PHYSIOLOGICAL ALTERATIONS OF MITOCHONDRIA UNDER DIABETES CONDITION AND ITS CORRECTION BY POLYPHENOL GOSSITAN

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ABSTRACT
The state of lipid peroxidation (LPO), respiration and oxidative phosphorylation, mitochondrial permeability transition pore (mPTP) and antioxidative activity of rat liver mitochondria in streptozotocin (STZ)-induced diabetes condition were studied, considered the ways of correction of detected membrane damages with the use of gossitan, isolated from cotton plant Gossypium hirsutum L. It was shown that the rate of respiration of liver mitochondria in states V₁ and V₂ increases during STZ-induced diabetes, which significantly reduces the respiratory control (RC) and ADP/O coefficients in comparison with the control. The findings suggest that the uncoupling of respiration and oxidative phosphorylation takes place during STZ-induced diabetes. It was shown that in the conditions of STZ-induced diabetes, the rate of swelling of rat liver mitochondria is higher than of the healthy ones; this means that mPTP of rat liver mitochondria is in the open state. Gossitan recovers mPTP to the normal condition, thereby removing the effect of STZ on mitochondria. Gossitan (per-os dose is 10 mg/kg of body weight, during 8 days) eliminates the detected functional disorders of rat liver mitochondria, probably due to its antioxidative properties.

Keywords: polyphenol compounds, mitochondria, antiradical activity, antioxidant activity, diabetes

INTRODUCTION
At the development of various pathologies, along with alterations in the physiological processes of the cell, the functional state of the mitochondria is disturbed (Oliveira, 2005). The function of mitochondria is important in the vital activity of each cell. In addition to disturbances in GLUT, 2000–3, 2006, experiments were performed on 30 white male rats weighing 180–200 g. Laboratory animals were divided into three groups: I group – control (n=10), II group – STZ-induced diabetes (n=10), III group - STZ-induced diabetes+gossitan (n=10). Control animals after daily starvation were entered intraperitoneally 0.2 ml of 0.9 % of the physiological solution.

Figure 1 Chemical structure of gossitan

STZ-induced diabetes in rats by a single intraperitoneal injection of STZ (Sigma) in 0.2 ml of citrate buffer at a dose of 50 mg/kg body weight after a 24-hour fast. After the injection of STZ to rats, in 12 days when the level of the glucose in blood reached 11 mmol/L, during 8 days animals were entered intraperitoneally: 0.2 ml of 0.9% of the physiological solution - II group and 10 mg/kg gossitan - III group (per-os dose is 10 mg/kg body weight). Previously, it was shown that these doses are STZ diabetogenic (Lenzen, 2018).

Blood glucose was determined using the glucose oxidase method set «Glucose-enzymatic-colorimetric test» (Cypress diagnostic, Belgium).
Mitochondrial isolation method

Mitochondria isolated from rat liver by differential centrifugation according to Schneider (Schneider et al., 1948). Nuclear and cellular fragments were removed by centrifugation at 600 g for 7 minutes in a centrifuge. The mitochondria were pelleted at 10000 g for 15 minutes at the same temperature. The mitochondrial pellet was washed twice in the isolation EDTA-free medium. The content of mitochondrial protein was determined by the Lowry method in the modification of the Peterson (Peterson, 1977).

mPTP condition measurement

mPTP condition assessed by the speed of Ca²⁺-dependent swelling of mitochondria, the mitochondrial suspension recording light scattering at 540 nm. Experiments were carried out in a swelling medium of 200 mM sucrose, 20 mM EGTA, 5 mM succinate, 2 µM rotenone, 1 µg/ml oligomycin, 20 mM Tris, 20 mM HEPES, and 1 mM KH₂PO₄, pH 7.2 (He, Lemasters, 2003). The concentration of mitochondria in the swelling experiments was 0.5 mg protein/ml.

Mitochondrial respiration and oxidative phosphorylation measurement

Mitochondrial respiration and oxidative phosphorylation were measured by polarography method (polarograph OH-105, Hungary) at 25°C. The assay medium contained 100 mM sucrose, 75 mM KCl, 10 mM Tris-HCl, 2.5 mM KH₂PO₄, pH 7.4 and 10 mM succinate as respiratory substrates. The protein concentration of mitochondria corresponded to 3 mg/ml of the reaction medium adenine (200 µM) was added as a respiratory stimulant. It was calculated the rate of mitochondrial respiration in different metabolic states: V₆ – respiration rate after making ADP, V₄ – respiration rate after spending ADP. The indices characterizing pair of oxidation and phosphorylation in mitochondria: respiratory control (RC) ratio (RC=V₆/V₄), and the coefficient of phosphorylation of ADP/O. Mitochondrial respiratory rate in different metabolic states is expressed in nanograms of consumed oxygen atoms per minute per 1 mg of mitochondrial protein. The respiratory control and ADP/O ratio was calculated according to the method of Chance (Chance et al., 1955).

Lipid peroxidation measurement

LPO experiments were carried out using thiobarbituric acid (TBA). The reaction was stopped by adding 0.220 ml of 70% trichloroacetic acid in the incubation medium. Thereafter mitochondrial suspensions were centrifuged for 15 minutes at 4000 r/min. Then 1 ml of 75% solution of TBA was added to 2 ml of the supernatant. The control tube was poured 2 ml of distilled water and 1 ml of TBA. The mixtures were incubated at 37°C water bath for 30 min. After cooling the absorbance was measured at 540 nm. The quantity of malondialdehyde (MDA) was calculated using a molar extinction coefficient equal to 1.56/10 µm. The rate of LPO reaction expressed in nM of MDA/mg of protein in an hour (Bolyarev, 1990).

DPPH kinetic analysis

The antiradical activity of polyphenols was determined by the standard method of measuring the kinetics of the optical density of an alcohol solution of the free radical (1,1-diphenyl-2-picrylhydrazyl) DPPH. The concentration of free radicals was 0.1 mM. The ratio of DPPH/polypenol was 1:10. The change in the optical density of the alcohol solution of a pair of planaraticus hormones was carried out in cuvettes with a long optical path of 1 cm, in a volume of 3 ml, on an SF-26 spectrophotometer (Marinova, 2011).

Drugs and chemicals

These given chemical reagents were used: EGTA, EDTA, cyclosporine A (“Sandoz”, Switzerland), rotenone, tri-hCl (Serva, Germany), Sucrose (Russia), DPPH (Sigma, USA), CaCl₂ (“Sigma”, USA). Other reagents were chemically pure and received from local companies. Gossitan was kindly provided by Experimental technology laboratory of the Institute of bioorganic chemistry Academy of Sciences of Uzbekistan.

Data analysis

Statistical analyses were performed using the statistical package Origin 6 (OriginLab Corporation, USA). The data were evaluated using parametric Student’s t-test, we expressed as ± m. Deemed authentic results are expressed at * P<0.05, ** P<0.01, *** P<0.001.

RESULTS AND DISCUSSION

Antioxidant activity of gossitan

Our previous results indicate the uncoupling of oxidative phosphorylation in the mitochondria of the liver in STZ-induced diabetes, with the development of ATP deficiency in the rat tissues and the transition of mPTP to the open state, i.e. permeabilization of mitochondrial membranes is observed (Pozilov et al., 2014). Gossitan reduces the effect of STZ diabetes on the function of mitochondria. It was shown that STZ intoxication increases the rate of LPO in liver mitochondria, causes a hyper compensated low-energy shift with increasing respiratory rates in all metabolic states and dissociation of oxidative phosphorylation (Vengerovskii, 2007). Amber antioxidant therapy normalized the processes of succinate and NAD-dependent energy production in mitochondria, with the restoration of the conjugation of oxidation and phosphorylation, and LPO in the liver decreased (Vengerovskii, 2007).

LPO is a radical molecular process in biological membranes and this way oxidizes free fatty acids that are part of unsaturated lipids and phospholipids of biological membranes. As a result of the oxidation of Fe²⁺ by molecular oxygen, this state is explained by the formation of peroxo radicals H₂O₂. In the case of hyperglicemia, impairment of oxidative phosphorylation in the liver is also disturbed. For this reason, LPO affects the influence on the structure and function of the membrane and also causes pathological changes. Violation of LPO processes causes functional changes in mitochondria (Razza, 2015). The violation of lipid metabolism in diabetes conditions is associated with oxidative stress (Giacono, 2010). ROS is formed and mutations of mitochondrial DNA take place and bioenergetic processes are disrupted. The increase of the free radicals in the cell and the weakening of antioxidant protection damage the membranes, proteins, and DNA of the mitochondria (Ferreira, 2003). In experimental diabetes, polyphenol compound gossitan inhibits the formation of MDA which indicates the intensity of LPO processes in damaged rat liver mitochondrial membranes. The experiments with different antioxidant type with an increase in blood glucose, the MDA content increases in the mitochondria of the liver. In the group of rats with induced STZ-diabetes, the MDA content in mitochondria of the liver increased by 124.2±7.3% compared to the control (Table 1).

| Table 1 Influence of gossitan on indicators of LPO in rat liver mitochondria with STZ-induced diabetes |
|---------------------------------------------------|
| Experimental conditions | MDA nmol/min mg protein | % |
| Control (I group) | 1.28±0.14 | 100 |
| STZ-induced diabetes (II group) | 2.87±0.31** | 224.2 |
| STZ-induced diabetes+gossitan (III group) | 1.62±0.17* | 126.5 |

Introduction of the polyphenol gossitan into the animal’s body’s group III with STZ-induced diabetes once a day during 8 days revealed the approximation of the glucose content in their blood to the norm. Also, the intensity of the LPO process in the mitochondrial membrane of animals receiving pharmacotherapy decreased by 98±6.1% in comparison with STZ-induced diabetes.

Therefore, under the conditions of diabetes after peroxide oxidation of phospholipids of the membrane and unsaturated fatty acids, the lipid bilayer of the mitochondrial membrane can be turned into a liquid-crystal membrane and as a result, the conductivity of the membrane will change seriously, and this causes the development of cellular dysfunction and pathological processes. Reducing in the rate of respiration, oxidative phosphorylation, and activity of the antioxidant system is restored by gossitan. Polyphenol gossitan ensures the stability of the liver membrane of animals with STZ-induced diabetes and corrects the disruption of ATP synthesis as well as improves the energy supply of cells.

The antiradical activity of the gossitan.

Different antioxidant capacity determining methods have different specificities for different solvents, reagents, pH conditions, or hydrophilic and hydrophobic substances (Gaybova et al., 2019). Determination of the end products of MDA peroxidation is a classic method for studying the antioxidant of biologically active compounds. In the literature, antioxidant polyphenols are associated with both their ability to chelate various metal ions (Mierzliak et al., 2014) and directly interact with peroxide radicals, but specific chemical processes can be complicated and as a result, the conductivity of the membrane will change seriously, and this causes the development of cellular dysfunction and pathological processes. Reduction in the rate of respiration, oxidative phosphorylation, and activity of the antioxidant system is restored by gossitan. Polyphenol gossitan ensures the stability of the liver membrane of animals with STZ-induced diabetes and corrects the disruption of ATP synthesis as well as improves the energy supply of cells.

In this regard, it is useful to use compounds that carry a free valence, which are stable organic radicals (Salakhutdinov et al., 2009). For example, ortho-substituted diphenols have four electrons that can regenerate various radicals (Fruehauf, 2007). In this regard, the antiradical activity of polyphenols can be directly related to their antioxidant.

In further experiments, the antiradical activity of gossitan was investigated. To do this, we used a technique based on the ability of antioxidants to restore 2,2'-diphenyl-1-picrylhydrazyl (DPPH) molecules. The kinetics of the recombination of drugs with a stable DPPH radical was studied. Adding gossitan to an alcoholic solution of a pair of charming mesons of gaff gives rise to a change in the color of
the solution, which corresponds to the transition of the block to a non-radical form. In fig. 5 (experimental points) the kinetics of the change in the optical density of the DPPH solution upon the addition of gossitan is presented.

From experimental data, it follows that gossitan has a high ability to quench free radicals. To quantify the antiradical activity of gossitan, the IC50 parameter was used by the time required to reduce the initial concentration of stable radicals in their reaction with the studied compound by 50%. In the reaction of DPPH with gossitan t50 at 17°C ~ 90 s (with a 1:1 ratio of basic substance to DPPH). For comparison, the data t50 at 20°C with an equimolar ratio of dihydroquercetin and unthiol to DPPH was 105 and 590 seconds, respectively (Gayibov et al., 2021).

Analysis of the kinetic curves shows that most of the DPPH molecules are restored in the first 3 minutes of the reaction, and then the reduction reaction proceeds more slowly. It is known that polyphenols, unlike low-molecular compounds (tocopherol, ascorbic acid, low molecular weight phenols, etc.) have both fast and slow-acting antiradical activity, it is possible, therefore, the kinetic curves do not fit the straight lines in the coordinates for the second-order reaction. Apparently, in this case, there are both direct reactions of the studied drugs with DPPH molecules with the formation of inactive products (first-order kinetics), and reactions related to the ability of DPPH molecules to form intermediate donor-acceptor complexes that react with new DPPH molecules (second-order kinetics).

### Table 2
| K 10^3, sec^{-1} | IC50, µM | t50, sec at 50 µM of substance |
|-----------------|---------|-----------------------------|
| gossitan        | 1.2     | 14.3                        |
| gossitan        | 105     | 105                         |

Thus, it was established that gossitan has a high antiradical activity compared with the known antioxidants.

**Influence of gossitan on the respiration and oxidative phosphorylation of rat liver mitochondria**

Corrective effect of polyphenol gossitan on the processes of respiration and oxidative phosphorylation of rat liver mitochondria at the STZ-diabetes condition in the presence of a FAD-dependent substrate was studied.

At the condition of STZ intoxication, the rate of respiration of rat liver mitochondria in the V3 state is increased by 37.2±2.8% compared with mitochondria of the control animals (healthy liver) (Fig. 1). Also, in comparison with the control, the rate of respiration of mitochondria in the V3 state was increased by 98.3±5.6%. At the same time, the coefficients of RC and ADP/O decrease by 31.0±2.8% and 41.8±3.5%, respectively, concerning the indices of the norm (Fig. 2).

![Figure 1](image1.png)

**Figure 1** The change in the relative optical density of a solution of DPPH in ethanol with the addition of gossitan. The concentration of a pair of charmed mesons is 0.1 mM.

The obtained results indicate the activation of mitochondrial respiration during oxidation of succinate by rat liver mitochondria with STZ-induced diabetes in states V3 and V4. The decrease in RC and ADP/O values of liver mitochondria in conditions of STZ-induced diabetes testifies to a serious disruption of ATP synthesis and oxygen consumption (Pozilov et al., 2015).

At pharmacotherapy of animals by the polyphenol compound gossitan (10 mg/kg per os) of the III group with STZ-diabetes, the restoration of metabolic processes of liver mitochondria was detected once a day for 8 days. In this case, the states V3 and V4, the rate of respiration of mitochondria under the influence of gossitan was inhibited by 25.1±1.8% and 65.5±5.5%, respectively, compared with the control. It was obtained that polyphenol compound gossitan recovers RC of mitochondria of the animals of the third group with STZ-induced diabetes by 16.1 ± 1.9%, and the ADP/O coefficient increased by 27.0±1.7% in comparison with the control (Fig 3).

![Figure 2](image2.png)

**Figure 2** The effect of gossitan on mitochondrial respiration in states V3 and V4 with succinate of the rat liver mitochondria in the STZ-induced diabetes condition. *P<0.05; **P<0.01; n=6.

Thus, it was established that gossitan has a high antiradical activity compared with the known antioxidants.

### Table 3

| V3/V4 | RC | ADP/O
|-------|----|--------|
| **   | ** | **    |

**Figure 3** The influence of gossitan on respiration control and ADP/O ratio in the rat liver mitochondria of with STZ-induced diabetes. *P<0.05; **P<0.01; n=5.

Hence, obtained results indicate that polyphenol gossitan decreases the glucose level in the blood plasma and corrects the dysfunction of the energetic metabolism processes in rat liver mitochondria under diabetes conditions. This provides the cell with energy in the form of ATP during pathological hyperglycemia.

**mPTP inhibition**

Mitochondria play a critical role in initiating both apoptotic and necrotic cell death. A major player in this process is the mitochondrial permeability transition pore (mPTP), which is a non-specific pore. mPTP opens in the inner mitochondrial membrane under conditions of elevated matrix [Ca2+]. (Halestrap et al., 2002). At first mPTP described in mitochondria isolated by R.A. Haworth and D.R. Hunter in the 1970s, and it led to a sharp increase in mitochondrial inner membrane permeability for water-soluble molecules up to 1500 Da (Haworth R.A., Hunter 1979). This increase in permeability is caused by Ca2+ ions, which are inducers of this mPTP opening, hence it is also called Ca2+ dependent megapore (Halestrap et al., 2002).

Our studies on rat STZ-induced diabetes models in rats showed a significant hypoglycemic effect in oral administration of gossitan. Figure 4 presents the results...
of experiments to study the effect of STZ-induced diabetes and the effect of gossitan on the permeability of rat liver mitochondria. In the experimental conditions (the incubation medium contained Ca-EGTA buffer), the swelling of mitochondria can be considered as a result of the open state of mPTP, and the suppression of swelling - as closed, i.e. With the help of this technique, one can assess the state of mPTP in the presence of STZ-induced diabetes and the action of gossitan. Incorporation of 10 μM Ca2+ into the incubation medium leads to swelling of the mitochondria in the rat liver mitochondria of the group I (Fig. 4). At the same time, the rate of swelling of liver mitochondria was 0.30 ΔA655/min. Under the same conditions, the swelling rate of mitochondria isolated from the liver of rats of group II (STZ-induced diabetes) was 0.74 ΔA655/min, which is 146.7% higher than the control group (Fig. 4). Since mitochondrial swelling can be regarded as the open state of the mPTP, the results indicate that, in the case of STZ-induced diabetes, the liver mPTP is in an open state. The correction mPTP function with gossitan in rat liver mitochondria with STZ-induced diabetes led to inhibition of the marked swelling. Thus, the swelling rate of mitochondria isolated from the liver of rats of group III (STZ diabetes + gossitan) was 0.52 ΔA655/min, which is 73.4% less than the swelling rate of liver mitochondria of rats of group II (Fig. 4).

Thus, the use of polyphenol gossitan under conditions of STZ-induced diabetes reliably inhibited the opening of the mitochondrial pore (Fig.4).

**Figure 4** Changes in the swelling of rat liver mitochondria under conditions of STZ-induced diabetes and during pharmacotherapy with gossitan. The incubation medium: sucrose - 200 mM, KH2PO4 - 1 μM, succinate - 5 μM, Ca2+ -EGTA-buffer 20 μM, HEPES - 20 mM, Tris-HCl - 20 mM, rotenone - 2 μM, oligomycin - 1 μM, pH 7.2 (*** - P < 0.01; ** - P < 0.05; * - P < 0.1; n = 5).

Thus, STZ-induced diabetes causes, including, the development of mitochondrial dysfunction, manifested by the discovery of mPTP. Therapy of rats with STZ-induced diabetes by gossitan corrects mitochondrial dysfunction, effectively affecting the state of mPTP. Our results indicate the uncoupling of oxidative phosphorylation in the liver mitochondria in STZ-induced diabetes, while ATP deficiency develops in rat tissues and the transition of the mPTP in an open state, i.e. permeabilization of mitochondrial membranes is observed. Gossitan reduces the effect of STZ-induced diabetes on mitochondrial function.

Inhibition of increased mPTP permeability in experimental diabetes using natural compounds has been reported in the literature (Ehigie et al., 2019; Pozilov et al., 2020). Our obtained results are consistent with the available literature data on the property of gossitan in inhibiting mPTP opening of rat liver mitochondria in STZ-diabetes model.

**CONCLUSIONS**

For the first time, it was revealed new hypoglycemic properties of polyphenol compounds. Oral administration of gossitan into diabetic animals at the concentration of 10.0 mg/kg of body weight for 8 days decreases the amount of glucose in the blood to the control indexes. The polyphenol gossitan effectively increase ATP synthesis - as decrease in the process LPO in mitochondrial membranes of liver with STZ-induced diabetes. Under conditions of STZ-induced diabetes, the liver mPTP is an open state, which can be one of the mechanisms of damage to the function of mitochondria, as well as cells in STZ-induced diabetes. In STZ-induced diabetes, an increase in respiratory rates in states V3 and V1 is observed, leading to the uncoupling of oxidative phosphorylation in liver mitochondria and ATP deficiency in rat tissues. The hypoglycemic agent gossitan effectively corrects the impairment of liver mitochondria caused by STZ.

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