Insulin sensitization via PPAR γ and glucose uptake through activation of PI3K/p-Akt signaling pathway by resveratrol in type 2 diabetic rats

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**A R T I C L E  I N F O**

**ABSTRACT**

**Background:** Increasing evidence in both experimental and clinical studies suggests that there is a close link between hyperglycemia, oxidative stress, and diabetic complications. Resveratrol a polyphenolic compound found in various natural food products. **Aim:** The aim of the present study was to screen insulin sensitization via PPARγ and glucose uptake through activation of PI3K/p-Akt signaling pathway by resveratrol in type 2 diabetic rats. **Material and methods:** Four groups male adult albino rats were used in this study: Negative control, Positive control, Therapeutic group and Standard group. **Results:** The treatment of resveratrol significantly reduced the elevated levels of blood glucose, Total cholesterol, Triglyceride, LDL-c, Urea and Creatinine in positive control as compared with negative control. Treatment of resveratrol also reverted back the decreased levels of insulin, HDL-c, Irisin, enzymatic antioxidant (catalase and superoxide dismutase) as well as decreased level of the non-enzymatic antioxidant (reduced glutathione) in tissue extracts from different organs of diabetic rats to near normal values. Resveratrol significantly increased expression of the PPAR γ gene in adipose tissue compared to positive control. It also

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regulated insulin mediated glucose uptake in adipose tissue through activation of PI3K/p-Akt signaling pathway. PPARγ gene showed many different expressions for other side the PPARγ sequences from the adipose tissue confirm there is a mutation with the gene isolated from positive control against therapeutic group, meaning the Type 2 diabetes cause a mutation in the gene sequencing compared to negative control. Hence, we find the opposite with the PPARγ sequencing in therapeutic group. **Conclusion:** These results clearly suggest that the resveratrol has an antioxidant effects and could improve adipose tissue insulin sensitivity and maintain glucose homeostasis in adipose tissue.

**INTRODUCTION**

Diabetes mellitus is a chronic metabolic disorder that constitutes a major public health problem throughout the world [1] and is characterized by chronic hyperglycemia due to abnormal insulin secretion or insulin receptor and post receptor events affecting metabolism of carbohydrate, protein and lipids [2]. Type 2 diabetes is the most common form of the disease and usually involves insulin resistance and β-cell dysfunction [3]. Insulin resistance which is the inability of cells to respond adequately to normal levels of insulin occurs primarily within the muscles, liver, and fat tissue [4]. Diabetes mellitus is associated with the production of reactive oxygen species (ROS) and consequently oxidative stress [5]. The increased oxidative stress due to free radical and accompanying decrease in antioxidants may be related to the complication of diabetes mellitus. Streptozotocin-diabetes provides a relevant example of endogenous chronic oxidative stress owing to hyperglycemia [6]. Hyperglycemia promotes the liberation of oxygen radicals which reduces the antioxidant in addition to damage pancreatic β-cells [7]. Irisin has been identified as a novel myokine that drives brown –fat- like conversion of white adipose tissue [8]. It also has been regarded as an anti-inflammatory factor, which is correlated to diabetes and severity of insulin resistance [9]. Herbal medicines important in the primary health care have been used for thousand years to fight diseases and improve body functions. Polyphenols present in these herbal remedies are considered as major nutrients responsible for improving general health and for providing cure for certain specific pathological conditions [10]. Resveratrol is a non-flavonoid polyphenol compound abundant in grapes, peanuts and other foods that are commonly consumed as part of human diet [11]. Humans have been exposed to dietary polyphenols for millions of years and have developed tolerance to this group of plant defense compounds [12]. Resveratrol has a variety of benefits on the health including anti-inflammatory, free radical scavenging, anticarcinogenic as well as...
cardiovascular protective [16] and neuroprotective activities [17]. The aim of the present study was to investigate the antioxidant property of resveratrol against the hyperglycemia – induced oxidative stress in normal and diabetic rats including animal models of nicotinamide – streptozotocin induced type 2 diabetes mellitus. Furthermore, this work was aimed to evaluate the insulin sensitization via PPARγ and glucose uptake through activation of PI3K/p-Akt signaling pathway by Resveratrol.

MATERIALS AND METHODS:
Materials:
Streptozotocin (STZ), nicotinamide (NIC) and Resveratrol were purchased from sigma chemicals Co. (St. Louis, Mo. USA) stored at -20°C and protected from light. Metformin HCl was purchased from chemical of industries development (CID) company, Egypt) as tablets. All other chemicals used in this study were purchased from standard commercial suppliers and were of analytical grade. BIOZOL reagent was purchased from BIOER TECHNOLOGY. MMLV Reverse Transcriptase, dNTPs, Taq polymerase, primers for PCR were purchased from Bioline.

Experimental Animals
Adult male albino rats weighing 200-280 gm were housed at the experimental animal house of the faculty of science, Zagazig University. The animals were maintained in controlled environment of temperature, humidity and light. The rats had free access to tap water and a commercial pellet rat chow ad libitum.

Induction of Type 2 Diabetes in Rats
Type 2 diabetes was induced in rats by a single intraperitoneal (i.P) injection of Streptozotocin (50 mg / kg body weight, STZ) in overnight fasting rats followed by the i.p administration of Nicotinamide (120 mg/kg b.wt, NIC) after 15 minutes. STZ was dissolved in cold citrate buffer (100mM, pH 4.5) and always freshly prepared for immediate use within 5 min., while NIC was dissolved in 0.9% (wt/v) sodium chloride [18]. The blood glucose levels in the animals were measured at 72 hours after the drug administration and those rats with fasting blood glucose levels greater than 250 mg/dl were considered to be diabetic and used for the further study [19].

Experimental design:
In this experiment, the rats were divided into 4 groups (10 rats in each group) as following:

Group I: Negative control (comprises normal rats).

Group II: Positive control (received (50 mg/kg b.wt, STZ) followed by the i.p administration of Nicotinamide (120 mg/kg b.wt, NIC) after 15 minutes.

Group III: Therapeutic group Diabetic rats administrated with Resveratrol (5mg/kg b.wt/d) in aqueous solution orally for 30 days.

Group IV: Standard group Diabetic rats administrated orally with metformin (100 mg/kg b.wt/d) dissolved in distilled water for 30 days.

The dosage was adjusted every week according to any change in body weight to maintain similar dose per kg body weight of rat over the entire period of study for each group and administrated to rats daily.

Samples collection:
At the end of the experiment and after last treatment, rats were fasted overnight; the blood samples were collected from the retro-orbital venous plexus under light ether anesthesia. where, blood samples were collected in three types of tubes, first containing sodium fluoride for estimation
of blood glucose, second containing ethylene diamine tetra acetic acid (EDTA) to get plasma by centrifugation at 4000 rpm for 20 min and third in empty tubes to get serum by centrifugation at 4000 rpm for 20 min. all these forms were used for various biochemical measurements.

A portion of Liver, heart, kidney and pancreas tissues were homogenized in ice-cold tris-Hcl buffer (100mM, pH 7.4) using Teflon homogenizer to prepare a10% (w/v) tissue homogenate for determination of reduced glutathione(GSH). An aliquot of the whole tissue homogenate was centrifuged at10000 rpm for 15 min at 4°C and the cytosolic supernatant was used for determination of the superoxide dismutase activity (SOD) and CAT. A portion of liver In addition to adipose tissue and skeletal muscle from each group were suspended in RNA later solution and stored at -70°C until RNA extraction.

Biochemical parameters:

**Determination of glucose**
Plasma glucose was estimated by using a commercial kit derived from Elitech Clinical Systems, France [20].

**Determination of serum insulin**
Serum insulin was estimated by using a commercial kit derived from SIEMENS Company, USA [21].

**Determination of lipid profile**
Serum Cholesterol and triglycerides were estimated by using a commercial kit derived from Spin react Company, Spain [22] and from vitro Scient Company, Germany [23] respectively. Serum high density lipoprotein Cholesterol (HDL-c) was estimated by using a commercial kit derived from vitro Scient Company, Germany [24]. Low density lipoprotein Cholesterol (LDL-c) and very low density lipoprotein (VLDL) were estimated according to the equations [25].

**Determination of Irisin**
Irisin concentration was determined by using a commercial kit derived from Glory Science Co., Ltd [26].

**Determination of kidney function tests**
Serum samples were screened for kidney function tests including urea and creatinine by using a commercial kit derived from Diamond Diagnostic Company, Germany [27] and from Spin react Company, Spain [28] respectively.

**Determination of catalase (CAT)**
Plasma and tissue CAT were estimated by using a commercial kit derived from Biodiagnostic Company, Egypt [29].

**Determination of superoxide dismutase (SOD)**
Tissue SOD was estimated by using a commercial kit derived from Biodiagnostic Company, Egypt [30].

**Determination of Glutathione reduced (GSH)**
Tissue GSH was estimated by using a commercial kit derived from Biodiagnostic Company, Egypt [31].

**RNA Extraction and Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR)**
RNA was extracted from liver, adipose tissue and skeletal muscle which are kept in RNA later by using BIOZOL reagent derived from BIOER TECHNOLOGY [32]. In RT-PCR, RNA was first reverse transcribed into DNA complement (cDNA) using reverse transcriptase enzyme. The following gene specific primers (forward and reverse) were used for the generation of cDNAs [33]:

**PPAR γ:** The sequence of PPAR γ primers and length of PCR products were as follows: Forward: 5′-TCAGGGCTGCCAGTTTCG-3’ and reverse: 5′-GCTTTTGCGCATCTC-3’. Product size: 1400 bp.

**PI3K α:** The sequence of PI3K primers and length of PCR products were as follows: Forward: 5′-CAAAGCGGACACCTATTGC-3’ and
reverse: 5′-GGTGGCAGTCTTTGT
TGATGA-3′. Product size: 1220 bp.

**P-Akt:** The sequence of p-Akt primers and length of PCR products were as follows: Forward: 5′-CGCTATTATGCATGAAGAT-3′ and reverse: 5′-TGTTGGCCACTT CATCCT-3′. Product size: 220 bp.

**β-actin:** The sequence of β-actin primers and length of PCR products were as follows: Forward: 5′-TGTTGTCCCTGTATGCCTCT-3′ and reverse: 5′-TAATGTCACGCAGATTTCC-3′. Product size: 320 bp.

PCR products were run on 1.2% (w/v) agarose gel, stained with ethidium bromide and photographed.

**DNA sequencing and analysis**
Three PPAR γ (Adipose tissue) PCR fragments were sequenced using sequencing facilities (ABI 3130xl Genetic Analyzer and ABI 3730xl DNA Analyzer). Multiple sequence alignments were performed using Clustal W program provided on European Bioinformatics Institute (EBI) server (http://www.ebi.ac.uk/Tools/clustalw2/) and analyzed with BioEdit 7.0 software (Tom Hall, Ibis Therapeutics).

**Statistical analysis**
All statistical analyses were done by a statistical for social science package "SPSS" version 14.0 for Microsoft Windows, SPSS Inc. Numerical data were expressed as mean ± SD. The levels of markers were analyzed by ANOVA. The correlations between biochemical data in different studied groups were evaluated by Box blots.

**RESULTS:**

**Plasma glucose and insulin**
Our results showed the levels of plasma glucose and insulin of normal and experimental rats. There was a significant (p<0.0001) elevation in plasma glucose, while the levels of insulin significantly (p<0.0001) decreased in the positive control (diabetic rats) as compared with negative control (normal rats). A significant (p<0.0001) decrease in plasma glucose and increase in insulin levels were observed in therapeutic group as well as in standard group. Moreover, normal rats did not exhibit any significant alterations in plasma glucose and insulin levels during the experimental period as shown in Table (1) and fig. (1- 2).

**Lipid profile**
Our results showed the levels of total cholesterol, triglycerides, high density lipoprotein-C (HDL-C), low density lipoprotein-C (LDL-C) and very low density lipoprotein-C (VLDL-C) in the serum of rats of different groups. Positive control had significantly (p<0.0001) elevated levels of serum total cholesterol, triglycerides, LDL-C and VLDL-C and significantly (p<0.0001) decreased level of high density lipoprotein-C (HDL-C). Treatment with resveratrol or metformin prevented the above changes in diabetic rats and improved towards normal levels as shown in Fig. (3-7).

**Irisin**
Our results indicated that a significant decrease of plasma irisin in positive control (diabetic group) when compared with negative control (normal rats) but, the diabetic rats treated with resveratro (therapeutic group), or metformin (standard group) showed an extreme significant (p < 0.0001 for both groups) elevation in irisin nearly to the normal value as shown in Fig. (8).

**Kidney function tests**
Our results showed a significant increase in urea and creatinine levels of positive control compared to negative control but in the diabetic rats administered with resveratrol (therapeutic group), urea level still remained significantly higher (p= 0.007) in comparison to negative control but creatinine level slightly decreased.
when compared with positive control in addition to the diabetic rats treated with metformin (standard group) showed a significant decrease in urea level (p<0.0001) and a significant decrease in creatinine level (p<0.0001) when compared with positive control as shown in Fig. (9-10).

**Effect of Resveratrol on enzymatic and non-enzymatic antioxidants**

Our results revealed that enzymatic antioxidants (Catalase and Superoxide dismutase) as well as non-enzymatic antioxidant (Glutathione reduced) were found to be lower in positive control compared to that negative control. These antioxidant levels significantly (p<0.0001) increased to a level closer to the normal values in therapeutic group and standard group as shown in fig. (11-23).

**Gene Transcriptional Changes**

**In liver tissue:** The PCR product of (PPAR γ, PI3K α, p-Akt and β-actin) were analyzed, PPAR γ PCR product showed the expected size of 1450 bp, but its absent with the St: standard (Metformin) group, PI3K α PCR product showed the expected size of 1210 bp, with -ve: Negative control, The: Therapeutic (Resveratrol) group, but its absent with St: standard (Metformin) group, +ve: positive control (diabetic group), β-actin PCR products showed the expected size of 320 bp with different treatments and p-Akt PCR product showed the expected size of 220 bp, but its absent with the The: Therapeutic (Resveratrol) group as shown in Fig. (24).

**In skeletal muscle:** PPAR γ PCR product showed the expected size of 1450 bp, but its absent with the The: Therapeutic (Resveratrol) group, PI3K α PCR product showed the expected size of 1210 bp, but its absent with St: standard (Metformin) group, Β-actin PCR products showed the expected size of 320 bp with different treatments and p-Akt PCR product showed the expected size of 220 bp, but its changed in molecular weight with the The: Therapeutic (Resveratrol) group as shown in Fig. (25).

**In adipose tissue:** PPAR γ PCR product showed the expected size of 1450 bp, but its absent with the St: standard (Metformin) group, PI3K α PCR product showed the expected size of 1210 bp, with -ve: Negative control, The: Therapeutic (Resveratrol) group, but its absent with St: standard (Metformin) group, +ve: positive control (diabetic group), β-actin PCR products showed the expected size of 320 bp with different treatments and p-Akt PCR product showed the expected size of 220 bp, but its absent with the The: Therapeutic (Resveratrol) group as shown in Fig.(26).

**DNA sequencing and analysis**

Three PPAR γ (Adipose tissue) PCR fragments were sequenced using sequencing facilities (ABI 3130xl Genetic Analyzer and ABI 3730xl DNA Analyzer). The sequences of the PPAR γ -ve: Negative control, +ve: positive control (diabetic group), and The: Therapeutic (Resveratrol group) were aligned and carefully analyzed. The analysis revealed differences between –ve and The in 17 amino acids and -ve and +ve in 30 amino acids, and between +ve and The in 13 amino acids (Fig. 27).

**DISCUSSION:**

Diabetes mellitus is considered a metabolic disease characterized by many various groups of disorders that disturb carbohydrate, protein and fat metabolism. The loss of glucose homeostasis and shortage or lack of insulin secretion is owing to diabetes syndrome. Hyperglycemia promotes the liberation of oxygen radicals which reduces the antioxidant potential in the body and has been shown to damage of pancreatic β-cells. GLUT-4 transporter is specifically expressed in two insulin-sensitive tissues i.e. adipose tissue and skeletal muscle and is essential for glucose uptake. Insulin resistance is due to impaired glucose transport by defects in insulin-mediated GLUT-4 translocation. Since adipose tissue is an insulin-sensitive
organ, resistance to insulin, resulting impaired vesicle GLUT-4 transfer affected glucose uptake by adipocytes [38]. Our results indicated that hyperglycemia was confirmed in the experimental animals (489.99 ± 38.58 mg/dl) in addition to the significant decrease in insulin level as compared to negative control. Treatment with Resveratrol or Metformin showed remarkably reduced in blood glucose level and ameliorated the elevation in insulin as compared with diabetic rats. Resveratrol improved insulin resistance in diabetic rats compared with positive control and there is evidence that resveratrol enhances insulin secretion and insulin tissue sensitivity in streptozotocin –nicotinamide induced diabetic rats. Resveratrol binding to the sulfonlylurea receptor in pancreatic β cell membrane is the mechanism of its action on insulin secretion. So that stimulation and activation of these receptors is associated with ATP-sensitive K+ channels blockage and therefore plasma membrane depolarization and the subsequent insulin release from pancreatic β cells [39]. In addition to that resveratrol has a non – insulin dependent effect triggering some of the similar intracellular insulin signaling such as increased expression and translocation of the GLUT-4 transporter [40]. T2DM conditions are frequently associated with dyslipidemia which leads to the development of insulin resistance [41] and is a significant risk factor for the development of cardiovascular disease [42]. Elevated circulating free fatty acid level is due to severe accumulation of epididymal adipose deposition in diabetic subjects [43]. Our results revealed that administration of resveratrol as well as metformin to T2DM animals decreased significantly the levels of serum total cholesterol, triglyceride, low density lipoprotein (LDL) cholesterol and very low density lipoprotein (VLDL) cholesterol as well increased high density lipoprotein (HDL) cholesterol this may be due to the phenolic hydroxyls contained in resveratrol structure through oxidation which leads to suppression of cholesterol, oxidation of unsaturated fatty acids, suppression of platelet aggregation, prevention accumulation of cholesterol and fat in the blood, improvement of peripheral blood circulation and thus prevention exerting hyperlipidemia [44]. Irisin secretion after Peroxisome proliferator-activated receptor gamma coactivator-1-alpha (PGC-1α) activation in response to the exercise could enhance insulin sensitivity and increase energy expenditure in animal experiments [45] furthermore, irisin stimulates browning of white adipose tissue through induced phosphorylation of p38 mitogen-activated protein kinase (p38 MAPK) and extracellular signal-regulated protein kinase (ERK) signaling pathway to prevent obesity and T2DM [46]. Our results revealed that a significant decrease of plasma irisin in positive control (diabetic group) when compared with negative control (normal rats) but, the diabetic rats treated with resveratrol (therapeutic group) or metformin (standard group) showed an extreme significant (p < 0.0001 for both groups) elevation in irisin nearly to the normal value. Through our result of the diabetic rats administered with resveratrol (therapeutic group), urea level still remained significantly higher in comparison to negative control but creatinine level slightly decreased when compared with positive control in addition to the diabetic rats treated with metformin (standard group) showed a significant decrease in urea level and a significant decrease in creatinine level when compared with positive control. The elevation of serum urea and creatinine levels in diabetic rats may indicate diminished ability of the kidneys to filter these waste products from the blood and excrete them in the urine [47]. The production of highly reactive oxygen species that are toxic to the cell, particularly the cell membrane in which these radicals interact with the lipid bilayer and produce lipid peroxides is induced by
oxidative stress. In type 2 diabetes, excessive ROS could promote the inhibition of insulin synthesis. The activity of the antioxidant enzymes, such as SOD and CAT are decreased in the tissues of diabetic rats. This may result in a number of deleterious effects due to the accumulation of ROS. One possible mechanism for this reduction in SOD and CAT activities may be due to the inactivation caused by the excess of free radicals and/or by non-enzymatic glycation due to the persistent hyperglycemia, which has been extensively reported to occur in diabetes. Catalase is involved in the elimination of H₂O₂ whereas superoxide dismutase acts to dismutate superoxide radicals to H₂O₂ which is then acted upon by GPx.

Our results indicated that the administration of resveratrol or metformin to the diabetic rats significantly increase the antioxidant enzyme activities, plasma and different tissues extracts of catalase and superoxide dismutase when compared with diabetic rats (positive control). The capacity of resveratrol to scavenge ROS is due to its ability to upregulate mRNA expression for antioxidant enzymes and may be attributed to a hydrogen-electron donation from its hydroxyl groups. Thus the observed increasing in the antioxidant enzyme activities in different organ extracts of liver, kidney, heart and pancreas in therapeutic group and in standard group when compared with positive control. Resveratrol exerts great protection against H₂O₂ induced oxidative injury through increased GSH levels. Our results revealed a good outcome of using the RSV on the biochemical assay and molecular level as well; against the results from the standard (Metformin) group compared for three different genes Akt, PI3k and PPAR γ, the consequence reveled there are many different on the gene expression in three tissues. The PPAR γ gene showed many different expressions for other side the PPAR γ sequences from the adipose tissue confirm there is a mutation with the gene isolated from the positive control against the therapeutic group, which meaning the T2DM causing a mutation in the gene sequencing compared with the negative control. Hence, we find the opposite with the PPAR γ sequcing in therapeutic group. PPARγ is the molecular target to treat T2DM which is downregulated during tissue insulin resistance. Scientific reports reveal that physiological activation of this receptor has been mediated by polyunsaturated fatty acids and their metabolites. Our study revealed that resveratrol induced PPARγ expression in the adipose tissue of diabetic rats administered with resveratrol (therapeutic group) but not upregulated in skeletal muscle. These findings suggested resveratrol normalized lipid metabolism. The PPAR family is involved in many aspects of lipid and glucose regulation such as fatty acid oxidation and adipogenesis. In addition, the PPARγ gene encoding a transcription factor from a nuclear receptor family, which binds to specific DNA sequences (PPARγ responsive elements) in the promoter of other genes and influences their expression, is another gene found to be connected with the insulin resistant monogenic T2DM. Based on its mechanism, PPARγ is also essential for
insulin action and glucose homeostasis. Rare mutations in this gene result in the syndrome of severe insulin resistance and subsequent T2DM that is accompanied by partial lipodystrophy (absence of fat in the limbs and gluteal region), lipid abnormalities (high triglycerides, low HDL cholesterol), hypertension and hepatic steatosis [63]. Activation of glucose transporter is a crucial event in insulin signaling cascade that leads to effective glucose disposal into peripheral tissues [64]. Impaired glucose disposal in peripheral tissues is linked with abnormal insulin signaling through reduction in the PI3K/p-Akt expressions [65]. The blood glucose-lowering effect of resveratrol in diabetic rats has been documented and found to be associated with a resveratrol-induced activation of Akt and endothelial NO synthase [66, 67]. The phosphorylation of Akt is known to be an essential step of insulin signalling [68]. The skeletal muscles are a major site of glucose disposal [69]. Glucose transport, which depends on insulin-stimulated translocation of glucose carriers to the cell membrane, is the rate-limiting step in the carbohydrate metabolism of skeletal muscle [70]. Insulin-stimulated glucose utilization is attributed primarily to the increase of glucose uptake in skeletal muscle [71]. Insulin-dependent diabetes such as in STZ-diabetic rats is a kind of abnormal metabolic state characterized by a deficiency in insulin secretion. Resveratrol can increase the utilization of glucose in the peripheral tissue via the insulin-independent mechanism [72]. Resveratrol was found to increase glucose uptake associated with the increase of Akt phosphorylation mediated via PI3K in the skeletal muscle. Furthermore, the expression of GLUT4 was upregulated in STZ-diabetic rats after repeated treatment with resveratrol [73].

CONCLUSION:
Resveratrol as a strong antioxidant against hyperglycemia-induced oxidative stress in rat model of type 2 diabetes which in turn may be accountable for its antidiabetogenic property. Resveratrol lowered plasma glucose through insulin-dependent and-independent mechanisms. Resveratrol increased insulin secretion in rats with sufficient insulin secretion function; furthermore, resveratrol could also produce a hypoglycemic effect in insulin-deficient STZ-diabetic rats via PI3K-Akt-signaling pathway to enhance glucose uptake into skeletal muscle. PPARγ sequences from adipose tissue confirm there is a mutation with the gene isolated from positive control against therapeutic group, meaning the T2DM cause a mutation in the gene sequencing compared with negative control.

REFERENCES:
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[44] Xie H., H. Han, Z. Chen, J. He, (2014): A Study on the Effect of Resveratrol on Lipid Metabolism in


Table 1: The effect of resveratrol on glucose and insulin levels

<table>
<thead>
<tr>
<th>Groups</th>
<th>Glucose (mg/dl)</th>
<th>Mean ± SD</th>
<th>% change</th>
<th>Insulin (µu/ml)</th>
<th>Mean ± SD</th>
<th>% change</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control</td>
<td>88.76 ± 8.14</td>
<td>-</td>
<td>13.26 ± 0.55</td>
<td>-</td>
<td>2.50 ± 0.67</td>
<td>-81.1</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Positive control</td>
<td>489.99 ± 38.58</td>
<td>452.0</td>
<td>2.50 ± 0.67</td>
<td>-81.1</td>
<td>2.50 ± 0.67</td>
<td>-81.1</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Therapeutic group</td>
<td>89.98 ± 5.14</td>
<td>1.4</td>
<td>16.24 ± 0.77</td>
<td>22.5</td>
<td>2.50 ± 0.67</td>
<td>-81.1</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Standard group</td>
<td>87.32 ± 2.82</td>
<td>-1.6</td>
<td>8.19 ± 0.24</td>
<td>-38.2</td>
<td>2.50 ± 0.67</td>
<td>-81.1</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>
Fig. (1): Box plots of insulin for comparison between Different studied groups

-ve= Negative control and +ve= Positive control.

Fig. (2): Box plots of glucose for comparison between Different studied groups

Fig. (3): Effect of Resveratrol on Cholesterol studied in all studied groups

Fig. (4): Effect of Resveratrol on Triglyceride in all groups
**Fig. (5):** Box plots of HDL-C for comparison between Different studied groups

**Fig. (6):** Box plots of LDL-C for comparison between Different studied groups

**Fig. (7):** Box plots for VLDL-C between Different studied groups

**Fig. (8):** Box plots of Irisin for comparison between Different studied groups

-ve= Negative control and +ve= Positive control.

The box represents the interquartile range. The whiskers indicate the highest and lowest values, and the line across the box indicates the median value. Overall significance of differences between laboratory data of all Groups was determined by ANOVA test (p < 0.0001).
Fig. (9): Box plots of urea for comparison between studied groups.

Fig. (10): Box plots of creatinine for comparison studied groups.

Fig. (11): Box Plots of catalase in plasma from different studied groups.

Fig. (12): Box plots of catalase in liver tissue from different studied groups.

Fig. (13): Box plots of catalase in kidney tissue from different studied groups.

Fig. (14): Box plots of catalase in heart tissue from different studied groups.
Fig. (15): Box plots of catalase in pancreas tissue from different studied groups

Fig. (16): Box plots of superoxide dismutase in liver tissue from different studied groups

Fig. (17): Box plots of superoxide dismutase in kidney tissue from different studied groups

Fig. (18): Box plots of superoxide dismutase in heart tissue from different studied groups
Fig. (19): Box plots of superoxide dismutase in pancreas tissue

Fig. (20): Box plots of Glutathione reduced in liver tissue

Fig. (21): Box plots of Glutathione reduced in kidney tissue

Fig. (22): Box plots of Glutathione reduced in heart tissue

Fig. (23): Box plots of Glutathione reduced in pancreas tissue
The effect of Resveratrol on different genes in liver tissue

Fig. (24): The effect of Resveratrol on different genes in liver tissue

The effect of resveratrol on different genes in skeletal muscle

Fig. (25): The effect of resveratrol on different genes in skeletal muscle

The effect of Resveratrol on different genes in Adipose tissue

Fig. (26): The effect of Resveratrol on different genes in Adipose tissue

M: DNA Marker, -ve: Negative control, +ve: positive control (diabetic group), St: standard (Metformin) group, The: Therapeutic (Resveratrol) group

-ve MGETLGMPYPDSEHGAFASALPMSTSQEITMVSTEMPFWPTNFG
+ve *******************FDGLD********************
The  *****************M*****************************

-ve ISSVDLSVMDDHSFDFITPVDFSSISISAPHYEDIPFTRADPMVA
+ve DVLKSDPF****************************
The  *****************D*****************************S

DYKYDLQYQSAIKVPEAPSYSEKTSYRHEEPSNSLMAIECRVCGDKASGF
***********************D*************************LKHGM***********************
Fig. (27): Amino acid sequence alignment of the (PPAR γ) Adipose tissue
(-ve): Negative control, (+ve): positive control (diabetic group), and (The): Therapeutic (Resveratrol) group. Mismatching amino acids are shown in bold. Symbols in “consensus” line show the biochemical similarity of mismatching amino acids.*means the same amino acids: - high degree of similarity, and space – completely dissimilar amino acids.