Original Research Article

Evaluation of Hypoglycemic and Hypolipidemic activities of Methanolic leaf extract of *Garcinia gummi-gutta Linn* by HFD with low dose STZ induced type II Diabetes Mellitus on rats

Abstract

Objective: The aim of the present study was to evaluate the hypoglycemic and hypolipidemic activities of methanolic leaf extract of *Garcinia gummi-gutta Linn*. by HFD with low dose STZ induced T2DM on rats. **Materials and Methods:** The animals were divided into five groups of six animals each; HFD was induced for 8 weeks. After 4th week of HFD treatment, type-II diabetes was induced by single dose of 35mg/kg (*i.p*) STZ, hyperglycaemia was confirmed by the elevated levels of blood glucose determined at 72h and the animals with blood glucose concentration (< 250mg/dl) were used for the study. The *in vitro* anti-diabetic activity was done by DNS method. **Results and Discussion:** The *in vitro* anti-diabetic activity by α-amylase inhibition activity by DNS method was very mild as compare to Acarbose and the IC_{50} value of Acarbose was very low (170.84µg/ml) than MEGG (1989.59µg/ml). However, potent *in vivo* anti-diabetic activity (P<0.001) was observed after induction HFD with low dose STZ induced T2DM rats at the end of 8th week, blood sugar level for MEGG high dose (173.40 ± 14.9mg/dl) was found to be almost same as that of standard drug Glibenclamide (164.60 ± 3.21mg/dl) as compared to control (287.90 ± 1.52). The lipid profile of the study showed the marked increase in TC, LDL, TG and reduction in HDL in HFD with low dose STZ diabetic rats, whereas in MEGG and

standard drug treated by Glibenclamide were found to be substantially decreased and fair amount of improvement in HDL level ($P<0.001$). Histologically, focal necrosis was observed in the diabetic rat pancreas whereas on standard and test mild and no evidence of necrosis were observed respectively, similar positive results were found in liver and adipocyte histology for standard and test groups against the HFD with STZ induced group **Conclusion:** Therefore MEGG possesses potent *in vivo* anti-diabetic effect as well as hypolipidimic effect and therefore MEGG might be a potent phytochemical alternative to prevent and treat T2DM and atherosclerosis and also to reduce its associated complications.

Keywords: Streptozotocin (STZ), High fat diet (HFD), Methanolic Leaf Extract of *Garcinia gummi-gutta Linn*. (MEGG). Type-II Diabetes Mellitus (T2DM)

INTRODUCTION

T2DM is a progressive disorder defined by deficits in insulin secretion and action that lead to abnormal glucose metabolism and related metabolic derangements[1]. Although the etiologies of type-1 and T2DM differ dramatically, both lead to hyperglycemic states, and both share common macro-vascular (coronary heart, cerebrovascular, and peripheral vascular disease) and micro-vascular (retinopathy, nephropathy, and neuropathy) complications. T2DM is most often diagnosed following routine screening. It is preceded by a state of pre-diabetes, which is defined by single fasting plasma glucose of 100-125mg/dl or an HbA1c of 5.7% to 6.4% in the absence of diabetes. Diabetes diagnosis is based on 2 confirmed values of: fasting plasma glucose (>125 mg/dl); HbA1c of 6.5% or greater; or (less commonly) glucose tolerance test results, or random plasma glucose of (≥ 200 mg/dl) plus symptoms of hyperglycemia[2].

Now there has been a tragic increase in diabetes across the world, paralleling the overweight and obesity epidemic. There are 95 percent of those people belonging to T2DM. Therefore, it is great urgency to find better treatments and novel prevention strategies for T2DM. To accomplish this goal, appropriate experimental models are considered as essential tools for understanding the molecular basis, pathogenesis of the vascular and neural lesions, actions of therapeutic agents, and genetic or environmental influences that increase the risks of T2DM. Although there are numerous animal models (natural as well as developed) available for the study of T2DM[3–6], the pattern of disease establishment and progress in most of them did not appear to be similar to the clinical situation in humans. Thus, there is a continued quest among the investigators with respect to the establishment of better animal model for T2DM by adjusting the existing methods, developing new methodologies, or a combination of both.

Many studies have reported that the rats fed with HFD develop insulin resistance but not frank hyperglycemia (or) diabetes[7–9]. It is suggested that the HFD might be a better way to initiate the insulin resistance which is one of the important features of T2DM. At the same time, STZ is widely used to reproducibly induce both insulin-dependent and non-insulin dependent diabetes mellitus presently by inducing β cell death through alkylation of DNA [10]. Although high-dose STZ severely impairs insulin secretion mimicking type-1 diabetes, low-dose STZ has been known to induce a mild impairment of insulin secretion which is similar to the feature of the later stage of T2DM[3, 4]. Therefore, investigators have started to develop a rat model by feeding the animal with HFD following low-dose STZ that would closely mimic the natural history of the disease events (from insulin resistance to β cell dysfunction) as well as metabolic characteristics of human T2DM[3-6].

Garcinia gummi gutta Linn., commonly known as 'Kodampuli' (or) 'Malabar tamarind', is a dicotyledonous tropical tree belonging to the family Clusiaceae (Guttiferae). *G. gummi gutta* is a semi-domesticated crop, with wide distribution in semi-evergreen to evergreen forests. In India, it is commonly found in the evergreen and Shola forests of Western Ghats, Karnataka and Kerala and also in the states of Maharashtra, Goa and Tamil Nadu[11, 12].

The leaves of *Garcinia* contain hydroxyl citric acid[13]. The presence of phytochemicals such as tannin, phlobatannin, saponin, flavanoids, terpenoids and cardiac glycosides has been reported in the crude extract of *Garcinia gummi gutta* leaves. [14] Most of these compounds contribute to the pharmacognostic properties of this plant against gastrointestinal infections. Several authors have linked the antimicrobial properties of the crude extracts to the presence of these bioactive compounds[15-17]. Much research has been carried out on the anti-inflammatory, anti-bacterial and anti-cancer properties of *Garcinia*[18-21]. A decoction made

from leaves of *Garcinia* is administered for rheumatism and bowel complaints. In cattle, it is used as a wash for mouth diseases. Hydroxy citric acid extracted from the mature fruit rind is used against obesity[22].

MATERIALS &METHODS

Plant Collection and Authentication

The fresh leaves of the plant *Garcinia gummi-gutta Linn* were collected from the surrounding areas of Mannar, Kerala during the month of February and authenticated by Botanical survey of India (BSI) southern circle, Coimbatore, Tamilnadu (BSI/SRC/5/23/2019/Tech./3239).

Preparation of plant material

The collected leaves were cleaned, washed with distilled water, dried under sunshade in dark room and powdered, after size reduction; leaves were sieved under sieve No. 40 and sieve No. 60, stored in airtight container at room temperature.

Selection of solvent for extraction

Dried leaf powder of *Garcinia gummi-gutta Linn* (500g) was defatted, extracted with 5 liters of 70% methanol using cold maceration process until exhausting. The collected extract was filtered with Whatman No.1 and then was evaporated under reduced pressure with rotary evaporator at 50 °C, lyophilized, powdered and kept on −20 °C until using.

Experimental Animals

Sprague Dawley rats of 6-8 weeks old with 160-180g body weight were obtained from KMCH College of pharmacy, Coimbatore. All rats were housed and maintained under

standard conditions of temperature ($25^0C \pm 5^0C$), relative humidity (55 ± 10%), and 12/12 h light/dark cycle. Animals were fed with commercial pellet diet for control, HDF diet for treatment groups and water *ad libitum* freely throughout the study. Protocol for the study was approved by the Institutional Animal Ethical Committee (KMCRET/M.Pharm/15/2019-20). Regular chow consisting of 5% fat, 53% carbohydrate, 23% protein, with total calorific value 25kJ/kg and HFD consisting of 22% fat, 48% carbohydrate, and 20% protein with total calorific value 44.3kJ/kg were given.

Acute Toxicity Study

Acute oral toxicity study was performed as per OECD-423 guidelines. The rats were fasted overnight with free excess of water and were grouped into four groups consisting of 3 animals each, to which the extract was administered orally at the dose level of 5mg/kg, 50mg/kg, 300 mg/kg and 2000mg/kg. They were observed for mortality; toxic symptoms such as behavioural changes, locomotor activity, convulsions; direct observation parameters such as tremor, convulsion, salivation, diarrhoea, sleep, coma, changes in skin and fur, eyes and mucous membrane, respiratory, circulatory, autonomic and CNS, somatomotor activity etc. periodically for 30 min during first 24h and specific attention given during first 4h daily for a total period of 14 days.

Induction of Hyperlipidemia in rats

The rats were divided into 5 groups (n=5) containing 6 rats, group-1 (normal control) animals were retained on standard laboratory animal diet, the remaining groups were fed with a HFD for a period of 8 weeks, however groups-3, 4 and 5 were intervened by Glibenclamide 5mg/kg (Ranbaxy, India), MEGG 200mg/kg and MEGG 400mg/kg respectively from 4^{th} week of the induction of HFD and continued till 8^{th} week (Table-1).

Experimental induction of diabetes

After 4th week of HFD treatment, rats overnight fasted group-2, 3, 4 and 5th rats were injected with single dose of 35 mg/kg (*i.p*), STZ (sigma chemical Co. U.S.A) dissolved in 0.1 M cold citrate buffer (PH 4.5), the initial fasting blood glucose and 48 hours after STZ administration blood samples were drawn by from tip of rat tail to confirm diabetes. The animals with blood glucose concentration more than 250 mg/dl were used for the study[23].

***In vitro* diabetic activity: Inhibition assay for α-amylase activity (DNS)**

Acabose (standard) and MEGG (test) of five concentrations (100, 200, 300, 400 and 500µg/ml) were prepared by dissolving in double distilled water. A total of 500µl of plant extract and 500 µl of 0.02M sodium phosphate buffer (pH 6.9 with 0.006M sodium chloride) containing α-amylase solution (0.5mg/ml) were incubated for 10 minutes at 25°C.After pre-incubation, 500µl of 1% starch solution in 0.02M sodium phosphate buffer (pH 6.9 with 0.006M sodium chloride) was added to each tube at 5s intervals. This reaction mixture was then incubated for 10 minutes at 25°C.1ml of DNS colour reagent was added to stop the reaction. These test tubes were then incubated in a boiling water bath for 5 minutes and cooled to room temperature. Finally, this reaction mixture was again diluted by adding 10ml distilled water following which absorbance was measured at 540nm[24].

Chemicals and reagents: The dialysis membrane and 1-4, α-D-Glucan-glucanohydrolase (α-amylase) were purchased from Hi-Media Laboratories, Mumbai, India. All other chemicals, reagents, kits and solvents used in this study were of analytical grade and procured locally

$$\text{Percentage Inhibition} = \frac{\text{Abs.}_{540}\ (\text{Control}) - \text{Abs.}_{540}\ (\text{Test})}{\text{Abs.}_{540}\ (\text{Control})} \times 100$$

Oral Glucose Tolerance Test (OGTT)

Rats were divided into five groups (n=5) and were administered normal saline, diabetic control (STZ, 35 mg/kg), Glibenclamide (10 mg/kg) and dose of 200 mg/kg and 400 mg/ kg (*p.o*) of MEGG at the end of 4th, week to 8th week after induction of diabetes. After an overnight fast (12–16 hours), glucose solution 2g/kg was administered 30 minutes after the administration of the extract (or) normal saline (or) drug, blood samples were withdrawn at by tip of rat tail vein after 60 minutes of glucose administration and the blood glucose levels were estimated using GOD-POD kit (Acuurex, India).

Histological examinations

Pancreas and liver were instantly dissected out at the end of 8th week, excised and rinsed in an ice cold saline solution. A portion of liver and pancreas were fixed in 10% neutral formalin fixative solution were fixed in 10% formalin, dehydrated in alcohol and then embedded in paraffin. Microtome sections of 4 5 µm thickness were made by using a rotary microtome. The sections were stained with haematoxylin–eosin (H&E) dye to observe histopathological changes[25].

RESULTS

Preliminary Phytochemical Screening

The methanol extract contained glycosides, saponins, flavonoids, terpenoids, steroids, tannins, proteins, amino acids and carbohydrates. The percentage yield of MEGG was found to be 4.3% w/w and soluble in alcohol and water.

Acute Toxicity Study

The MEGG showed the normal behaviour of the treated rats and no toxic effects were observed at a higher dose of 2g/kg body weight. Hence, there were no lethal effects observed in any of the groups till the end of the study, MEGG 200mg/kg and MEGG 400mg/kg were chosen as low and high dose respectively for *in vivo* anti-diabetic activity.

Effect of MEGG and Acarbose on α-amylase inhibition activity by DNS method

Percentage inhibition activity for anti-diabetic activity was assessed at concentration ranges from 100 µg/ml to 500 µg/ml for standard and test and the maximal inhibition effect at 500µg/ml concentration was found to be 60.88% and 25.44% for Acarbose and MEGG respectively [Table-2] and the IC_{50} value of Acarbose and MEGG was found to be 170.84µg/ml and 1989.59µg/ml respectively [Figure-1]. It implies MEGG may have mild *in vitro* anti-diabetic effect by inhibition of α-amylase activity.

Blood glucose levels of after induction of HFD with low dose STZ rat

At dose 200mg/kg and 400 mg/kg of MEGG, fasting blood glucose levels were assessed in normal rats at various time intervals with the standard drug group treated by Glibenclamide [Table-3 and Figure-2], demonstrate that the MEGG exhibited significant hypoglycemic activity on HFD with low dose STZ induced T2DM rats. At the end of 8^{th} week of treatment, there was a 42.83%, 32.93%, and 39.77% decrease ($P < 0.001$) of blood glucose levels with Glibenclamde (standard), MEGG 200mg/kg and MEGG 400mg/kg (test) as compare to diabetes control group.

Serum lipid parameters of control and treatment groups after induction of HFD with low dose STZ rats

Lipid profile showed significant ($P < 0.001$) reductions of 58.65%, 47.12%, 54.71% of T. Cholesterol, 39.07%, 20.90%, 28.57% LDL, 54.56%, 24.91% 38.91% VLDL and 31.72%, 15.15% 26.94% of TGL (Triglyceride) were found after treatment with Glibenclamide (standard) MEGG at doses of 200 mg/kg and 400 mg/kg (test) respectively as compare to T2DM rats after HFD with low dose STZ induced diabetic rats. It was also observed there was a significant ($P < 0.001$) increase of 25.38%, 9.45%, 15.53% HDL level were found after treatment with Glibenclamide (standard) MEGG at doses of 200mg/kg and 400mg/kg (test) respectively as compare to T2DM rats. [Table-4 and Figure-3].

Changes of Histopathology of the Pancreas and liver

At the end 8th week of treatment period, the histo-pathological examination of the pancreas of the control rats showed normal β cells with abundant granular cytoplasm, in HFD with low dose STZ induced T2DM rats were irregular, not well defined and necrosis of the cells was observed, whereas in standard (Glibenclamide) and test (high dose of MEGG) showed the presence of more viable β cells with mild and no evidence of focal necrosis respectively [Figure-4].

The histo-pathological examination of HFD and STZ induced diabetic group showed disordered liver structure with hepatocellular necrosis and extensive vacuolization in contrast to control group. As in the case of Standard and low dose of MEGG illustrate the presence of low infiltration of lymphocytes, however in high dose MEGG treated group showed nearly normal hepatocellular architecture with normal nucleus cytoplasm and distinct hepatic layer, indicating that high dose of MEGG has nearly healed the hepatocellular damage caused by HFD with STZ induction [Figure-5].

Similar histo-pathological illustrations were found in adipocytes, as in the case of HFD and STZ treated diabetic group showed increase in the size of the cells and inflammatory cell infiltration, whereas in standard, low dose and high dose of MEGG treated group showed decrease in size of the cells without any inflammatory infiltration, establish the potent effect of MEGG against HFD with STZ induction [Figure-6].

DISCUSSION

Currently, many studies have reported that the HFD fed rats develop insulin resistance. At the same time, low-dose STZ has been known to induce a mild impairment of insulin secretion which is similar to the feature of the later stage of T2DM [4, 5]. Plants serve as an excellent source of various therapeutic agents, with the major advantages of using plants is that they seldom show the deleterious side effects commonly associated with other allopathic drugs. This study investigated the ability of *Garcinia gummi-gutta Linn* to serve as effective anti-diabetic agents.

Preliminary phytochemical screening showed MEGG contained glycosides, saponins, flavonoids, terpenoids, steroids, tannins, proteins, amino acids and carbohydrates. *In vitro* study of α-amylase inhibition activity assay provide mild (or) no anti-diabetic activity of test drug compare to standard drug (Acarbose) in terms of the ability to reduces glucose absorbance by acting on small intestine to cause decrease in production of enzymes needed to digest carbohydrates, the results showed MEGG minimally inhibit α-amylase enzyme than standard drug Acarbose.

In vivo low dose STZ with HFD induced T2DM rats results showed, of STZ caused rapid destruction of pancreatic β-cells in rats, which led to impaired glucose stimulated insulin

release and insulin resistance, both of which are marked features of T2DM rats. The fasting blood glucose level was estimated at the end of 4^{th}, 5^{th}, 6^{th}, 7^{th} and 8^{th} week by tip of rat tail vein showed the diabetic effect is stable from the starting of STZ induction till the end of 8^{th} week. The data illustrates a marked increase in serum glucose levels as compared to normal rats. The animals with blood glucose concentration more than 250mg/dl was selected and used for the study.

The study showed that the treatment of diabetic rats with Glibenclamide and MEGG caused a potential amelioration of glucose tolerance and dose depended effect was observed with MEGG. It implies MEGG might have similar mechanism of action as Glibenclamide which belongs to the class of sulfonylurea derivatives, produces hypoglycemic effect by stimulating insulin release on pancreatic β cells by inhibiting the K^+/ATPse pump.

In the present study, the rise in blood glucose was accompanied with a marked increase in TC, LDL-C, TG and reduction in HDL-C in HFD with low dose of STZ diabetic rats, whereas the standard (Glibenclamide) and test (MEGG) produced great improvement of the altered serum lipid variables, thus MEGG has the potential to prevent the formation of atherosclerosis and coronary heart disease which are the secondary diabetic complications of severe diabetes mellitus. The hypothesis is further supported by the pancreatic histology which showed protection of pancreatic β-cells from toxic effects of STZ and focal necrosis was observed in the diabetic rat pancreas. However, was less obvious in treated groups.

CONCLUSION

In conclusion, MEGG possess potent *in vivo* anti-diabetic effects and mechanism of action contributing the acute anti-hyperglycemic effect of the extract would most likely by multiple mechanisms by both increased lease of insulin, as well as by increasing the sensitivity of insulin receptor. In addition to that it also possesses potent anti-atherosclerotic effect as it effectively improves cholesterol profile might be due to the presence of flavonoids and glycosides present in MEGG. MEGG might be a potent phytochemical alternative to prevent and treat T2DM and atherosclerosis and also to reduce its associated complications. However, isolation of phytochemical and its pharmacological evaluation would conform the specific phytochemical, precise mechanism of action and the therapeutic potential of *Garcinia gummi gutta* in treating T2DM and anti-atherosclerotic drug therapy.

REFERENCES

1. American Diabetes Association. Diagnosis and classification of diabetes mellitus. Diabetes Care. 2010;33: (Suppl. 1) S62–S69.
2. Taskinen MR. Diabetic dyslipidemia. Atheroscl Suppl. 2002; 3:47–51.
3. Jenson T, Stender, Deckert T. Abnormalities in plasma concentration of lipoprotein and fibrogen in type 1 (insulin dependent) diabetic patients with increased urinary albumin excretion. Diabology. 1998; 31:142-6.
4. Moller D. New drug targets for type 2 diabetes and the metabolic syndrome: A review. Nature. 2004; 414:821-7.
5. Yamauchi T, Kamon J, Ito Y, Tsuchida A, Yokomizo T. Kita S. *et al*. Cloning of adiponectin receptors that mediate antidiabetic metabolic effects. Nature. 2003; 423:762–769.
6. Verges B, Petit JM, Duvillard L. Dautin G. *et al.* Adiponectin is an important determinant ofapoA-I catabolism. Arterioscler Thromb Vasc Biol. 2006; 26:1364–1369.
7. Kern PA, Di Gregorio GB, Lu T, Rassouli N, Ranganathan G. Adiponectin expressionfrom human adipose tissue: relation to obesity, insulin resistance, and tumor necrosis factor-α expression. Diabetes. 2003; 52:1779–1785.
8. Antuna-Puente B, Feve B, Fellahi S, Bastard JP. Adipokines: the missing link between insulin resistance and obesity. Diabetes Matabol. 2008; 34:2-11.
9. Trujillo ME, Scherer PE. Adiponectin: journey from an adipocyte secretory protein to biomarker of the metabolic syndrome. J Intern Med. 2005; 257:167–175.
10. Steppan CM, Lazar MA. The current biology of resistin. J Intern Med 2004; 255(4):439-447.

11. Selvaraj TI, Avadhani M. Medicinal Properties of Malabar Tamarind [Garcinia cambogia (Gaertn.) DESR.]. Int J Pharm Sci Rev Res, 2013; 20: 101-7. 2.
12. Abraham Z, Malik SK, Rao GE, Narayanan SL, Biju SL. Collection and Characterization of Malabar Tamarind [Garcinia cambogia (Gaertn.) Desr.]. Genet Resour Crop Ev, 2006; 53: 401-6.
13. Hemshekhar M, Sunitha K, Santhosh MS, Devaraja S, Kemparaju K, Vishwanath BS, Niranjana SR, Girish KS. An overview on Genus Garcinia: Phytochemical and Therapeutical Aspects. Phytochem Rev, 2011; 10(3): 325-51.
14. Devi Prasad AG, Raghavendra MG, Shyma TB. Antimicrobial Activity of Tribal Medicines Collected from Wayanad District, Kerala. World J Pharm Res, 2014; 3(2): 2476-92. 7.
15. Adesokan AA, Akanji MA, Yakubu MT. Antibacterial Potentials of Aqueous Extract of Enantia chlorantha Stem Bark. Afr J Biotechnol, 2007; 6: 2502-5.
16. Oyeleke SB, Dauda BEN, Boye OA. Antibacterial activity of Ficus capensis. Afr J Biotechnol, 2008; l7: 1414-17.
17. Sahm DF, Washington JA. Antibacterial Susceptibility Tests: Dilution methods. In: Lennette, EH (eds). Manual of Clinical Microbiology Fifth edition, Washington DC; American Society of Microbiology: 1990; 1105-18.
18. Duke SO, Dayan FE, Hernandez A, Duke MV, Abbas HK. Natural Products as Leads for New Herbicide Modes of Action. In: Proceedings of the 1997 Brighton Crop Protection Conference – Weeds, 1997; 2: 579-86.
19. Acuna UM, Jancovski N, Kennelly EJ. Polyisoprenylated Benzophenones from Clusiaceae: Potential Drugs and Lead Compounds. Curr Top Med Chem, 2009; 9(16): 1560-80.
20. Shara M, Onia SE, Schmidt RE, Yasmin T, Zaedetto-Smith A, Kincaid A, Bagchi M, Chatterji A, Bagchi D, Stohs SJ. Physico-chemical Properties of a Novel (-)-Hydroxycitric Acid Extract and its Effect on Body Weight, Selected Organ Weights, Hepatic Lipid Peroxidation and DNA Fragmentation, Hematology and Clinical Chemistry, and Histopathological Changes over a Period of 90 Days. Mol Cell Biochem, 2004; 260: 171-86.
21. Dhanya P, Benny PJ. Antifungal Effect of Methanolic Extracts of Leaves of Garcinia gummi gutta L. Int J Pharm Sci Rev Res, 2013; 59: 330-3.
22. Devi Prasad AG, Shyma TB, Raghavendra MP. Informant Consensus Factor and Antimicrobial Activity of Ethnomedicines used by the Tribes of Wayanad District, Kerala. Afr J Microbiol Res, 2013; 7(50): 5657-63. 19
23. Chege BM, Waweru MP, Frederick B, Nyaga NM.The freeze-dried extracts of Rotheca myricoides (Hochst.) Steane & Mabb possess hypoglycemic, hypolipidemic and hypoinsulinemic on type 2 diabetes rat model. J.Ethnopharmacol. 2019 Nov 15;244:112077.
24. Sathiavelu A et al: In Vitro anti-diabetic activity of aqueous extract of the medicinal plants Nigella sativa, Eugenia jambolana, Andrographis paniculata and Gymnema sylvestre Int. J. Drug Dev. & Res., April-June 2013, 5 (2): 323-328
25. Kedar P, Charaborthy CH. Effect of bitter guard (Momordica charantia) seed and glibenclamide in streptozotocin induced diabetes mellitus. Indian J Exp Biol 1982;20:232-5.

Tables

Table-1 Effect of MEGG and Acarbose on α-amylase inhibition activity by DNS method

Group	Group Name	Drug/Vehicle Treatment
1	Vehicle Control	Normal saline with normal diet for 8 weeks
2	HFD induced diabetic control	HFD + STZ 35mg/kg (*i.p*)
3	HFD induced positive diabetic control	HFD + STZ + Glibenclamide 5 mg/kg (*p.o*)
4	Test-1 (low dose MEGG)	HFD + STZ + MEGG 200 mg/kg (*p.o*)
5	Test-2 (high dose MEGG)	HFD + STZ + MEGG 400 mg/kg (*p.o*)

Table-2 Effect of MEGG and Acarbose on α-amylase inhibition activity by DNS method

S.no	Concentration (µg/ml)	Percentage inhibition of Acarbose (%)	Percentage inhibition of MEGG (%)
1	100	44.17	18.46
2	200	53.85	22.50
3	300	57.12	23.87
4	400	58.59	24.48
5	500	60.88	25.44

Table-3 Blood glucose levels of control and treatment groups before and after induction of HFD with low dose STZ rats

Group No	4th week (mg/dl)	5th week (mg/dl)	6th week (mg/dl)	7th week (mg/dl)	8th week (mg/dl)
1	95.81 ± 1.70	97.11 ± 0.93	99.47 ± 2.64	97.23 ± 1.66	95.61 ± 2.57
2	98.54 ± 1.27	281.20 ± 3.63	290.70 ± 2.96	289.30 ± 2.93	287.90 ± 1.52
3	98.84 ± 1.88	187.00 ± 7.31	174.70 ± 6.74	169.80 ± 3.43	164.60 ± 3.21
4	98.26 ± 2.63	237.30 ± 5.29	219.10 ± 6.13	197.90 ± 4.25	193.10 ± 2.90
5	96.56 ± 2.61	203.30 ± 5.29	183.80 ± 3.87	182.00 ± 3.13	173.40 ± 14.9

Values are expressed as means ± SD (n=6). Statistical evaluation was done by one way ANOVA followed by Duncan's test, ***p < 0.001 as compared with control group.

Table-4: Serum lipid parameters of control and treatment groups after induction of HFD with low dose STZ rats (end of 8th week)

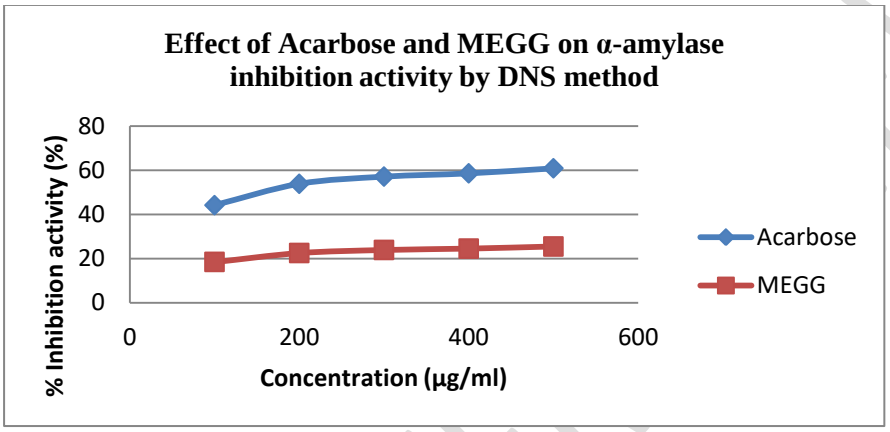
Group No	Total cholesterol (mg/dl)	Triglycerides (mg/dl)	HDL (mg/dl)	LDL (mg/dl)	VLDL (mg/dl)
1	111.1 ± 2.039	72.24 ± 1.597	42.85 ± 1.433	38.63 ± 0.855	15.24 ± 0.801
2	284.4 ± 2.927	175.6 ± 1.597	19.64 ± 1.051	72.59 ± 1.637	39.94 ± 0.866
3	117.6 ± 1.880	119.9 ± 1.508	26.32 ±	44.23 ±	21.42 ±

			1.375	1.346	1.214
4	150.4 ± 3.713	149.0 ± 3.190	21.69 ± 1.819	57.42 ± 1.464	29.99 ± 0.835
5	128.8 ± 3.008	128.3 ± 3.472	23.25 ± 1.208	51.85 ± 1.256	24.40 ± 1.071

Values are expressed as means ± SD (n=6). Statistical evaluation was done by one way ANOVA followed by Duncan's test, ***p < 0.001 as compared with control group.

Figures

Figure-1



IC_{50} value of Acarbose = 170.84 µg/ml
IC_{50} value of MEGG = 1989.59 µg/ml

Figure-2

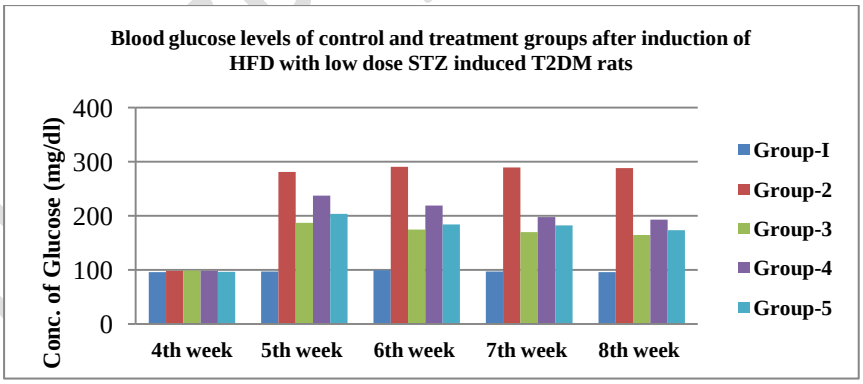


Figure-3

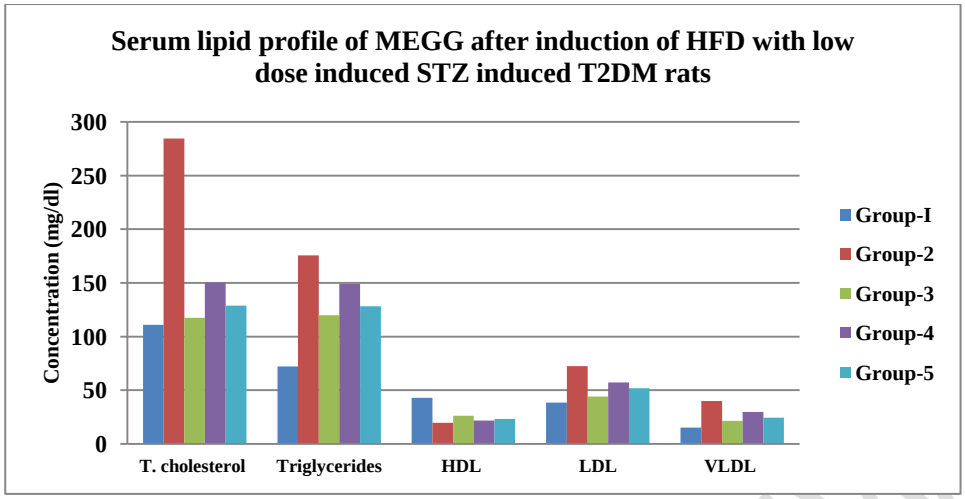


Figure-4: HISTOPATHOLOGY OF PANCREAS

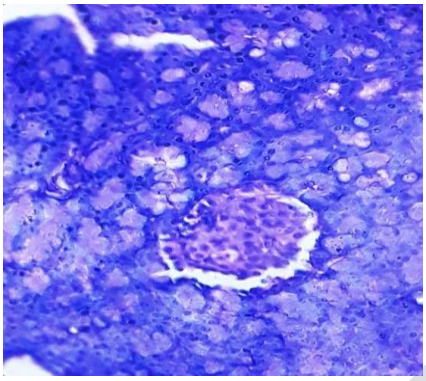


Figure-4a: Control Group
Pancreatic section of normal control group rats showing normal β cells with abundant granular cytoplasm

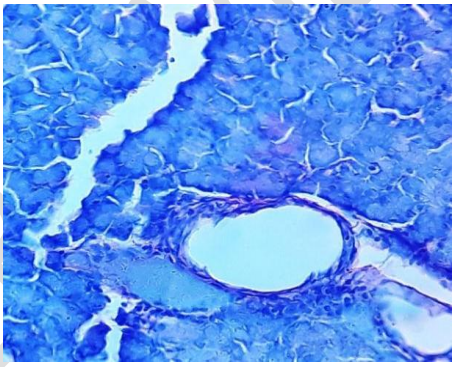


Figure-4b: Diabetic Group (HFD-STZ)
Pancreatic section of HFD with low dose STZ induced T2DM rats with irregular, not well defined and necrosis of the cells.

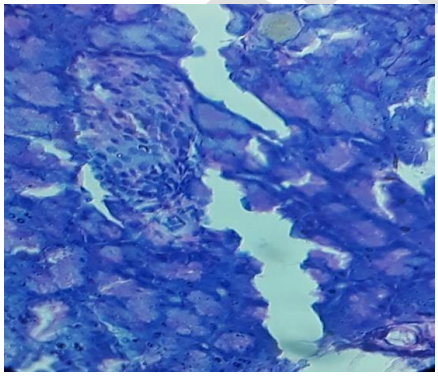


Figure-4c: Positive Group (Glibenclamide+HFD+STZ)
Pancreatic section of Positive control of HFD with low dose STZ induced T2DM rats with viable β cells with mild focal necrosis

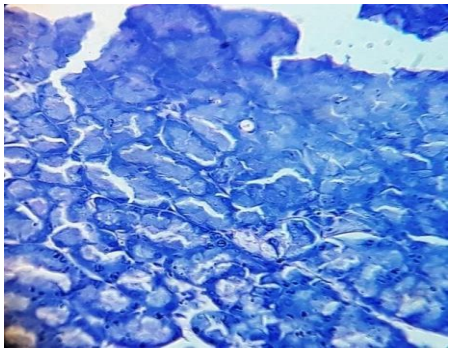


Figure-4d: Test-1 (Group (MEGG-200mg+HFD+STZ) Pancreatic section of Positive control of HFD with low

dose STZ induced T2DM rats with more viable β cells without focal necrosis.

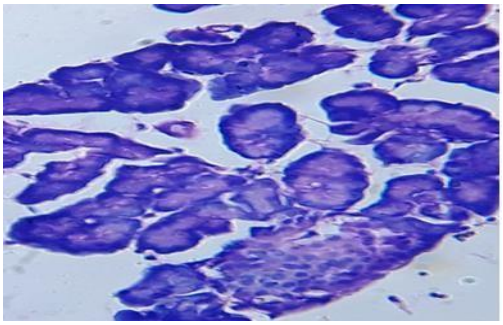


Figure-4e: Test-2 (MEGG-400mg+HFD+STZ)

In high dose treated group there is restoration of normal β cells and shows granular cytoplasm.

Figure-5: HISTOPATHOLOGY OF LIVER

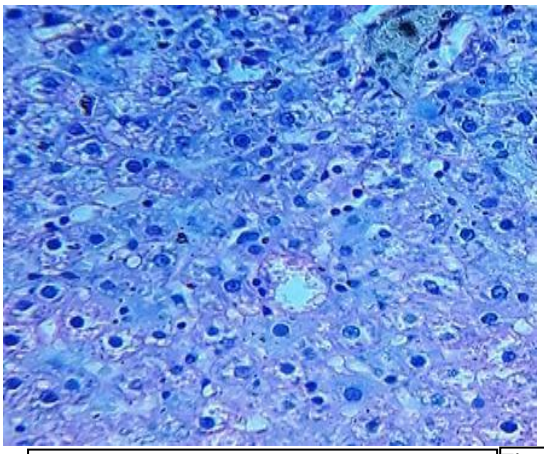


Figure-5a: Control Group

Normal control group shows typical histological structure of rat liver

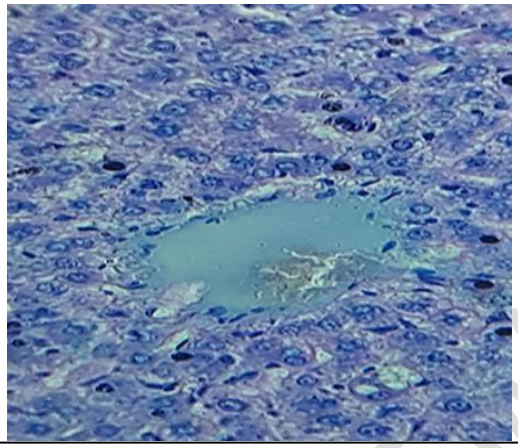
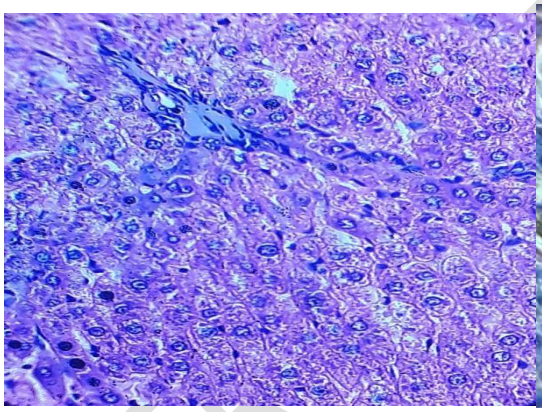


Figure-5b: Diabetic Group (HFD-STZ)

HFD and STZ induced diabetic group shows disordered liver structure with hepatocellular necrosis and extensive vacuolization.



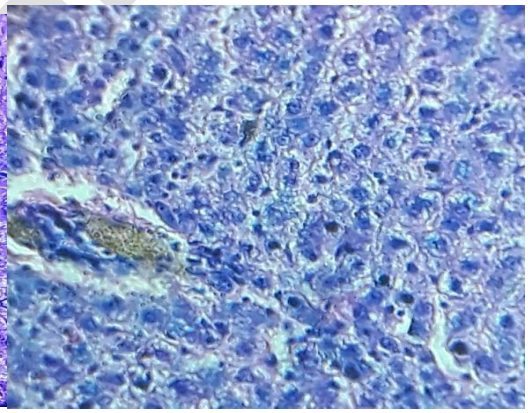


Figure-5c: Positive Group (Glibenclamide+HFD+STZ)

Glibenclamide treated group shows slight lymphocyte infiltration and preserved cell architecture.

Figure-5d: Test-1 Group (MEGG-200mg+HFD+STZ)

Low dose treated group shows lymphocyte infiltration

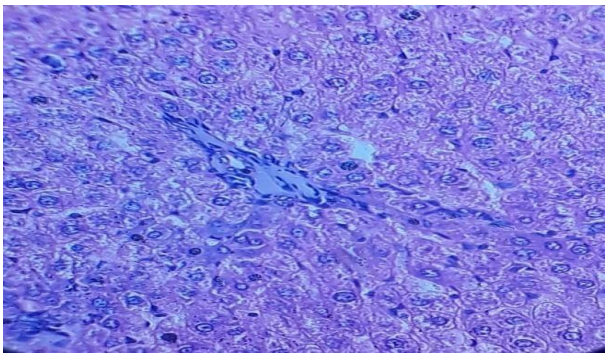


Figure-5e: Test-2 (MEGG-400mg+HFD+STZ)
High dose treated group shows nearly normal hepatocellular architecture with normal nucleus cytoplasm and distinct hepatic layer.

Figure 6: HISTOPATHOLOGY OF ADIPOSE TISSUE

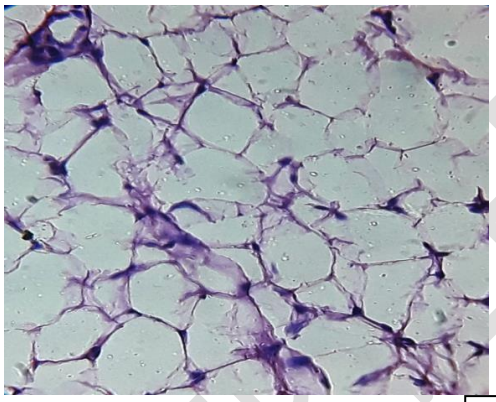


Figure-6a: Control Group
Histopathology of normal control group shows the normal size of adipose cells.

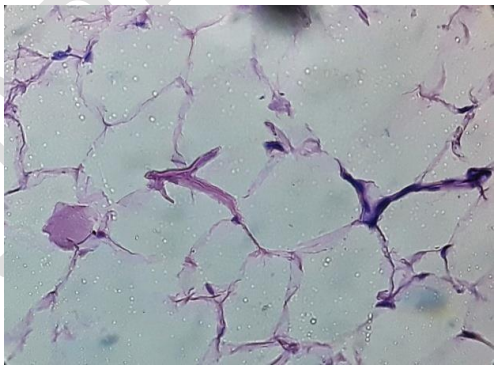


Figure-6b: Diabetic Control Group
HFD and STZ treated diabetic group shows increase in the size of the cells and inflammatory cell infiltration

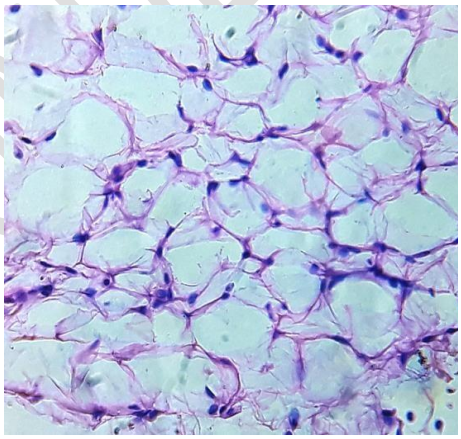


Figure-6c: Positive Group: (Glibenclamide+HFD+STZ)
Glibenclamide treated group shows decrease in the size of the cells

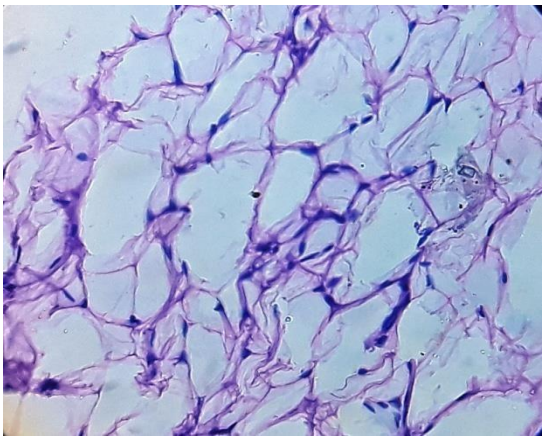


Figure-6d: Test-1 Group (MEGG-200mg+HFD+STZ)
Low dose treated group shows decrease in the size of the cells compared to HFD and STZ treated diabetic group.

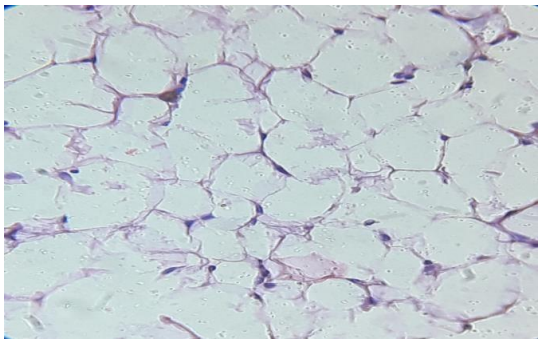


Figure-6e: Test-2 Group (MEGG-400mg+HFD+STZ)
High dose treated group shows decrease in the size of the cells compared to HFD and STZ treated diabetic group.