Effect of White and Orange Sweet Potato (*Ipomoea batatas*) on Type 2 Diabetic Rats

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**Abstract:** The present study was carried out to compare the effects of oral administration of freeze-dried white and orange sweet potato suspension in three various forms (Whole, pith and cortex) of white and orange sweet potato on type 2 diabetic rats after 5 weeks of treatment on body weight gain percent, serum level of fasting blood glucose (FBG), insulin and glycated hemoglobin (HbA,c), serum levels of total cholesterol (TC), triglycerides(TG), lipoprotein fractions; total antioxidant status and malondialdehyde (MDA), were determined. Forty adult male albino of Wistar rats were divided into eight groups as follows: group1: negative control group, group 2: positive control group (Diabetic rats), groups 3, 4, 5, 6, 7 and 8 were injected with STZ and orally administered white whole, white pith, white cortex, orange whole, orange pith and orange cortex sweet potato respectively. The results showed that orally administering freeze-dried white whole sweet potato to type 2 diabetic rats for 5 weeks significantly decreased the elevated levels of FBG and HbA,c and increased serum level of insulin, improved TC, TG, lipoprotein fractions, when compared to other treatment groups and to the positive control group. MDA and total antioxidant status were significantly improved as compared to the positive control group. The results suggest that consumption of freeze-dried sweet potato had significant reduction of hyperglycemia and hyperlipidemia as well as improved antioxidant effects in diabetic rats. Therefore, it is recommended that freeze-dried white whole sweet potato may be beneficial for patients with type 2 diabetes mellitus. Further research is required to know the mechanism of the therapeutic effect of sweet potato and to identify the responsible active compounds for the effective positive role against diabetes and oxidative stress.

**Key words:** Streptozotocin · Sweet Potato · Rats · Diabetes Mellitus · Lipid Profile and Antioxidant

**INTRODUCTION**

Diabetes Mellitus (DM) is a chronic disease that occurs when the pancreas is no longer able to make insulin, or when the body cannot efficiently use of the insulin it produces. Not being able to produce insulin or use it effectively leads to raised glucose levels in the blood (Known as hyperglycemia). Over the long-term high glucose levels are associated with damage to the body and failure of various organs and tissues [1].

Plants have been the source of medicinal treatment for thousands of years. They play an essential role in the primary health care of 80% of the world’s developing and developed count anti-diabetic ingredients. Functional plant foods such as fenugreek, curry leaves, bitter gourd, garlic and sweet potato are few among 45 plants that have shown experimental or clinical anti-diabetic activity [2].

Sweet Potatoes (SP) can be differentiated into several types based on the color of the tuber, like white, yellow, orange, white striped - purple and purple. In each type of sweet potato has a nutrient content and functionally different [3]. Both sweet-potato roots and leaves are considered to be rich sources of phenolic compounds, which contribute toward the antioxidant activity of sweet potato tissues [4].

Despite the name, sweet potato may be beneficial to persons with type 2 diabetes, resulting from its content, which could aid in stabilizing blood sugar level and reduce insulin resistance [5].

In the Kingdom of Saudi Arabia there were no studies conducted to compare the effect of sweet potato on type 2 diabetes mellitus from 2014 G until 2016 G. Therefore, our investigation was conducted to study the effect of oral administration of dried skinned, skinless white and orange-fleshed Sweet Potato to type 2 diabetes mellitus rats.
MATERIALS AND METHODS

Materials
Sweet Potato: Fresh white and orange sweet potato used in this research were purchased from a local market, Jeddah, Kingdom of Saudi Arabia.

Experimental Animals: A total of (n = 40) adult male albino rats of Wister strain weighing about 200 – 250 grams were obtained from the animal experimental Unit of King Fahd Center for Medical Research, King Abdul-Aziz University, Jeddah, Saudi Arabia.

Diet Formula: Standard nutritionally balanced diet according to Reeves [6]. The diet was obtained from King Fahd Centre for Medical Research, it consists of the following ingredients: crude protein, crude fat, crude fibre, vitamin mix, mineral mix, choline chloride, corn starch and energy. The diet was purchased from the manufacturer (Grain Silos & Flour Mills Organization, KSA).

Streptozotocin (STZ): Streptozotocin, Zansor (STZ; product number S1312) was purchased from Sigma - Aldrich Chemicals Company (St. Louis, Missouri, United States).

Kits: Kits for biochemical analysis included: enzymatic glucose kits, colorimetric kits for total cholesterol (TC), triglycerides (TG) and high density lipoprotein cholesterol (HDL-c) were purchased from Human Gesellschaft for Biochemical, Germany. ALPCO immunoassay insulin ELISA kits was purchased from Alpco Recycling Inc, United States. Cayman's kits for assays of malondialdehyde (MDA), total antioxidant capacity assay and HbA1c kits were purchased from Cayman Chemical Company, USA.

Methods
Preparation of Sweet Potato: Fresh white and orange sweet potato were washed, sliced, boiled in water (Gentle boiling) with the lid of the cooking vessel on for 20 minutes. This was followed by simmering heat (lid of cooking vessel off) for a further 10 minutes, then the sweet potato was divided in to two parts: the first part was used as whole and the other part separated from the cortex to use the cortex and the pith, finally Freeze-dried each part alone by using Lyophilization (freeze-dried) for 72hrs. The lyophilized obtained powders were kept at room temperature in a close package until used according to Bahado-Singh et al. [5]. Lyophilization was done using a Freeze-Dryer Lyophilizer Millorock Bench- Top Freeze Dryer, Germany.

Preparation of the Basal Diet: The composition of the basal diet according to Reeves [6] is presented in Table 1.

Experimental Design and Grouping of Rats: A total of 40 male rats were kept for two weeks for acclimatization in animal housing condition at a temperature of (22±3 ºC), relative humidity (50 – 55%) and 12 hours light/ dark cycle and feed basal diet and water ad libitum. After acclimatization period, the rats were classified in to two main groups (5 rats each) as follows:

Group (1): The first group (5 rats) kept as control negative group (Untreated group), fed on basal diet only.

While the other seven groups (35 rats) were intraperitoneally injected with streptozotocin (STZ) mixing with 0.1M citrate buffer solution pH = 4.5 at the dose of 60mg/kg body weight [7] after 72 hours of injection the blood samples were taken from tail's vein to determine blood glucose level using Accu-chek Active Blood Glucose glucometer. The development of hyperglycemia was confirmed by the elevated glucose level in blood 200-300 mg/dl according to Wang et al. [8]. These rats were distributed into the following groups:

Group (2): Kept as control positive group (Diabetic group), fed on basal diet only.

Group (3): Diabetic rats were fed on basal diet and orally given solution of white whole sweet potato (WWSP) (3000mg / kg body weight (b. wt) daily dissolved in 30 ml water.

Group (4): Diabetic rats were fed on basal diet and orally given solution of white pith sweet potato (WPSP) (3000mg / kg body weight (b. wt) daily dissolved in 30 ml water.

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>20.0%</td>
</tr>
<tr>
<td>Crude fat</td>
<td>4.0%</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>5.0%</td>
</tr>
<tr>
<td>Vitamin mix</td>
<td>1.0%</td>
</tr>
<tr>
<td>Mineral mix</td>
<td>3.50%</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.25%</td>
</tr>
<tr>
<td>Corn starch</td>
<td>100%</td>
</tr>
<tr>
<td>Energy</td>
<td>2850 kcal/kg</td>
</tr>
</tbody>
</table>

Table 1: The composition of the basal diet
Group (5): Diabetic rats were fed on basal diet and orally given solution of white cortex sweet potato (WCSP) (300mg / kg body weight (b. wt) daily dissolved in 3 ml water.

Group (6): Diabetic rats were fed on basal diet and orally given solution of orange whole sweet potato (OWSP) (3000mg / kg body weight (b. wt) daily dissolved in 30 ml water.

Group (7): Diabetic rats were fed on basal diet and orally given solution of orange pith sweet potato (OPSP) (300mg / kg body weight (b. wt) daily dissolved in 3 ml water.

Group (8): Diabetic rats were fed on basal diet and orally given solution of orange cortex sweet potato (OCSP) (300mg / kg body weight (b. wt) daily dissolved in 3 ml water.

Blood Collection and Serum Separation: Rat’s weight was recorded at the beginning of the experiment and biweekly thereafter. The percent body weight gain (BWG %) was calculated. At the end of the experimental period (7 weeks), rats were fasted overnight, then blood samples were collected in tubes from the retro orbital plexus using microhematocrit capillary tubes, then blood samples were centrifuged at 3000 RPM for 15 min to separate serum, which was stored on -20°C until biochemical analysis for HbA1c, insulin, lipid profile, malondialdehyde and total antioxidant according to Margoni et al. [9].

Serum Biochemical Analysis Serum samples were used for determination of glucose by enzymatic GOD / POD kits according to Trinder [10]. Insulin was estimated using enzyme linked immunosorbent assay ELISA method as described by Clark and Hales [11] glycated hemoglobin (HbA1c) according to Karl et al. [12]. Serum total cholesterol (TC) was estimated according to Allain et al. [13] serum triglycerides (TG) according to Trinder [10] lipoprotein fractions according to Fridewald et al. [14]. Malondialdehyde (MDA) according to Yoshioka et al. [15]. Determination of total antioxidant assay according to Miller and Rice –Evans [16].

Statistical Analysis: Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) for Windows, version 20 (SPSS Inc., Chicago, IL, USA). Collected data was presented as mean±standard deviation (SD). Analysis of Variance (ANOVA) test was used for determining the significances among different groups according to Armitage et al. [17]. All differences were consider significant if p ≤ 0.05.

RESULTS

Results presented in Table 2, showed the effect of freeze-dried whole, pith and cortex of white and orange sweet potatoes on BWG%, FI and FER in streptozotocin diabetic rats.

The presented data indicated that untreated diabetic rats (positive rats) had significant decrease in body weight gain percent and feed efficiency ratio and significant increase in feed intake compared with non-diabetic rats.

In contrast, the present data demonstrated that treated diabetic rats with whole, pith and cortex of white and orange sweet potato had significant decrease in body weight gain percent and feed intake and significant increase in feed efficiency ratio, compared with the untreated diabetic rats.

Recorded data showed that diabetic rats treated with whole, pith and cortex of white sweet potato showed significant reduction at p ≤ 0.05 in body weight gain percent compared with diabetic rats treated with whole, pith and cortex of orange sweet potato.

Feed efficiency ratio significantly increased in treated diabetic rats with whole, pith and cortex of white sweet potato compared with that treated with whole, pith and cortex of orange sweet potato.

Diabetic rats treated with whole, pith and cortex of white sweet potato had the best reduction in feed intake, which was significant at p ≤ 0.05 as compared with diabetic rats treated with orange sweet potato.

Results presented in Table 3 showed the effect of freeze-dried whole, pith and cortex of white and orange sweet potato on glucose, insulin and HbA1c in streptozotocin diabetic rats.

The presented data indicate that untreated diabetic rats (Positive rats) had significant increase in serum levels of glucose and HbA1c, and significant decrease in insulin level compared with non-diabetic rats.

In contrast, the present data demonstrate that diabetic rats treated with whole, pith and cortex of white and orange sweet potato had significant decrease in serum levels of glucose and HbA1c and significant increase in serum insulin, compared with untreated diabetic rats.
Table 2: Effect of addition freeze-dried white and orange sweet potato in three various forms on body weight gain percent (BWG %), daily feed intake (FI) and feed efficiency ratio (FER) in streptozotocin diabetic rats.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control (-ve)</th>
<th>Control (+ve)</th>
<th>(WWSP) (3000mg/kg/day)</th>
<th>(WPSP) (3000mg/kg/day)</th>
<th>(WCSP) (3000mg/kg/day)</th>
<th>(OWSP) (3000mg/kg/day)</th>
<th>(OPSP) (3000mg/kg/day)</th>
<th>(OCSP) (3000mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWG% Mean±SD</td>
<td>43.50±2.02</td>
<td>23.40±3.32</td>
<td>14.82±1.39</td>
<td>25.20±2.25</td>
<td>26.25±2.16</td>
<td>21.33±2.92</td>
<td>21.80±1.91</td>
<td>28.00±1.76</td>
</tr>
<tr>
<td>FI (g/rat/d) Mean±SD</td>
<td>22.80±1.19</td>
<td>29.53±1.83</td>
<td>27.22±1.46</td>
<td>27.61±1.29</td>
<td>25.8±1.37</td>
<td>26.66±0.73</td>
<td>25.02±0.93</td>
<td>19.15±1.59</td>
</tr>
<tr>
<td>FER Mean±SD</td>
<td>0.124±0.018</td>
<td>0.048±0.014</td>
<td>0.118±0.015</td>
<td>0.082±0.069</td>
<td>0.112±0.054</td>
<td>0.094±0.036</td>
<td>0.092±0.062</td>
<td>0.056±0.031</td>
</tr>
</tbody>
</table>

WWSP: White Whole Sweet Potato. WPSP: White Pith Sweet Potato. WCSP: White Cortex Sweet Potato. OWSP: Orange Whole Sweet Potato. OPSP: Orange Pith Sweet Potato. OCSP: Orange Cortex Sweet Potato. BWG%: Body weight gain percent. FI: Feed Intake. FER: Feed Efficiency Ratio. Values denote arithmetic means±standard deviation of the mean. Means with different letters (a, b, c, d, e and f) in the same column differ significantly at P ≤ 0.05 Using one-way ANOVA test, while those with similar letters are non-significant.

Table 3: Effect of addition freeze-dried white and orange sweet potato in three various forms on the serum levels of glucose concentration, insulin and glycated hemoglobin (HbA1c) in streptozotocin diabetic rats.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control (-ve)</th>
<th>Control (+ve)</th>
<th>(WWSP) (3000mg/kg/day)</th>
<th>(WPSP) (3000mg/kg/day)</th>
<th>(WCSP) (3000mg/kg/day)</th>
<th>(OWSP) (3000mg/kg/day)</th>
<th>(OPSP) (3000mg/kg/day)</th>
<th>(OCSP) (3000mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose mg/dl Mean±SD</td>
<td>70.20±1.11</td>
<td>133.20±3.40</td>
<td>69.30±1.35</td>
<td>88.92±1.04</td>
<td>112.50±3.82</td>
<td>93.15±1.58</td>
<td>97.85±1.43</td>
<td>125.40±2.02</td>
</tr>
<tr>
<td>Insulin µU/ml Mean±SD</td>
<td>8.55±3.77</td>
<td>0.50±0.28</td>
<td>6.59±5.70</td>
<td>2.98±5.49</td>
<td>3.45±5.23</td>
<td>2.41±2.71</td>
<td>1.79±0.77</td>
<td>0.47±0.19</td>
</tr>
<tr>
<td>HbA1c, % Mean±SD</td>
<td>3.63±0.18</td>
<td>8.59±0.65</td>
<td>4.85±0.83</td>
<td>6.37±1.43</td>
<td>4.94±1.18</td>
<td>6.61±1.24</td>
<td>7.35±0.50</td>
<td>7.42±2.65</td>
</tr>
</tbody>
</table>

WWSP: White Whole Sweet Potato. WPSP: White Pith Sweet Potato. WCSP: White Cortex Sweet Potato. OWSP: Orange Whole Sweet Potato. OPSP: Orange Pith Sweet Potato OCSP: Orange Cortex Sweet Potato HbA1c: Glycated hemoglobin. Values denote arithmetic means±standard deviation of the means. Means with different letters (a, b, c, d, e and f) in the same column differ significantly at p ≤ 0.05 Using one-way ANOVA test, while those with similar letters are non-significant.

Diabetic rats treated with whole, pith and cortex of white sweet potato showed significant reduction at p ≤ 0.05 in serum levels of glucose compared with diabetic rats treated with whole, pith and cortex of orange sweet potato.

The serum insulin level significantly increased in treated diabetic rats with whole, pith and cortex of white sweet potato, compared with that treated with whole, pith and cortex of orange sweet potato.

Diabetic rats treated with whole, pith and cortex of white sweet potato had the best reduction in serum levels of HbA1c, which was significant at p ≤ 0.05 as compared with diabetic rats treated with orange sweet potato.

Results presented in Table 4 showed the effect of freeze-dried whole, pith and cortex of white and orange sweet potato on serum levels of lipoprotein fractions in streptozotocin diabetic rats.

The presented data indicated that untreated diabetic rats (Positive rats) had significant increase in serum levels of total cholesterol, triglycerides, LDL-C and VLDL-C. In addition, the data indicate significant decrease in serum level of HDL-C compared with non-diabetic rats.

In contrast, the present data demonstrated that diabetic rats treated with whole, pith and cortex of white and orange sweet potato had significant decrease in serum levels of total cholesterol, triglycerides, LDL-C and VLDL-C and significant increase in serum HDL-C, compared with that untreated diabetic rats.

Recorded data of diabetic rats treated with whole, pith and cortex of white sweet potato showed significant reduction at p ≤ 0.05 in serum levels of total cholesterol, triglycerides compared with diabetic rats treated with white, pith and cortex of orange sweet potato.
Table 4: Effect of addition freeze-dried white and orange sweet potato in three various forms on the serum levels of lipid profile (total cholesterol CH, triglycerides TG, high-density lipoprotein HDL-C, low-density lipoprotein LDL-C and very-low-density lipoprotein VLDL-C) in streptozotocin diabetic rats.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cholesterol mg/dl Mean±SD</th>
<th>Triglycerides mg/dl Mean±SD</th>
<th>HDL-C mg/dl Mean±SD</th>
<th>LDL-C mg/dl Mean±SD</th>
<th>VLDL-C mg/dl Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (-ve)</td>
<td>43.98±0.56 e f</td>
<td>47.83±1.01 f</td>
<td>41.96±0.58 e f</td>
<td>7.58±1.46 e f</td>
<td>9.72±0.59 e f</td>
</tr>
<tr>
<td>Control (+ve)</td>
<td>68.89±0.59 e f</td>
<td>128.88±1.74 f</td>
<td>22.13±0.47 d</td>
<td>12.76±3.89 e f</td>
<td>20.28±3.21 e f</td>
</tr>
<tr>
<td>(WWSP) (3000mg/kg/day)</td>
<td>39.83±0.60 e f</td>
<td>44.29±0.65 f</td>
<td>43.12±0.59 e f</td>
<td>10.90±1.90 e f</td>
<td>14.39±2.78 e f</td>
</tr>
<tr>
<td>(WPSP) (3000mg/kg/day)</td>
<td>50.93±1.10 e f</td>
<td>61.26±0.90 f</td>
<td>32.78±0.89 b</td>
<td>9.98±3.93 e f</td>
<td>15.43±4.48 e f</td>
</tr>
<tr>
<td>(WCSP) (300mg/kg/day)</td>
<td>40.91±0.50 f</td>
<td>54.91±0.97 f</td>
<td>42.50±0.76 e</td>
<td>9.77±0.68 e f</td>
<td>14.35±1.41 e f</td>
</tr>
<tr>
<td>(OWSP) (3000mg/kg/day)</td>
<td>46.40±0.31 f</td>
<td>45.17±0.60 h</td>
<td>39.25±0.95 b</td>
<td>9.59±3.62 e f</td>
<td>15.78±1.62 e f</td>
</tr>
<tr>
<td>(OPSP) (3000mg/kg/day)</td>
<td>58.78±0.62 b</td>
<td>80.58±1.29 b</td>
<td>37.28±0.89 b</td>
<td>9.58±3.02 c</td>
<td>16.20±3.02 b</td>
</tr>
<tr>
<td>(OCSP) (300mg/kg/day)</td>
<td>51.33±0.88 c</td>
<td>71.74±0.90 c</td>
<td>35.58±0.82 c</td>
<td>10.18±3.71 b</td>
<td>16.20±3.02 b</td>
</tr>
</tbody>
</table>

WWSP: White Whole Sweet Potato. WPSP: White Pith Sweet Potato. WCSP: White Cortex Sweet Potato. OWSP: Orange Whole Sweet Potato. OPSP: Orange Pith Sweet Potato. OCSP: Orange Cortex Sweet Potato. HbA1c: Glycated hemoglobin. Values denote arithmetic means±standard deviation of the means. Means with different letters (a, b, c, d, e and f) in the same column differ significantly at p < 0.05. Using one-way ANOVA test, while those with similar letters are non-significant.

Table 5: Effect of addition freeze-dried white and orange sweet potato in three various forms on the serum levels of malondialdehyde (MDA) and total antioxidant in streptozotocin diabetic rats.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>MDA nmol / ml Mean±SD</th>
<th>Total-Antioxidant Mm/ l Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (-ve)</td>
<td>0.25±0.013 d</td>
<td>1.76±0.19 b</td>
</tr>
<tr>
<td>Control (+ve)</td>
<td>0.55±0.099 a</td>
<td>0.14±0.01 a</td>
</tr>
<tr>
<td>(WWSP) (3000mg/kg/day)</td>
<td>0.24±0.016 e</td>
<td>1.60±1.13 c</td>
</tr>
<tr>
<td>(WPSP) (3000mg/kg/day)</td>
<td>0.25±0.004 d</td>
<td>0.89±0.61 e</td>
</tr>
<tr>
<td>(WCSP) (300mg/kg/day)</td>
<td>0.25±0.019 f</td>
<td>0.47±0.56 f</td>
</tr>
<tr>
<td>(OWSP) (3000mg/kg/day)</td>
<td>0.24±0.019 e</td>
<td>2.11±0.25 e</td>
</tr>
<tr>
<td>(OPSP) (3000mg/kg/day)</td>
<td>0.30±0.054 b</td>
<td>1.17±0.83 d</td>
</tr>
<tr>
<td>(OCSP) (300mg/kg/day)</td>
<td>0.26±0.022 c</td>
<td>0.47±0.27 f</td>
</tr>
</tbody>
</table>

WWSP: White Whole Sweet Potato. WPSP: White Pith Sweet Potato. WCSP: White Cortex Sweet Potato. OWSP: Orange Whole Sweet Potato. OPSP: Orange Pith Sweet Potato. OCSP: Orange Cortex Sweet Potato. MDA: Malondialdehyde. Values denote arithmetic means±standard deviation of the means. Means with different letters (a, b, c, d, e, f and g) in the same column differ significantly at p < 0.05. Using one-way ANOVA test, while those with similar letters are non-significant.

The serum HDL-C level significantly increased in diabetic rats treated with whole, pith and cortex of white sweet potato compared with that treated with whole, pith and cortex of orange sweet potato.

Diabetic rats treated with whole, pith and cortex of white sweet potato had the best reduction in serum levels of LDL-C and VLDL-C, which was significant at p < 0.05 as compared with diabetic rats treated with orange sweet potato.

Results presented in table 5 showed the effect of freeze-dried whole, pith and cortex of white and orange sweet potato on malondialdehyde and total-antioxidant in streptozotocin diabetic rats.

The presented data indicated that untreated diabetic rats (Positive rats) had significant increase in serum level of malondialdehyde and significant decrease in total-antioxidant level compared with non-diabetic rats.

In contrast, the present data demonstrated that diabetic rats treated with whole, pith and cortex of white and orange sweet potato had significant decrease in serum level of malondialdehyde and significant increase in serum total-antioxidant, compared with untreated diabetic rats.

Recorded data of diabetic rats treated with whole, pith and cortex of white sweet potato showed significant reduction at p < 0.05 in serum levels of malondialdehyde compared with diabetic rats treated with whole, pith and cortex of orange sweet potato.

The serum total-antioxidant level significantly increased in diabetic rats treated with whole, pith and cortex of white sweet potato compared with that treated with whole, pith and cortex of orange sweet potato.
DISCUSSION

Diabetes is recognized as one of the leading causes of morbidity and mortality in the world, while about 2.5 to 7% of the world's population has been diagnosed with diabetes mellitus, it is still expected to increase in the future [18]. In spite of the fact that synthetic drugs such as insulin-like substances are the most important therapeutic agents known to medicine, researchers have been making efforts to find insulin-like substances from plant sources for the treatment of diabetes [19]. Recent scientific investigation and clinical studies had confirmed the efficacy of some medicinal plants and herbal preparations in improving the normal glucose homeostasis.

In fact, about 800 species of plants had been reported in improving the metabolism of carbohydrates and their effectiveness against diabetes mellitus [20]. However, only a few compounds of anti-hyperglycemic plants had shown the efficacy in the management of diabetes in randomized trials [21] such as sweet potato (*Ipomoea batatas*) which suppressed the increases of blood glucose and HbA1c levels in streptozotocin-induced type 2 diabetes in model rats and restored insulin release [22].

Concerning body weight percent (BWG%) and daily Feed intake (FI) in positive control group, the results revealed that there was a significant (P ≤ 0.05) increase in FI, while there were significant decreases in final body weight and BWG% as well as feed efficiency ratio (FER), compared with the negative control group. The obtained results were in agreement with Gupta *et al.* [23] who reported that, STZ-induced diabetes showed signs of weight loss compared with rats non-injected with STZ. Moreover, Zafar *et al.* [24] reported that STZ in a dose of 45 mg/kg induced significant reduction in the body weight of diabetic animals compared with non-diabetic.

Dietary fiber serves as a useful tool in the control of oxidative processes in food products and as a functional food ingredient [27]. In addition, dietary fiber decreases the absorption of cholesterol from the gut in addition to delaying the digestion and conversion of starch to simple sugars, an important factor in the management of diabetes [28]. Allen *et al.* [29] indicated that sweet potatoes are rich in dietary fiber with a content of about 3.0 grams per 100 grams of weight.

Our results demonstrated that oral administration of white and orange sweet potato in three various forms to diabetic rats caused a significant (P ≤ 0.05) reduction in BWG%, FER and increased in FI when compared with untreated diabetic rats (positive control group). Treatment with white whole sweet potato (WWSP) was more effective than with other treatments. These results were in agreement with Thompson *et al.* [30] who reported that diets high in fiber and low in glycemic index, such as sweet potatoes, enhance weight reduction beyond what is seen with calorie restriction alone. In addition, Fairbanks *et al.* [31] concluded that body weight was 10% lower after the transition to the high-fiber diet. These results could be explained on the basis that increasing the amount of fiber and protein in the diet led to a spontaneous weight loss, a result that is consistent with findings from the human studies on the effects of fiber and protein on body weight. Research has shown that dietary fiber increases satiety, slows gastric emptying and decreases post-meal hunger, thus reducing caloric intake. Fiber also has secondary effects of interfering with nutrient absorption and increasing caloric excretion [32].

In the current study, the results revealed that STZ-induced diabetes in rats showed significant (P ≤ 0.05) increase in serum glucose as well as glycated hemoglobin (HbA1c) level accompanied by a significant (P ≤ 0.05) decrease in serum insulin level when compared with the control negative group. These data were in agreement with the results reported by Yaghmoor and Khoja [33] who concluded that STZ-induced diabetes in rats in a dose of 60 mg/kg had a negative effect in glucose concentration and insulin level. Moreover, Kakadiya *et al.* [34] observed elevation in HbA1c of diabetic animals combined with high blood glucose level.

Sheela *et al.* [35] stated that the intramuscular injection of 60 mg/kg streptozotocin had significant higher blood glucose and glycosylated hemoglobin (HbA1c) levels when compared to the normal control group, this it could be attributed to the reaction between glucose and hemoglobin which led to the production of glucose with the free amino groups of the N-terminals of the b-chain of the hemoglobin molecules. Each 1% reduction in
glycosylated hemoglobin is associated with a 37% reduction in microvascular complications, 18% fewer myocardial infarction and 21% fewer DM-related deaths [36].

In addition, Kumar et al. [37] reported that rat injected with streptozotocin had shown a marked raise in plasma glucose level and a decrease in insulin level. The present results may be explained by streptozotocin action in β-cells which was accompanied by characteristic alterations in blood insulin and glucose concentrations, two hours after injection, the hyperglycemia is observed with a concomitant drop in blood insulin, about six hours later, hypoglycemia occurred with high levels of blood insulin and finally hyperglycemia developed and blood insulin levels decreased. This may be attributed to STZ (N-nitro derivative of glucosamine) which is particularly toxic to the pancreas and injection with STZ leads to the degeneration of the Langerhans islets β-cells Hayashi et al. [38].

Sweet Potato (Ipomoea batatas) is rich in ascorbic acid, a well-known antioxidant molecule. The plant also contains large amounts of dietary fibers, which may interfere with glucose absorption and result in further reduction in blood glucose levels [22].

On the other hand, treatment of diabetic rats with white and orange sweet potato in three various forms (white whole sweet potato (WWSP), white pith sweet potato (WPSP), white cortex sweet potato (WCSP), orange whole sweet potato (OWSP), orange pith sweet potato (OPSP) and orange cortex sweet potato (OCSP)) exhibited a remarkable amelioration effect on glycemic control. The white whole sweet potato (WWSP) was more effective than the other treatments. While there was a significant lowering in glucose concentration (P = 0.01) and glycated hemoglobin (HbA1c) (P = 4.45±0.83) and significant improvement in insulin levels at (P ≤ 0.05) when compared with the untreated diabetic group. It exhibited a remarkable glycemic control in the diabetic group. These results are in agreement with Kusano and Abe [39] who suggested that the white skinned sweet potato has unique properties such as hypoglycemic activity by inducing pancreatic beta cells regeneration and increasing insulin expression. Furthermore, Niwa et al. [22] revealed that the Ipomoea batatas cause significant suppression on blood glucose levels after 3 weeks of treatments when compared with the diabetic untreated group. Jang et al. [40] reported that oral administration of white skinned sweet potato after 14 days revealed more reduction in blood glucose level. This effect might be because white skinned sweet potato can decrease blood glucose levels, which implies that WSSP can block free radical production and prevent the production of ROS during diabetes. Moreover, Suksumboon et al. [41] showed that the sweet potato improved glycemic control and HbA1c in type 2 diabetes mellitus when compared with diabetic untreated group. This could be because white skinned sweet potato has active constituents of caipao with anti-diabetic activity that includes acidic glycoprotein and anthocyanins [42].

Streptozotocin (STZ)-induced diabetes in rats showed significant increases in serum TC, TG, LDL-C and VLDL-C levels accompanied with a significant decrease in serum HDL-C level when compared with the control negative group. A similar result was reported in STZ-induced diabetes in rats by a single intraperitoneal injection in a dose of 60 mg/kg bwt which showed negative effects in the total cholesterol and triglycerides when compared to normal rats [43]. In addition, Ramudu et al. [44] stated that there were significant increases in TC, TG and phospholipid levels in STZ-induced diabetes in rats against non-diabetic rats. This effect may be attributed to DM, which affects the lipid profile. Moreover, low insulin levels are associated with high levels of chylomicrons, very-low-density lipoprotein (VLDL-C) and lipoprotein lipase deficiency, which result in hypertriglyceridaemia [45]. Insulin influences many sites of mammalian lipid metabolism, it stimulates synthesis of fatty acids in liver, adipose tissues and in the intestine, insulin deficiency has also been reported to increase the cholesterol synthesis and increase the activity of lipoprotein lipase in white adipose tissue [46].

In this respect, our results revealed that treatment of diabetic rats with white and orange sweet potato in three various forms exhibited a remarkable amelioration in lipid profile. Treatment with the white whole group of sweet potato (WWSP) was more effective than other treated groups. There were significant reductions at (P ≤ 0.05) in total cholesterol, triglycerides, low-density lipoprotein cholesterol and very-low-density lipoprotein cholesterol. On the other hand, there was a significant increase in high-density lipoprotein cholesterol level compared with the untreated diabetic group. These results are consistent with the results of Trinidad et al. [47] who revealed that sweet potato increased HDL-C and decreased LDL-C while moderately raised serum cholesterol levels. Sustainable intake of sweet potato may be promising in the prevention of cardiovascular disease risk as well as obesity and type 2 diabetes mellitus. Ludvik et al. [48] stated that cholesterol level in the Ipomoea batatas group was lower than in the untreated groups. Moreover, Ludvik et al. [48] showed that there were reductions in both total cholesterol and LDL-C levels in the group of rats fed on...
sweet potato (*Ipomoea batatas*) compared with untreated diabetic group. These effects might be due to the hypocholesterolemic property of dietary fiber associated with the water-soluble fractions of fiber, which is fermentable in the colon, e.g. galactomannans, uronic acid, glucomannans and galacturonic acids. However, various water-soluble fibers may differ in their ability to reduce serum cholesterol [49]. Moreover, sweet potato is a rich source of dietary fiber and has a high in pectin content as well as galaturonic acid; sweet potato has also significant amounts of resistant starch, which is fermentable in the colon [47]. This might be the cause by which sweet potato tends to reduce lipids in the treatment groups.

In the present study, STZ-induced diabetic rats showed a significant increase in MDA level at (P= 0.35±0.099) accompanied by significant decreases in serum total anti-oxidant enzymes activity at (P= 0.14±0.01) compared with the negative control group. A similar result was reported by Erejuwa et al. [50] who concluded that STZ- induced diabetes in rats in a dose of 60 mg/kg; i.p. had a negative effect in malondialdehyde (MDA). This effect may be due to hyperglycemia which enhances the generation of reactive oxygen/nitrogen species (ROS/RNS) and reduces antioxidant potential, thus causing oxidative stress which is implicated in β-cell dysfunction and other diabetic complications [51]. Our results were consistent with the results of Rani and Mythili [52] who indicated a significant increase in MDA levels among diabetic patients in comparison to the controls (Non diabetic). According to their study, there had been a decrease in total antioxidant status among diabetic cases, this decrease could be attributed to increased oxidative stress as evidenced by lipid peroxidation. The antioxidant decrease reflects the war of antioxidants against oxidative stress to minimize the oxidative damage. When the total antioxidant status is high and enough to combat the oxidative stress, the MDA levels are in the normal limits and vice versa. The total antioxidant status gives the sum total of both exogenous as well as endogenous antioxidants. Abdel Jaleel et al. [53] reported that the induction of hyperglycaemia with STZ was accompanied with a decrease in the serum total antioxidant capacity when compared with normal rats. This may be attributed to the induction of experimental hyperglycaemia with STZ resulting in enhanced lipid peroxidation. Hypoglycemia was considered one of the factors responsible for the development of oxidative stress.

In recent years, Plant foods including roots, fruits, vegetables and spices are the sources of naturally occurring antioxidants for humans [54]. Furthermore, Niwa et al. [22] had reported that free radicals induced oxidative stress-related gene expressions and peroxidization of plasma membrane and that contributed to the development of various diabetic complications.

Numerous epidemiological and biomedical studies indicated that the consumption of fruits and vegetables rich in polyphenols may help protect the human body against many chronic diseases such as diabetes, cancer and cardiovascular ailments [55]. In the current study, treatment of diabetic rats with white and orange sweet potato exhibited remarkably amelioration effects. The orange whole sweet potato (OWSP) of sweet potato was more effective than other treatment groups. There were significant reduction in malondialdehyde at (P= 0.24±0.019) and significant increase at (P= 2.11±0.25) in total antioxidants. It exhibited remarkable oxidative stress control in diabetic group. These results are consistent with Dwi-Primayanti et al. [56] who stated that consuming sweet potato (*Ipomoea batatas*) probably play a role in reducing the free radical and thus reducing the risk of disease and slowing the aging process, also significantly decreased the MDA plasma level. This could be due to the fact that sweet potato (*Ipomoea batatas*) contains antioxidant compounds that can prevent various types of damages caused by oxidative stress and protect cells from free radicals. Intake of antioxidant may prevent damage caused by free radicals by breaking the chain reaction of free radicals, free radicals oxidize antioxidants that produce more stable and less reactive radical.

The antioxidant activity varied widely among the sweet potato clones, these results were in agreement with Everette and Islam [57] who reported that the orange-fleshed sweet potato contain carotenoids (β-carotene), total phenolic compounds and had high antioxidant properties. There were significant correlations between the carotenoids and phenolic compounds and the antioxidant capacity and this was due to the antioxidant capacity which may be associated with the ability of carotenoids to quench oxygen by a conjugated double-bond system and maximum protection is given by those with nine or more double bonds. On the other hand, the antioxidant capacity may also be associated with the presence of phenolic acids in sweet potato roots, as previously concluded by a study with this food [58].

On the other hand, Padda and Picha [55] reported that the small roots (Sized) of sweet potato may be potentially used as good sources of antioxidant activity and phenolic...
content compared with the full-sized marketable roots. Chlorogenic acid is the major phenolic acid in root tissues in sweet potatoes. Moreover, they also indicated that the antioxidant activity of sweet potato root tissue increases with increased total phenolic content and the cortex tissue from roots of sweet potato that had higher antioxidant activity than the pith tissue.

In conclusion, the results suggests that consumption of freeze-dried sweet potato has a significant reduction of hyperglycemia and hyperlipidemia as well as improved antioxidant effects. Thus could be attributed to its fiber content and its active biochemical compounds that have potent antioxidant activity.

REFERENCES


