

Effect of Curcumin on Lipid Profile, Oxidative Stress and Blood Glucose in Experimental Dexamethasone-Induced Diabetes in Rats

Azizollah Pourmahmoudi; PhD¹, Mohammad Sharif Talebianpoor; PhD^{*2}, Tahereh Vafaiee Nejad; BSc³, Mahnaz Mozafari; BSc³, Mohammad Shafee Talebianpoor; MSc⁴ & Mahboobe Hosseinikia; MSc³

¹ Department of Food & Nutrition, School of Health, , Yasuj University of Medical Science, Yasuj, Iran.

² Department of Pharmacology, Yasuj University of Medical Science, Yasuj, Iran.

³ Department of Food & Nutrition, Yasuj University of Medical Science, Yasuj, Iran.

⁴ School of Nursing and Midwifery, Yasuj University of Medical Sciences, Yasuj, Iran.

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*Corresponding author:

hamdidelaviz@yahoo.com
Pharmacology Department,
School of Medicine, Yasouj
University of Medical
Sciences, Yasouj, Iran.

Postal code: 7591875114

Tel: +98 743 3225519

ABSTRACT

Background: The present study was conducted to evaluate the effect of curcumin as a flavonoid antioxidant on serum lipid profile, oxidative stress, and blood glucose in experimental models of type 2 diabetes (DM2). **Methods:** Subcutaneous daily injection of dexamethasone (5 mg/kg/day) for a month was performed to induce DM2. For this purpose, 28 adult male Wistar rats were divided into four groups: healthy control group received dexamethasone carrier containing normal saline + ethanol 4% , diabetic control group took 5 mg/kg/day dexamethasone, diabetic group 1 underwent the treatment with 50 mg/kg/day curcumin, and diabetic group 2 underwent treatment with 100 mg/kg/day curcumin. Seven days after dexamethasone injection, curcumin (50 and 100 mg/kg/day) was administrated intraperitoneally for 23 days. At the end of one month, the fasting blood sugar (FBS) level was measured and recorded by glucometer. Later, after a 30-day period, the animals were anesthetized with ether and their blood samples were collected from the heart puncture to measure their serum triglyceride (TG), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C) and malondialdehyde (MDA). **Results:** The findings showed that curcumin could decrease FBS ($P < 0.05$), LDL-C ($P < 0.01$), TG ($P < 0.001$), and MDA ($P < 0.001$) and increase HDL-C ($P < 0.001$) at the end of 30 days. **Conclusion:** These effects of curcumin can be mediated by increasing either the pancreatic secretion of insulin or releasing from insulin bonds as well as enhancing insulin receptor sensitivity. Moreover, it may prevent the glucose absorption, reduce the activity of 3-hydroxy- 3-methyl glutaryl- CoA reductase (HMG-CoA), or improve the function of liver and pancreas through potent antioxidant properties.

Keywords: Curcumin; Diabetes; Dexamethasone; Rat

Introduction

In recent decades, the incidence of diabetes Mellitus, especially type 2 diabetes (DM2) has

been increasing throughout the world and it is believed that the growing prevalence of this disease

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will be accelerated over the next 15 years. Based on the national diabetes statistics report-2020, 10.5% of the US population have diabetes (Atlanta, 2020). In a study conducted by Mirzaei et al., the prevalence of diabetes was 14.1% in Yazd province, center of Iran (Mirzaei et al., 2020).

Diabetes is a disease of the endocrine system, which exists in two different types. DM2, also called non-insulin dependent diabetes, is commonly found in over 40 years old and obese people. The most important feature of the pathogenesis of DM2 is insulin dysfunction associated with insulin resistance.

Diabetic complications can be divided into the microvascular and macrovascular categories (Kirpichnikov and Sowers, 2001). This increased incidence of such diseases is considered as the leading cause of mortality among diabetic patients (Avogaro et al., 2004). Diabetic nephropathy is also one of the major causes of death due to diabetes (Longo et al., 2012).

DM2 is associated with the occurrence of a phenomenon called insulin resistance, which in fact occurs following a period of long-term insulin resistance, during which glucose level remains within the normal range at the cost of increased insulin (Goldstein, 2002).

Synthetic drugs, apart from its beneficial effects, have no maximum efficiency, but have many side effects. In this respect, medicinal plants have shown fewer complications and can be added to different diets (Sumbul et al., 2011).

Due to the growing prevalence of diabetes throughout the world and despite the efforts of medical science in the management of diabetic complications, medicinal plants and traditional medicine were employed extensively in recent years to control diabetes in different populations (Liu et al., 2007). Since the late nineteenth century, extensive studies were conducted on the treatment of diabetes and respective complications using medicinal plants; for example, Ginger and Aloe vera (Ajabnoor, 1990). Among various plants of interest, turmeric (*Curcuma longa*) is a plant with useful properties.

Given the important role of oxidative stress in the development of these side effects, much research has been conducted on strengthening the antioxidant

system and their effectiveness in preventing diabetic complications in humans and experimental models. As a result, many positive results were reported. Accordingly, the present study examined the effects of curcumin, as the main substance found in turmeric root. Several studies demonstrated anti-diabetic effects of curcumin (Chuengsamarn et al., 2012a).

Curcumin is a yellow pigment derived from turmeric. Over the past few years, numerous studies demonstrated that curcumin exerts several anticancer effects in various types of cancers by suppressing cell proliferation and metastasis inducing cell death. Curcumin has a broad range of activities including antioxidant, anticarcinogenic, anti-inflammatory, hypocholesterolemic, wound healing, antispasmodic, anticoagulant, antitumor, and hepatoprotective activities. Curcumin also exhibits protective effects against cancer formation. The antiproliferative effect of curcumin can be attributed to its ability to regulate protein kinases, cell cycle, and transcription factors including NF- κ B. In a melanoma cell line, curcumin exhibited a potent antiproliferation effect by inhibiting the binding activity of NF- κ B.

In these studies, the findings showed that curcumin prevented the death of beta cells, improving the function of beta cells (Chuengsamarn et al., 2012b). One of the mechanisms for anti-diabetic effects of curcumin is the stimulation of PPAR gamma receptors, such as anti-diabetic drug of thiazolidinediones (Kuroda et al., 2005). In animal models of type I diabetes (DM1), curcumin was able to lower complications of diabetes, such as cataracts (Suryanarayana et al., 2005), glucose, and lipid (Sidhu et al., 1999) as well as to accelerate diabetic wound healing (Majithiya and Balaraman, 2005).

Since curcumin has strong antioxidant properties, reactive oxygen species (ROS) such as superoxide radicals, hydroxyl radicals, and hydrogen peroxide play a pivotal role in the pathogenesis of diabetes. Therefore, we hypothesised that curcumin might have a protective role against this condition (Anwar and Meki, 2003, Bonnefont-Rousselot et al., 2000). Consequently, the aim of this study was to

investigate the anti-diabetic effect of injectable curcumin at the doses of 50 and 100 mg/kg in the model of dexamethasone-induced diabetes in rats. To the best of our knowledge, no study has ever been carried out in this regard.

Materials and Methods

The dried rhizomes of *C. amada* were obtained from Green Pharmacy, Yasuj, Iran. Rhizomes of *C. amada* were grounded to a powder using a pulverizer and screened for 20 min for getting different particle sizes. The different particle sizes of *C. amada* powder used for the experimentation were within the range of 0.05 to 0.5 mm. Standard curcumin was prepared from Merck Co. Germany. Ultrasonic horn (tip diameter of 20 mm) with 250 W rated output power and 22 kHz frequency obtained from Bandlin Co (Germany) were used for the extraction based on the Ultrasound-Assisted Extraction (UAE) approach. Water bath was placed around the extraction flask to ensure that the solvent reservoir temperature did not increase drastically. Ultrasonic horn was operated in pulse mode (5 s on followed by 5 s off) and hence the solvent was not heated much. During the extraction, 6 g of *C. amada* powder was mixed with 150 ml of solvent to keep the ratio of solute to solvent similar to the conventional extraction operation. The mixture was irradiated for 1h and samples were withdrawn at regular intervals for the analysis.

In the present research, the effects of curcumin were tested on 28 adult male Wistar rats, which were divided into four groups of seven as follows:

1. Healthy control group, receiving dexamethasone carrier containing normal saline + ethanol 4%
2. DM2 control group taking 5 mg/kg/day dexamethasone
- 3- DM2 group 1 under treatment with 50 mg/kg/day curcumin by subcutaneous injection for 23 days, which dexamethasone was injected after the seventh day
- 4- DM2 group 2 under treatment with 100 mg/kg/day curcumin by subcutaneous injection

for 23 days, which dexamethasone was injected after the seventh day.

The study duration was 30 days. DM2 was developed using daily subcutaneous injection of 5 mg/kg/day dexamethasone for 30 days (Ogawa *et al.*, 1992).

The rats were weighed again after 30 days. At the end of this period, the animals were anesthetized with ether. The animal was fixed on autopsy tray and 5 ml syringe was inserted into the rat heart to take blood samples. The needle was removed and blood sample was emptied into the sterile and labeled blood collection tubes by inserting the syringe tip on the inner edge of the tubes. The tubes containing blood samples were centrifuged at 3000 rpm for 15 minutes to separate the serums that were then stored at -20 °C until testing the study factors, including serum triglyceride (TG), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C), malondialdehyde (MDA), and blood glucose.

Instrumentations: Spectroscopic analysis was carried out using Doublebeam Shimadzu recording UV-Visible Spectrophotometer (Kyoto, Japan) model 1601 with 10 mm path length matched quartz cells used for analytical purpose. Stock solutions of curcumin containing 100 mg/ml were prepared in methanol and its aliquots were transferred in a series of 10 ml volumetric flasks in varying fractions and their volumes were made with methanol to prepare different standard dilutions varying from 0.01 to 10 mg/ml. Curcumin 5 µg/ml solution was scanned using a UV spectrophotometer within the range of 200-800 nm. Methanol was used as blank. Wavelength corresponding to maximum absorbance of curcumin in methanol was observed at 421 nm.

Preparation of blood samples: Centrifugation at 3000 rpm for 15 minutes was used to separate the serums, which were stored at -20 °C for subsequent measurements.

Measurement of biochemical parameters: The samples for measurement of TG, HDL-C, and LDL-C were transferred to the laboratory of

Yasuj Shahid Beheshti Hospital, Iran using BT3000 auto analyzer device.

Measurement of oxidative stress markers: The basic principle of measuring MDA is the reaction between the product of lipid peroxidation, i.e., MDA and thiobarbituric acid (TBA). Absorption of pink complex resulting from this reaction at high temperature was read by spectrophotometer at a wavelength of 532 nm and the concentration was determined using the standard curve. The MDA concentration was calculated for MDA-TBA complex. The amount of plasma MDA was reported as $\mu\text{M/l}$.

Data analysis: The obtained data were analyzed in SPSS software through one-way ANOVA and Tukey's test. The differences were considered significant at $P\text{-value} \leq 0.05$.

Results

According to the results obtained from the current study, no significant difference was found between the groups in biochemical parameters at the study baseline. Comparison of the mean weight between the pre- and post- test groups showed no significant differences between different groups. However, the mean weight in diabetic control group was decreased by 10% at the end of the period compared to the baseline, but this weight loss was not statistically significant. In the healthy control and group treated with curcumin, the weight gain was 6.2% and 3.4%, respectively, but the difference was not statistically significant. The mean serum glucose levels of diabetic control group revealed significant difference compared with other groups

(Figures 2A&B). No significant difference was observed in the mean glucose level in the groups treated with curcumin at the doses of 50 and 100 mg/kg/day compared to the healthy controls. Evaluation of the mean LDL-C in the studied groups showed that the highest level of LDL-C was related to the diabetic control group. A significant difference was seen between the diabetic control group and other groups; this difference indicates the effect of curcumin on reducing LDL-C in diabetic animals (Figure 2C).

The highest mean level of serum TG was related to the diabetic control group and the least amount was observed in the healthy control group. In other words, dexamethasone-induced diabetes increased the serum TG levels (96.2 ± 6.7 mg/dl). In addition, the mean serum TG levels in the groups 1 and 2 treated with the dose of 50 and 100 mg/kg/day were reduced significantly compared to the diabetic control group (Figure 2D).

According to Figure 2F, the mean HDL-C shows that the lowest HDL-C level was related to the diabetic control group and the highest value was found in the group treated with curcumin dose of 100 mg/kg/day. Curcumin with low dose of 50 mg/kg/day increased HDL-C, but this increase was not significant. These data suggest that curcumin could increase HDL-C levels (Figure 2E).

The results of Figure 2G show the maximum amount of MDA in diabetic control group (4.9 ± 0.29 $\mu\text{mol/l}$) and the least amount in the healthy control group (1.8 ± 0.12 $\mu\text{mol/l}$). Both doses of curcumin could significantly reduce MDA levels compared to the diabetic control group.

Table 1. Comparison (mean \pm SD) of weight and biochemical parameters in four groups.

Variables/groups	Healthy control	Diabetic control	Curcumin 50	Curcumin 100	P-value
Weight before (kg)	256.0 ± 10.5	270.0 ± 5.8	263.0 ± 9.0	259.0 ± 9.6	
Weight after (kg)	272.0 ± 10.5	243.0 ± 4.7	260.0 ± 12.5	268.0 ± 8.2	
Low density lipoprotein cholesterol (mg/dl)	51.0 ± 4.3	67.0 ± 3.8	45.5 ± 4.5	34.5 ± 4.1	
High density lipoprotein cholesterol (mg/dl)	36.0 ± 1.9	22.5 ± 1.3	28.5 ± 0.84	36.0 ± 1.7	
Triglyceride (mg/dl)	5.2 ± 4.4	96.2 ± 6.7	68.8 ± 4.1	69.0 ± 4.2	
Blood glucose (mg/dl)	124.0 ± 5.7	233.0 ± 12.0	116.0 ± 8.1	134.0 ± 8.7	
Malondialdehyde ($\mu\text{M/l}$)	1.80 ± 0.12	4.90 ± 0.29	2.88 ± 0.31	2.68 ± 0.18	

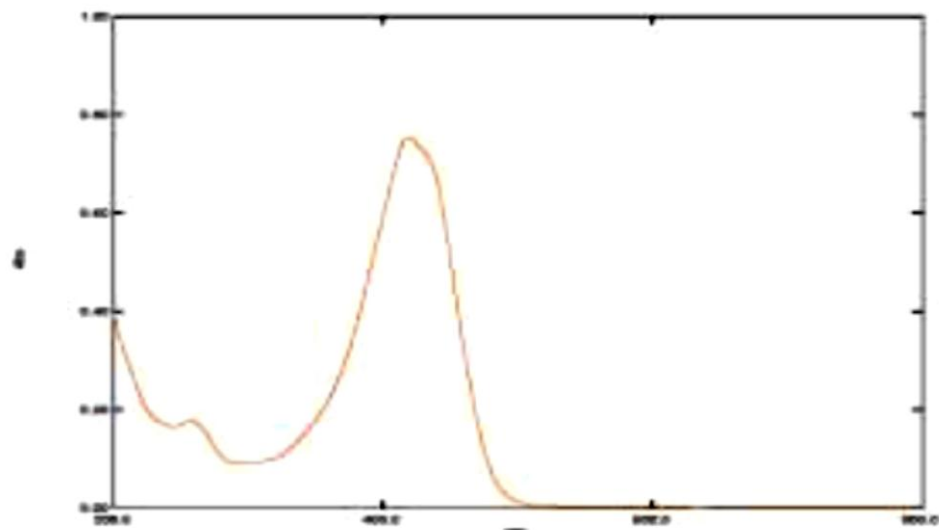
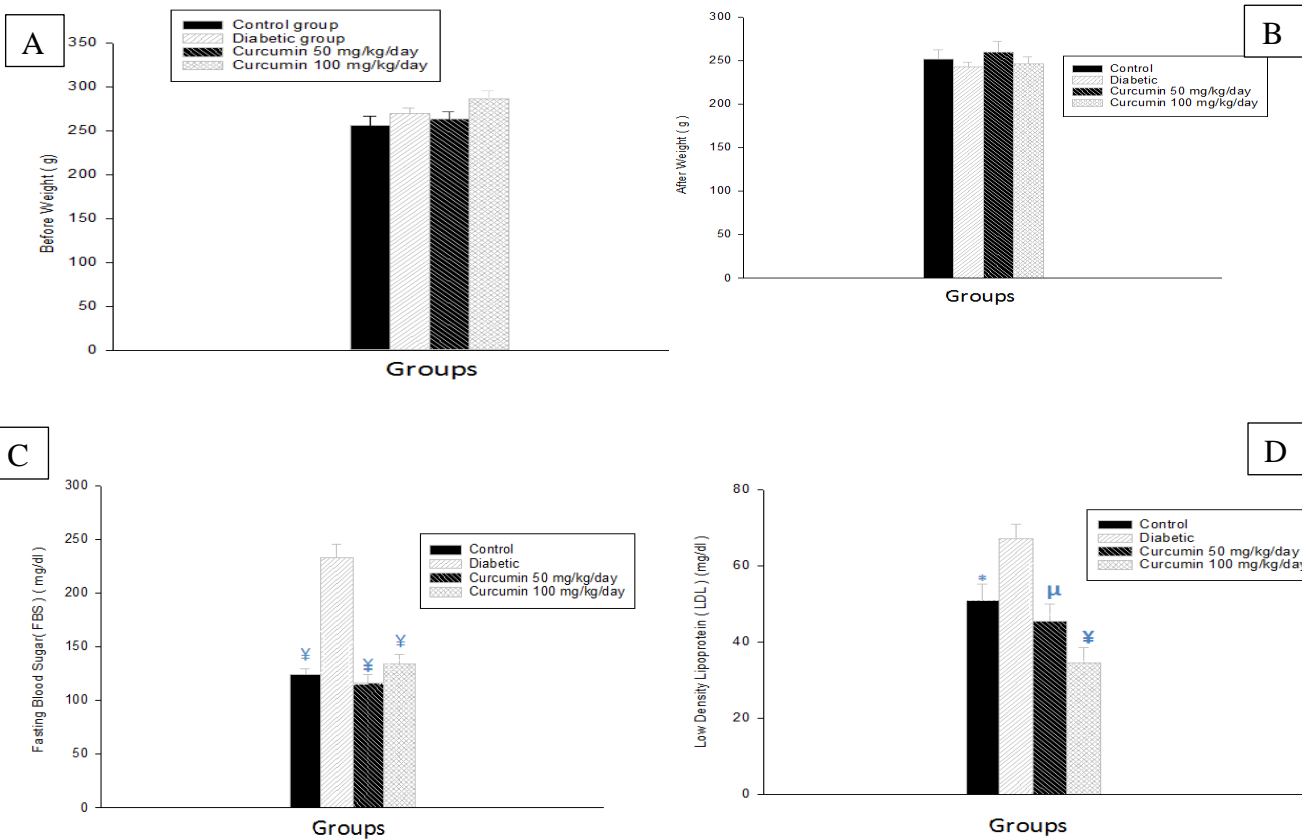


Figure 1. UV spectrum of Curcumin



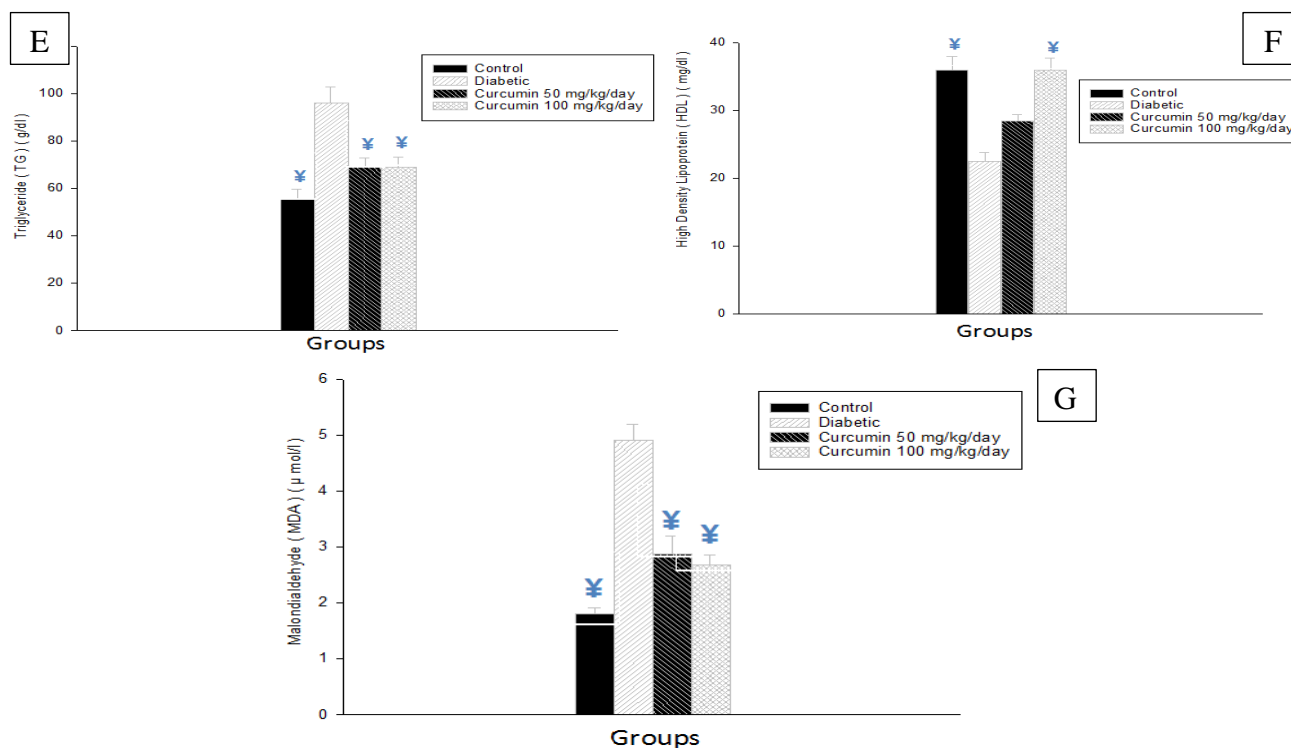


Figure 2. Evaluation of anthropometric and biochemical values among studied groups at the end of treatment, as compared to diabetes.

Discussion

In present study, as shown in **Table 1** and **Figure 2**, dexamethasone injection in diabetic rats increased obviously the blood glucose levels. At the end of the period, curcumin could alter blood glucose levels; so, this was not significantly different from the amount of glucose in healthy control group. Kuhad et al. and Kuroda et al. demonstrated that the curcumin decreased insulin resistance and glucose tolerance, which ultimately reduced blood sugar in dexamethasone-induced diabetes (Kuhad and Chopra, 2007, Kuroda *et al.*, 2005). The results of the present study are consistent with the findings of these researchers. Curcumin reduced the production of inflammatory cytokines and decreased insulin resistance and glucose levels consequently (Maradana *et al.*, 2013, Sajithlal *et al.*, 1998). According to the findings of present study, curcumin may reduced blood glucose levels in diabetic rats by increasing either the pancreatic secretion of insulin, released from insulin bonds as well as enhancing insulin receptor sensitivity (Seo *et al.*, 2008). Previous

studies indicated that the dexamethasone-induced diabetes decreased body weight (Shpilberg *et al.*, 2012). In present study, injection of dexamethasone resulted in the weight loss of animals, but the difference was not significant (**Table 1** and **Figure 2C**). Weight loss in diabetic control group was due to the lack of fat storage because of insulin resistance (Martínez *et al.*, 2016).

In the present study, it curcumin could largely prevent weight loss caused by dexamethasone and curcumin inhibited insulin resistance. Curcumin also increased lipid synthesize and fat storage. As a result, weight gain increased in the treated groups by activating the enzyme lipoprotein lipase and inhibiting enzyme hormone-sensitive lipase.

In dexamethasone-induced diabetic rats, increase blood glucose levels could enhance the levels of LDL-C and serum TG but decreased HDL-C (Hazra *et al.*, 2008). Hormone sensitive lipase (HSL), as natural intercellular lipase has the ability to hydrolyze TG, cholesterol esters, and other lipids (Sekiya *et al.*, 2009). HSL increases

the level of free fatty acids, transfers them to the liver, and improves the release of TG from the liver. Insulin is known as anti-lipolytic factor and decreases serum TG by reducing the activity of HSL and inhibiting its phosphorylation. Furthermore, insulin increases lipoprotein lipase activity (LPL) on the surface of fat cells, which encourages the entry of fatty acids into the adipose tissue and fat storage (Nishino *et al.*, 2007, Szkudelski and Szkudelska, 2002). Administration of dexamethasone (when the existing insulin resistance reduces LPL activity) decreases TG uptake from TG-rich lipoprotein and ultimately increases TG levels in serum. Direct relationship was reported between the serum LPL activity and HDL-C (Tsutsumi, 2003). In the present study, similar changes were observed in the diabetic control group. Increased TG and LDL-C as well as decreased HDL-C were found in the diabetic control group than the other groups (**Table 1**). Omayma AR et al. showed that curcumin could lead to lower triglyceride and LDL-C levels and increase HDL-C (Omayma *et al.*, 2016). These findings are consistent with the results of the other studies (Omayma *et al.*, 2016, Pari and Murugan, 2007). Curcumin may reduce the serum lipids by inhibiting enzymes involved in lipid synthesis in the liver or improving oxidative stress conditions. Curcumin can decrease HSL activity probably by increasing insulin sensitivity and thus reduces the serum lipids in rats. In general, favorable effects of curcumin on lipid profile can be attributed to the increase in the lipolysis cycle (Belhan *et al.*, 2020).

In patients with diabetes, free fatty acid causes the release of oxygen free radicals, resulting in oxidative stress (McGarry, 2002). Given the reduced antioxidant defense in diabetics, increased production of free radicals may lead to cell dysfunction and oxidative damage to the membrane and increase sensitivity to lipid peroxidation (Ceriello *et al.*, 1991). In this study, symptoms similar to diabetes were observed after administration of dexamethasone in diabetic control group. Following a 30-day course of dexamethasone in the diabetic control group, levels

of MDA, as a product of lipid peroxidation, showed a significant increase (**Figure 2G**). In insulin resistance condition, the production of free radicals is increased such as superoxide anion and peroxynitrite (Jansson, 2007). It is known that oxidative stress is both a cause and a consequence of insulin resistance in diabetes (Calles-Escandon and Cipolla, 2001). Curcumin is a strong antioxidant that can reduce insulin resistance and thereby slows down the disease process of diabetes. It should be noted that the increase in serum TG and insulin resistance may lead to enhance expression of IL-1, IL-6, and TNF (Kim *et al.*, 2007). A part of the observed effect of curcumin is probably due to its anti-inflammatory effect (Jurenka, 2009).

Curcumin has an inhibitory effect on Wnt/JNK1 signaling pathway, which may suppress apoptosis and inflammation (Zhou *et al.*, 2020). Vitali et al. concluded that curcumin decreased proinflammatory cytokines including: TNF- α and IL-6 in vaginal and cervical tissues (Vitali *et al.*, 2020). Therefore, curcumin can be considered as a compound with dual antioxidant and anti-inflammatory effects that improve diabetic complications.

Conclusion

In summary, curcumin with antioxidant properties had a significant effect on the improvement of metabolic complications (FBS, LDL-C, TG and HDL-C) in diabetic rats at the two different doses. These findings can introduce the curcumin as a good candidate for diabetes treatment, especially DM2, which begins with insulin resistance

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Authors' Contributions

Pourmahmoudi A developed the study idea and theory, participated in drafting the manuscript. Sharif Talebianpoor M supervised the project, participated in drafting the manuscript, performed

the analysis the data. Vafaiee Nejad T contributed in sample preparation. Mozafari M contributed in sample preparation. Hosseinikia M participated in drafting the manuscript. All authors read the manuscript and verified it.

Conflict of interest

none declared

References

- Ajabnoor MA 1990. Effect of aloes on blood glucose levels in normal and alloxan diabetic mice. *Journal of Ethnopharmacology*. **28** (2): 215-220.
- Anwar MM & Meki A-RM 2003. Oxidative stress in streptozotocin-induced diabetic rats: effects of garlic oil and melatonin. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*. **135** (4): 539-547.
- Atlanta G 2020. National diabetes statistics report, 2020. Centers for Disease Control and Prevention, US Department of Health and Human Services.
- Avogaro A, de Kreutzenberg SV, Negut C, Tiengo A & Scognamiglio R 2004. Diabetic cardiomyopathy: a metabolic perspective. *American Journal of Cardiology*. **93** (8): 13-16.
- Belhan S, et al. 2020. Effects of curcumin on sperm quality, lipid profile, antioxidant activity and histopathological changes in streptozotocin-induced diabetes in rats. *Andrologia*. **52** (6): e13584.
- Bonnefont-Rousselot D, Bastard J, Jaudon M & Delattre J 2000. Consequences of the diabetic status on the oxidant/antioxidant balance. *Diabetes and Metabolism*. **26** (3): 163-177.
- Calles-Escandon J & Cipolla M 2001. Diabetes and endothelial dysfunction: a clinical perspective. *Endocrine Reviews*. **22** (1): 36-52.
- Ceriello A, Giugliano D, Quatraro A, Russo PD & Lefebvre P 1991. Metabolic control may influence the increased superoxide generation in diabetic serum. *Diabetic Medicine*. **8** (6): 540-542.
- Chuengsamarn S, Rattanamongkolgul S, Luechapudiporn R, Phisalaphong C & Jirawatnotai S 2012a. Curcumin extract for prevention of type 2 diabetes. *Diabetes Care*. **35** (11): 2121-2127.
- Chuengsamarn S, Rattanamongkolgul S, Luechapudiporn R, Phisalaphong C & Jirawatnotai S 2012b. Curcumin extract for prevention of type 2 diabetes. *Diabetes care*. DC_120116.
- Goldstein BJ 2002. Insulin resistance as the core defect in type 2 diabetes mellitus. *American Journal of Cardiology*. **90** (5): 3-10.
- Hazra A, Pyszczynski NA, DuBois DC, Almon RR & Jusko WJ 2008. Modeling of corticosteroid effects on hepatic low-density lipoprotein receptors and plasma lipid dynamics in rats. *Pharmaceutical Research*. **25** (4): 769-780.
- Jansson PA 2007. Endothelial dysfunction in insulin resistance and type 2 diabetes. *Journal of Internal Medicine*. **262** (2): 173-183.
- Jurenka JS 2009. Anti-inflammatory properties of curcumin, a major constituent of *Curcuma longa*: a review of preclinical and clinical research. *Alternative Medicine Review*. **14** (2).
- Kim F, et al. 2007. Toll-like receptor-4 mediates vascular inflammation and insulin resistance in diet-induced obesity. *Circulation Research*. **100** (11): 1589-1596.
- Kirpichnikov D & Sowers JR 2001. Diabetes mellitus and diabetes-associated vascular disease. *Trends in Endocrinology & Metabolism*. **12** (5): 225-230.
- Kuhad A & Chopra K 2007. Curcumin attenuates diabetic encephalopathy in rats: behavioral and biochemical evidences. *European Journal of Pharmacology*. **576** (1-3): 34-42.
- Kuroda M, et al. 2005. Hypoglycemic effects of turmeric (*Curcuma longa* L. rhizomes) on genetically diabetic KK-Ay mice. *Biological and Pharmaceutical Bulletin*. **28** (5): 937-939.
- Liu CT, Sheen LY & Lii CK 2007. Does garlic have a role as an antidiabetic agent? *Molecular Nutrition & Food Research*. **51** (11): 1353-1364.
- Longo DL, et al. 2012. Harrison's principles of internal medicine. McGraw-hill New York.

- Majithiya JB & Balaraman R** 2005. Time-dependent changes in antioxidant enzymes and vascular reactivity of aorta in streptozotocin-induced diabetic rats treated with curcumin. *Journal of Cardiovascular Pharmacology*. **46** (5): 697-705.
- Maradana MR, Thomas R & O'sullivan BJ** 2013. Targeted delivery of curcumin for treating type 2 diabetes. *Molecular Nutrition & Food research*. **57** (9): 1550-1556.
- Martínez BB, et al.** 2016. Experimental model of glucocorticoid-induced insulin resistance. *Acta Cirurgica Brasileira*. **31** (10): 645-649.
- McGarry JD** 2002. Banting lecture 2001: dysregulation of fatty acid metabolism in the etiology of type 2 diabetes. *Diabetes*. **51** (1): 7-18.
- Mirzaei M, Rahmaninan M, Mirzaei M & Nadjarzadeh A** 2020. Epidemiology of diabetes mellitus, pre-diabetes, undiagnosed and uncontrolled diabetes in Central Iran: results from Yazd health study. *BMC Public Health*. **20** (1): 166.
- Nishino N, Tamori Y & Kasuga M** 2007. Insulin efficiently stores triglycerides in adipocytes by inhibiting lipolysis and repressing PGC-1 α induction. *Kobe Journal of Medical Sciences*. **53** (3): 99-106.
- Ogawa A, et al.** 1992. Roles of insulin resistance and beta-cell dysfunction in dexamethasone-induced diabetes. *Journal of Clinical Investigation*. **90** (2): 497-504.
- Omayma A, Ragab A, Abdel-Majeed A, Hassanin K & Abdelghaffar M** 2016. Biochemical effect of curcumin on hyperlipidemia induced in rats. *Medicamentul Veterinar*. **10** (1): 49-53.
- Pari L & Murugan P** 2007. Antihyperlipidemic effect of curcumin and tetrahydrocurcumin in experimental type 2 diabetic rats. *Renal Failure*. **29** (7): 881-889.
- Sajithlal G, Chithra P & Chandrakasan G** 1998. Effect of curcumin on the advanced glycation and cross-linking of collagen in diabetic rats. *Biochemical Pharmacology*. **56** (12): 1607-1614.
- Sekiya M, et al.** 2009. Hormone-sensitive lipase deficiency suppresses insulin secretion from pancreatic islets of Lepob/ob mice. *Biochemical and Biophysical Research Communications*. **387** (3): 511-515.
- Seo KI, et al.** 2008. Effect of curcumin supplementation on blood glucose, plasma insulin, and glucose homeostasis related enzyme activities in diabetic db/db mice. *Molecular Nutrition & Food Research*. **52** (9): 995-1004.
- Shpilberg Y, et al.** 2012. A rodent model of rapid-onset diabetes induced by glucocorticoids and high-fat feeding. *Disease Models & Mechanisms*. **5** (5): 671-680.
- Sidhu GS, et al.** 1999. Curcumin enhances wound healing in streptozotocin induced diabetic rats and genetically diabetic mice. *Wound Repair and Regeneration*. **7** (5): 362-374.
- Sumbul S, Ahmad MA, Asif M & Akhtar M** 2011. Myrtus communis Linn.-A review. *Indian Journal of Natural Products and Resources*. **2** (4): 395-402.
- Suryanarayana P, et al.** 2005. Curcumin and turmeric delay streptozotocin-induced diabetic cataract in rats. *Investigative Ophthalmology & Visual Science*. **46** (6): 2092-2099.
- Szkudelski T & Szkudelska K** 2002. Streptozotocin induces lipolysis in rat adipocytes in vitro. *Physiological Research*. **51** (3): 255-260.
- Tsutsumi K** 2003. Lipoprotein lipase and atherosclerosis. *Current Vascular Pharmacology*. **1** (1): 11-17.
- Vitali D, et al.** 2020. Curcumin can decrease tissue inflammation and the severity of HSV-2 infection in the female reproductive mucosa. *International Journal of Molecular Sciences*. **21** (1): 337.
- Zhou J, Wu N & Lin L** 2020. Curcumin Suppresses Apoptosis and Inflammation in Hypoxia/Reperfusion-Exposed Neurons via Wnt Signaling Pathway. *International Medical Journal of Experimental and Clinical Research*. **26**: e920445-920441.