, 1989; Szkudelski, 2001). The liver contains high Super Oxide Dismutase (SOD), Catalase and Glutathione Peroxidase activities, which scavenge these free radicals (Halliwell and Gutteridge, 1989; Szkudelski, 2001). But the islet cells have low concentrations of these enzymes and are vulnerable to the cytotoxic effects of the free radicals (Szkudelski, 2001). The selective toxicity on β-cell after the alloxan injection, leads to reduction in insulin level, which leads to alteration in glucose metabolism and utilization (Arumugam *et al.*, 2008) thereby causing hyperglycemia (Arumugam *et al.*, 2008). Generally, prolonged uncontrolled high blood glucose has been shown to results in elevated levels of serum glucose, glycated hemoglobin and oxidative stress indices. (Asayama *et al.*, 1986). Following injection with Alloxan, the animals displayed the expected symptoms of insulin-dependent diabetes mellitus, i.e., hyperglycaemia, polydipsia, polyuria, depression of body mass, increase in food and water intake and as previously observed by Robert, (2001).

In the current study, the observed drastic decrease (loss) in body weight of the alloxan-induced diabetic rats as compared to normal control rats (Table 1) could be due to the selective destruction of pancreatic ß-cells of the islets of Langerhans (insulin producing cells) by alloxan (Szkudelski, 2001). This leads to insulin

deficiency and leading to decrease in peripheral glucose uptake and utilization and increase gluconeogenesis. These cause increase degradation of structural proteins thereby affecting the body weight of the animals (Ladan *et al.*, 2007). During this study, the observed body weight gain in the entire treated groups of rats after the first, second and third weeks of repeated treatment with the different parts could be a function of antidiabetic effect of the Okra fruit parts. The Okra fruit parts ability to reduce hyperglycaemia and improve glucose metabolism may lead to improved peripheral glucose uptake and utilization, glycogen synthesis and decrease gluconeogenesis. These spare structural protein from degradation (muscle wasting) and help maintain the weight.

The significant decrease in fasting blood glucose level observed in the groups treated with all doses of the fruit might be due to various factors associated with Okra such as high fiber content, high viscosity, inhibition of intestinal glucose diffusion and absorption as well as inhibition of some enteric intestinal enzymes such as α-glucosidase and α- amylase that are all associated with hypoglycemic effect (Subrahmanyam *et al.*, 2011; Sabitha *et al.*, 2011 and John *et al.*, 2013). This finding is supported by some previous work on other Okra fruit varieties. Subrahmanyam *et al.*, (2011) and Chanida *et al.*, (2009) have reported the hypoglycemic effect of Okra fruit where Okra fruit extract was found to inhibit α- glucosidase and α- amylase enzymes. Okra dietary fiber could bind to glucose and prevent or delay it absorption from the intestinal lumen (John *et al.*, 2013), and this could be beneficial with respect to reducing the amount of accessible glucose absorbed from the small intestine (John *et al.*, 2013) hence reducing postprandial blood glucose level.

In the present study, significant increase in the levels of glycated haemoglobin (HbA_{1c}) observed in non-treated diabetic control rats than the normal control group might be due to the persistent hyperglycemia which may results to the non-enzymatic glycation of plasma proteins (Rohlfing *et al.*, 2000). leading to the production of more powerful oxidizing species (Khaw *et al.*, 2001).. This contributes to increased levels of glycated haemoglobin (Rohlfing *et al.*, 2000). HbA_{1c} concentration is associated with diabetic micro, macrovascular complications and risk of death (Rohlfing *et al.*, 2000 and Khaw *et al.*, 2001). Administration of the fruit reduced the elevated levels of HbA_{1c} in treated diabetic rats compared with that of the diabetic control. All these indicate its potentials to prevent the diabetic associated complications. It has been reported that agents with antioxidant or free radical scavenging property may inhibit oxidative reactions associated with glycation (Baynes, 1991). The antiglycation properties of the Okra fruit parts might be connected with the antioxidants rich compounds (*e.g.*, carotenoids, riboflavin, ascorbic acid, thiamine, nicotinic acid etc.) identified in Okra fruit (Habtamu *et al.*, 2014). Also, the decrease in blood glucose levels might also contribute to decreased levels of glycated haemoglobin in the treated rats. The trend of decreased % glycated hemoglobin levels as observed in the treated groups with the different parts of the Okra fruit showed that, the level of glycation was found to be reduced more in the WO_3 followed by OP_3 then OS_3 treated group. The decrease in hemoglobin concentration in diabetic untreated group cmapared with the treated groups and control might be due to decrease protein synthesis associated with diabetes (Subrahmanyam *et al.*, 2011)

The significant elevation in lipid profile parameters in the diabetic rats as compared to the normal control rats is in line with the findings of Yadav *et al.*, (2004). This might be as a result of increased breakdown of lipids and mobilization of free fatty acids (FFA) from the peripheral deposits as a result of paucity in glucose due insulin deficiency (Garg and Grundy, 1990; Ladan *et al.*, 2007). Also, Insulin could inhibit the hormone-sensitive lipases, and these become active in the absence of insulin (Ladan *et al.*, 2007). Other hormones such as glucagon and catecholamines are known to increase during diabetes (Ceriello *et al.*, 2013) and are known to stimulate lipolysis in the adipose tissue (Yadav *et al.*, 2004). Administration of different doses of the different part of the Okra fruit showed significant reduction in TC, TG, LDL, VLDL and significant increase in the level of HDL-C than that of the diabetic control rats demonstrate the

hypolipidaemic effect of the Okra fruit. There could be two possibilities for the normalization of the altered parameters in the lipid profile. Firstly, the rate of lipolysis may be normalized by the improved normoglycaemia (due to hypoglycemic effect of the fruit) leading to inhibition of hormone-sensitive lipases thereby reducing rate of lipolysis. (Raju *et al.*, 2001). Secondly, since the attainment of normoglycaemia in the animals was achieved by the ability of Okra to retard postprandial blood glucose level, this could lead to activation of lipogenesis and inhibition of lipolysis in the rats' adipose tissue (Muhammad *et al.*, 2006). The Okra fiber/ mucilage could also decrease the absorption of dietary cholesterol from the intestine because it could binds with the bile salts and reduces their enterohepatic circulation there by resulting in increased degradation of cholesterol to bile salts and its disposal from the body (Viuda-Martos *et al.*, 2010).

Conclusion

The findings of this study indicated the alloxan-induced biochemical changes like hyperglycaemia, increased glycated haemoglobin and hyperlipidaemia were markedly restored to near normal levels by the different parts of Ex-Maradi Okra fruit variety. This study also demonstrated that both the peel and the seed of Ex-maradi Okra fruit variety possess significant hypoglycaemic and hypolipidaemic effects and can be used in the development of Okra-based anti-diabetic nutraceutical for the management of diabetes mellitus.

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