

## Ameliorative Potentials of *Cyperus Esculentus* Oil on Type 2 Diabetes Induced by High Fat Diet and Low Dose Streptozotocin in Male Wistar Rats

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### ABSTRACT

The aim of this study is to investigate the ameliorative potentials of *Cyperus esculentus* (Tigernut) oil, in type 2 diabetes induced with the combination of high fat diet and a low dose streptozotocin (35mg/kg) in male Wistar rats. Forty rats weighing between 100-115g were divided randomly into group of five ( $n = 8$ ), 3 groups were subsequently fed with a high fat diet (HFD) for 30 days and the other 2 were maintained on normal rat chow (NPD). Results revealed an increase in body weight amongst the groups fed with a HFD and treatment with *C. esculentus* oil significantly ( $p < 0.05$ ) reduced the body weight (HFD+STZ+CEO). Glycated hemoglobin (HbA1C), G6PDH and  $\alpha$ -Amylase activity were significantly stabilized in *C. esculentus* oil treated group. Oral glucose tolerant test with a load

dose of 150 mg/kg glucose showed there was a rapid blood sugar level clearance in HFD+STZ+CEO as compared to untreated group (HFD+STZ). Atherogenic index (AIP) levels was significantly ( $p < 0.05$ ) lowered in the treated groups (HFD+STZ+GLI  $0.262 \pm 0.40$  and HFD+STZ+CEO  $0.18 \pm 0.03$ ) when compared to untreated groups (HFD+STZ  $0.495 \pm 0.66$  and NFD+STZ  $0.495 \pm 0.57$ ) as well as Triglyceride and VLDL levels. Enzymatic antioxidants activities were enhanced by *C. esculentus* oil. Therefore, *C. esculentus* oil may be used as either a therapeutic agent or as a dietary choice for the management of type 2 diabetes.

**Key words:** *Cyperus esculentus* (Tigernut) oil; Diabetes Mellitus, High fat diet

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### INTRODUCTION

The World Health Organization estimated that 9% of the world's population was diabetic in 2014, over 90% of these are Type 2 Diabetes and that adult onset diabetes causes 5 million deaths per year, mostly from heart diseases<sup>[1]</sup>. Also, 40,815 deaths in adults due to diabetes were recorded, the burden of the disease has silently been on the increase over the years and it is expected to explode over the next decade<sup>[2]</sup>. Type 2 diabetes is strongly associated with obesity, and as such is a major problem for middle/low-income population as well as in developing countries where urbanization has brought rapid changes in lifestyle with respect to both diet and sedentary life. Although genetic make-up might partially determine an individual's response to changes in the environment, the main drive of the world increase in Type 2 Diabetes Mellitus (DM) are increasing obesity, less physical activity lifestyle, high calorie diets rich in carbohydrate/fat and increased ageing population<sup>[3]</sup>. The is evidence supporting the fact that pre-diabetes could be reversed and type 2 DM could

be prevented by maintaining a healthy body weight, eating diets rich in green leafy vegetables/fruits, moderate daily exercise for at least 30 min, quitting smoking and moderate consumption of alcohol<sup>[4]</sup>. However, diabetes is also characterized by dramatic complications with the eye, kidney, lower limbs, slowed wound healing and impotence especially if it is poorly managed over time<sup>[5]</sup>. Heart and blood circulation diseases such as cardiovascular disease (CVD), coronary heart disease (CHD), peripheral vascular disease and cerebrovascular disease is a major cause of death, incidentally diabetic patients develop CVD typically 14.6 years earlier than non-diabetic subjects and often with much greater severity<sup>[6,7]</sup>.

Streptozotocin injection in rats destroys the pancreatic beta cells, culminating into insulin deficiency and could lead to symptoms characteristics of human type-1-diabetes such as frequent urination, increased thirst and elevated blood glucose levels<sup>[8,9]</sup>. However, intake of high-fat diet (HFD) in rat could lead to obesity, hyperinsulinemia, and insulin resistance<sup>[10]</sup>. Hyperlipidemia is a common problem today due to greater sedentary lifestyle and changing food choice towards more junk meals. Drugs and diet are important in the management of high lipid and lipoprotein levels in blood. Previous studies have shown that the uncontrolled consumption of high fat diet also leads to insulin resistance (IR) because the saturated fatty acids (SFA) can interfere with the action of insulin<sup>[11]</sup>. High fat diet leads to insulin resistance (IR), which increases the chances of developing diabetes mellitus and its associated complications such as diabetic nephropathy, retinopathy, neuropathy, gastroparesis, oxidative stress, etc. Furthermore oxidative stress has been associated with pathologies such as atherosclerosis and diabetes mellitus<sup>[12]</sup>. The fundamental aspect in the etiology of DM is that insulin resistance (IR) is linked to a wide array of other complications including hyperlipidemia. Thus, it is of paramount importance to establish an animal model, to have a better understanding of the pathological process involved in insulin resistance (IR) and hyperlipidemia, which would further aid in developing new therapeutic drugs which would modulate both the conditions<sup>[13]</sup>.

*Cyperus esculentus* oil is underutilized, there is currently no available study on the effect of this oil on high fat diet induced diabetes and other coronary heart disease risk factor; thus the present work was to investigate the ameliorating potential of *Cyperus esculentus* oil on high fat induced diabetes.

## MATERIALS AND METHODS

### Collection of plant

Tiger nut was collected from a local farm in Maiduguri, Borno State, Nigeria and identified at Botany Department, University of Ibadan. The tubers were visually inspected, defective tubers manually removed and discarded. Hence, only matured healthy tubers were selected, washed, air dried at room temperature, crushed to fine pieces prior to extraction.

### Oil extraction

4kg of the powdered tubers was transferred into a glass container and 7.5litres of redistilled n-hexane was added and extracted by cold maceration 72 hours, extract was sieved using muslin clothe. Extraction process was repeated using another 5litres of the solvent for 72 hours and process was repeated. The extracts were pooled together, was further filtered using Whatman NO:40 filter paper and the filtrate was then concentrated using Rotary evaporator at 30°C, oil was further concentrated using vacuum oven set at 30°C and a pressure of 700 mg/Hg. 1.3kg oil was obtained from 4 kg crushed dried seed corresponding to 32.59% yield.

### Analysis of feed

The proximate content for protein, carbohydrate, fat, ash and moisture were done according to standard procedure<sup>[14]</sup> and mineral analyses was by Atomic Absorption Spectrophotometry (AAS).

**Table 1** Feed composition.

| Parameters  | Normal Chow | Formulated Chow |
|-------------|-------------|-----------------|
| Protein     | 21%         | 29.90%          |
| Fat(Butter) | 3.50%       | 40%             |
| Fibre       | 6.00%       | 3.70%           |
| Calcium     | 0.80%       | 0.12%           |
| Phosphorus  | 0.8         | 0.32            |
| Cholesterol |             | 2%              |
| Dry Matter  |             | 88.91%          |

### Chemical

All the chemicals used in this study were of analytical grade, unless stated otherwise. Streptozotocin (Santa Cruz, U.S.A), Potassium chloride (BDH Chemical Ltd, England), dipotassium hydrogen phosphate  $K_2HPO_4$  (Hopkins and Williams Ltd, England) and anhydrous potassium dihydrogen phosphate  $KH_2PO_4$  (BDH Chemical Ltd, England).

### Animals used

A total of 40 male Wistar rats between the weights of 100-115g were procured from the central animal house, College of Medicine, University of Ibadan, Nigeria for the study and were allowed to acclimatize for two weeks. Three selected groups were subsequently fed with a high fat diet for 30 days. The rats were kept in clean, well ventilated cages and their beddings of wood shavings were changed every three days. The animals were allowed free access to clean drinking water. Animal care and handling were carried out according to standard protocols approved by the Animal Ethics Committee of the University.

### High fat diet (HFD)-fed and streptozotocin treatment

The rats were divided into two dietary regimens consisting of 16 rats fed normal chow and 24 rats fed with a high fat diet for a period of 30 days. After 30 days, the experimental groups were administered intraperitoneally (I.P) with low dose of Streptozotocin (STZ) (35 mg/kg) dissolved in a citrate buffer (0.1 M, pH 4.5) as described by (Srinivasan *et al*, 2004). After 72 hours, blood from caudal vein was used to determine fasting blood sugar level using ACCU-CHEK Glucometer; rats with values  $\geq 179.85 \pm 4.3$  were considered diabetic and were use in the study. Rats were grouped as follows: normal control (NPD) received corn oil and negative control (NPD+STZ) untreated. The other three groups were fed high fat diet with low dose streptozotocin 35 mg/kg (HFD+STZ) and received *Cyperus esculentus* oil (0.5 mL) (HFD+STZ+CEO), standard drug glimepiride 2 mg/kg orally (HFD+STZ+GLI) and the other group remained untreated (HFD+STZ) respectively for a period of 21days.

### Sample preparation

The organs collected were washed in ice cold 1.15% KCl solution, blotted with filter paper, weighed and homogenized in four volumes of the homogenizing phosphate buffer (pH 7.4) using a Teflon homogenizer. The resulting homogenate was centrifuged at 10,000G for 15 minutes in a cold centrifuge model 4000 at (4°C). The supernatant was collected and used for antioxidant analysis.

**Biochemical analysis**

Blood glucose level was measured weekly with glucometer, glycated hemoglobin, Randox kit was used for enzymatic hydrolysis to determine Glucose 6 phosphate,  $\alpha$ -Amylase, triglyceride, total cholesterol and high density lipoprotein-cholesterol. Friedewald equation was used for calculating low density lipoprotein cholesterol and atherogenic index<sup>[15,16]</sup>. Liver Protein concentrations were determined by Bradford method<sup>[17]</sup>. Catalase activity was determined according to the method of Claialborne, 1985<sup>[18]</sup>, the method of Beutler *et al*<sup>[19]</sup> 1963 was followed in estimating the level of reduced glutathione (GSH), the activity of SOD was determined by the method of Misra and Fridovich 1972<sup>[20]</sup> and Glutathione peroxidase (GPX) activity was measured according to the procedure of Rotruck *et al*<sup>[21]</sup> 1963 respectively.

**Statistical analysis**

Data were treated by ANOVA (analysis of variance) and mean separation was done using Turkey HSD and Duncan. Paired T-test was used to establish difference in timely events among same individual group animals and  $p < 0.05$  were considered significant. Data was expressed as means  $\pm$  standard deviation. All statistical analysis was done using IBM SPSS Version 22 and Microsoft Excel.

**RESULTS**

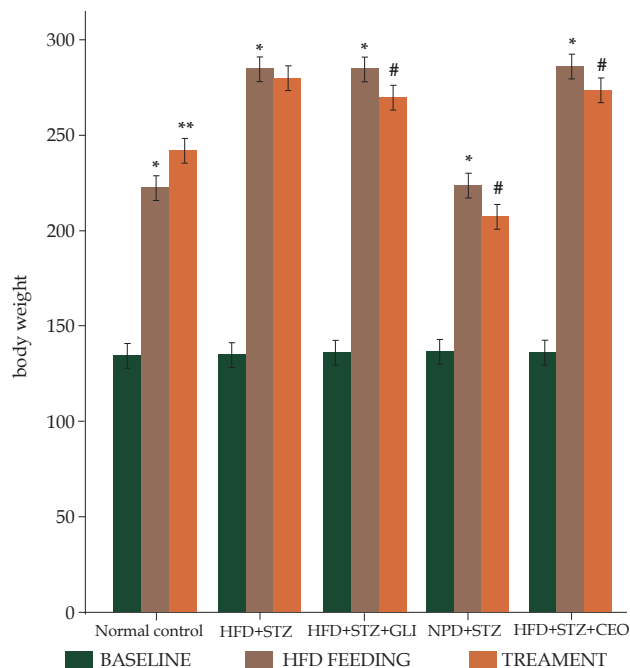
**Body weight and High fat diet**

Figure 1 demonstrates the effect of high fat diet and *C. esculentus* oil on male Wistar rats. Following two (2) weeks of acclimatization, they rats body weights were measured and reported as baseline. Selected groups were fed high fat diet for a period of 30 days and body weights were also measured and reported as HFD feeding. Thus, there was a significant increase in the body weight of rats fed HFD; HFD+STZ 285.20  $\pm$  2.25, HFD+STZ+GLI 285.20  $\pm$  4.93 and HFD+STZ+CEO 286.80  $\pm$  4.32 relative to the baseline of the same groups. However, after treatment, body weights were significantly reduced  $p < 0.05$  for HFD+STZ+GLI 270.40  $\pm$  7.96, HFD+STZ+CEO 273.80  $\pm$  5.26 and NPD+STZ 207.60  $\pm$  8.56 relative to after HFD feeding of the same group 285.40  $\pm$  4.93, 285.80  $\pm$  4.32 and 224.40  $\pm$  6.11 respectively.

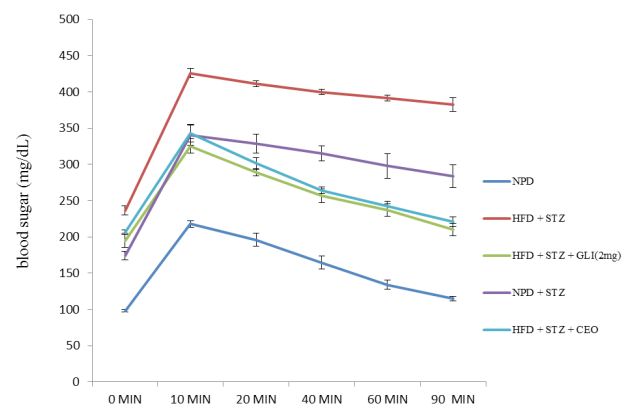
**High fat diet, *Cyperus esculentus* oil and Blood sugar levels**

Table 2 shows the effect of high fat diet and *C. esculentus* oil on blood sugar levels. After two weeks of acclimatization, the blood sugar levels of all the rats were determined and recorded as (Baseline). a subset of 24 rats were fed manipulated high fat diet and subsequently, the experimental groups were intraperitoneally injected 35 mg streptozotocin and after 72 hours, blood sugar levels were determined and reported as (After induction) and there was a significant blood sugar levels increase  $p < 0.05$  relative to the baseline. However,

treatment for the period of three (3) weeks revealed that *C. esculentus* oil treated group, similar to the reference drug, significantly reduced the blood sugar level relative to the untreated groups; HFD+STZ and NPD+STZ. Also, after 21 days of treatment, a load dose of 150 mg/kg of glucose was administered and blood sugar clearance was monitored for 90 minutes as shown in figure 2. Blood sugar clearance was low in the high fat diet (HFD+STZ) untreated group relative to untreated normal pellet diet (NPD) animals. However



**Figure 1** Effect of High fat diet and *Cyperus esculentus* oil on body weight. \* Significant increase ( $p < 0.05$ ) vs baseline; \*\* Significant increase ( $p < 0.05$ ) vs after HFD feeding; # Significant decrease ( $p < 0.05$ ) vs after HFD feeding.



**Figure 2** Effect of *Cyperus esculentus* oil on oral glucose tolerance test.

**Table 2** Effect of high fat diet (HFD) and *Cyperus esculentus* oil on glucose level.

| Groups         | Baseline         | After induction   | Treatment Duration |                    |                    |
|----------------|------------------|-------------------|--------------------|--------------------|--------------------|
|                |                  |                   | Week one           | Week two           | Week three         |
| Normal control | 96.8 $\pm$ 6.3   | 99.8 $\pm$ 84.49  | 100.4 $\pm$ 6.69a  | 101.20 $\pm$ 5.93a | 99.40 $\pm$ 2.40a  |
| HFD+STZ        | 103.83 $\pm$ 4.6 | 241.3 $\pm$ 16.3* | 253.67 $\pm$ 12.1d | 244.50 $\pm$ 9.1d  | 241.17 $\pm$ 8.7d  |
| HFD+STZ+GLI    | 101.28 $\pm$ 74  | 253 $\pm$ 7.9*    | 222.28 $\pm$ 7.9cd | 212 $\pm$ 7.0c     | 196.7 $\pm$ 9.9c   |
| NPD+STZ        | 104.14 $\pm$ 4.9 | 179.85 $\pm$ 4.3* | 178.28 $\pm$ 4.2b  | 177 $\pm$ 8.5b     | 175.85 $\pm$ 6.54b |
| HFD+STZ+CEO    | 104.43 $\pm$ 61  | 260.57 $\pm$ 8.4* | 235.57 $\pm$ 7.3c  | 218.14 $\pm$ 8.5c  | 199.71 $\pm$ 7.7c  |

Values are mean $\pm$ SD: Means with different alphabet as superscript within each column variable are significantly ( $p < 0.05$ ) different and \* indicates significant increase ( $p < 0.05$ ) vs baseline. The abbreviations denote HFD: high fat diet, NPD: normal pellet diet, CEO: *Cyperus esculentus* oil, GLI: glimepiride, STZ: Streptozotocin. \* Significant increase ( $p < 0.05$ ) vs baseline

treatment with glimepiride (HFD+STZ+GLI) and *C. esculentus* oil (HFD+STZ+CEO) significantly cleared blood sugar when compared to the untreated groups.

**Glycated hemoglobin, glucose 6 phosphate dehydrogenase and  $\alpha$ -Amylase**

Figure 3 reveals the effect of *C. esculentus* oil on Glycated hemoglobin, glucose 6 phosphate dehydrogenase and  $\alpha$ -Amylase. At the end of the present study, blood samples were collected, plasma level of HBA1C and serum G6PDH and  $\alpha$ -Amylase were determined. The levels of HBA1C and  $\alpha$ -Amylase were significantly elevated in negative control  $p < 0.05$  relative to the normal control whereas, G6PDH was significantly reduced. However, treatment with *C. esculentus* oil significantly  $p < 0.05$  reduced the levels of HBA1C,  $\alpha$ -Amylase and increased the levels of G6PDH relative to the untreated groups (HFD+STZ & NPD+STZ).

***Cyperus esculentus* oil and high fat diet on lipid profile**

Table 3 shows the effect of high fat diet (HFD) and *C. esculentus* oil on lipid profile. After acclimatization animals were bled to obtain baseline plasma lipid profile levels and following high fat diet feeding

for the period of 30 days (After HFD), the lipid profile levels were also determined and TRIG and CHOL levels was significantly increased ( $p < 0.05$ ) relative to the baseline. However, after treatment with *C. esculentus* oil as shown in table 4. TRIG, CHOL, LDL, and AIP levels were significantly lowered ( $p < 0.05$ ) as compared to the untreated groups (HFD+STZ) and (NPD+STZ) respectively. Meanwhile, HDL-CHOL in *C. esculentus* oil treated group (HFD+STZ+CEO) was significantly increased ( $p < 0.05$ ) relative to untreated groups.

**Effect of *Cyperus esculentus* oil on Antioxidant levels**

Table 5 shows that there was a significant ( $p < 0.05$ ) decrease in catalase levels in the untreated groups HFD+STZ  $0.76 \pm 0.23$  and NPD+STZ  $0.91 \pm 0.29$  as compared to the normal group  $2.54 \pm 1.77$ . Meanwhile, the levels of Glutathione Peroxidase (GPx), Reduced Glutathione (GSH), and Superoxide Dismutase (SOD) scavenging activity were significantly increased ( $p < 0.05$ ) in *C. esculentus* oil treated group (HFD+STZ+CEO) relative to the untreated group (HFD+STZ). Lipid Peroxidation (LPO) showed no significant difference ( $p > 0.05$ ) between the experimental groups. However, they was significant difference ( $p < 0.05$ ) between the normal control and the experimental groups.

**Table 3** Effect of high fat diet (HFD) on lipid profile

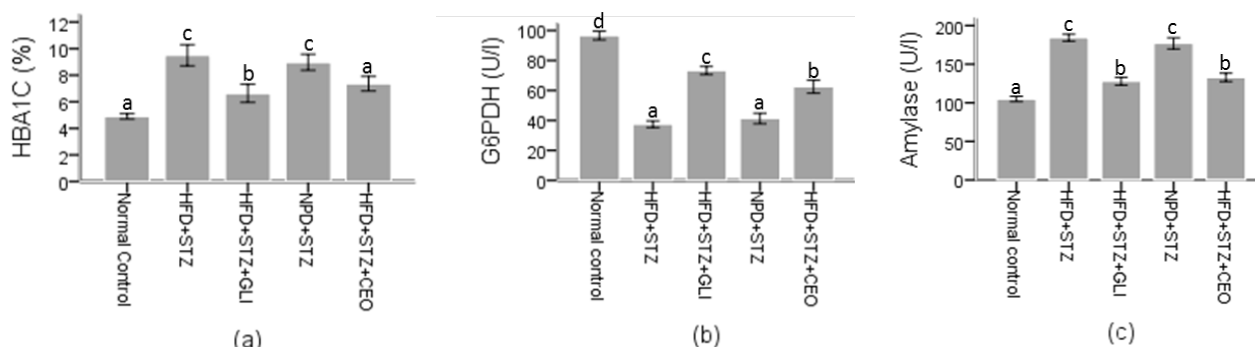
| Groups         | TRIG        |              | CHOL        |              | HDL-CHOL    |             |
|----------------|-------------|--------------|-------------|--------------|-------------|-------------|
|                | Baseline    | After HFD    | Baseline    | After HFD    | Baseline    | After HFD   |
| Normal Control | 158.83±13.7 | 171.82±14.1  | 167.7±24.5  | 163.52±30.9  | 123.0±11.9  | 137.05±2.0  |
| HFD+STZ        | 176.90±26.4 | 326.80±38.3* | 169.85±26.3 | 257.25±17.1* | 124.02±13.2 | 104.97±19.4 |
| HFD+STZ+GLI    | 183.45±45.3 | 310.40±58.9* | 156.47±26.2 | 260.07±13.5* | 123.05±18.7 | 110.05±6.9  |
| NPD+STZ        | 181.97±63.5 | 296.25±28.0* | 163.50±17.8 | 254.41±9.9*  | 121.15±16.2 | 110.32±13.4 |
| HFD+STZ+CEO    | 180.17±32.4 | 292.6 ±38.9* | 138.12±25   | 250.92±24*   | 127.25±25   | 130.2±19.15 |

Data are expressed as means±SD: the abbreviations denote HFD: high fat diet, NPD: normal pellet diet, CEO: *Cyperus esculentus* oil, GLI: glimepiride, STZ: Streptozotocin, TRIG: triglyceride, CHOL: cholesterol, HDL-CHOL: high density lipoprotein cholesterol. \* Significant ( $p < 0.05$ ) vs baseline. \*\* Significant ( $p < 0.05$ ) vs after HFD.

**Table 4** Effect of *Cyperus esculentus* oil on lipid profile after treatment

| GROUPS         | TRIG        | CHOL          | HDL-Chol     | VLDL         | AIP         |
|----------------|-------------|---------------|--------------|--------------|-------------|
| Normal control | 163.52±6.5a | 131.36±20.12a | 131.30±7.9b  | 32.70±2.89a  | 0.094±0.05a |
| HFD+STZ        | 316.9±62.5c | 252.35±18.7c  | 100.23±8.4a  | 63.38±12.49c | 0.495±0.66c |
| HFD+STZ+GLI    | 223.97±8.2b | 171.86±15.7b  | 122.64±9.77b | 44.79±1.65b  | 0.262±0.40b |
| NPD+STZ        | 315.9±28.5c | 226.95±9.4c   | 100.95±7.9a  | 63.19±5.70c  | 0.495±0.57c |
| HFD+STZ+CEO    | 206.11±11ab | 152.25±22.4ab | 134.76±6.3b  | 41.22±2.20ab | 0.18±0.03b  |

Data are expressed as means±SD: Means with different alphabet as superscript within each column variable are significantly ( $p < 0.05$ ) different from each other. The abbreviations denote HFD: high fat diet, NPD: normal pellet diet, CEO: *Cyperus esculentus* oil, GLI: glimepiride, STZ: Streptozotocin, TRIG: triglyceride, CHOL: cholesterol, HDL-CHOL: high density lipoprotein cholesterol, VLDH: very low lipoprotein, AIP: atherogenic index plasma.



**Figure 3** Effect of *C. esculentus* oil on (a), Glycated hemoglobin (b), Glucose 6 phosphate dehydrogenase and (c)  $\alpha$ -Amylase. The abbreviations denotes, HBA1C: Glycated hemoglobin, G6PDH: Glucose-6-phosphate dehydrogenase, denote HFD: high fat diet, NPD: normal pellet diet, CEO: *Cyperus esculentus* oil, GLI: glimepiride, STZ: Streptozotocin.



## DISCUSSION

The prevalent form of diabetes mellitus (DM) by far is type 2 diabetes, affecting about 90 % of people with diabetes, while the remaining 10 % mainly are affected by type-1-diabetes or gestational diabetes<sup>[22]</sup>. Type 2 diabetes mellitus (T2DM) is a metabolic syndrome, which is characterized by fat accumulations, impairment in insulin action<sup>[23]</sup> and of course, it is associated with overweight. In this light, the present study, fed a subset of rats manipulated high fat diet (HFD) comprising of saturated fat in form of butter 40% and cholesterol 2% (Table 1) for 30days. Thus, the body weight of the rats (Figure 1) were significantly increased  $p < 0.05$  in the groups fed with HFD compared to the groups fed with NPD. The increased body weight found in HFD rats might be due to the consumption of a diet rich in energy in the form of saturated lipids (butter) and eventual fat deposition in various body parts<sup>[10]</sup>. Also, there was an observed decreased psychomotor activity in HFD fed groups relative to the NPD-fed animals, which perhaps resulted in less energy dissipation and reduction in energy expenditure contributes to increased body weight<sup>[24]</sup>. Generally excessive weight gain is another factor which predisposes a patient to development of both type 2 DM and CVD<sup>[25]</sup>. In this light, of course administration of *C. esculentus* oil significantly reduced the body weight of the rats, perhaps attenuating the development of DM and CVD. Apparently, weight loss is a fundamental treatment modality<sup>[26]</sup> and it is a key therapeutic goal in both the prevention and management of type 2 diabetes<sup>[27]</sup>.

High fat diet leads to insulin resistance (IR), which increases the chances of developing DM plus the associated complications<sup>[12]</sup>. The accumulation of fat in visceral organ such as liver, the pancreas leads to synergy that interact with IR and fat to bring about type 2 DM<sup>[28]</sup>. In agreement with these reports, in this study, blood sugar levels of groups fed high fat diet and intraperitoneal injection of low streptozotocin 35mg/kg (HFD+STZ) significantly increased ( $p < 0.05$ ) relative to groups fed normal pellet diet (NPD) table 2 and the result is consistent with the findings of<sup>[29]</sup>. However after 21days of treatment with standard drug glimepiride 2 mg/kg and *C. esculentus* oil, there was a significant reduction ( $p < 0.05$ ) of blood sugar levels vis-à-vis (HFD+STZ). Additionally, previous studies have shown that herbal remedies consumption of tigernut (*Cyperus esculentus*) is relatively popular in some societies as an antidiabetic agent<sup>[30,31]</sup> and tigernut-supplemented diet (25% w/w) for four weeks recorded a significant decrease in blood sugar levels<sup>[32]</sup>. The result of the oral glucose tolerance test (OGTT) (Figure 2) demonstrated a rapid blood sugar level clearance in treated groups (HFD+STZ+GLI) and (HFD+STZ+CEO) relative to the untreated group (HFD+STZ) and the reduced blood sugar clearance may be attributed to accumulation of fats in diet in visceral tissues.

To further confirm the hypoglycemic capacity of *C. esculentus*, glycated hemoglobin (HbA1C) glucose-6-phosphate dehydrogenase (G6PDH), and  $\alpha$ -Amylase levels were investigated (Figure 3 b, c & d). Glycated hemoglobin (HbA1C) is formed in a non-enzymatic pathway by hemoglobin's normal exposure to high plasma glucose levels<sup>[33]</sup>, Glucose-6-phosphate dehydrogenase (G6PDH) catalyzes the first step in the hexose monophosphate (HMP) shunt an alternative pathway for the catabolism of glucose to yield pentose sugar<sup>[34]</sup> and alpha-amylase, is an enzymes involved in the digestion of carbohydrates<sup>[35]</sup>. HbA1C, G6PDH and  $\alpha$ -Amylase are good predictors of DM and in this light, of course, the present study revealed that, treatment with *C. esculentus* oil demonstrated a reduced level of HbA1C, inhibited  $\alpha$ -Amylase and enhanced G6PDH. Thus, this ability marks *C. esculentus* an excellent therapeutic choice for the

management of DM.

DM is characterized by increased morbidity and mortality from cardiovascular disease (CVD)<sup>[5]</sup> and among the established risk factors for coronary heart disease (CHD), the lipid triad (elevated triglyceride, LDL-cholesterol levels and decreased HDL-cholesterol concentrations) is a major predisposing factor for atherosclerosis in DM<sup>[36]</sup>. In this light, of course, the present study demonstrates that triglyceride and cholesterol levels were significantly increased ( $p < 0.05$ ) after 30 days of HFD feeding relative to the established baseline (Table 3). Thus, confirming the contribution of diet rich in high fat diet on CVD which is a related complication in DM. Administration of *C. esculentus* oil stabilized the lipid profile status of the rats by lowering levels of TRIG, CHOL, VLDL & AIP whereas increased levels of HDL (Table 4) and this result correspond with the report that *C. esculentus* oil, which is also known as the new health care oil, has a very high nutritional value due to its unique preventative effects on high blood fat levels and cardiovascular disease<sup>[37]</sup>.

Evidence suggests that oxidative stress may contribute to the pathogenesis of Type 2 DM by either increasing insulin resistance or impairing insulin secretion<sup>[38]</sup>. Several studies have also shown that DM (types 1 and 2) is accompanied by increased formation of free radicals and decreased antioxidant capacity, leading to oxidative damage of cell components<sup>[39]</sup>. In conformation with this report, the result of this study (Table 5) indicates that the levels of antioxidant parameters (SOD, CAT, GSH, GPx) significant decreased ( $p < 0.05$ ) in the untreated group (HFD+STZ) as compared to the normal control and the group treated with *C. esculentus* oil (HFD+STZ+CEO). In the same light, the increased levels of antioxidant in *C. esculentus* oil treated group corroborates the finding that, that *C. esculentus* oil possesses a free radical scavenging ability<sup>[40]</sup>. *C. esculentus* oil also contains phytosterol, vitamin E and  $\beta$ -carotene<sup>[41, 42]</sup> and predominantly consists of oleic acid with values ranging from 65.5 to 76.1%<sup>[42, 43]</sup>. Such substances, together with the unsaturated fatty acids of *C. esculentus* oil, may be responsible for the overall antioxidant activity of *C. esculentus* oil and dietary antioxidants have been hypothesized to possess a protective effect against the development of diabetes by inhibiting peroxidation chain reactions<sup>[41]</sup>.

## CONCLUSION

Dietary based therapies may be potent alternative for managing and preventing diabetes and its related complications. The result of the present study revealed that *C. esculentus* oil, significantly aided weight reduction, reduced blood sugar levels, stabilized glycated hemoglobin, glucose 6 phosphate dehydrogenase, inhibited  $\alpha$ -Amylase, improved the lipid profile status and enhanced antioxidant capacity. Therefore, *C. esculentus* oil may be used as either a therapeutic agent or as a dietary choice for the management of type 2 diabetes.

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