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Recent advances in the pharmacological activities of thiazole derivatives: A comprehensive review

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Abstract
Thiazole is a privileged five-membered nitrogen and sulphur-containing heterocyclic scaffold that has attracted considerable attention in medicinal chemistry because of its remarkable structural versatility and broad spectrum of biological activities. Numerous naturally occurring and synthetic thiazole derivatives have been developed as potential therapeutic agents owing to their favorable pharmacokinetic properties, high target selectivity, and diverse mechanisms of action. This review provides a comprehensive overview of the recent advances in the pharmacological activities of thiazole derivatives, emphasizing their significance in modern drug discovery and development. The article discusses the chemistry and structural characteristics of the thiazole nucleus and summarizes its therapeutic potential in various disease conditions, including cancer, microbial infections, viral diseases, inflammation, oxidative stress, diabetes, neurological disorders, cardiovascular diseases, and parasitic infections. Furthermore, recent structure–activity relationship studies are highlighted to illustrate the influence of structural modifications on biological efficacy and selectivity. The review also presents several clinically approved thiazole-containing drugs and promising investigational compounds that demonstrate the therapeutic relevance of this scaffold. Despite substantial progress, challenges related to drug resistance, toxicity, and pharmacokinetic optimization remain significant barriers to clinical translation. Future perspectives focusing on rational drug design, molecular hybridization, computational approaches, and targeted therapeutic strategies are discussed to facilitate the development of next-generation thiazole-based therapeutics. Overall, this review underscores the immense pharmacological potential of thiazole derivatives and their continuing importance as versatile scaffolds for the discovery of novel and effective therapeutic agents.#

Keywords: Quinazolinone derivatives, Medicinal chemistry, Pharmacological activities, Drug discovery, Structure–activity relationship, Molecular targets, Therapeutic applications

Introduction

Thiazole is an important five-membered aromatic heterocyclic ring containing one nitrogen and one sulphur atom, which serves as a privileged scaffold in medicinal chemistry due to its unique physicochemical properties and remarkable biological versatility [1]. The presence of heteroatoms within the thiazole nucleus enhances its electronic distribution, chemical stability, and ability to interact with diverse biological targets, making it an attractive pharmacophore for the development of novel therapeutic agents. Thiazole derivatives occur naturally in several biologically active molecules, including vitamin B1 (thiamine), and have also been extensively synthesized to generate compounds with improved pharmacological profiles [2-3].

Over the past few decades, thiazole-based compounds have gained considerable attention because of their broad spectrum of pharmacological activities, including anticancer, antimicrobial, antiviral, antifungal, anti-inflammatory, antioxidant, antitubercular, antidiabetic, anticonvulsant, antiparasitic, and cardiovascular protective effects. Many clinically approved drugs, such as sulfathiazole, ritonavir, abafungin, and meloxicam, incorporate the thiazole scaffold, highlighting its significance in modern drug discovery and pharmaceutical development. Structural modification of the thiazole ring through molecular hybridization and rational drug design has further expanded its therapeutic potential by improving potency, selectivity, and pharmacokinetic properties [4-6].

Recent advances in synthetic methodologies, computational drug design, molecular docking, and structure–activity relationship (SAR) studies have accelerated the identification of highly potent thiazole derivatives targeting a wide range of enzymes, receptors, and signaling pathways implicated in human diseases. Consequently, thiazole has emerged as one of the most extensively investigated heterocyclic scaffolds for the development of next-generation therapeutics [7].

This review comprehensively summarizes the chemistry, structural characteristics, and diverse pharmacological activities of thiazole derivatives, with particular emphasis on recent research developments, structure–activity relationships, mechanisms of action, clinically relevant thiazole-containing drugs, and future perspectives. By consolidating current knowledge, this review aims to provide valuable insights that may facilitate the rational design and development of novel thiazole-based therapeutic agents for the management of various diseases.

Chemistry of Thiazole

Thiazole is a five-membered aromatic heterocyclic compound with the molecular formula C_3H_3NS, consisting of one sulphur atom at position 1 and one nitrogen atom at position 3. The aromaticity of the thiazole ring arises from the delocalization of six π-electrons, which imparts exceptional chemical stability and unique electronic properties. The electronegative nitrogen atom contributes to the basic character of the ring, whereas the sulphur atom enhances its polarizability and facilitates interactions with biological macromolecules [8-10]. Thiazole exhibits diverse chemical reactivity, with electrophilic substitution occurring predominantly at the C-5 position and nucleophilic

substitution favoured at the C-2 position due to the electron-deficient nature of the ring. Numerous synthetic approaches, including the Hansch thiazole synthesis, Cook–Heilbron synthesis, Gabriel synthesis, and cyclization of α-haloketones with thioamides or thiourea, have been developed to prepare structurally diverse thiazole derivatives. The ease of functionalization at different positions of the thiazole nucleus enables the design of novel compounds with enhanced physicochemical properties and improved pharmacological activities, making thiazole an indispensable scaffold in contemporary medicinal chemistry and drug discovery [11-12].

Review of literature

Manal Ebadi S *et al.,* (2025) reported the design, synthesis and biological evaluation of a novel series of coumarin based thiazole derivatives as potential anti-bacterial agents and synthesized by using conventional method and screened for *in-vitro* anti-bacterial activity against *Enterococcus faecalis* and *Achromobacter xylosoxidans* by broth dilution method. Among those Compound 1 shows potent activity *E. faecalis* (MIC_s: 25, 12.5µg\ml) and *A. xylosoxidans* (MIC_s: 50, 25µg\ml) when compared with the standard drug Ciprofloxacin [13].

Fitsum Lemilemu *et al.,* (2021) reported the synthesis, anti-bacterial and anti-oxidant activities of thiazole-based Schiff base derivatives; a combined experimental and computational study and synthesized by using screening for *in-vitro* anti-bacterial activity against Gram negative E. coli (14.40 ± 0.04) and Gram positive S. aureus (15.00 ± 0.01mm) by disk diffusion assay. Among those Compound 2 shows more potent activity (MIC_S: 200µg\ml) when compared with the standard drug Amoxicillin [14].

Di Zhao *et al.,* (2022) reported the green synthesis and anti-bacterial activity of ferrocene-based thiazole derivatives in choline chloride/glycerol eutectic solvent. Synthesized using preliminary screening for *in-vitro* anti-bacterial activity against Gram positive *B.subtilis* and Gramnegative *E.coli*. Among that Compound 3 possessed the best activity with the MIC value of 7.8125 µg ml^{-1} when compared with the standard drug Ciprofloxacin (15.625µg ml^{-1}) [15].

Abeer El-Naggar M *et al.,* (2022) reported the design, synthesis and docking studies of new hydrazinyl-thiazole derivatives as anticancer and antimicrobial agents. Evaluated for *in-vitro* cytotoxic or anti-cancer activity against breast carcinoma (MCF-7 cell line), hepatocellular carcinoma (HePG-2) and colorectal cancer (HCT-116) cell using MTT assay method. The Compound 4 showed board spectrum activity (IC_{50} = 3.81 to 11.34µM) when compared with the standard drug Roscovitine (IC_{50}=9.32 to 13.82µM) [16].

Fawziah Al-Salmi A *et al.,* (2023) reported the anticancer Studies of Newly Synthesized Thiazole Derivatives: Synthesis, Characterization, Biological Activity, and Molecular Docking. Evaluated for *in-vitro* cytotoxic or anti-cancer activity against MCF-7 and HePG-2 cell using MTT assay method. The Compound 5 blocked VEGFR-2 (vesicular endothelial growth factor receptor-2) IC_{50} = 0.15µM when compared with the standard drug Sorafenib [17].

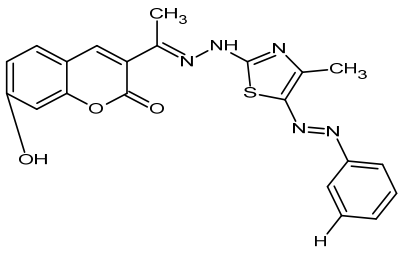
Hesham Gomaa A. M. *et al.,* (2025) reported the Design, synthesis and biological investigation of new thiazole-based derivatives as multi-targeted inhibitors endowed with antiproliferative, antioxidant, and antibacterial properties. Evaluated for *in-vitro* anti-cancer activity against A-549(lung cancer), MCF-7(breast cancer), HT-29 (colon cancer) cell using MTT assay method, EGFR inhibition assay and VEGFR-2 inhibition assay. Among those Compound 6 (GL_{50}= 30nM) shows highest anti proliferative activity when compared with the standard drug Erlotinib (GL_{50} = 33nM) [18].

Anna Biernasiuk *et al.,* (2021) reported the newly synthesized thiazole derivatives as potential antifungal compounds against candida albicans synthesized using broth microdilution method, checkered board technique and erythrocyte assay. Among those Compound 7 (MIC_{50}=0.008-0.98µg\ml), when compared with the standard drug Nystatin [19].

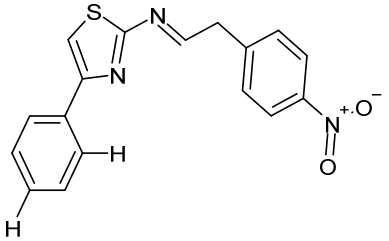
Andreea-Iulia Pricopie *et al.,* (2019) reported the design and synthesis of novel 1,3-thiazole and 2-hydrazinyl-1,3-thiazole derivatives as potential anti-candida agents. The synthesized compounds were evaluated for *in-vitro* antifungal activity against *candida albicans, candida parasilosis*, and *candida zeylanoides* using the broth microdilution method. Among the synthesized Compounds 8 (MIC=3.9µg\mL) exhibited the antifungal activity when compared with the standard drug fluconazole (MIC=15.62µg\mL) [20].

Zafer Asım Kaplancıklı *et al.,* (2017) reported the synthesis of a series of 12 novel benzimidazole-thiazole derivatives and evaluated their *in-vitro* anticandidal activity against *candida albicans, candida glabrata, candida krusei* and *candida parapsilosis* using the EUCAST broth microdilution method. Among these Compound 9 exhibited the highest anti-candidal activity with MIC_{50} value of 1.56µg\mL. when compared with the standard drug ketoconazole and fluconazole [21].

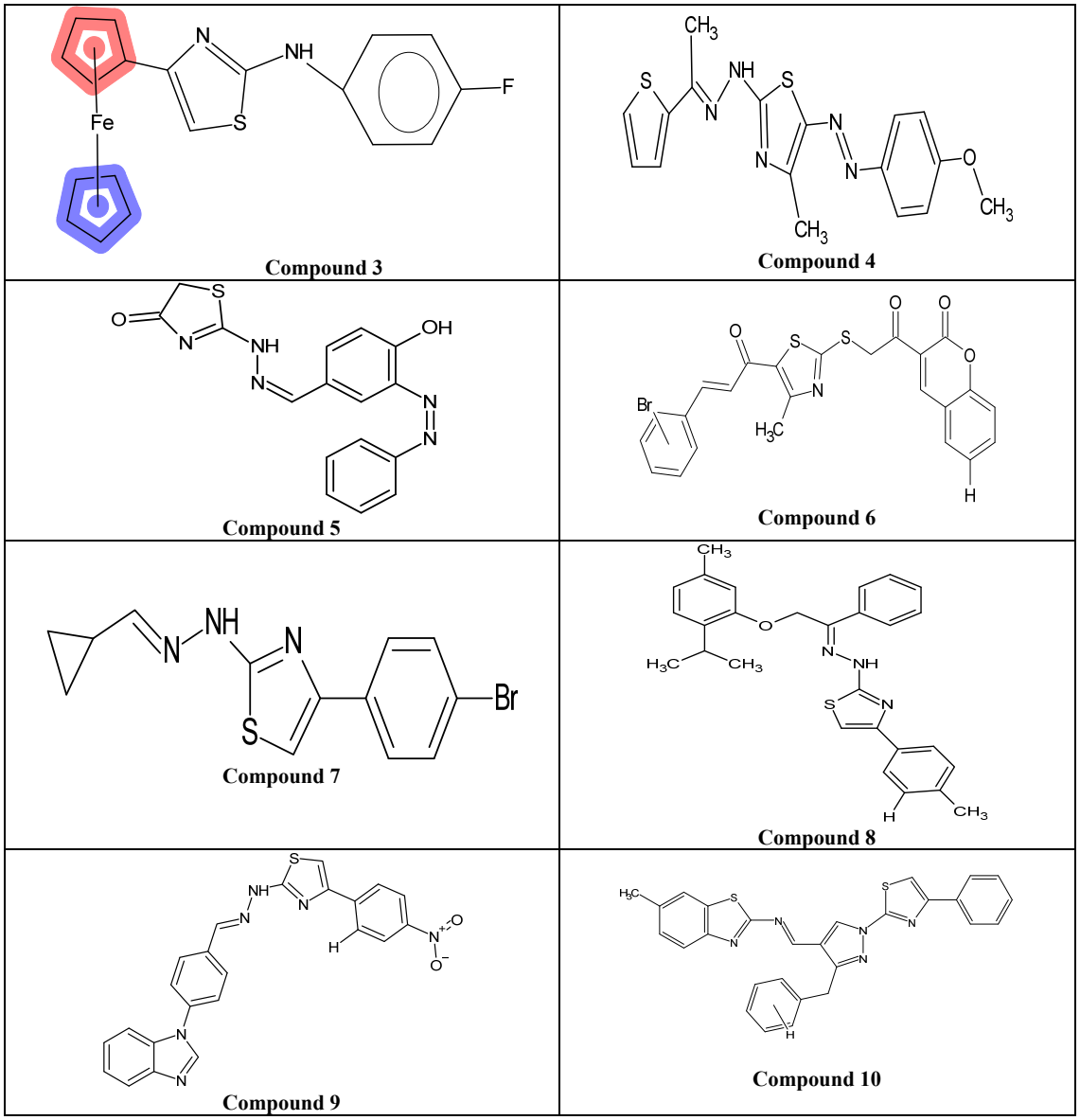
. Diksha Sharma *et al.,* (2022) reported the design and synthesis of a novel series of thiazole-based pyrazoles bearing benzothiazole moiety and evaluated them for anti-malarial, anti-helmintic, anticancer and anti-infective activity and synthesized compound were screened for *in-vitro* anti-malarial activity against plasmodium falciparum by using the Rieckmann micro assay method. Among that the Compound 10 (IC_{50}= 0.24µg\mL) exhibit the most potent anti-malarial activity when compared with the standard drug chloroquine and quinine [22].



Compound 1



Compound 2



Stepan Sysak *et al.,* (2026) reported the synthesis of novel flavone-thiazole-aryl hybrid derivatives and synthesized compound were evaluated for *in-vitro* anti-plasmodial activity against the chloroquine-resistant plasmodium falciparum FcB-1 strain using the SYBR green fluorescence assay. Among those Compound 11 (IC_{50}=1.9µM) when compared with the standard drug Artesunate [23].

Ramanjaneyulu Rayala *et al.,* (2023) reported the synthesis of novel of piperazine-based thiazole derivatives using a paralell solid phase synthesis approach. The synthesized compounds were evaluated *in-vitro* for anti-plasmodial activity against the chloroquine resistant plasmodium falciparum Dd2 strain using the SYBR green fluorescence assay. The Compound 12 showed the high potency with an EC_{50} of 102 nM against the Dd2 strain when compared with the standard drug Chloroquine [24].

Yuvraj Sable R. *et al.,* (2025) reported the Furan-thiazole hydrazone scaffolds as promising anti tubercular agents and synthesized by using conventional method and compounds were tested for *in-vitro* against *Mycobacterium tuberculosis* H37Rv, *Staphylococcus aureus*, and *Escheriachia coli* using Microplate Alamar blue assay method. Compound 13 exhibit the good anti tubercular activity with MIC value of 3.12µg $mL^{-1}$when compared with the standard drug Pyrazinamide [25].

Hemant Deshmukh S *et al.,* (2025) reported the Design, synthesis, biological evaluation, and computational insights of 2-(Aryl) benzo[d]imidazo[2,1-b] thiazole-7-sulfonamide derivatives as potent antitubercular agents and evaluated for their *in-vitro* anti tubercular activity against *Mycobacterium tuberculosis* (H37Rv strain) by using Microplate Alamar blue assay method. The Compound 14 exhibited potent antitubercular activity with minimum inhibitory concentrations (MICs) of 1.6 µg/mL, when compared to some standard drugs like Isoniazid [26].

Yuvraj Sable R. *et al*., (2025) reported the Design, synthesis and antitubercular evaluation of piperazinyl-pyrazolyl-2-hydrazinyl thiazole derivatives and synthesized and evaluated for *in-vitro* anti tubercular activity against *Mycobacterium tuberculosis* by using Microplate Alamar blue assay method. The Compound 15 (MIC = 1.6µg/mL) showing the highest potency when compared to the standard drugs Isoniazid and Ethambutol [27].

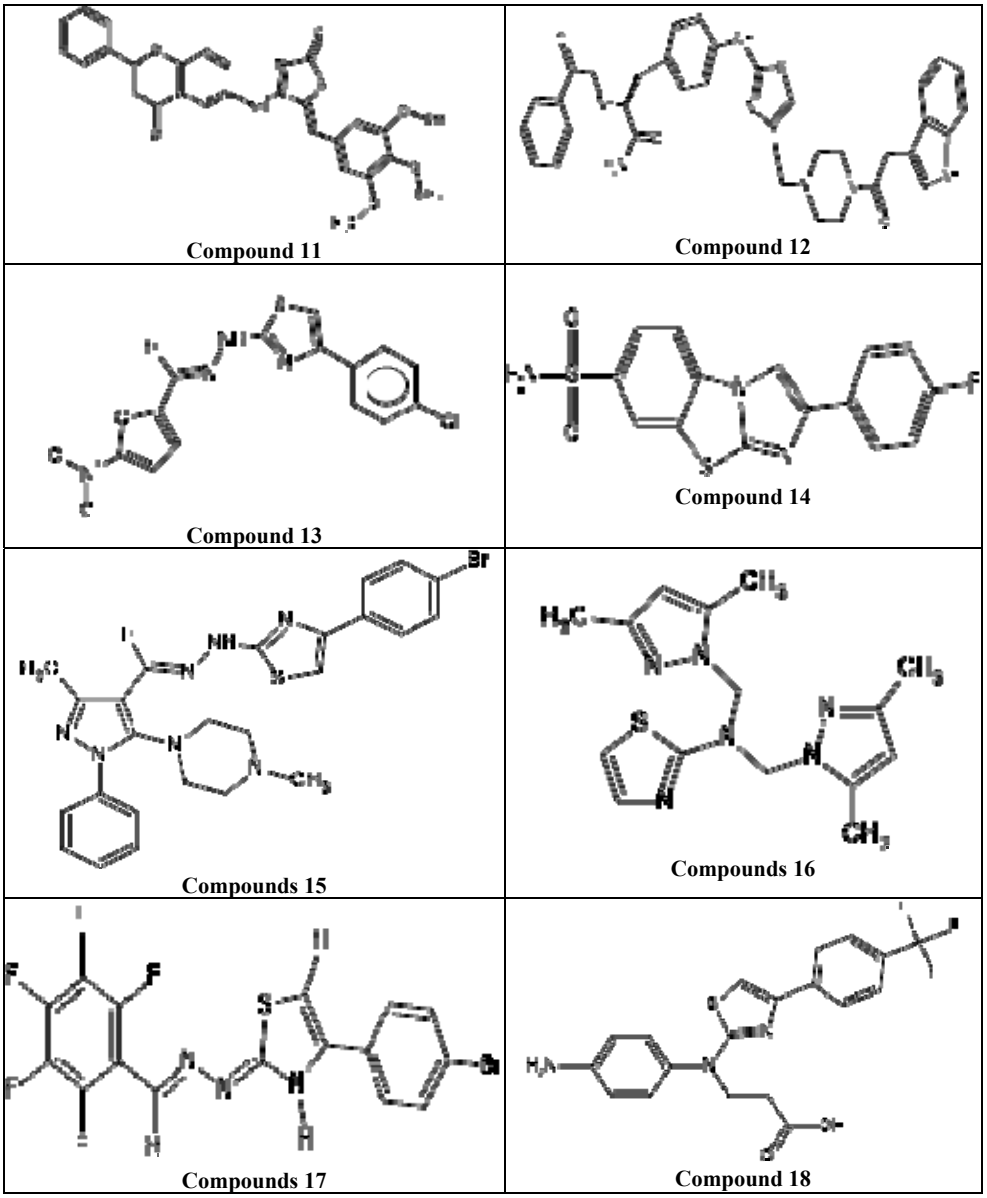
Yassine Kaddouri *et al.,* (2020) reported the new thiazole, pyridine and pyrazole derivatives as antioxidant agents and evaluated for *in-vitro* antioxidant activity by using DPPH scavenging assay method. The Compound 16 showed the best antioxidant activity with an IC_{50}= 4.67 µg/mL when compared with the standard drug Ascorbic acid (IC_{50} = 2 µg/mL) [28].

Abdul Ghafoor *et al*., (2024) reported the Synthesis, characterization and molecular docking studies of bioactive 1,3-Thiazoles as promising antibacterial and antioxidant agents and evaluated for *in-vitro* antioxidant activity using DPPH and ABTS assays. Compounds 17 exhibited better antioxidant activity with an IC_{50} value of; 4.949 and 4.884 mg/mL when compared with the standard drug Butylated hydroxytoluene (BHT) [29].

Ruta Minickait *et al.,* (2022) reported the Synthesis of Novel Aminothiazole Derivatives as anti-oxidant agent and evaluated for *in-vitro* antioxidant activity by DPPH, reducing power, FRAP method. The Compound 18 (106.53µmol/L) when compared with the standard drug Butylated hydroxytoluene (BHT) [30].

19. Vinuta Kamat *et al.,* (2020) reported the Pyridine-Thiazole-Based Hydrazides with promising Anti-inflammatory agents and evaluated for *in-vitro* anti-inflammatory activity by using Denaturation of the bovine serum albumin method. The Compound 19 shows highest anti-inflammatory activity with IC_{50} value of 46.29 µg/mL when compared with the standard drug Diclofenac sodium [31].

Mater Mahnashi H. *et al.,* (2024) reported the modification of 4-(4-chlorothiophen-2-yl) thiazol-2-amine derivatives for the treatment of analgesia and inflammation and evaluated for *in-vitro* anti-inflammatory activity by using COX-1 (Cyclooxygenase-1), COX-2 (Cyclooxygenase-2), and 5-LOX (5-Lipoxygenase) inhibition assay. The Compound 20 shows anti-inflammatory activity with IC_{50} value of 23.08 when compared with the standard drug Aspirin [32].

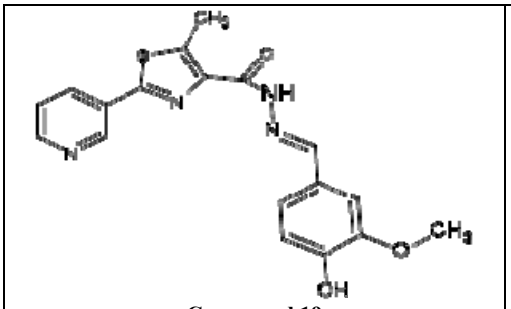


Compound 11 | **Compound 12**

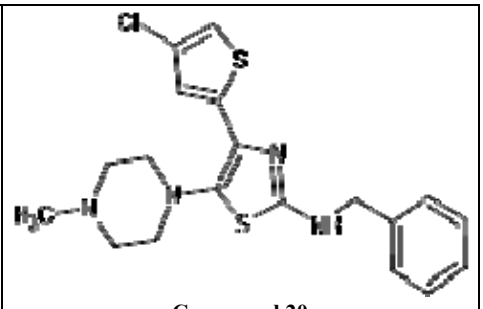
Compound 13 | **Compound 14**

Compounds 15 | **Compounds 16**

Compounds 17 | **Compound 18**



Compound 19



Compound 20

Abdel-Sattar Hamad Elgazwy S. *et al.,* (2012) reported the Synthesis, Biological Evaluation of Some 2,3-dihydropyrazoles and Thiazoles as Anti-inflammatory agents and synthesized by using conventional method and screened for *in-vivo* anti-inflammatory activity by using carrageenan-induced rat paw edema assay method. The Compound 21 (≥ 70% inhibition) shows excellent anti-inflammatory activity when compared with the standard drug Indomethacin [33].

Rafat Mohareb M. *et al.,* (2017) reported the Anti-inflammatory and Anti-ulcer activities of new fused thiazole derivatives and synthesized by using conventional method and screened for *in-vivo* anti-ulcer activity by using pylorus ligation-induced gastric ulcer (Shay rat) method. The Compound 22 (0.22 ± 0.05) and showed the maximum antiulcer activity when compared with the standard drug Ranitidine [34].

Ayesha Khan *et al.,* (2026) reported the Synthesis of new benzothiazole derivatives with in-depth *in-vitro, in-vivo* anti-ulcer activities and evaluated for *in-vitro* anti-ulcer activity ethanol-induced gastric ulcer method. The Compound 23 (3 ± 0.2) shows better anti-ulcer activity when compared with the standard drug Omeprazole [35].

Aurigena Antunes de Araújo *et al.,* (2026) reported the *in-vivo* analgesic, anti-infammatory, and antigastric ulcer activities and *in-silico* analysis of 5-benzylidene 3-carboxyalkyl-2-thio-4-thiazolidinone derivatives and evaluated using conventional *in-vivo* experimental model in rat by using ethanol induced gastric ulcer method. The Compound 24 shows highest anti-ulcer activity when compared with the standard drug indomethacin [36].

Elif Gürsoy *et al.,* (2019) reported the design and synthesis of novel imidazo[2,1-b] thiazole derivatives as potent antiviral agents and evaluated for *in-vitro* anti- viral activity against diverse viruses in mammalian cell cultures by using in-*vitro* cell culture assay. The Compound 25 was effective against Feline coronavirus in CRFK cells, with an antiviral EC_{50} value of 4.8 µg/mL when compared with standard drug Ribavirin and Urtica dioica agglutinin (UDA) [37].

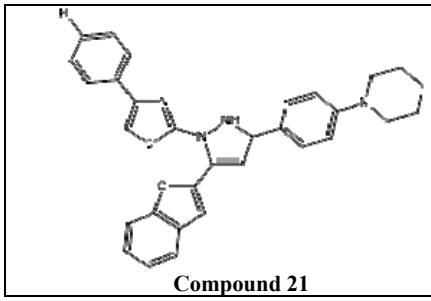
Mohamed Zakaria Y. *et al.,* (2024) reported the Biological and computational assessments of thiazole derivative-reinforced bile salt enriched nano carriers: a new gate in targeting SARS-CoV-2 spike protein and evaluated for *in-vitro* anti-viral activity by using *in-vitro* biological assay and computational method. The Compound 26 shows potent anti-viral activity against SARS-CoV-2 with IC50 values (0.71 mgmL−1 [38].

Sraa Abu-Melha *et al.,* (2020) reported the clean grinding technique: A facile synthesis and *in-silico* antiviral activity of Thiazole Moiety against SARS-CoV-2 Main Protease ($M^{[pro]}$) and evaluated for *in-silico* anti-viral activity by using molecular docking combined with molecular dynamics simulation (MDS). The Compound 27 (−8.1 ± 0.33 kcal/mol) when compared with the standard drug Nelfinavir [39].

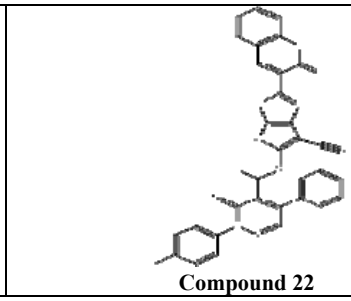
Rafaqat Hussain *et al.,* (2023) reported the imidazopyridine-based thiazole derivatives as potential antidiabetic agents and evaluated for *in-vitro* anti-diabetic activity by using *in-vitro* α-glucosidase inhibition assay. The Compound 28 with IC_{50} values of 5.57 ± 3.45 when compared with the standard drug Acarbose [40].

Shankar Gharge *et al.,* (2024) reported the Novel rhodamine –thiazole hybrids as potential antidiabetic agents and evaluated for *in-vitro* anti diabetic activity by using *in-vitro* HPA, HLAG inhibition, and peroxisome proliferator-activated receptor-gamma (PPAR-γ) expression assays. The Compound 29 shows highest anti diabetic activity against HPA with an IC [50] value of 27.13 ± 1.02 µM when compared with the standard drug Acarbose [41].

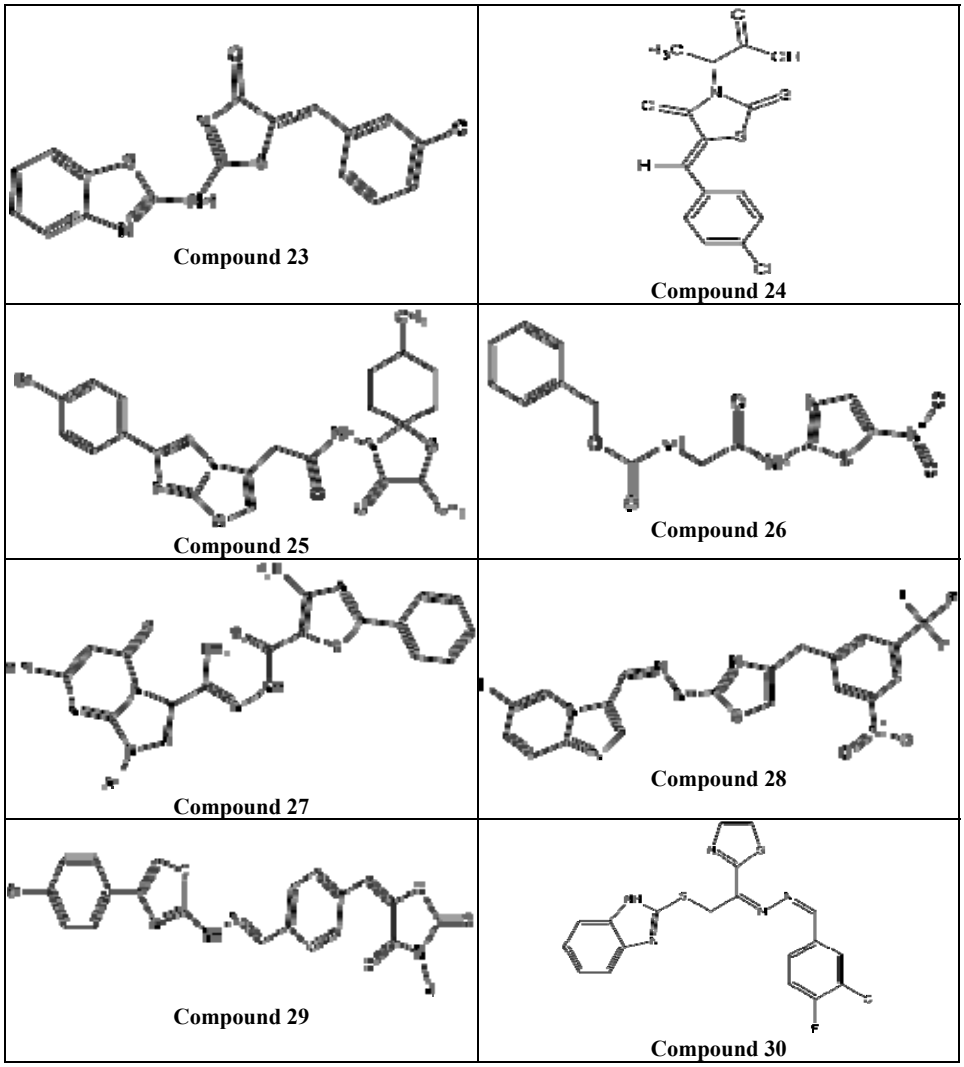
Shoaib Khan *et al.,* (2024) reported the Novel benzimidazole-based thiazole derivatives as a magic bullet for controlling diabetes mellitus based on synthetic and computational approaches and evaluated for *in-vitro* anti-diabetic activity by using α-Amylase inhibition assay and α-Glucosidase inhibition assay method. The Compound 30 shows better anti-diabetic activity with IC_{50} value of 3.50 ±0.20 µM for α-amylase and 4.20 ±0.20 µM for α-glucosidase when compared with the standard drug Acarbose [42].



Compound 21



Compound 22



Conclusion

Thiazole derivatives represent one of the most important heterocyclic scaffolds in medicinal chemistry because of their remarkable chemical versatility and broad spectrum of pharmacological activities. Extensive research has demonstrated their potential as anticancer, antimicrobial, antiviral, anti-inflammatory, antioxidant, antidiabetic, anticonvulsant, and antiparasitic agents. Advances in synthetic methodologies, structure–activity relationship studies, and computer-aided drug design have facilitated the development of highly potent and selective thiazole-based therapeutics. Nevertheless, further investigations focusing on pharmacokinetic optimization, toxicity evaluation, and clinical validation are required. Overall, thiazole derivatives continue to offer immense opportunities for the discovery and development of safe, effective, and innovative therapeutic agents for the treatment of diverse human diseases.

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