MATERNL AND FETAL HEPATIC INJURY IN GESTATIONAL DIABETIC RATS: PROTECTIVE ROLE OF CINNAMALDEHYDE AND ELLAGIC ACID

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ABSTRACT

Objective: This study aims to determine the protective effect of cinnamaldehyde (Ci) and ellagic acid (EA) on maternal and fetal hepatic injury caused by fatty-sucrosed-diet/streptozotocin (FSD/STZ)-rat model of gestational diabetes (GD).

Methods: Female Wistar rats were allocated into four groups. Group I fed with a normal diet, while Groups II, III, and IV feds with FSD for 8 weeks (five pre-gestational and three gestational). One week before mating onward, Group III and IV administered daily oral dose of 20 mg/kg Ci or 50 mg/kg EA, respectively. At the 7th day of gestation, FSD-fed groups injected intraperitoneally with STZ (25 mg/kg b.wt) to induce GD mellitus. At the end of gestation, maternal and fetal blood, pancreas and liver samples were taken for the subsequent analysis.

Results: Ci and EA potentially protect from the elevated glucose, triglycerides, total cholesterol, liver transaminases, and the depleted serum insulin, high-density lipoprotein-cholesterol, total proteins and albumin of GD-rats. As well, tested agents alleviated the altered fetal glucose and insulin levels. Alongside, Ci and EA reduced the maternal and fetal liver lipid peroxidation and increased their total thiols and total peroxidases. Furthermore, Ci and EA kept the normal intact of maternal and fetal pancreatic islets and preserve their livers away from the pathological changes observed in GD group that included fatty depositions, inflammation, hepatocytic necrosis and fibrosis, congested veins, diminutive storable glycogen and proteins, and the numerous proliferating cell nuclear antigen nuclei.

Conclusion: Ci and EA have potent hepatitis protective effects through their insulin-sensitizing action and activating the antioxidant defense.

Keywords: Diabetes, Oxidative stress, Lipid profile, Liver architecture, Hepatocytes proliferation, Natural products.

INTRODUCTION

Gestational diabetes mellitus (GDM) is the most frequent issue facing mothers during pregnancy. The International Diabetes Federation reported that GDM develops in one of 25 pregnancies worldwide, with increasing prevalence in the population with low- to middle-income countries [1]. GDM is defined as the impaired glucose tolerance that affecting pregnant women who have never before had diabetes [2]. It represents the failure to adapt the metabolic demands of pregnancy through both inadequate insulin secretion and insulin resistance which mimicking the pathophysiological characteristics of type 2 diabetes. GDM is associated with potential complications for the health of mothers and their babies concerning the future risk of metabolic syndrome, type 2 diabetes, and cardiovascular disorders (CVDs) [3]. The liver is the focal organ of carbohydrate metabolism, blood glucose homeostasis, and detoxifying processes. Until now, the link between GDM and risk of hepatic injury is still unclear. Recent epidemiological studies suggested that GDM is an early marker for the development of non-alcoholic fatty liver disease (NAFLD) [4]. NAFLD is the hepatic indicator of the metabolic syndrome, and it covers a disease spectrum ranging from steatosis to fibrosis, cirrhosis, and hepatocellular carcinoma (HCC) [5].

Insulin is the commonly used therapeutic agent for GDM management. But rather than its inadequacy for many pregnant women [6], it may increase the risk of acquiring viral hepatitis because of the contact with needles. On the other hand, however, pharmacologic intervention with oral synthetic antidiabetic drugs (mainly metformin and glyburide) seemed to be tempting, hepatotoxicity of these drugs emerged common clinical complications [7] besides the paucity of data on the exposure of fetuses to them during pregnancy. As opposed to conventional medications, antioxidants from plant-based and natural products are emerging as a future therapy and an alternative way to prevent and treat life-threatening disease. Cinnamaldehyde (Ci) and ellagic acid (EA) are bioactive natural compounds extracted from Cinnamomum zeylanicum bark and Padina boryana Thivy, respectively. Recent studies reported that both of them have potent antioxidant and anti-inflammatory properties besides their hypoglycemic action in type 1 and type 2 diabetic rats [8-11]. To date, there is still a lack of data describing their protective effect on the GD liver injury. Hence, the present study was conducted using a rat model of GDM induced by fatty-sucrosed diet (FSD) combined with low dose streptozotocin (STZ) to investigate the possible protective activities of Ci and EA on the maternal and fetal hepatic tissues and explore their possible mechanisms using different biochemical, histopathological, and immunohistochemical examinations.

METHODS

Plant materials collection and extract preparation
Bark of C. zeylanicum was collected from the botanical garden of Cairo University, Egypt, while P. boryana algae were gathered from the Red Sea, Safaga province, eastern coast, Egypt. Samples were authenticated by the Taxonomy Division, Botany Department, Faculty of Science, Beni-Suef University, Egypt. Ci and EA were extracted according to Subash-Babu et al. [9] and Abu El-Soud et al. [12] phytochemical investigation’s, respectively.

Chemicals and reagents
Glucose, triglycerides (TG), total cholesterol, and high-density lipoprotein-cholesterol (HDL-cholesterol) kits were procured...
from Spinreact Co. (Spain). Rat insulin ELISA kit was obtained from BioSource Europe S.A. (Belgium). Total proteins, albumin, alanine transaminase (ALT), and aspartate transaminase (AST) kits were obtained from Human Diagnostics (Germany). STZ, ethyl acetate, n-hexane, 5,5'-dithiobis-2-nitrobenzoic acid, 1,1,3,3-tetramethoxypropane, and thiobarbituric acid were purchased from Sigma Chemical Co. (USA), while pyrogallol was procured from Fluka Analytical (Germany). Diet ingredients were purchased from Oxford Laboratories, India. All other chemicals were obtained from commercial suppliers.

Experimental animals
Female albino Wistar rats (Rattus norvegicus) weighing about 100-120 g were obtained from the animal house of VACERA Co., Helwan city, Egypt. Rats were housed individually in standard cages and maintained in an air-conditioned atmosphere, set at 25°C with alternatively 12 h light and dark cycles for a week before the beginning of the experiment for acclimatization. Rats fed with two types of diets either normal diet (ND) or FSD and allowed to drink water ad libitum. The composition of both diets was illustrated elsewhere [13]. All animal experiments were approved by the Institutional Animal Care and Use Committee (IACUC), Beni-Suef University, Egypt (BSU/FS/2015/5/11).

Experimental design
The experimental design is described in Fig. 1. A total of 60 albino Wistar rats were randomly divided into four groups (15 animals/group) as follows:

Group I (normal pregnant [NP]): Fed on ND. Four weeks after dietary manipulation, rats have received 0.5% dimethyl sulfoxide (DMSO) as a vehicle by oral gavage daily to the end of the experiment.

Group II (GD): Fed on FSD. Four weeks after dietary manipulation, rats have received the vehicle by oral gavage daily to the end of the experiment.

Group III (GD pre-treated with Ci [GD+Ci]): Fed on FSD. Four weeks after dietary manipulation, rats have received Ci (20 mg/kg b.wt. dissolved in 0.5% DMSO) by oral gavage [9] daily to the end of the experiment.

Group IV (GD pre-treated with EA [GD+EA]): Fed on FSD. Four weeks after dietary manipulation, rats have received EA (50 mg/kg b.wt. dissolved in 0.5% DMSO) by oral gavage [10] daily to the end of the experiment.

After 5 weeks from the onset of the experiment, rats of all groups were mated overnight with males. Positive vaginal smear checked in the morning indicated the zero day of the gestation (rats with negative vaginal smear were excluded). The time before mating indicated the pre-gestational period while that after mating indicated the gestational period. At the 7th day of pregnancy (end of the 6th week), dams were fasted for 16 h and those of Groups II, III, and IV were injected with STZ intraperitoneally (25 mg/kg b.wt. in citrate buffer; pH 4.5) [13], while those of Group I was injected only with the citrate buffer. Blood samples were collected at the 20th day of gestation (8th week; post-STZ) from the lateral tail vein of each dam for estimation of fasting glucose and insulin levels to evaluate the development of GDM. At the 21st day of gestation, overnight fasted dams were sacrificed under light diethyl ether anaesthesia.

Samples preparations
Blood was collected from the jugular vein of each dam, centrifuged, and sera were kept at −23°C for future biochemical analyses. As well, fetuses of each dam were delivered and blood pool was collected from the jugular veins where sera were separated for measurement of glucose and insulin concentrations. After dissection of dams and their fetuses, pancreas and liver samples were fixed in 10% neutral-buffered formalin for histopathological processing. Another liver samples were homogenized in phosphate buffer saline (PBS) at 4°C, centrifuged at 4000 rpm for 10 min and the clear homogenates were separated and stored at −23°C for subsequent determination of antioxidants and oxidative stress markers.

Biochemical assays
Both maternal and fetal serum glucose and insulin levels were determined using the corresponding reagent kits, while maternal TG, total cholesterol, HDL-cholesterol, total proteins, albumin, ALT, and AST concentrations were also detected. Lipid peroxidation (LPO) of maternal and fetal liver homogenates was assessed by measuring malondialdehyde (MDA) concentrations according to the method of Yagi [14], while total thiols (as non-enzymatic antioxidants) and total peroxidases (as enzymatic antioxidants) were estimated according to the methods of Koster et al. [15] and Kar and Mishra [16], respectively.

Histological and histochemical staining
Fixed pancreas and liver tissues were dehydrated, cleared, paraffin-embedded, and sectioned (5 μm thick) using Leica rotary microtome (Germany). After deparaffinization and rehydration, maternal pancreatic sections were stained with the modified aldehyde fuchsin-method [17], while those of fetuses were stained with hematoxylin and eosin (H and E) [18]. Liver sections were stained with H and E, periodic acid–Schiff (PAS) reaction [19], and mercuric bromophenol blue method [20] for the demonstration of any histopathological alterations, glycogen, and total proteins, respectively.

Immunohistochemical staining
For immunohistochemical localization of proliferating cell nuclear antigen (PCNA), liver sections (5 μm) were deparaffinized, rehydrated, and immunostained by the peroxidase-antiperoxidase method. In brief, high-temperature antigen unmasking technique was employed in 0.01 M citrate buffer (pH 6) in a microwave oven twice for 5 min each. Blocking of the non-specific reaction was performed with 1% normal goat serum, 3% non-fat milk, and PCNA mouse monoclonal antibody (Novocastra NCL-L-PCNA; Leica Biosystems, UK) (1:100). After rinsing in phosphate-buffered saline (0.01 mol/L PBS, pH 7.4), the sections were incubated with secondary antiserum. They were then washed in PBS and incubated in avidin and biotin complex (ABC) reagents (ABC kit, Vector Laboratories, Inc) and in peroxidase reaction (3,3'-diaminobenzidine tetrahydrochloride, Sigma) containing 0.01% H2O2 in PBS buffer. For the control reaction, some slides were processed by omitting the primary antibody and other slides through omitting the primary and secondary antibodies (Bhan, 1995) [21].

Fig. 1: In vivo experimental design. ND: Normal diet, FSD: Fatty-sucrosed diet, DMSO: Dimethyl sulfoxide, Ci: Cinnamaldehyde, EA: Ellagic acid, STZ: Streptozotocin. NP: Normal pregnant, GD: Gestational diabetic, GD+Ci: Gestational diabetic pre-treated with cinnamaldehyde, GD+EA: gestational diabetic pre-treated with ellagic acid.
Statistical analysis
Data were presented as mean±standard error of the mean of ten rats. Measured variables were analyzed using one-way ANOVA test followed by Tukey-Kramer test for post hoc analysis. p<0.05 were considered statistically significant. All statistical analyses were performed using the SPSS v.22 software (SPSS Inc., Chicago, USA).

RESULTS
Effect of Ci and EA on maternal and fetal glycemic state
GD-dams showed significant elevation of blood glucose level with a marked decrease in their serum insulin as compared to NP ones (Table 1). Similarly, GD raised the fetal glucose and insulin serum concentrations markedly as compared to those of NP-dams. Oral administration of Ci (20 mg/kg b.wt) and EA (50 mg/kg b.wt) resulted in an obvious improvement of these parameters, whereby Ci achieved more glycemic control than EA.

Effect of Ci and EA on maternal lipid and protein profiles
Maternal data in Table 1 clarified significant increase (p<0.05) in serum TG and total cholesterol levels of GD-dams than NP-dams with noticeable depletion of their HDL-cholesterol, total proteins, and albumin serum ratios. Both of Ci and EA revealed profound amelioration of these parameters with an interest in their abilities to increase HDL-cholesterol concentrations than normal rats.

Effect of Ci and EA on maternal liver function enzymes
Levels of serum ALT and AST displayed marked increase in GD-rats in comparison to those of normal ones. Ci administration seemed to be more potent in reducing these enzymes serum concentration than EA.

Effect of Ci and EA on maternal and fetal oxidative and antioxidant parameters
Our results revealed significant elevation in MDA concentration in maternal and fetal liver samples of GD-group with a concomitant reduction of total thiols content and total peroxidase activity than those of normal group (Table 1). Otherwise, notable attenuation of MDA production parallel to the marked increase in total thiols concentration and peroxidases activity was achieved by both treatment agents with preferability to Ci.

Histopathological assessments
Light microscopical examination of modified aldehyde fuchsin-stained pancreatic sections from NP-rats demonstrated a normal architecture of islets of Langerhans (as the endocrine portion) and pancreatic acini (as the exocrine portion) (Inset in Fig. 2a). Three main types of islets cells are well recognized (Fig. 2a). Beta-cells are the most abundant and occupied the core of the islet, while alpha and delta cells are detected at the periphery. Delta cells are usually located adjacent to alpha cells and are somewhat large in size. In contrast, fatty-sucrose-diet-feeding/25 mg/kg b.wt streptozotocin induces variable structural alterations of pancreatic islet cells including pyknotic, irregular and/or hyperchromatic nuclei, vacuolated cytoplasm, and visible necrotic area. Significant reduction in total islets volume and cells number was also noticed (Fig. 2b). On the other hand, Fig. 2c and d, respectively, illustrated great protection and restoration of the normal islets configuration under Ci and EA administration where alpha, beta, and delta cells looked more intact. Ci seemed to stimulate a marked increase in the total islets volume than EA (Inset in Fig. 2c).

Fig. 3a depicted the normal histological structure of fetal pancreatic section from NP-group stained with H. and E. It consists of acinar exocrine lobules separated by septa and diffused with typical endocrine islets. Instead, fetal pancreatic islets of GD rats showed numerous vaculations and its cells appeared hyperplastic at both islets core and periphery (Fig. 3b). Maternal manipulation of Ci made the fetal pancreatic islets more organized with a lesser extent of cells hyperplasia that existed only at the islets periphery (Fig. 3c). Furthermore, EA administration nearly restored the islets integrity except for the appearance of some vaculations within (Fig. 3d).

H and E stained liver section from NP-group demonstrated the normal hepatic microarchitecture (Fig. 4a), where a typical lobule appeared with a central vein and hepatocytes plates radiating from it toward the periphery. Blood sinusoids and Kupffer cells are located between these plates. Conversely, liver of GD rats showed obvious histopathological alterations that include dilatation and congestion of portal veins (Fig. 4b), obscure sinusoids and distorted cell plates (Fig. 4d), appearance of signet ring and/or ballooning hepatic cells (that characterize the accumulation of fat droplet in liver tissue; inset in Fig. 4b and 4d), besides inflammatory infiltration of leukocytes into the liver parenchyma (Fig. 4c). Moreover, many hepatocytes underwent cytoplasmic vacuolar degeneration in addition to the appearance of the necrotic and fibrotic area (Fig. 4d and inset in Fig. 4d). Oral administration of Ci and EA 1 week before mating onward caused marked recovery of the normal structure of the liver where the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>NP</th>
<th>GD</th>
<th>GD+Ci</th>
<th>GD+EA</th>
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<tr>
<td>Fasting glucose (mg/dl)</td>
<td>64.7±2.11</td>
<td>267.44±9.53a</td>
<td>71.83±6.43b</td>
<td>119.12±0.9c</td>
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<td>Fasting insulin (μIU/ml)</td>
<td>27.12±0.46</td>
<td>21.25±0.24a</td>
<td>26.30±0.27b</td>
<td>24.77±0.26b</td>
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<td>Triglycerides (mg/dl)</td>
<td>58.72±1.44</td>
<td>189.64±1.34a</td>
<td>60.90±1.7b</td>
<td>59.28±1.23b</td>
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<tr>
<td>Total cholesterols (mg/dl)</td>
<td>81.12±1.45</td>
<td>185.13±2.5a</td>
<td>130.08±0.8b</td>
<td>118.59±1.11c</td>
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<tr>
<td>HDL cholesterols (mg/dl)</td>
<td>58.06±1.54</td>
<td>52.52±1.18a</td>
<td>89.76±1.12b</td>
<td>76.04±2.12b</td>
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<td>Total proteins (g/dl)</td>
<td>7.48±0.08</td>
<td>5.88±0.19a</td>
<td>7.32±0.14a</td>
<td>6.92±0.10b</td>
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<td>Albumin (g/dl)</td>
<td>4.76±0.12</td>
<td>3.66±0.09a</td>
<td>4.42±0.11a</td>
<td>4.32±0.22a</td>
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<tr>
<td>ALT (U/l)</td>
<td>36.4±1.05</td>
<td>95.58±1.8a</td>
<td>41.98±0.95a</td>
<td>70.60±0.86b</td>
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<td>AST (U/l)</td>
<td>160.60±3.48</td>
<td>241.50±1.75a</td>
<td>161.10±1.45a</td>
<td>209.16±2.04b</td>
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<td>MDA (nmol/g tissue)</td>
<td>54.63±1.64</td>
<td>120.93±2.18a</td>
<td>80.85±2.4b</td>
<td>89.29±1.91a</td>
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<td>Total thiols (nmol/100 mg tissue)</td>
<td>769.57±6.86</td>
<td>558.85±5.55a</td>
<td>711.73±5.01a</td>
<td>644.95±7.24a</td>
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<td>Total peroxidase (U/g tissue)</td>
<td>124.48±2.70</td>
<td>76.06±1.82a</td>
<td>110.58±4.97a</td>
<td>94.90±4.86b</td>
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<td>Fetal parameters</td>
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<td>Glucose (mg/dl)</td>
<td>42.94±1.46</td>
<td>161.50±4.12a</td>
<td>52.10±2.18b</td>
<td>86.44±2.60a</td>
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<td>Insulin (μIU/ml)</td>
<td>3.60±0.14</td>
<td>6.20±0.16a</td>
<td>4.01±0.19b</td>
<td>4.98±0.12b</td>
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<td>MDA (nmol/g tissue)</td>
<td>19.03±0.81</td>
<td>45.00±2.37a</td>
<td>24.91±1.54a</td>
<td>29.76±1.22a</td>
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<td>Total thiols (nmol/100 mg tissue)</td>
<td>252.43±4.72</td>
<td>136.32±1.84a</td>
<td>211.60±7.31a</td>
<td>190.05±1.54a</td>
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<tr>
<td>Total peroxidase (U/g tissue)</td>
<td>43.40±3.33</td>
<td>23.51±3.51a</td>
<td>38.02±2.70a</td>
<td>32.77±4.05a</td>
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</table>

Table 1: Effect of Ci and EA on maternal and fetal biomarkers at term pregnancy

Results are presented as mean±SEM of ten dams. *p<0.05 versus NP, **p<0.05 versus GD. NP: Normal pregnant, GD: Gestational diabetic, GD+Ci: Gestational diabetic pre-treated with cinnamaldehyde, HDL-cholesterol: High-density lipoprotein-cholesterol, ALT: Alanine transaminase, AST: Aspartate transaminase, MDA: Malondialdehyde, Ci: Cinnamaldehyde, SEM: Standard error of the mean
leukocytic infiltration, fatty accretion, vacuolated hepatocytes, and necrotic area are almost disappeared (Fig. 4 e and f, respectively).

The fetal liver section from NP-group displayed a homogeneous mass of parenchymal hepatocytes that arranged in poorly defined lobules. Each lobule distinguished by a central vein and composed of irregular branched and interconnected hepatic strands which anastomose to form a network enclosing a system of tortuous blood sinusoids (Fig. 4g). The fetal hepatic tissue of GD-rats revealed apparent changes. Central veins appeared dilated and engorged with blood (Fig. 4h), regions of necrosis and fibrosis were observed, and autolysis of some nuclei and dilated sinusoid were noticed (Fig. 4i and j). Treatment with Ci and EA induced significant protection of the normal fetal hepatic configuration against the GD stress (Fig. 4k and l, respectively). Meantime, some sinusoidal dilatations were still detected in their hepatic tissue.

Histochemical demonstration of glycogen and proteins content
A strong PAS-positive reaction was viewed in hepatocytes of maternal and fetal livers of NP-group indicating the presence of a large storable amount of glycogen (Fig. 5a and e). On the other hand, liver cells of GD-rats and their fetuses were almost depleted of glycogen (Fig. 5b and f). Ci and EA-treated dams revealed marked increase of their hepatic glycogen content which approximated that of the control ones (Fig. 5c and d, respectively). Moreover, the fetal liver of these both treated groups showed intensive glycogen deposition (Fig. 5g and h), but to a lesser extent in that of GD+EA-group than GD+Ci-one. By the same manner, a dense blue color was observed in the liver sections from NP-dams and fetuses illustrating an intensive reaction toward the protein granules which appeared randomly distributed in the ground cytoplasm of the hepatocytes (Fig. 5i and m). In contrast, both maternal and fetal livers from GD-group depicted a weak reactivity of bromophenol blue stain that indicated a significant diminution of the total proteins content (Fig. 5j and n). However, after treatment with Ci a considerable amount of proteins was accumulated in the maternal and fetal hepatocytes (Fig. 5k and o). Liver section from EA-treated rats displayed a moderate amount of proteins (Fig. 5l), and liver of their fetuses showed a marked increase of proteins content (Fig. 5p) than that of the diabetic one.

Hepatic expression of PCNA
PCNA expression was immunohistochemically localized in maternal and fetal hepatic tissues (Fig. 6). In NP-group, a very weak expression of PCNA was found in few hepatocytes of dam’s livers but not in those of their fetuses (Fig. 6a and e). In contrast, parenchymal hepatocytes of GD-rats demonstrated strong PCNA-positive immunoreaction (Fig. 6b). As well as, fetal livers of this diabetic group displayed numerous PCNA-nuclei (Fig. 6f). Negative localization of PCNA in hepatic cells of GD+Ci rats was clearly observed (Fig. 6c), while their fetuses show pale brown color of PCNA-staining. In GD+EA group, maternal and fetal hepatic expression of PCNA was significantly weak when compared with that of the GD-group (Fig. 6d and h).

DISCUSSION
Our data indicated a marked elevation of maternal serum glucose level with diminished insulin secretion in GD-group. FSD-feeding stimulated
A state of glucose intolerance and insulin resistance through the glucose-fatty acid cycle [22]. In brief, feeding of diets rich in fats gives an increased source of fatty acids availability. The preferential utilization of these fatty acids for oxidation blunts the insulin-mediated reduction of liver glucose output and decreases glucose uptake by peripheral tissues which considered common features of insulin resistance. As well, the injected low dose of STZ resulted in morphological alterations for the pancreatic islets leading to subsequent suppression of insulin biosynthesis as a result of reactive oxygen species (ROS)-generation [23]. Oral administration of Ci achieved potent control of blood glucose level and stimulated more insulin secretion than EA through providing intense protection for pancreatic islets and increasing β-cell mass as seen from the histological screening of the maternal pancreas.

The persistent hyperglycemia of GD-rats considered, also, a principal mediator of ROS generation through the auto-oxidation of glucose molecules [24]. As the liver is the main organ of oxidative and detoxifying activities, ROS react with polyunsaturated fatty acids of hepatocellular membranes leading to its peroxidation [23]. The increase of LPO impairs membrane function by decreasing its fluidity, increases its permeability, and changing activities of some bounded enzymes leading to cell death [25]. The present study hypothesized that the pre-treatment with Ci and EA significantly protects from MDA formation (main product of lipid peroxides) through their strong free radical scavenging action [8,26]. On the other hand, we observed changes in the hepatic enzymatic and non-enzymatic antioxidants in the different groups. Our results indicated depletion in total thiols concentration in the liver of GD-dams when compared to NP-ones. Thiols are organic compounds that have the sulphydryl (SH)-group. Among all the body antioxidant’s, thiols constitute the master portion of the body antioxidants that play a major role in defense against ROS. The functional consequences of liver total thiols losses in diabetic dams include protein misfolding, catalytic inactivation, and decreased antioxidative capacity [27]. Moreover, the decrease in activities of hepatic total peroxidases (main enzymes correlated to neutralization of hydrogen peroxide [28]) in GD-rats could be due to STZ-generated
ROS [29]. Ci administration significantly reverted back these altered antioxidants more than EA as a result of its ability to provoke potent control of the glycemic state.

Aberrations in the maternal serum lipid profile have been also reported in GD-group. GDM-dams showed significant increase in serum TG and total cholesterol concentrations with a diminished HDL-cholesterol level. Dietary manipulation of FSD increased the absorption of cholesterol and TG from the small intestine leading to hypercholesterolemia and hypertriglyceridemia. In addition, Raz et al. [30] have been linked the insulin insufficiency to the dysfunction of lipoprotein lipase (LPL) causing progressive impairment of TG catabolism and its uptake by the peripheral tissues. The antilipemic action of Ci and EA reside in their ability to stimulate insulin secretion and action, stimulating LPL and increasing TG clearance. Interestingly, both treating agents increased serum HDL-cholesterol concentration than normal dams. This potentially prevents the future development of CVDs [31,32]; commonly GDM complications.

A vital indicator in assessing hepatic injury is the serum level of liver transaminases. The observed increment of ALT and AST in the circulation of GD-dams may discuss the fatty changes in their livers. The excess free fatty acids as a result of FSD-feeding is known to be directly toxic to hepatocytes through mechanisms include cell membrane disruption, mitochondrial dysfunction, and toxin formation which decrease the liver cell membrane-stabilizing action, and consequently, the seep out of these enzymes from the liver cytosol to the circulation [33]. Another potential explanation for elevated serum transaminases is the hepatotoxic effect of STZ which generates ROS causing loss of the functional integrity of liver cell membranes and leakage of these enzymes into the bloodstream [34]. On the other hand, hepatocytes work exclusively to synthesize proteins and the
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AUTHORS CONTRIBUTIONS

All the authors have contributed equally.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES


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