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IN-VIVO ANTIDIABETIC EVALUATION OF QUINOLINE–1,3,4-THIADIAZOLE HYBRIDS IN ALLOXAN-INDUCED DIABETIC RATS

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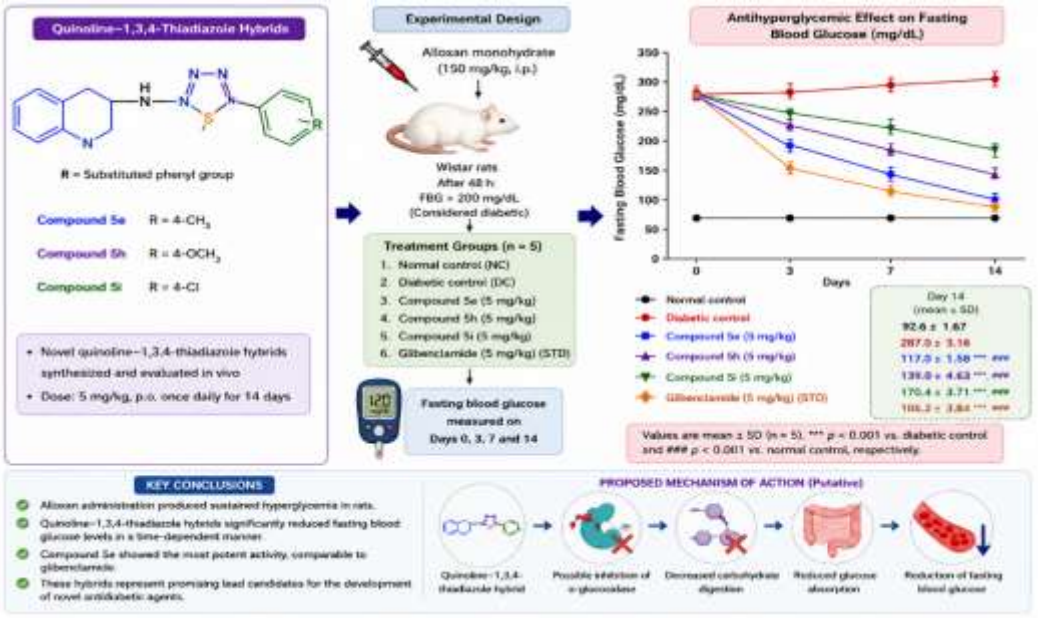
Abstract:



Diabetes mellitus is a chronic metabolic condition associated with severe microvascular and macrovascular complications and characterised by chronic hyperglycemia. Although several antidiabetic drugs are available, the search for safer and more effective treatment choices is a serious challenge. In the present investigation, alloxan-induced diabetic rat model was utilised to examine the in vivo antihyperglycemic potential of newly synthesised quinoline–1,3,4-thiadiazole hybrids. Alloxan monohydrate (150 mg/kg) was injected intraperitoneally into Wistar rats to induce experimental diabetes. Diabetic rats with fasting blood glucose levels > 200 mg/dL were chosen at random to receive vehicle, test compounds (5 mg/kg, p.o.) or glibenclamide (5 mg/kg, p.o.) for fourteen days in a row. Fasting blood glucose was tested on days 0, 3, 7 and 14. Persistent hyperglycemia was observed in the diabetic control group due to alloxan administration while therapy with the quinoline-1,3,4-thiadiazole hybrids resulted in a significant reduction of fasting blood glucose in a time-dependent manner. After 14 days of treatment, compound 5e demonstrated the highest antihyperglycemic activity among the studied derivatives, reducing the fasting blood glucose from 264.8 ± 2.58 mg/dL to 117.0 ± 1.58 mg/dL. Its impact was comparable to conventional drug glibenclamide (107.4 ± 4.82 mg/dL). Compounds 5h and 5i also produced significant glucose-lowering effects although to a lesser extent than 5e. The results indicated that 5e could be a lead contender and quinoline-1,3,4-thiadiazole hybrids have a promising in vivo antihyperglycemic activity.

Keywords: Diabetes mellitus, Quinoline 1,3,4-thiadiazole, Alloxan, Antihyperglycemic activity, Wistar rats, Glibenclamide.

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder characterised by abnormal carbohydrate, lipid, and protein metabolism secondary to persistent hyperglycemia due to defects in insulin secretion, insulin action, or both. The global incidence of diabetes has increased significantly over the past decades (1, 2). Hyperglycemia has a huge negative impact on patients' quality of life and increases healthcare costs (3), as it can lead to major microvascular and

macrovascular complications such as diabetic nephropathy, neuropathy, retinopathy, cardiovascular diseases, and stroke (4, 5). Thus, the development of safer and more effective antidiabetic medications continues to be one of the main aims of research in medicinal chemistry. The quinoline scaffold has attracted much attention due to its antibacterial, anti-inflammatory, anticancer, antioxidant and antidiabetic properties. Similarly, the 1,3,4-thiadiazole ring is regarded as an important pharmacophore with enhanced biological activity, metabolic stability and favourable pharmacokinetic features (6). Quinoline and 1,3,4-thiadiazole derivatives have demonstrated promising α-glucosidase inhibitory and antihyperglycemic activity in many studies, and they are promising as lead structures for the development of the antidiabetic medicines (7-9). Molecular hybridisation, which fuses two or more bioactive pharmacophores into one molecular framework, has been a successful method for the production of multifunctional medicinal agents. The hybridization of quinoline and 1,3,4-thiadiazole pharmacophores is expected to enhance biological activity. (10) is expected to improve the biological activity by combining the good pharmacological features of both the scaffolds. In earlier studies, Quinoline–1,3,4-thiadiazole hybrids have shown promising in vitro antidiabetic action but limited investigations are available on their antihyperglycemic performance in experimental diabetic animal models. Thus, a thorough in vivo examination is required to assess their therapeutic potential. Based on these considerations, the present work was designed to evaluate the antihyperglycemic efficacy of newly synthesised quinoline–1,3,4-thiadiazole hybrids with that of the standard α-glucosidase inhibitor glibenclamide in alloxan-induced diabetic Wistar rats (9, 11, 12). Although there are significant advances in the development of quinoline-based antidiabetic medicines, most of the investigations have focused primarily on chemical synthesis, computational studies and in vitro α-glucosidase and α-amylase inhibition experiments. While these approaches give useful initial evidence of biological activity, they do not properly predict the in vivo pharmacological efficacy and therapeutic potential of newly synthesised drugs. Therefore, further in vivo testing is still needed for the confirmation of their antihyperglycaemic effect and to find promising lead candidates for further pharmaceutical development.

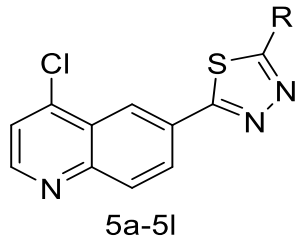
2. MATERIALS AND METHOD

2.1 Chemicals

Alloxan monohydrate was used for the induction of experimental diabetes. Glibenclamide (Glybovin) tablets 5 mg from Otsira Genetica was purchased from a local pharmacy. Drugs were prepared and administered in normal saline. All other chemicals and reagents used in the study were analytical grade.

2.2 Synthesis of desired product

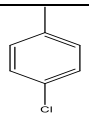
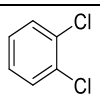
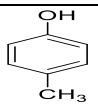
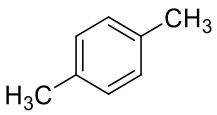
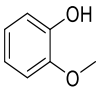
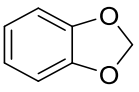
For the desired product (4-chloroquinoline-6-yl-1,3,4-thiadiazole) (5a-5l) using mainly two key reactions: Vilsmeier-Haack reaction and Schiff base formation by using different aldehydes (13) followed by chlorination and thionation, these compounds were designed as potential α-glucosidase inhibitors.

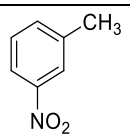
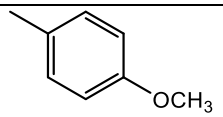
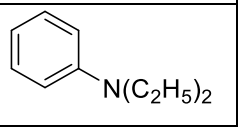


5a-5l

Fig 1: Quinoline–1,3,4-Thiadiazole

Table 1: Substituted R groups

S.no	Compounds	R	S.no	Compounds	R
1	5a		7.	5g	
2.	5b		8.	5h	
3.	5c		9.	5i	
4.	5d		10	5j	

5.	5e		11.	5k	
6.	5f		12.	5l	

2.2.1Selection of compounds for biological evaluation

Twelve compounds were synthesized in my previous work. Of these, compounds 5e, 5h and 5i were chosen for biological evaluation based on the result of molecular docking and their pharmacokinetic study. These complexes had the highest binding affinity to the target protein as well as good interactions with the active site.

2.3 Animal

Wistar rats with an average weight of 150-220 g were obtained from the authorized supplier. Animals were kept under conventional laboratory conditions in polycarbonate cages under a 12 h light/12 h dark cycle at 25 ± 2°C and relative humidity of 55 ± 5%. Animals were fed with a commercial pellet diet and water ad libitum (14).

2.4 Grouping

Thirty Wistar rats were randomly divided into six experimental groups (n = 5 per group). i.e., normal control, Diabetic control, test compound 5e, 5h and 5i and last one is standard. In each group there are 5 animals are selected.

Table 2: Experimental Groups

S. No	Groups	Treatment	Animals in each group
1	Group 1	Vehicle (Normal Control)	05
2	Group 2	Diabetic Control (Alloxan Treated) (i.p)	05
3	Group 3	Test Compound 5e at a dose of 5 mg/kg BW in normal saline for 14 days (p.o)	05
4	Group 4	Test Compound 5h at a dose of 5 mg/kg BW in normal saline for 14 days (p.o)	05
5	Group 5	Test Compound 5i at a dose of 5 mg/kg BW in normal saline for 14 days (p.o)	05
6	Group 6	Glibenclamide at the dose of 5mg/kg BW in normal saline for 14 days (p.o)	05

2.5 Induction of Experimental Diabetes

Diabetes mellitus in the experimental animal was induced after an overnight fast with a single i.p. injection of freshly prepared alloxan monohydrate (150 mg/kg body weight of animal) in normal saline. The animals were given 5% glucose solution for 24 hours before the alloxan was injected to reduce the possibility of an acute hypoglycemic shock after alloxan injection. After 48 hours the blood glucose level was measured in the fasting state with use of the digital glucometer. rats with fasting blood glucose>200mg/dL were considered diabetic, and included in the study (15, 16).

2.6 Preparation and Administration of Test Compounds

All synthesized quinoline–1,3,4-thiadiazole were kept refrigerated until further use. For every dose fresh dosing suspension was prepared by dispersion of adequate amount of each compound in normal saline to achieve the required dose. The test compounds were administered orally at a dosage of 5 mg/kg of body weight. In all treatment groups, the volume of administration was kept at around 5 mL/kg.

2.7 Preparation and Administration of Standard Drug

Glibenclamide (5 mg) tablets were finely powdered and freshly suspended in normal saline before oral administration. It gives through orally at dosage of 5 mg/kg body weight it was given daily for 14 days (17, 18).

2.8 Determination of Fasting Blood Glucose

Fasting blood glucose was taken on Days 0, 3, 7 and 14 during the treatment period. Blood samples were taken overnight fast by tail vein and glucose concentration was measured using a calibrated digital glucometer. The concentration of blood glucose was reported in mg/dL.

2.9 Statistical Analysis

The statistical analysis was done by calculation of the mean ± SD among the result using Two Way ANOVA followed by Dunnett's multiple comparisons tests. All the Statistical data were calculated using the software Graph Pad Prism Version. 8.02.

3. RESULT

3.1 Effect of Quinoline–1,3,4-Thiadiazole derivatives on Fasting Blood Glucose Levels in Alloxan-Induced Diabetic Rats

The fasting blood glucose (FBG) levels over the 14-day treatment period in alloxan-induced diabetic rats were examined for the antihyperglycemic effect of the synthesized quinoline-1,3,4-thiadiazole hybrids. Results are given in table 1 and figure 1.

Table 3: Fasting blood glucose level

S. No.	Groups	Day 0	Day 3	Day 7	Day 14
1	Group 1: Normal Control	92.2±1.92	92.4±2.07	92.4±1.67	92.6±1.67
2	Group 2: Diabetic Control	266±2.91	264.6±3.36	281.4±5.17	287±3.16
3	Group 3: Test Compound 5e	264.8±2.58	240±3.16	182.8±1.92	117±1.58
4	Group 4: Test Compound 5h	267.8±1.92	256.8±2.16	206±5.04	139±4.63
5	Group 5: Test Compound 5i	268.2±2.58	257.4±2.88	235.6±3.13	170.4±3.71
6	Group 6: Standard	264±2.73	233.8±3.96	165.8±2.58	107.4±4.82

The fasting blood glucose levels of all the diabetic groups were above 200 mg/dL at the end of 48 h after alloxan administration indicating the induction of diabetes. Blood glucose levels ranged between 264.0 ± 2.73 and 268.2 ± 2.58 mg/dL at baseline (Day 0), therefore providing a comparable diabetic condition before the start of treatment. No statistically significant difference was seen among the diabetic groups. However, the normal control group had physiological glucose levels (approximately 92 mg/dL) throughout the period of the examination.

The diabetic control group showed persistent and progressive hyperglycemia over the study, with fasting blood glucose increasing from 266.0 ± 2.91 mg/dL on Day 0 to 287.0 ± 3.16 mg/dL on Day 14, confirming the long-term diabetic condition in the untreated animals.

The time-dependent reduction in fasting blood glucose levels was seen after oral administration of quinoline-1,3,4-thiadiazole hybrids. Of the synthetic medicines, compound 5e 2-(4-chloroquinoline-6-yl)-5-(2-methyl-5-nitrophenyl)-1,3,4-thiadiazole (5 mg/kg) was the most potent antihyperglycemic agent. Blood glucose decreased significantly from 264.8 ± 2.58 mg/dL at baseline to 240.0 ± 3.16 mg/dL on Day 3, then dropped significantly to 182.8 ± 1.92 mg/dL on Day 7 and 117.0 ± 1.58 mg/dL on Day 14.

Compound 5h 2-(5-(4-chloroquinoline-6-yl)-1,3,4-thiadiazole-2 yl)-4-methoxyphenol (5 mg/kg) also significantly reduced fasting blood glucose levels during the treatment period, which were 139.0 ± 4.63 mg/dL on Day 14. The reduction was considerable but smaller than that of 5e for its efficacy of antihyperglycemic.

Following treatment with Compound 5i 2-(4-chloroquinoline-6-yl)-5-(2,5-dimethyl phenyl)-1,3,4-thiadiazole (5 mg/kg), the blood glucose levels steadily dropped as well. The fasting blood glucose level was reduced from 268.2 ± 2.58 mg/dL to 170.4 ± 3.71 mg/dL after 14 days of treatment which showed the moderate antihyperglycemic activity.

The typical medicine Glibenclamide (5 mg/kg) (19, 20) lowered the fasting blood glucose most from 264.0 ± 2.73 mg/dL on Day 0 to 107.4 ± 4.82 mg/dL on Day 14. Compound 5e had a fairly similar effect on glucose as the standard treatment.

Statistical investigation using Two Way ANOVA followed by Dunnett's multiple comparisons tests. showed that treatment with the produced compounds considerably decreased the fasting blood glucose levels compared to the diabetes control group ($P < 0.0001$). Among the derivatives tested, compound 5e exhibited the highest therapeutic effectiveness.

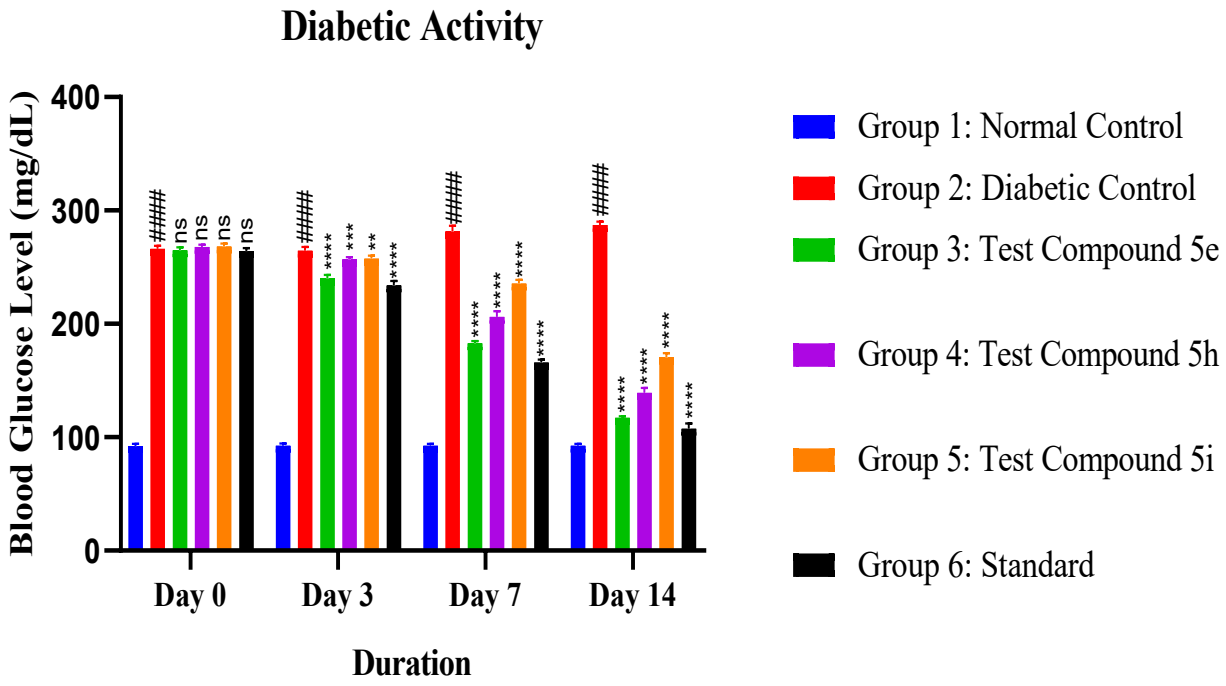


Fig. Alloxan-induced diabetic activity

All data were analysed via two-way analysis of variance (ANOVA) followed by Dunnett's multiple comparisons tests using GraphPad Prism software. Data presented are Mean ± SD (n =5). ns P values are considered non-significant versus diabetic group; ****P<0.0001, ***P<0.001 and **P<0.01 when compared to diabetic group and ####P<0.0001 compared to normal control.

4. DISCUSSION

Table 4 Comparison of the present study with previously reported antidiabetic studies

Study	Compounds	Experimental model	Major findings	Comparison with the present study
Present study	Quinoline–1,3,4-thiadiazole derivatives	Alloxan-induced diabetic rats	After 14 days, compound 5e decreased fasting blood glucose from 264.8 ± 2.58 to 117.0 ± 1.58 mg/dL; Compounds 5h and 5i likewise significantly lowered glucose.	Compound 5e showed an antihyperglycemic effect comparable to glibenclamide at a relatively low oral dose (5 mg/kg).
Design and synthesis of a novel quinoline thiazolidinedione hybrid as a potential antidiabetic PPARγ modulator	Quinoline–thiazolidinedione hybrid	Alloxan-induced diabetic rats	The lead quinoline derivative ((Z)-5-benzylidene-3-((2-chloroquinolin-3-yl)methyl)thiazolidine-2,4-dione) showed a significant decrease in the blood glucose levels as compared to the diabetes control, confirming the antidiabetic potential of quinoline based derivative (21).	The present study suggests that quinoline hybridization has been shown to improve the antihyperglycemic efficacy in vivo.

New Quinoline Analogues: As Potential Diabetics Inhibitors and Molecular Docking Study	Quinoline–1,3,4-thiadiazole analogues	STZ-induced diabetic rats	The most active analogue, following considerable inhibition of α-amylase and α-glucosidase in vitro, significantly decreased the hyperglycaemia (12).	enhances the in vivo glucose-lowering effect seen in this investigation and supports the medicinal potential of quinoline–1,3,4-thiadiazole derivatives.
In vivo and in silico evaluations of a synthetic pyrano[3,2-c]quinoline derivative as a potent anti-diabetic agent	pyrano[3,2-c]quinoline derivatives	STZ-induced diabetic rats	Oral administration improved the stage of the diabetes and significantly decreased fasting blood glucose(22).	These findings further support the antidiabetic potential of quinoline-containing scaffolds in chemically induced diabetes animals.

This study showed that in alloxan-induced diabetic rats, oral quinoline–1,3,4-thiadiazole hybrids drastically decreased fasting blood glucose levels. Compound 5e showed the highest antihyperglycaemic effect of the synthesised compounds after 14 days of therapy with the fasting blood glucose reduced from 264.8 ± 2.58 mg/dL to 117.0 ± 1.58 mg/dL. This effect was similar to that of the commonly used drug glibenclamide. Compounds 5h and 5i also considerably decreased blood glucose levels although to a lesser extent.

The obtained results are in keeping with the previous studies, which showed the antidiabetic potential of hybrid compounds based on quinoline. Table 4 summarizes the significant glucose-lowering efficiency of quinoline-containing derivatives observed in several chemically induced diabetic animal models. A recent study added to the usefulness of quinoline hybridization in the development of antidiabetic medications by describing a quinoline–thiazolidinedione hybrid and demonstrating a substantial antihyperglycemic effect in alloxan-induced diabetic rats.

Similarly, quinoline–1,3,4-thiadiazole analogues exhibited significant antidiabetic activity in streptozotocin-induced diabetic rats after their potent α-amylase and α-glucosidase inhibitory activity. Although the present work did not test the enzyme inhibition in vivo, the significant decrease of fasting blood glucose seen in Compound 5e suggests that this mechanism could be involved in the pharmacological effect. However, further mechanistic studies are required to confirm this idea.

Additional support for the present findings is studies with pyranoquinoline derivatives that improved glycaemic control significantly in streptozotocin-induced diabetic rats. All these findings demonstrate that the quinoline nucleus is a versatile pharmacophore which have always shown antihyperglycemic action in different chemically induced models of diabetes.

In contrast to many of the previously reported quinoline based hybrid compounds, which required higher oral dosages to achieve similar pharmacological effects, Compound 5e significantly reduced glucose at a dose as low as 5 mg/kg. This was an important discovery in present investigation. The results of the present study suggest that the biological effect of the quinoline scaffold can be increased by the structural modification of the 1,3,4-thiadiazole ring. The increased activity of Compound 5e with respect to Compounds 5h and 5i shows that the substitution pattern is significant in defining the antihyperglycemic potency.

5. CONCLUSION

The present study successfully demonstrated the in vivo antihyperglycaemic potential of newly synthesised quinoline–1,3,4-thiadiazole hybrids in an alloxan-induced diabetic rat model. The potential of this class of heterocyclic hybrids as antidiabetic agents was evidenced by the fact that oral administration of the test compounds for 14 days caused a significant decrease in the fasting blood glucose levels as compared to the diabetic control group. Compound 5e exhibited the highest antihyperglycemic activity among the synthesized derivatives. among the derivatives evaluated and decreased fasting blood glucose to nearly normal levels with an efficacy comparable to that of the standard drug glibenclamide (5 mg/kg). Compounds 5h and 5i also demonstrated potent antihyperglycemic activity, which was less potent than that of compound 5e.

The positive in vivo activity of compound 5e supports the hypothesis that molecular hybridisation of the quinoline and 1,3,4-thiadiazole pharmacophores provides an effective technique for the design of new antidiabetic drugs. These findings highlight compound 5e as a promising lead candidate for further optimisation and offer pharmacological validation of this hybrid scaffold.

In the present study, fasting blood glucose levels were measured, but more research using biochemical, histological and molecular investigations are required to elucidate the specific mechanism of action. Future studies should explore insulin

levels, glycated haemoglobin (HbA1c), oxidative stress and inflammatory biomarkers, pancreatic histology, pharmacokinetic profile, chronic toxicity and long-term efficacy trials. All these outcomes demonstrate that quinoline–1,3,4-thiadiazole hybrids are good candidates for further preclinical studies and a good platform for the creation of safer and more effective antidiabetic therapies.

REFERENCES

1. Rachman A, Unja EE, Trifianingsih D. OVERVIEW OF KNOWLEDGE OF TYPE 2 DIABETES MELLITUS PATIENTS ABOUT THE 5 PILLARS OF DIABETES MELLITUS MANAGEMENT AT SUAKA INSAN HOSPITAL BANJARMASIN. J Kontribusia: Research Dissemination for Community Development. 2026;9(2):175-83.
2. Sahare H, Tatode A, Qutub M, Umekar M, Taksande B, Premchandani T, et al. Exercise induced irisin dynamics and their correlation with beta cell function and peripheral insulin sensitivity in diabetes. Obesity Medicine. 2026:100730.
3. DeFronzo RA, Ferrannini E, Groop L, Henry RR, Herman WH, Holst JJ, et al. Type 2 diabetes mellitus. Nature Reviews Disease Primers. 2015;1(1):15019.
4. Davies MJ, Aroda VR, Collins BS, Gabbay RA, Green J, Maruthur NM, et al. Management of Hyperglycemia in Type 2 Diabetes, 2022. A Consensus Report by the American Diabetes Association (ADA) and the European Association for the Study of Diabetes (EASD). Diabetes Care. 2022;45(11):2753-86.
5. Ghazaee SP, Tumanov V, Voloshyna N, Marchenko-Tolsta K, Hameed M. A Review of the Novel Antidiabetic Medications: Efficacy, Safety and Innovation. New Emirates Medical Journal. 2023;4(1).
6. J K, Loganathan CG, R R, Dutta S, Paik A, Dasgupta A, et al. Recent Advances in Quinoline Derivatives: Biological and Medicinal Insights. ChemistrySelect. 2025;10(41):e03934.
7. Taha M, Sultan S, Imran S, Rahim F, Zaman K, Wadood A, et al. Synthesis of quinoline derivatives as diabetic II inhibitors and molecular docking studies. Bioorganic & Medicinal Chemistry. 2019;27(18):4081-8.
8. Jain AK, Sharma S, Vaidya A, Ravichandran V, Agrawal RK. 1,3,4-Thiadiazole and its Derivatives: A Review on Recent Progress in Biological Activities. Chemical Biology & Drug Design. 2013;81(5):557-76.
9. Kale DS, Shaikh SA, Bhoi RT, Borse GR, Sonawale SB. 1,3,4-thiadiazole derivatives as antidiabetic agents: Design, synthesis, biological evaluation, and in silico studies. Journal of Molecular Structure. 2026;1351:144226.
10. Ali Z, Rehman W, Rasheed L, Alzahrani AY, Ali N, Hussain R, et al. New 1,3,4-Thiadiazole Derivatives as α-Glucosidase Inhibitors: Design, Synthesis, DFT, ADME, and In Vitro Enzymatic Studies. ACS Omega. 2024;9(7):7480-90.
11. Taha M, Khan AA, Rahim F, Hayat S, Imran S, Iqbal N, et al. Synthesis, in vitro evaluation and molecular docking studies of hybrid 4-quinolinyl bearing 1,3,4-thiadiazole-2-amine as a new inhibitor of α-amylase and α-glucosidase. Journal of Molecular Structure. 2023;1282:135173.
12. Taha M, Salahuddin M, Rahim F, Imran S, Hussain S, Uddin N, et al. New Quinoline Analogues: As Potential Diabetics Inhibitors and Molecular Docking Study. Polycyclic Aromatic Compounds. 2024;44(1):67-89.
13. Taha M, Sultan S, Imran S, Rahim F, Zaman K, Wadood A, et al. Synthesis of quinoline derivatives as diabetic II inhibitors and molecular docking studies. Bioorganic and Medicinal Chemistry. 2019;27(18):4081-8.
14. Sabu M, Kuttan R. Anti-diabetic activity of medicinal plants and its relationship with their antioxidant property. Journal of Ethnopharmacology. 2002;81(2):155-60.
15. Rohilla A, Ali S. Alloxan induced diabetes: mechanisms and effects. International Journal of Research in Pharmaceutical and Biomedical Sciences. 2012;3(2):819-23.
16. Ighodaro OM, Adeosun AM, Akinloye OA. Alloxan-induced diabetes, a common model for evaluating the glycemic-control potential of therapeutic compounds and plant extracts in experimental studies. Medicina. 2017;53(6):365-74.
17. Kulkarni NV, Revankar VK, Kirasur B, Hugar MH. Transition metal complexes of thiosemicarbazones with quinoxaline hub: an emphasis on antidiabetic property. Medicinal Chemistry Research. 2012;21(5):663-71.
18. Orji NJ, Okoro UC, Onyejekwe OB, Ezugwu JA, Kumar S, Eze CC, et al. Synthesis, molecular docking, toxicity profile and antidiabetic properties of new dipeptide sulfonamide bearing carboxamides. Results in Chemistry. 2026;23:103184.
19. Aboushouk AA, Saad HM, Rohiem AH, Gad El-Karim DRS. New Insights on the potential therapeutic effects of glibenclamide and Obeticholic acid against Alloxan-Induced diabetes mellitus in rat model. International Immunopharmacology. 2024;143:113469.
20. Ozougwu JC. Anti-diabetic effects of *Allium cepa* (onions) aqueous extracts on alloxan-induced diabetic *Rattus norvegicus*. Journal of Medicinal Plants Research. 2011;5(7):1134-9.
21. Ibrahim AM, Shoman ME, El-Dien RTM, Saber EA, Abdelnaser M, Maher SA, et al. Design and synthesis of a novel quinoline thiazolidinedione hybrid as a potential antidiabetic PPARγ modulator. Scientific Reports. 2025;15(1):19207.
22. Zare N, Bandarian F, Esfahani EN, Larijani B, Mahdavi M, Mohammadi-Khanaposhtani M, et al. In vivo and in silico evaluations of a synthetic pyrano[3,2-c]quinoline derivative as a potent anti-diabetic agent. Journal of Diabetes & Metabolic Disorders. 2024;23(1):809-15.