Send Orders for Reprints to reprints@benthamscience.net

Current Organic Chemistry, XXXX, *XX*, 1-12

REVIEW ARTICLE

A Review on Emerging Insights and Novel Innovations in Thiazole Derivatives as Antibacterial Agents

Jatin Kishore Sharma[1] and Sushil Kumar[1,*]

[1]*School of Pharmaceutical Sciences, Faculty of Pharmacy, IFTM University, Lodhipur Rajput Moradabad, Moradabad, 244102, (U.P.), India*

Sushil Kumar

ARTICLE HISTORY

Received: May 04, 2025
Revised: August 03, 2025
Accepted: August 22, 2025

DOI:
10.2174/0113852728412160251128070613

Abstract: The rise in bacterial infections, driven by antibiotic resistance, global travel, and poor infection control, poses a major healthcare challenge. Bacteria grow and spread through binary fission, nutrient acquisition, and immune evasion, with the peptidoglycan layer (consisting of sugars and peptides) being crucial for cell wall integrity and protection. Thiazole, a heterocycle containing nitrogen and sulphur, is important in medicinal chemistry and is found in compounds, such as vitamin B1 (thiamine) and penicillin derivatives (sulfazole, ritonavir, abafungin). These thiazole derivatives disrupt bacterial cell wall synthesis by interfering with peptidoglycan-forming enzymes. They are also used as vulcanizing accelerators, anthelmintics, and anticancer agents. This review synthesizes current knowledge on the biological relevance and synthetic approaches of antibacterial thiazole derivatives, with a focus on their mechanisms of action and recent advances in their development.

Keywords: Thiazole, heterocyclic compounds, anticancer, biological significances, antibacterial, peptidoglycan.

1. INTRODUCTION

The bacterial cell wall plays a crucial role in preserving structural integrity, shape, and stress endurance, thereby supporting bacterial viability. This barrier, present in both gram-positive and gram-negative bacteria, is primarily composed of a cross-linked polymer called peptidoglycan [1-3]. The synthesis of peptidoglycan starts in the cytoplasm, where precursor molecules are created and subsequently transported across the cytoplasmic membrane by flippases. Outside the membrane, enzymes known as glycosyltransferases and transpeptidases polymerize these precursors to form the peptidoglycan sacculus. This mesh-like structure is crucial for providing structural integrity and countering osmotic pressure, which is vital for bacterial growth and division [4]. Disrupting peptidoglycan synthesis inhibits bacterial growth and is a primary target for many antibiotics, as it compromises cell wall integrity and reduces bacterial proliferation [5]. To address this challenge, medicinal chemistry has turned to novel molecular scaffolds, particularly heterocyclic compounds, known for their structural diversity and broad pharmacological potential [6-9]. Among these, thiazole derivatives have garnered significant attention. First synthesized by Hantzsch and Weber in 1887, thiazoles are five-membered heterocycles containing nitrogen and sulphur atoms, exhibiting properties akin to pyridine and pyrimidine. Molecular electrostatic potential (MEP) analysis reveals that the nitrogen atom carries the highest negative charge, while sulphur and carbon remain relatively neutral [10-11]. Thiazole derivatives exhibit a wide range of biological properties, encompassing antioxidant, analgesic, and antimicrobial effects, such as antibacterial, carbonic anhydrase enzyme inhibition [12-13], antifungal, antimalarial, anticancer, antiallergic, antihypertensive, anti-inflammatory, and antipsychotic properties (Fig. **1**) [14-22].

*Address correspondence to this author at the School of Pharmaceutical Sciences, Faculty of Pharmacy, IFTM University, Lodhipur Rajput Moradabad, 244102, (U.P.), India; E-mail: drsushiliftm@gmail.com

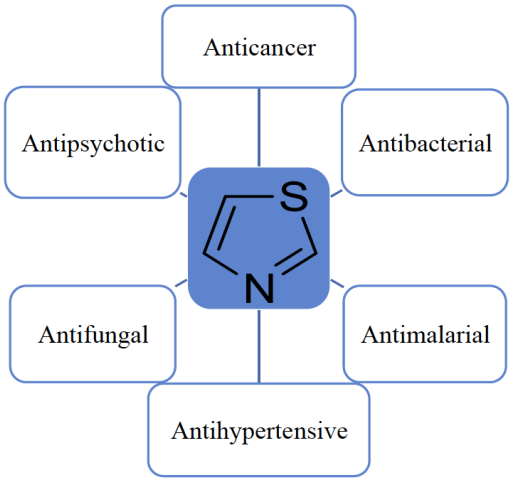


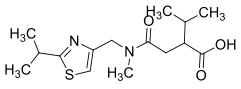
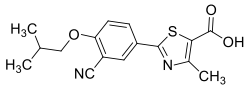
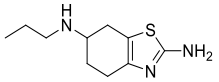
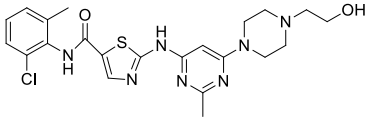
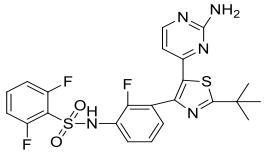
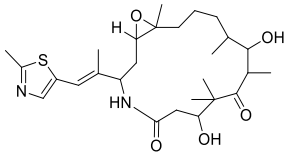
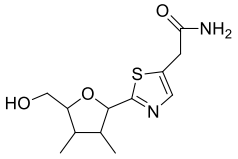
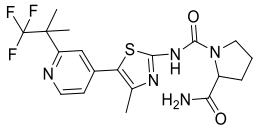
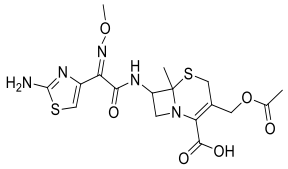
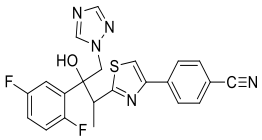
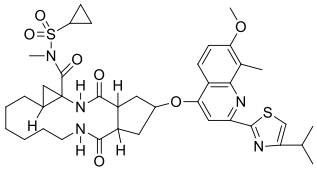
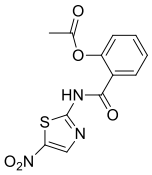
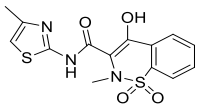
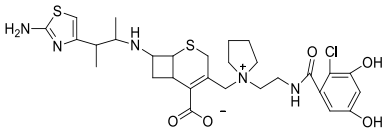
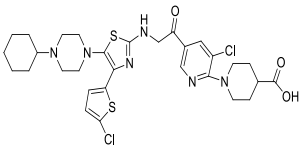
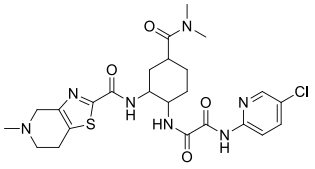
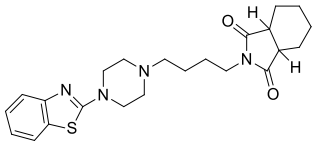
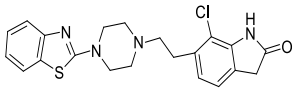
Fig. (1). Biological activity of thiazole.

Remarkably, more than 18 FDA-approved drugs, including ritonavir (a), febuxostat (b), pramipexole (c), dasatinib (d), dabrafenib (e), ixabepilone (f), tiazofurin (g), alpelisib (h), cefotaxime (i), isavuconazole (j), simeprevir (k), nitazoxanide (l), meloxicam (m), cefocoiderl (n), avatrombopag (o), edoxaban (p), perospirone (q), and ziprasidone (r), as well as numerous experimental compounds, contain the thiazole framework (Table **1**) [23-24].

A recent study has underscored the amphiphilic nature of thiazole derivatives, revealing their efficacy against microorganisms by integrating into microbial cell membranes, including those of bacteria and fungi. This unique property is attributed to the combination of hydrophobic (lipid-attracting) and hydrophilic elements within the thiazole structure (Fig. **2**), which enhances their ability to penetrate bacterial cell membranes and exert inhibitory effects. Consequently, thiazole compounds are effective in both types of bacteria.

1385-2728/XX $65.00+.00

Table 1. FDA-approved thiazole-containing drugs.

 (a) Approved in 1996 by AbbVie (originally developed by Abbott Laboratories).	 (b) Approved in 2009 by Takeda Pharmaceutical Company.	 (c) Approved in 1997 by Boehringer Ingelheim.
 (d) Approved in 2006 by Bristol-Myers Squibb	 (e) Approved in 2013 by Novartis.	 (f) Approved in 2007 by Bristol-Myers Squibb
 (g) Investigational drug	 (h) Approved in 2019 by Novartis	 (i) Approved in 1980 by Sanofi-Aventis
 (j) Approved in 2015 by Astellas Pharma (marketed as Cresemba)	 (k) Approved in 2013 by Janssen Pharmaceuticals (Johnson & Johnson)	 (l) Approved in 2002 by Romark Pharmaceuticals
 (m) Approved in 2000 by Boehringer Ingelheim	 (n) Approved in 2019 by Shionogi Inc.	 (o) Approved in 2018 by Dova Pharmaceuticals (acquired by Swedish Orphan Biovitrum, Sobi)
 (p) Approved in 2015 by Daiichi Sankyo	 (q) Not FDA-approved (approved in Japan in 2001 by Mitsubishi Tanabe Pharma)	 (r) Approved in 2001 by Pfizer

This integration into microbial cell membranes causes cytoplasm leakage, disrupts cell physiology, and ultimately induces apoptosis [19, 25, 26].

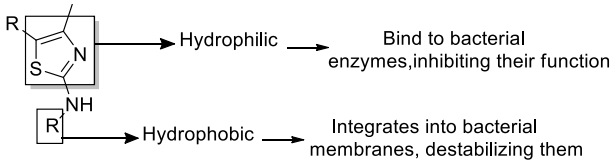


Fig. (2). Amphiphilic nature of thiazole.

2. STUDY DESIGN

A comprehensive literature search was conducted using PubMed, ScienceDirect, Scopus, Web of Science, and Google Scholar to identify relevant studies on thiazole derivatives. Keywords, such as "thiazole," "antibacterial," "antimicrobial," "mechanism of action," "synthesis," and "SAR," were used with Boolean operators. Inclusion criteria comprised peer-reviewed original research, systematic reviews, and patents related to the synthesis, antibacterial evaluation, and mechanisms of thiazole derivatives, published in English. Non-English articles, studies on unrelated biological ac-

tivities, and those lacking sufficient data were excluded. Two independent reviewers screened titles, abstracts, and full texts for relevance, resolving any disagreements through discussion. Relevant data, including compound type, synthesis method, bacterial targets, mechanisms of action, and SAR insights, were extracted and thematically analyzed.

3. CHEMISTRY OF THIAZOLE

Pure thiazole is a pale-yellow, flammable liquid with a pyridine-like smell and boils between 116-118 °C. Its aromatic nature stems from the electron delocalization from the sulphur atom, forming a 6π-electron system. This high aromaticity is confirmed by proton NMR, where the chemical shifts of protons in the thiazole ring range from 7.27 to 8.77 ppm (Fig. **3**) [27-28].

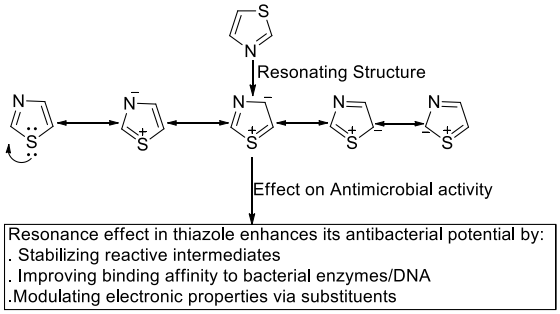


Fig. (3). Resonating structure of thiazole.

The calculated π-electron density indicates that electrophilic substitution is most likely to occur at the C-5 position, with the C-4 position as the next favoured site. On the other hand, nucleophilic substitution tends to take place at the C-2 position (Fig. **4**) [29].

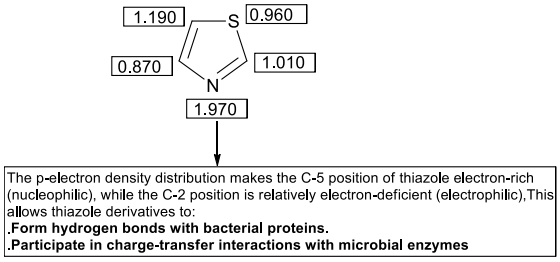


Fig. (4). Pi-electron density of thiazole.

4. BACKGROUND ON BACTERIAL CELL WALL AND PEPTIDOGLYCAN

The bacterial cell wall is essential for preserving the structural integrity and shape of bacterial cells. It safeguards against osmotic pressure and environmental stress. The peptidoglycan layer, made up of cross-linked polymers, is crucial to the cell wall's structure and function. Peptidoglycan synthesis begins in the cytoplasm, where precursor molecules are produced, which are then transported across the cytoplasmic membrane [30]. Enzymes like glycosyltransferases and transpeptidases polymerize these precursors to form the peptidoglycan sacculus. Disruption of this process compromises cell wall integrity, leading to inhibited bacterial growth [31]. Several widely used antibiotics, including penicillin, sulfathiazole, ampicillin, ceftriaxone, and cefotaxime, exhibit significant efficacy in inhibiting peptidoglycan synthesis (Fig. **5**). These drugs target key enzymes involved in the formation of the peptidoglycan layer, an essential component of the bacterial cell wall, thereby disrupting bacterial growth and proliferation. Their availability in the market underscores their critical role in combating bacterial infections and maintaining public health [32].

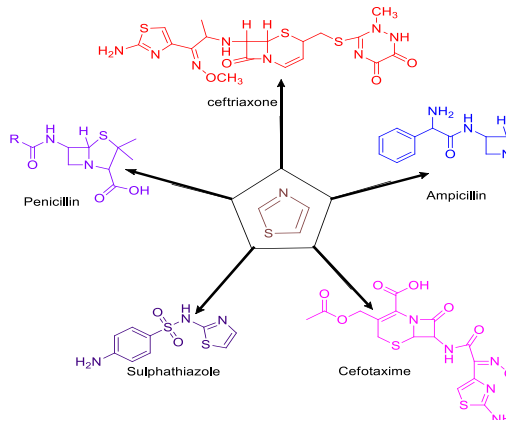


Fig. (5). Thiazole-containing antibiotics.

5. THIAZOLE DERIVATIVES: CHEMICAL STRUCTURE AND BIOLOGICAL ACTIVITY

Thiazole, a heterocyclic compound containing nitrogen and sulphur atoms, plays a crucial role in inhibiting peptidoglycan synthesis. Its presence in various natural and synthetic compounds underscores its effectiveness in targeting the bacterial cell wall, thereby disrupting its formation, impairing bacterial growth and survival [33]. This study will detail the chemical structure of thiazole derivatives and their role in inhibiting bacterial cell wall synthesis.

6. MECHANISMS OF INHIBITION

Various thiazole derivatives inhibit peptidoglycan synthesis (Fig. **6**).

6.1. Enzymatic Mechanism

D-Ala-D-Ala ligase is an important enzyme in microbiology and pharmacology due to its crucial role in bacterial cell wall synthesis. It participates in the production of peptidoglycan, a key component responsible for maintaining bacterial cell integrity and shape [34]. Thiazole antibiotics target this enzyme, disrupting the assembly of the peptidoglycan layer, which leads to bacterial cell wall breakdown and ultimately bacterial cell death [35]. Several synthetic thiazole derivatives (1-4) have demonstrated substantial activity against D-Ala-D-Ala ligase, as illustrated in Fig. (**7**) [36-38].

Disruption of the lipid II cycle is a crucial mechanism by which synthetic thiazole derivatives inhibit bacterial cell wall synthesis. Lipid II is a key precursor in the peptidoglycan biosynthesis pathway, and its disruption leads to weakened cell walls and bacterial cell death. Thiazole derivatives can interfere with enzymes involved in the lipid II cycle, such as MurA and MurB, key components of peptidoglycan synthesis and crucial for bacterial cell wall integrity. MurA catalyzes the first step in this process, converting UDP-N-acetylglucosamine to UDP-N-acetylenolpyruvylglucosamine. Inhibitors, including thiazole derivatives, bind to MurA's active site, preventing this conversion through hydrogen bonds and π-π interactions. MurB, which reduces UDP-N-acetylenolpyruvylglucosamine to UDP-N-acetylmuramic acid, is similarly targeted by thiazole derivatives that bind tightly to its active site, disrupting peptidoglycan formation [39-41].

6.2. Synergistic Mechanisms

The synergistic mechanism of thiazole derivatives involves enhancing antibacterial activity when combined with other antimicrobial agents. They increase the binding affinity of antibiotics to tar-

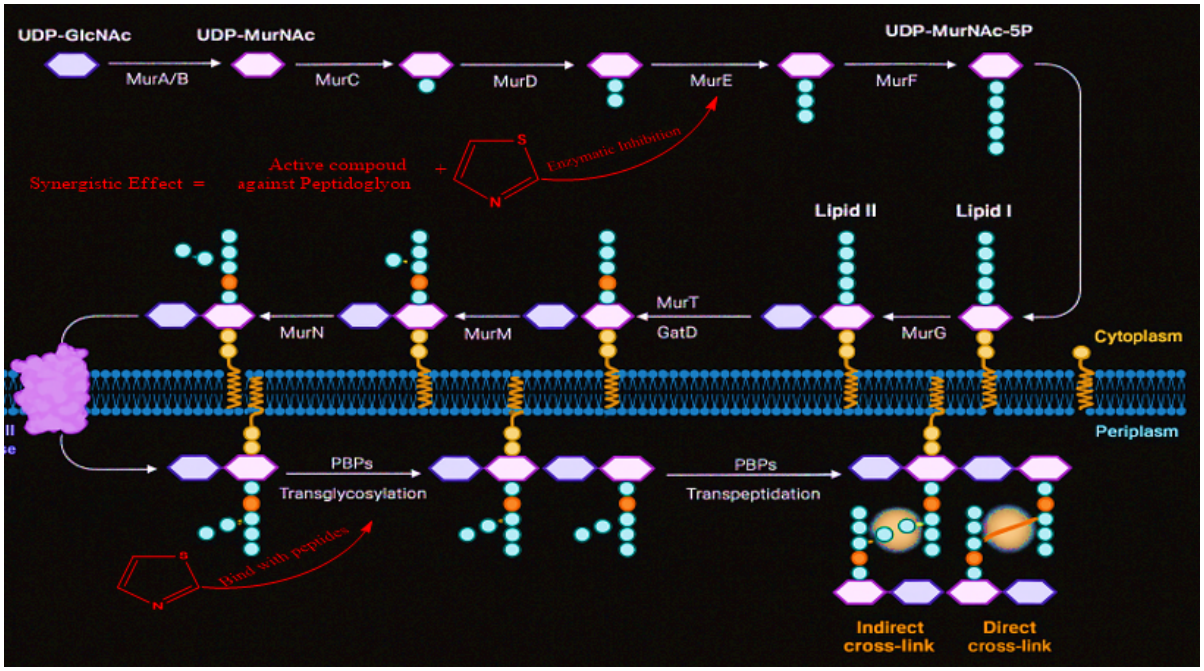


Fig. (6). Mechanisms of inhibition of peptidoglycan by thiazole derivatives. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

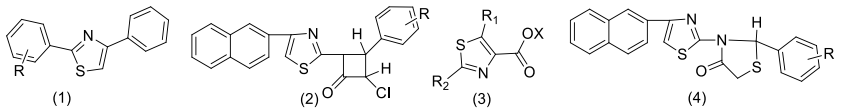


Fig. (7). Synthetic thiazole antibiotics demonstrating activity against D-Ala-D-Ala ligase [36-38].

get sites, disrupt multiple bacterial processes, such as cell wall synthesis and membrane integrity, reduce resistance development by attacking multiple targets simultaneously, and improve antibiotic penetration into bacterial cells. These combined effects make thiazole derivatives effective in developing new combination therapies to combat antibiotic-resistant bacteria [42].

Examples:

The following are examples of thiazole derivatives that exhibit notable antibacterial activity:

6.2.1. Azo-thiazole Derivatives vs. S. aureus

Compound Tested: Azo-thiazole derivatives (**5-7**)

Potency: MIC = **10 µg/mL** against *Staphylococcus aureus* (4× lower than azithromycin [40 µg/mL]) (Fig. **8**).

Implication: Structural modifications (azo linkage) enhance anti-staphylococcal activity [43].

6.2.2. Synergy with β-Lactams vs. MRSA

Combination: Thiazole derivative + ampicillin

Result: Significant synergy (decrease bacterial growth *vs.* monotherapy; $p < 0.01$).

Implication: Re-sensitizes MRSA to β-lactams [44].

6.2.3. Ciprofloxacin Potentiation vs. Gram-Negatives

Combination: Thiazole derivative + ciprofloxacin

Result: Enhanced inhibition of *E. coli* and *P. aeruginosa* ($p <$ 0.05).

Implication: Overcomes resistance in Gram-negative pathogens [45].

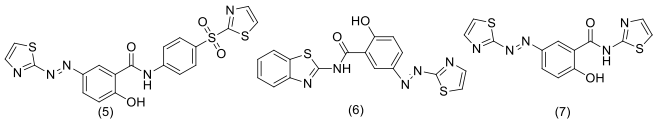


Fig. (8). Potent azo-thiazole derivatives against the bacterial cell wall.

6.3. Binding Mechanism

Designing small molecules that can bind to disease-associated proteins is a crucial aspect of new drug discovery. Atomistic computational modeling significantly enhances the efficiency of this process. However, accurately determining the binding free energy between a small molecule (ligand) and its target protein remains a major challenge. Molecular docking is a widely used computational technique that predicts ligand binding positions within target proteins and estimates protein-ligand binding energies. These binding energies help identify the most promising compounds for specific target proteins [46]. Thiazole compounds have demonstrated strong binding affinities for various important proteins, as shown in Table **2**, highlighting their potential to modulate these targets [47-49].

6.4. *In Vitro* and *In Vivo* Studies

Recently, there has been increasing interest in developing new antimicrobial agents to combat microbial resistance. Consequently, greater emphasis is being placed on screening and evaluating antimicrobial activity. Well-established bioassays, such as disk diffusion, well diffusion, and broth or agar dilution, are commonly employed. Advanced techniques, including flow cytometry and bioluminescent assays, can rapidly provide insights into antimicrobial effects and cell damage; however, their use is limited due to the

Table 2. Synthetic thiazole derivatives with their binding energy, target protein, and structural feature.

S. No.	Thiazole Derivatives	Structure Feature	Target Protein	PDB ID(Suggested)	References
1	Thiazole-oxadiazole hybrids	Thiazole ring fused with substituted oxadiazole ring	Penicillin-binding proteins	3FWL	[50]
2	4-Hydroxythiazole derivatives	Substitution of hydroxy group at position 4^{th}	Penicillin-binding proteins	3FWL	[51]
3	2,5-Disubstituted thiazole derivatives	Substitution due to substituted benzaldehyde	D-Ala-D-Ala	1R44	[52]
4	2,4-Disubstituted 1,3-thiazole	Substitution of nitro group on phenyl	D-Ala-D-Ala	1QMF	[53]
5	2-Thioxo-4-thiazolidinone based substitutions	Sulphur based substitution on thiazole ring	Transpeptidase Enzyme	3VMA	[54]
6	Thiazole-thiazolidine hybrid	Thiazole fused with substituted thiazolidinone	Penicillin-binding proteins	3PTE	[55]
7	2-Amino-4-phenylthiazole	Substitution at amine and phenyl group	D-Ala-D-Ala	1R44	[56]
8	Thiazole-NCS derivatives	Substitution by the halogen and nitro group	Cell wall biosynthesis enzyme	1UAE	[57]
9	Thiazole-imidazole conjugate	Thiazole fused with imidazole ring	Transglucosylase enzyme	1QOK	[58]

Table 3. ***In vivo*** **and** ***in vitro*** **activity of the synthetic thiazole derivatives with their structural features.**

S. No.	Structural Features	*In Vivo* Activity	*In Vitro* Activity	References
Schiff Base of Thiazolyl-Triazole	Thiazole-Triazole ring system	Assessing the effectiveness of treatments in mice infected with MRSA and *S. pneumoniae*	Compounds demonstrated antibacterial activity against *Staphylococcus aureus* and *Listeria monocytogenes*	[60-61]
Thiazole-Hydrazone Derivatives	Thiazole is attached with the hydrazone group in a moiety	Potent against the *S. aureus* and *M. tuberculosis*	Improved survival rate in mice infected with *M. tuberculosis*	[62-63]
Thiazole-Aminothiazole Derivative	Substitution of aminothiazole on thiazole ring	Inhibited penicillin-binding proteins (PBPs) and transglycosylase enzymes in *Staphylococcus aureus*	Potent against the *E. coli*-infected murine models	[64-65]
Thiazole-Pyrimidine Derivative	Substituted pyrimidine is attached with substituted thiazole derivative	Potent against the *S. pneumoniae* and *S. aureus stain.*	Effective in reducing inflammation in mice infected with *S. pneumoniae*	[66]
Thiazole-Benzene Sulphonamide Hybrid	Thiazole is linked with the benzene sulphonamide	Active against the *S. aureus* and *E. coli*	Reduced bacterial load in murine model of *S. aureus*	[67]
Benzimidazole-Based Organophosphorus Compounds	Benzimidazole-based organophosphorus compounds	-	Evaluated for general cytotoxic and systemic toxic effects	[68]

need for specialized equipment and further validation to ensure reproducibility and standardization [59]. Thiazole derivatives have demonstrated significant potency against bacterial cell wall synthesis, with both *in vitro* and *in vivo* activity summarized in Table **3**.

7. SYNTHESIS OF THIAZOLE DERIVATIVES

The investigation of thiazole derivatives has gained prominence over the years due to their diverse applications. One of the most appealing features of these compounds is that they can be synthesized in high yields from readily available starting materials using straightforward synthetic methods. The unique structure and significance of thiazole compounds have driven the development of various synthetic strategies employing different conditions, catalysts, and approaches (Table **4**) [69]. Several synthetic routes for thiazole derivatives have been reported, including:

7.1. Hantzsch Thiazole Synthesis

N,N,5-trimethyl-4-phenylthiazole-2-amine is formed through the reaction between methylpropane thioamide and 2-chloro-1-phenylpropane-1-one using methanol (CH_3OH). The reaction proceeds over 3 hours, yielding a product with a good yield (Fig. **9**) [70].

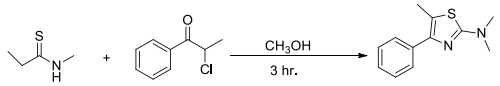


Fig. (9). Synthesis of thiazole by hantzsch synthesis.

7.2. Synthesis of Aminothiazoles

The Hantzsch condensation reaction between 2-bromoacetophenones and thiourea, without the use of any catalyst, leads to the formation of 2-aminothiazoles (Fig. **10**) [71].

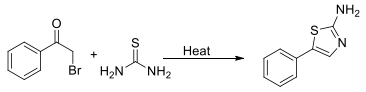


Fig. (10). Synthesis of aminothiazoles.

7.3. One-Pot Synthesis

The reaction of 1-iodo-2-nitroarenes with aldehyde and sodium sulphide, using copper as a catalyst, results in the formation of 2-substituted benzothiazoles. This three-component reaction proceeds at 100°C for 12 hours (Fig. **11**) [72].

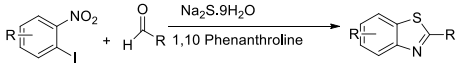


Fig. (11). Thiazole derivatives synthesized by the one-pot method.

7.4. Synthesis of 5-aryl Thiazoles

The reaction involves N-formyl-N-(2-oxo-2-phenylethyl) formamide reacting with trimethylamine and phosphorus pentasulfide at 60°C for 45-60 minutes to obtain 5-phenylthiazoles (Fig. **12**) [73].

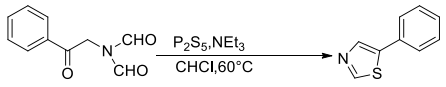


Fig. (12). Synthesis of 5-phenylthiazoles.

7.5. Synthesis of 4-Substituted 2-aminothiazoles

The reaction between potassium thiocyanate and vinyl azides, using palladium (III) acetate as a catalyst, takes place at 80°C for 12 hours. Upon completion, this reaction results in the formation of 4-substituted 2-aminothiazoles (Fig. **13**) [74].

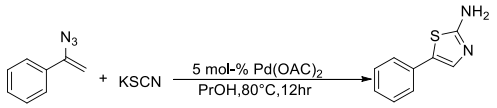


Fig. (13). Synthesis of 4-substituted aminothiazoles.

7.6. Synthesis of 2-Arylbenzothiazoles

The process starts with 2-aminothiophenol and an aryl aldehyde in air, using a DMSO oxidant system without a catalyst, to form 2-arylbenzothiazoles (Fig. **14**) [75].

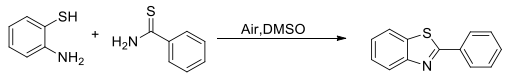


Fig. (14). Formation of 2-arylbenzothiazoles.

7.7. Preparation of 2-Amino-4-methylthiazole, Followed by a Condensation Reaction

The reaction of chloroacetone with thiourea, followed by the addition of solid sodium hydroxide (NaOH), results in the formation of 2-amino-4-methylthiazole (Fig. **15**) [76].

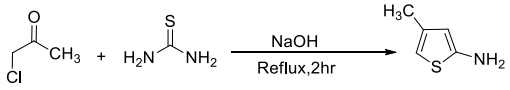


Fig. (15). Synthesis of thiazole derivatives by condensation reaction.

7.8. Synthesis of 2-Aryl-4,5-Dihydeothiazole-4-Carboxylic Acid

The reported product, 2-aryl-4,5-dihydrothiazole-4-carboxylic acid, is obtained by condensing L-cystine with aryl nitriles over 24-48 hours. Racemization occurs in a $NaHCO_3$/NaOH buffered aqueous alcoholic medium (Fig. **16**) [77].

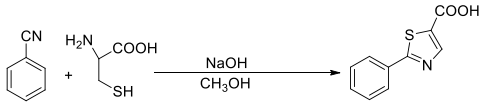


Fig. (16). Synthesis of 2-aryl-4,5-dihydeothiazole-4-carboxylic acid.

8. LITERATURE SURVEY

Recent studies have demonstrated the antibacterial potential of thiazole derivatives, highlighting their effectiveness against various bacterial strains. These compounds have shown significant promise as potential alternatives to traditional antibiotics.

Bobade and colleagues conducted a comprehensive study evaluating the antibacterial potential of several thiazole derivatives (compounds **8** and **9a, 9b**). Their results demonstrated significant inhibitory effects against both Gram-positive bacteria (*Staphylococcus aureus*, *Enterococcus faecalis*) and Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*), with MIC values ranging from 0.25 to 128 µg/mL depending on the strain and compound (Fig. **17**) [78].

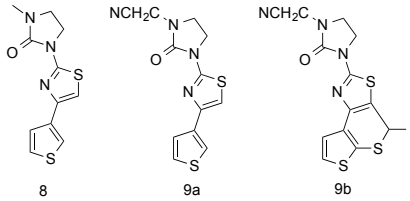


Fig. (17). Potent thiazole derivative against the various bacterial strains.

Sharifzadeh and colleagues synthesized a series of novel compounds (10a-i) and evaluated their antibacterial activity. Compounds 10a-d showed moderate efficacy against *E. coli,* while 10e-i exhibited reasonable activity against *S. aureus*; however, the study's lack of mechanistic insights, comparative data with clinical antibiotics, and *in vivo* validation limits the interpretability of these promising *in vitro* results, highlighting the need for further investigation to assess their true therapeutic potential (Fig. **18**)[79].

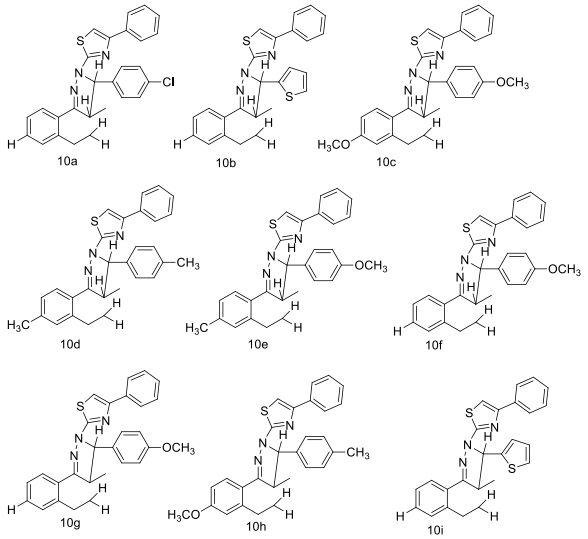


Fig. (18). Synthetic thiazole derivative effective against *E. coli* and *Staphylococcus aureus* bacteria.

Desai and colleagues investigated 1,3,5-triazine-based triazole derivatives (**11a-11c**), which demonstrated significant antibacterial activity against *E. coli*, *S. aureus*, *P. aeruginosa*, and *S. pyogenes* using the Mueller-Hinton broth dilution method. While the broad-spectrum efficacy is promising, the study lacks mechanistic insights into the compounds' mode of action, dose-response relationships, and cytotoxicity data, which are crucial for evaluating therapeutic potential. Additionally, comparative studies with standard antibiotics would help contextualize the reported activity. Further *in vivo* and pharmacokinetic studies are needed to validate these *in vitro* findings and assess clinical applicability (Fig. **19**) [80].

Aliamali and colleagues reported that novel thiazole derivatives (12a-12c) demonstrated significant antibacterial activity when tested using the agar diffusion method. These compounds exhibited potent inhibitory effects against several oral pathogens, including bacteria commonly associated with dental caries and tooth decay, such as *Streptococcus mutans* and *Lactobacillus acidophilus* (Fig. **20**) [81].

Table 4. Comparative table of thiazole synthesis methods.

Synthesis Method	Starting Materials	Catalyst/Conditions	Temperature / Time	Key Product	Figs.	Yield/Note
Hantzsch Thiazole Synthesis	Methylpropane thioamide + 2-chloro-1-phenylpropane-1-one	Methanol as a solvent	Room temp / 3 hrs	N, N,5-trimethyl-4-phenylthiazole-2-amine	(Fig. 9)	Good yield
Aminothiazole Synthesis	2-Bromoacetophenone + Thiourea	Catalyst-free	Not specified	2-Aminothiazoles	(Fig. 10)	Simple, efficient
One-Pot Synthesis	1-Iodo-2-nitroarene + Aldehyde + Sodium sulfide	Copper catalyst	100°C / 12 hrs	2-Substituted Benzothiazoles	(Fig. 11)	Three-component synthesis
5-Aryl Thiazole Synthesis	N-Formyl-N-(2-oxo-2-phenylethyl)formamide	P_2S_5 + Trimethylamine	60°C / 45-60 mins	5-Phenylthiazoles	(Fig. 12)	Moderate reaction time
4-Substituted 2-Aminothiazole Synthesis	Vinyl azide + Potassium thiocyanate	Pd(III) acetate	80°C / 12 hrs	4-Substituted 2-Aminothiazoles	(Fig. 13)	Pd-catalyzed C-N and C-S coupling
2-Arylbenzothiazole Synthesis	2-Aminothiophenol + Aryl aldehyde	DMSO, no catalyst	Ambient, Air	2-Arylbenzothiazoles	(Fig. 14)	Green chemistry approach
Condensation Reaction	Chloroacetone + Thiourea + NaOH	No catalyst (NaOH added post-reaction)	Not specified	2-Amino-4-methylthiazole	(Fig. 15)	Simple workup
Dihydrothiazole Carboxylic Acid Synthesis	L-Cystine + Aryl nitriles	$NaHCO_3$/NaOH buffered medium in alcohol	Room temp / 24-48 hrs	2-Aryl-4,5-dihydrothiazole-4-carboxylic acid	(Fig. 16)	Racemization occurs

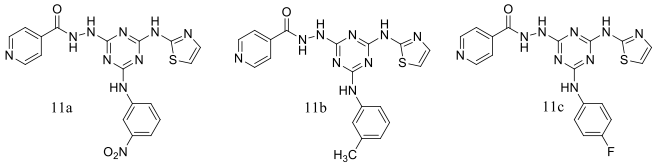


Fig. (19). Potential thiazole derivative against various stains.

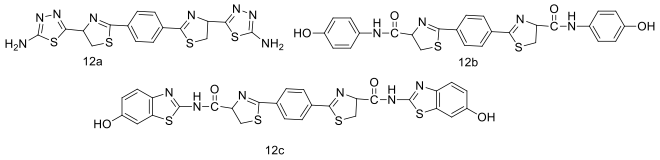


Fig. (20). Thiazole derivative effective against tooth decay.

Desai N C and colleagues synthesized a series of novel 1,3,4-oxadiazole-based thiazole derivatives (13a-13f) and evaluated their antibacterial properties using the broth dilution method. The findings revealed that these derivatives exhibited significant activity against *S. pyogenes* and *P. aeruginosa* bacteria (Fig. **21**) [82].

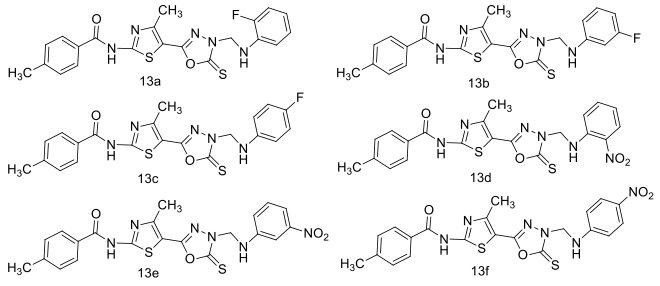


Fig. (21). Thiazole derivative effective against *S. pyogenes* and *P. aeruginosa* bacteria.

Ansari and colleagues reported a series of novel 3-(2-(5-(2-chloroquinoline-3-yl)-3-substituted phenyl-4,5-dihydro-1H-pyrazol-1-yl)thiazol-4-yl)-6-H/halo-2H-chromen-2-ones derivatives (14a-c). The antibacterial activity of these derivatives was evaluated using the serial plate dilution technique. The findings showed that all derivatives exhibited strong antimicrobial activity against *E. coli* and *S. aureus* (Fig. **22**) [83].

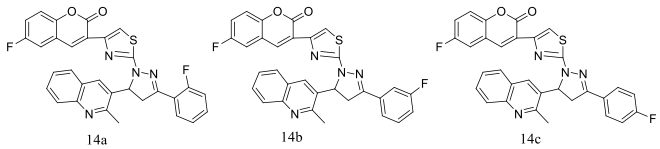


Fig. (22). Thiazole derivative against *E. coli* and *S. aureus.*

Nastasa and colleagues described the synthesis of new hydrazone-containing thiazole derivatives (15a-15g) and assessed their antibacterial properties using the agar diffusion method. The findings showed that these compounds demonstrated strong biological activity against *S. aureus* and *E. coli bacteria* (Fig. **23**) [84].

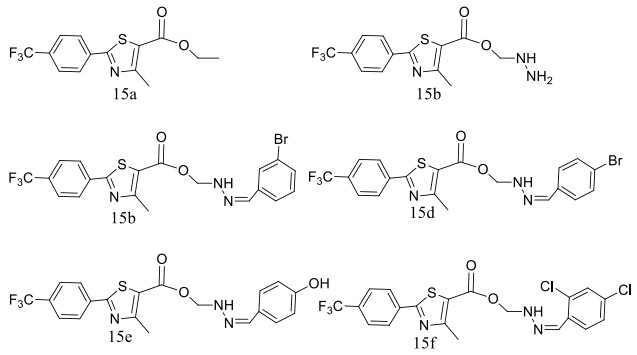


Fig. (23). Hydrazone -Thiazole derivative against *S. aureus* and *E. coli.*

Gaffer and colleagues investigated a series of aryl azothiazole derivatives (16a-16b) and assessed their antibacterial activity using the agar diffusion method. The results showed that both derivatives exhibited strong antibacterial activity against Gram-positive bacteria, including *Staphylococcus aureus* and *Bacillus subtilis*, suggesting notable efficacy within this class (Fig. **24**) [85].

Yurttaş and colleagues identified a series of novel hydrazone-bridged thiazole-pyrrole derivatives (17a-f) and evaluated their antimicrobial activity using the broth dilution method. Their analy-

sis showed that all compounds exhibited potent activity against *Staphylococcus aureus* and *Enterococcus faecalis,* with MIC values typically in the low micromolar range (< 10 µg/mL), demonstrating noteworthy antibacterial efficacy (Fig. **25**) [86].

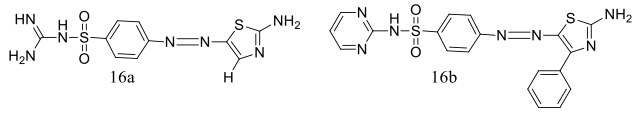


Fig. (24). Thiazole derivatives effective against Gram-Positive bacteria.

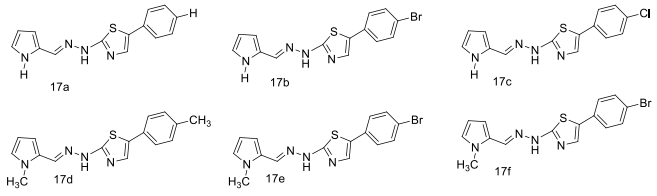


Fig. (25). Potent thiazole derivative effective against various bacteria.

Yadlapalli and colleagues synthesized a new derivative (18) that demonstrated strong antibacterial activity against *Bacillus licheniformis*, *Enterobacter cloacae*, and *E. coli*-like bacteria, attributed to the inclusion of the 4-NO_2 group (Fig. **26**) [87].

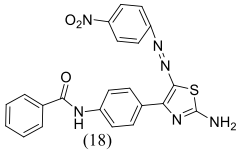


Fig. (26). Potent thiazole derivative effective against *Bacillus licheniformis*, *Enterobacter cloacae*, and *E. coli.*

Mohamed and colleagues synthesized several antibacterial agents, and the antibacterial activities of several fluorinated-2- (3-(benzofuran-2-yl)pyrazol-1-yl)thiazole derivatives (19a-19c) were assessed against *B. subtilis* and *S. aureus*. Ciprofloxacin was used as a reference drug. The results demonstrated that the compounds exhibited robust antibacterial activity against various bacteria, comparable to that of the reference drug (Fig. **27**) [88].

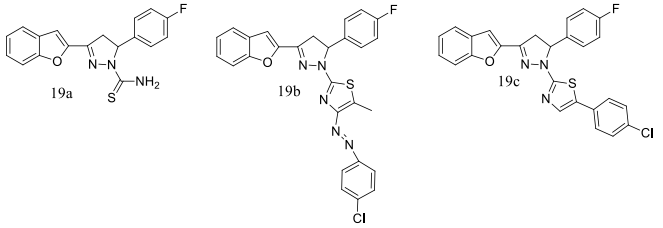


Fig. (27). Potent thiazole derivatives effective against *B. subtilis* and *S. aureus.*

Sreedevi M and colleagues synthesized a series of derivatives (20a-20b) that exhibited enhanced antibacterial activity against various pathogens, including *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, as evaluated by the cup-plate method (Fig. **28**) [89].

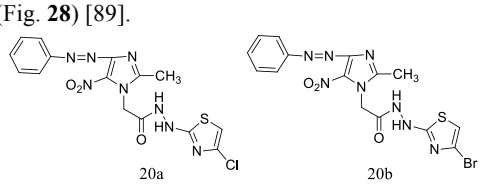


Fig. (28). Thiazole derivatives showed antibacterial activity using the cup plate method.

Arora P and colleagues conducted an extended synthesis process, resulting in a series of 2,4-disubstituted 1,3-thiazole derivatives (21a-21c) with notable antibacterial activity. The presence of nitro groups on the phenyl substituents contributed to their activity, demonstrating effectiveness against *Bacillus subtilis* and *Escherichia coli* (Fig. **29**) [90].

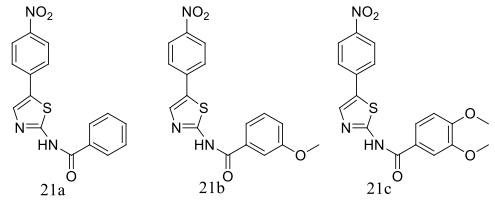


Fig. (29). Potent thiazole derivatives effective against *B. subtilis* and *E. coli.*

Deepika Sharma and colleagues synthesized a novel series of 4-(4-bromophenyl)-thiazol-2-amine derivatives. These compounds were confirmed by their physicochemical and spectral properties. The antimicrobial activity results indicated that compounds (22a-22d) exhibited potential antibacterial effects when compared to the standard drug, norfloxacin. These newly discovered compounds exhibited promising *in vitro* antibacterial activity against *Staphylococcus aureus, Bacillus subtilis,* and *Escherichia coli* (Fig. **30**) [91].

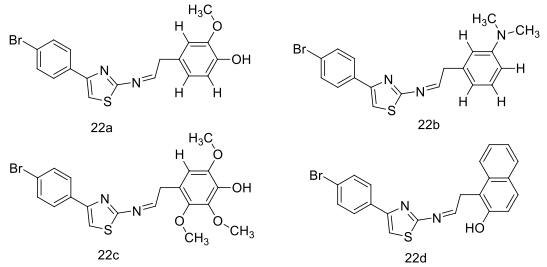


Fig. (30). Potent thiazole derivatives effective against *Staphylococcus aureus, Bacillus subtilis,* and *Escherichia coli.*

Saima Ejaz and colleagues synthesized 2-aminothiazole derivatives. At concentrations of 375 µg/mL and 250 µg/mL, derivatives 23a and 23b demonstrated significant antibacterial activity against the gram-negative *Pseudomonas aeruginosa* and the gram-positive *Staphylococcus epidermidis* (Fig. **31**) [92].

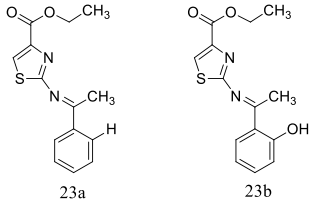


Fig. (31). Potent thiazole derivative effective against the Gram-Negative *P. aeruginosa* and the gram-positive *S. epidermidis*.

Karegoudar and colleagues synthesized a series (24a-24c) of antibacterial agents. In which 2,3,5-trichlorobenzene carbothioamide was condensed with phenacyl bromide or dichloroacetone. Additionally, the reaction of 2,3,5-trichlorobenzaldehyde thiosemicarbazone with phenacyl bromides resulted in the formation of the (phenylidenehydrazino)-1,3-thiazole derivative. According to their susceptibility testing, these compounds demonstrated strong antibacterial activity, with MIC values comparable to the standard ciprofloxacin dose (Fig. **32**) [93].

Swath Krishna and colleagues developed a novel antibacterial molecule (25) featuring a triazole moiety on the side chain of a thiazole core. This compound exhibited effective antibacterial activity against *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, and *Bacillus subtilis* in tests. The primary distinction

between this and other hybrid compounds, such as -CH3, -NO2, and -F derivatives, was its broad spectrum of activity (Fig. **33**) [69].

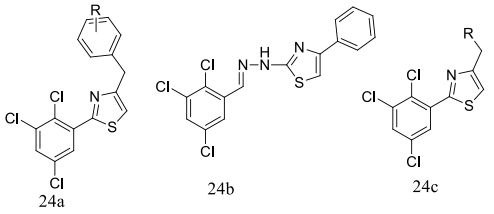


Fig. (32). Thiazole derivatives showing strong antibacterial activity in susceptibility testing.

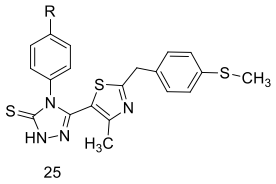


Fig. (33). Thiazole derivative effective against *Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus,* and *Bacillus subtilis.*

Sherif M. H. Sanad and colleagues reported the synthesis of new hybrid thiazole (26) using a one-pot, three-component methodology. The prepared compound demonstrated significant activity against *S. aureus, S. mutans*, and *E. coli* compared with reference antibiotics (Fig. **34**) [94].

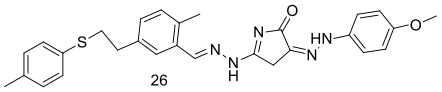


Fig. (34). Thiazole derivative effective against *S. aureus, S. mutans,* and *E. coli.*

El-Naggar AM and colleagues synthesized heteroaryl thiazole derivatives (27a-27b) and assessed their antibacterial activity against *E. coli, B. cereus, and S. Typhimurium* (Fig. **35**)[95].

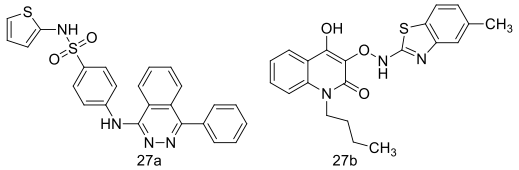


Fig. (35). Thiazole derivatives effective against *E. coli, B. cereus,* and *S. typhimurium*.

Fitsum Lemilemu and colleagues synthesized a thiazole-based Schiff base compound (28) that demonstrated favourable activity against both gram-negative *E. coli* and gram-positive *S. aureus*. These activities were notable compared with the reference antibiotic, amoxicillin (Fig. **36**) [96].

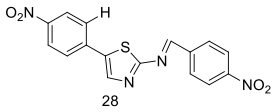


Fig. (36). Thiazole derivative effective against *E. coli* and *S. aureus.*

9. FUTURE DIRECTION AND RESEARCH

Given the increasing challenge posed by antibiotic-resistant bacterial infections, continued research into thiazole derivatives is crucial. Future studies should focus on.

9.1. Mechanisms of Action

Exploring the precise mechanisms by which thiazole derivatives inhibit peptidoglycan synthesis to provide deeper insights into their antibacterial efficacy and potential as new therapeutic agents [97-98].

9.2. Structural Modifications

Investigating structural modifications and the synthesis of novel thiazole derivatives in order to lead to the discovery of more potent and selective antibacterial agents. Incorporating computational methods, such as molecular docking and SAR studies, will aid in the design of effective derivatives [99-100].

9.3. Broad-Spectrum Activity

Assessing the spectrum of activity of thiazole derivatives against a wider range of bacterial strains, including multidrug-resistant pathogens, to evaluate their potential as broad-spectrum antibiotics [101-103].

9.4. Combination Therapies

Evaluating the synergistic effects of thiazole derivatives with existing antibiotics to enhance their antibacterial efficacy and potentially reduce the development of resistance [104].

9.5. Bioavailability and Pharmacokinetics

Conducting in-depth studies on the bioavailability, pharmacokinetics, and toxicity of thiazole derivatives to ensure their safety and efficacy in clinical applications [105-107].

CONCLUSION

Thiazole derivatives hold significant promise in medicinal chemistry, particularly for combating antibiotic-resistant bacterial infections by targeting peptidoglycan synthesis and disrupting cell wall integrity. Structure-Activity Relationship (SAR) analysis reveals that electron-withdrawing groups (such as halogens and nitro substituents), lipophilic side chains, and fused heterocyclic or aryl systems significantly enhance antibacterial potency. Derivatives featuring halogenated phenyl rings and alkylthio groups exhibit the highest activity. These findings highlight the importance of strategic structural modifications to improve efficacy and the spectrum of activity. Future research should focus on optimizing these features, assessing safety and pharmacokinetics, and exploring synergistic combinations to fully harness the therapeutic potential of thiazole-based compounds.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: study conception and design: SK data collection: JKS; analysis and draft manuscript: SK and JKS.

LIST OF ABBREVIATIONS

MIC	=	Minimum Inhibitory Concentration
NMR	=	Nuclear Magnetic Resonance
PDB ID	=	Protein Data Bank Identifier
D-Ala-D-Ala ligase	=	D-Alanine-D-Alanine ligase
MurA	=	UDP-N-acetylglucosamine enolpyruvyl transferase
MurB	=	UDP-N-acetylglucosamine enolpyruvyl reductase
PBPs	=	Penicillin-Binding Proteins
SAR	=	Structure-Activity Relationship
B. cereus	=	*Bacillus cereus*
B. subtilis	=	*Bacillus subtilis*

E. cloacae	=	*Enterobacter cloacae*
E. coli	=	*Escherichia coli*
E. faecalis	=	*Enterococcus faecalis*
L. acidophilus	=	*Lactobacillus acidophilus*
MRSA	=	Methicillin-Resistant *Staphylococcus aureus*
M. tuberculosis	=	*Mycobacterium tuberculosis*
P. aeruginosa	=	*Pseudomonas aeruginosa*
S. aureus	=	*Staphylococcus aureus*

CONSENT FOR PUBLICATION

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Prof. M.P. Pandey, Vice Chancellor of IFTM University, Moradabad (U.P.), India, for his invaluable support throughout this work.

AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the author(s) used a paraphrasing and grammar-checking tool (Quillbot)solely for language editing and improving clarity of presentation. No AI-based content generation tool was used. All scientific content, analysis, and conclusions were independently developed and thoroughly reviewed by the author(s), who take full responsibility for the accuracy, originality, and integrity of the published work.

REFERENCES

[1] Emelyanenko, A.M.; Makvandi, P.; Moradialvand, M.; Boinovich, L.B. Harnessing extreme wettability: Combatting spread of bacterial infections in healthcare. *Surf Innov.,* **2024**, *12*(7), 1-31. http://dx.doi.org/10.1680/jsuin.24.00048

[2] Zhydzetski, A.; Głowacka-Grzyb, Z.; Bukowski, M.; Żądło, T.; Bonar, E.; Władyka, B. Agents targeting the bacterial cell wall as tools to combat Gram-positive pathogens. *Molecules,* **2024**, *29*(17), 4065. http://dx.doi.org/10.3390/molecules29174065 PMID: 39274911

[3] Hashimi, A.; Tocheva, E.I. Cell envelope diversity and evolution across the bacterial tree of life. *Nat. Microbiol.,* **2024**, *9*(10), 2475-2487. http://dx.doi.org/10.1038/s41564-024-01812-9 PMID: 39294462

[4] Garde, S.; Chodisetti, P.K.; Reddy, M. Peptidoglycan: Structure, synthesis, and regulation. *Ecosal Plus,* **2021**, *9*(2), ecosalplus.ESP-0010-2020. http://dx.doi.org/10.1128/ecosalplus.ESP-0010-2020 PMID: 33470191

[5] El-Araby, A.M.; Fisher, J.F.; Mobashery, S. Bacterial peptidoglycan as a living polymer. *Curr. Opin. Chem. Biol.,* **2025**, *84*, 102562. http://dx.doi.org/10.1016/j.cbpa.2024.102562 PMID: 39700530

[6] Balanean, L.; Braicu, C.O.; Berindan-Neagoe, I.; Nastasa, C.; Tiperciuc, B.; Verite, P.H.; Oniga, O. Synthesis of novel 2-methylamino-4-substituted-1,3-thiazoles with antiproliferative activity. *Revista de Chimie-Bucharest,* **2014**, *65*, 1413-1417.

[7] Rusu, A.; Moga, I.M.; Uncu, L.; Hancu, G. The role of five-membered heterocycles in the molecular structure of antibacterial drugs used in therapy. *Pharmaceutics,* **2023**, *15*(11), 2554. http://dx.doi.org/10.3390/pharmaceutics15112554 PMID: 38004534

[8] Tiwari, P.; Kumar, S.; Sharma, J.K.; kumari, A. Synthesis and computational studies of new chalcone derivatives as anxiolytics and skeletal muscle relaxants. *Cent. Nerv. Syst. Agents Med. Chem.,* **2025**, *25*. http://dx.doi.org/10.2174/0118715249384074250709074253 PMID: 40685725

[9] Sharma, J.K.; Kumari, A.; Kumar, A.; Kumar, S.; Verma, S. Synthesis, computational studies, and biological evaluation of chalcones as antifungal agents. *Antiinfect. Agents,* **2025**, *23*, 23. http://dx.doi.org/10.2174/0122113525369092250309111235

[10] Ali, S.H.; Sayed, A.R. Review of the synthesis and biological activity of thiazoles. *Synth. Commun.,* **2021**, *51*(5), 670-700. http://dx.doi.org/10.1080/00397911.2020.1854787

[11] Eryılmaz, S.; Türk Çelikoğlu, E.; İdil, Ö.; İnkaya, E.; Kozak, Z.; Mısır, E.; Gül, M. Derivatives of pyridine and thiazole hybrid: Synthesis, DFT, biological evaluation *via* antimicrobial and DNA cleavage activity. *Bioorg. Chem.,* **2020**, *95*, 103476. http://dx.doi.org/10.1016/j.bioorg.2019.103476 PMID: 31838288

[12] Payaz, D.Ü.; Kucukbay, F.Z.; Kucukbay, H.; Angeli, A.; Supuran, C.T. Benzothiazole derivatives incorporating glycine, methionine, alanine, and phenylalanine moieties as carbonic anhydrase inhibitors with antioxidant potential. In: *Privileged Scaffolds in Drug Discovery*; Academic Press, **2019**; pp. 343-349.

[13] Kucubay, F.Z.; Buğday, N.; Küçükbay, H.; Tanc, M.; Supuran, C.T. Design and synthesis of benzothiazole-based carbonic anhydrase inhibitors. In: *Privileged Scaffolds in Drug Discovery*; Academic Press, **2016**; pp. 1221-1225.

[14] Jaishree, V.; Ramdas, N.; Sachin, J.; Ramesh, B. *In vitro* antioxidant properties of new thiazole derivatives. *J. Saudi Chem. Soc.,* **2012**, *16*(4), 371-376. http://dx.doi.org/10.1016/j.jscs.2011.02.007

[15] Alharbi, A.; Qurban, J.; Abualnaja, M.M.; Abumelha, H.M.; Saad, F.A.; El-Metwaly, N.M.; El-Metwaly, N.M. Molecular modeling and docking studies of new antioxidant pyrazole-thiazole hybrids. *J. Mol. Struct.,* **2022**, *1267*, 133582. http://dx.doi.org/10.1016/j.molstruc.2022.133582

[16] Saravanan, G.; Alagarsamy, V.; Prakash, C.R.; Kumar, P.D.; Selvam, T.P. Synthesis of novel thiazole derivatives as analgesic agents. *Asian J. Pharm. Res.,* **2011**, *1*(4), 134-138.

[17] Mishra, I.; Mishra, R.; Mujwar, S.; Chandra, P.; Sachan, N. A retrospect on antimicrobial potential of thiazole scaffold. *J. Heterocycl. Chem.,* **2020**, *57*(6), 2304-2329. http://dx.doi.org/10.1002/jhet.3970

[18] Ayati, A.; Emami, S.; Moghimi, S.; Foroumadi, A. Thiazole in the targeted anticancer drug discovery. *Future Med. Chem.,* **2019**, *11*(15), 1929-1952. http://dx.doi.org/10.4155/fmc-2018-0416 PMID: 31313595

[19] Singh, I.P.; Gupta, S.; Kumar, S. Thiazole compounds as antiviral agents: An update. *Med. Chem.,* **2020**, *16*(1), 4-23. http://dx.doi.org/10.2174/1573406415666190614101253 PMID: 31203807

[20] Gomha, S.; Khalil, K.; Abdel-aziz, H.; Abdalla, M. Synthesis and antihypertensive α-blocking activity evaluation of thiazole derivatives bearing pyrazole moiety. *Heterocycles,* **2015**, *91*(9), 1763-1773. http://dx.doi.org/10.3987/COM-15-13290

[21] Helal, M.H.M.; Salem, M.A.; El-Gaby, M.S.A.; Aljahdali, M. Synthesis and biological evaluation of some novel thiazole compounds as potential anti-inflammatory agents. *Eur. J. Med. Chem.,* **2013**, *65*, 517-526. http://dx.doi.org/10.1016/j.ejmech.2013.04.005 PMID: 23787438

[22] Mishra, C.B.; Kumari, S.; Tiwari, M. Thiazole: A promising heterocycle for the development of potent CNS active agents. *Eur. J. Med. Chem.,* **2015**, *92*, 1-34. http://dx.doi.org/10.1016/j.ejmech.2014.12.031 PMID: 25544146

[23] Aziz, H. Insights into antimicrobial potential of functionalized thiazoles: *In vitro* and *in silico* analysis. *J. Mol. Liq,* **2025**, *424*, 127064. http://dx.doi.org/10.1016/j.molliq.2025.127064

[24] Alam, MA Chapter 1 - Thiazole, a privileged scaffold in drug discovery. In: *Privileged Scaffolds in Drug Discovery*; Academic Press, **2023**; pp. 1-19. http://dx.doi.org/10.1016/B978-0-443-18611-0.00027-9

[25] Hupfer, M.L.; Kaufmann, M.; Roussille, L.; Preiß, J.; Weiß, D.; Hinrichs, K.; Deckert, V.; Dietzek, B.; Beckert, R.; Presselt, M. Arylic versus alkylic—Hydrophobic linkers determine the supramolecular structure and optoelectronic properties of tripodal amphiphilic push-pull thiazoles. *Langmuir,* **2019**, *35*(7), 2561-2570. http://dx.doi.org/10.1021/acs.langmuir.8b03893 PMID: 30694677

[26] Zhu, X.; Zhang, Y.; Ma, Z.; He, Y.; Song, P.; Wang, R. Construction of thiazole-zwitterionic copolymer nanospheres with iso-bifunctional groups for excellent antibacterial activity. *Prog. Org. Coat,* **2024**, *186*, 108084. http://dx.doi.org/10.1016/j.porgcoat.2023.108084

[27] Borcea, A.M.; Ionuț, I.; Crișan, O.; Oniga, O. An overview of the synthesis and antimicrobial, antiprotozoal, and antitumor activity of thiazole and bisthiazole derivatives. *Molecules,* **2021**, *26*(3), 624. http://dx.doi.org/10.3390/molecules26030624 PMID: 33504100

[28] Sarangi, P.K.N.; Sahoo, J.; Swain, B.D.; Paidesetty, S.K.; Mohanta, G.P. Thiazoles as potent anticancer agents: A review. *INDIAN DRUGS,* **2016**, *53*(11), 5-11. http://dx.doi.org/10.53879/id.53.11.10755

[29] Eicher, T.; Hauptmann, S.; Speicher, A. *The chemistry of heterocycles: Structures, reactions, synthesis, and applications*; John Wiley & Sons, **2013**.

[30] Seltmann, G.; Holst, O. *The bacterial cell wall*; Springer Science & Business Media, **2002**. http://dx.doi.org/10.1007/978-3-662-04878-8

[31] Egan, A.J.F.; Cleverley, R.M.; Peters, K.; Lewis, R.J.; Vollmer, W. Regulation of bacterial cell wall growth. *FEBS J.,* **2017**, *284*(6), 851-867. http://dx.doi.org/10.1111/febs.13959 PMID: 27862967

[32] Mohanty, P.; Behera, S.; Behura, R.; Shubhadarshinee, L.; Mohapatra, P.; Barick, A.K.; Jali, B.R. Antibacterial activity of thiazole and its derivatives: A review. *Biointerface Res. Appl. Chem.,* **2021**, *12*(2), 2171-2195. http://dx.doi.org/10.33263/BRIAC122.21712195

[33] Khamitova, A.; Berillo, D.; Lozynskyi, A.; Konechnyi, Y.; Mural, D.; Georgiyants, V.; Lesyk, R. Thiadiazole and thiazole derivatives as potential antimicrobial agents. *Mini Rev. Med. Chem.,* **2024**, *24*(5), 531-545. http://dx.doi.org/10.2174/1389557523666230713115947 PMID: 37448365

[34] Miller, D.J.; Hammond, S.M.; Anderluzzi, D.; Bugg, T.D.H. Aminoalkylphosphinate inhibitors of D-Ala-D-Ala adding enzyme. *J. Chem. Soc., Perkin Trans 1,* **1998**, (1), 131-142. http://dx.doi.org/10.1039/a704097k

[35] Rajagopal, K.; Dhandayutham, S.; Nandhagopal, M.; Narayanasamy, M.; I Elzagheid, M.; Rhyman, L.; Ramasami, P. Thiazole derivatives: Synthesis, characterization, biological and DFT studies. *J. Mol. Struct.,* **2022**, *1255*, 132374. http://dx.doi.org/10.1016/j.molstruc.2022.132374

[36] Kaspady, M.; Narayanaswamy, V.; Raju, M.; Rao, G. Synthesis, antibacterial activity of 2,4-disubstituted oxazoles and thiazoles as bioisosteres. *Lett. Drug Des. Discov.,* **2009**, *6*(1), 21-28. http://dx.doi.org/10.2174/157018009787158481

[37] Sanz-Cervera, J.F.; Blasco, R.; Piera, J.; Cynamon, M.; Ibáñez, I.; Murguía, M.; Fustero, S. Solution versus fluorous versus solid-phase synthesis of 2,5-disubstituted 1,3-azoles. Preliminary antibacterial activity studies. *J. Org. Chem.,* **2009**, *74*(23), 8988-8996. http://dx.doi.org/10.1021/jo9016265 PMID: 19894729

[38] Patel, K.H.; Mehta, A.G. Synthesis and antifungal activity of azetidinone and thiazolidinones derivatives of 2-amino-6-(2-naphthalenyl)thiazolo[3,2-d]thiadiazole. *E-J. Chem.,* **2006**, *3*(3), 267-273.

[39] Kaur Manjal, S.; Kaur, R.; Bhatia, R.; Kumar, K.; Singh, V.; Shankar, R.; Kaur, R.; Rawal, R.K. Synthetic and medicinal perspective of thiazolidinones: A review. *Bioorg. Chem.,* **2017**, *75*, 406-423. http://dx.doi.org/10.1016/j.bioorg.2017.10.014 PMID: 29102723

[40] Aboushady, Y. *Design and synthesis of MurA enzyme inhibitors and their evaluation as antibacterial agents*; Saarländische Universitäts- und Landesbibliothek, **2023**.

[41] Kumar, D.; Sarkar, N.; Roy, K.K.; Bisht, D.; Kumar, D.; Mandal, B.; Rajagopal, M.; Dey, Y.N. The potential of Mur enzymes as targets for antimicrobial drug discovery. *Curr. Drug Targets,* **2023**, *24*(8), 627-647. http://dx.doi.org/10.2174/1389450124666230608150759 PMID: 37291783

[42] Jain, A.K.; Vaidya, A.; Ravichandran, V.; Kashaw, S.K.; Agrawal, R.K. Recent developments and biological activities of thiazolidinone derivatives: A review. *Bioorg. Med. Chem.,* **2012**, *20*(11), 3378-3395. http://dx.doi.org/10.1016/j.bmc.2012.03.069 PMID: 22546204

[43] Muhammed Aziz, D.; Hassan, S.A.; Amin, A.A.M.; Abdullah, M.N.; Qurbani, K.; Aziz, S.B. A synergistic investigation of azo-thiazole derivatives incorporating thiazole moieties: A comprehensive exploration of their synthesis, characterization, computational insights, solvatochromism, and multimodal biological activity assessment. *RSC Advances,* **2023**, *13*(49), 34534-34555. http://dx.doi.org/10.1039/D3RA06469G PMID: 38024963

[44] Wang, X.; Zhao, C.; Wang, Q.; Wang, Z.; Liang, X.; Zhang, F.; Zhang, Y.; Meng, H.; Chen, H.; Li, S.; Zhou, C.; Li, H.; Wang, H. *In vitro* activity of the novel β-lactamase inhibitor taniborbactam (VNRX-5133), in combination with cefepime or meropenem, against MDR Gram-negative bacterial isolates from China. *J. Antimicrob. Chemother.,* **2020**, *75*(7), 1850-1858. http://dx.doi.org/10.1093/jac/dkaa053 PMID: 32154866

[45] Zang, W.; Li, D.; Gao, L.; Gao, S.; Hao, P.; Bian, H. The antibacterial potential of ciprofloxacin hybrids against *Staphylococcus aureus*. *Curr. Top Med. Chem.,* **2022**, *22*(12), 1020-1034. http://dx.doi.org/10.2174/1568026622666220317162132 PMID: 35301951

[46] Sulimov, V.B.; Kutov, D.C.; Sulimov, A.V. Advances in docking. *Curr. Med. Chem.,* **2020**, *26*(42), 7555-7580. http://dx.doi.org/10.2174/0929867325666180904115000 PMID: 30182836

[47] Gomha, S.M.; Abdelhady, H.A.; Hassain, D.Z.H.; Abdelmonsef, A.H.; El-Naggar, M.; Elaasser, M.M.; Mahmoud, H.K. Thiazole-based thiosemicarbazones: Synthesis, cytotoxicity evaluation and molecular docking study. *Drug Des. Devel. Ther.,* **2021**, *15*(3), 659-677. http://dx.doi.org/10.2147/DDDT.S291579 PMID: 33633443

[48] Khamees, H.A.; Mohammed, Y.H.E.; Swamynayaka, A.; Al-Ostoot, F.H.; Sert, Y.; Alghamdi, S.; Khanum, S.A.; Madegowda, M. Molecular structure, DFT, vibrational spectra with fluorescence effect, hirshfeld surface, docking simulation and antioxidant activity of thiazole derivative. *ChemistrySelect,* **2019**, *4*(15), 4544-4558. http://dx.doi.org/10.1002/slct.201900646

[49] Łączkowski, K.Z.; Świtalska, M.; Baranowska-Łączkowska, A.; Plech, T.; Paneth, A.; Misiura, K.; Wietrzyk, J.; Czaplińska, B.; Mrozek-Wilczkiewicz, A.; Malarz, K.; Musioł, R.; Grela, I. Thiazole-based nitrogen mustards: Design, synthesis, spectroscopic studies, DFT calculation, molecular docking, and antiproliferative activity against selected human cancer cell lines. *J. Mol. Struct.,* **2016**, *1119*(1), 139-150. http://dx.doi.org/10.1016/j.molstruc.2016.04.058

[50] Farghaly, T.A.; Alfaifi, G.H.; Gomha, S.M. Recent literature on the synthesis of thiazole derivatives and their biological activities. *Mini Rev. Med. Chem.,* **2024**, *24*(2), 196-251. http://dx.doi.org/10.2174/1389557523666230726142459 PMID: 37496137

[51] Thakur, S.; Sharma, R.; Yadav, R.; Sardana, S. The potential of thiazole derivatives as antimicrobial agents. *Chem. Proc,* **2022**, *12*(36), 36. http://dx.doi.org/10.3390/ecsoc-26-13673

[52] Sayiner, H.S.; Yilmazer, M.I.; Abdelsalam, A.T.; Ganim, M.A.; Baloglu, C.; Altunoglu, Y.C.; Gür, M.; Saracoglu, M.; Attia, M.S.; Mahmoud, S.A.; Mohamed, E.H.; Boukherroub, R.; Al-Shaalan, N.H.; Alharthi, S.; Kandemirli, F.; Amin, M.A. Synthesis and characterization of new 1,3,4-thiadiazole derivatives: Study of their antibacterial activity and CT-DNA binding. *RSC Advances,* **2022**, *12*(46), 29627-29639. http://dx.doi.org/10.1039/D2RA02435G PMID: 36321093

[53] Pricopie, A.I.; Focşan, M.; Ionuţ, I.; Marc, G.; Vlase, L.; Găină, L.I.; Vodnar, D.C.; Simon, E.; Barta, G.; Pîrnău, A.; Oniga, O. Novel 2, 4-disubstituted-1, 3-thiazole derivatives: Synthesis, anti-Candida activity evaluation and interaction with bovine serum albumin. *Molecules,* **2020**, *25*(5), 1079. http://dx.doi.org/10.3390/molecules25051079 PMID: 32121062

[54] Althagafi, I.; El-Metwaly, N.; Farghaly, T.A. New series of thiazole derivatives: Synthesis, structural elucidation, antimicrobial activity, molecular modeling and MOE docking. *Molecules,* **2019**, *24*(9), 1741. http://dx.doi.org/10.3390/molecules24091741 PMID: 31060260

[55] Djukic, M.; Fesatidou, M.; Xenikakis, I.; Geronikaki, A.; Angelova, V.T.; Savic, V.; Pasic, M.; Krilovic, B.; Djukic, D.; Gobeljic, B.; Pavlica, M.; Djuric, A.; Stanojevic, I.; Vojvodic, D.; Saso, L. *In vitro* antioxidant activity of thiazolidinone derivatives of 1,3-thiazole and 1,3,4-thiadiazole. *Chem. Biol. Interact.,* **2018**, *286*, 119-131. http://dx.doi.org/10.1016/j.cbi.2018.03.013 PMID: 29574026

[56] Kartsev, V.; Geronikaki, A.; Zubenko, A.; Petrou, A.; Ivanov, M.; Glamočlija, J.; Sokovic, M.; Divaeva, L.; Morkovnik, A.; Klimenko, A. Synthesis and antimicrobial activity of new heteroaryl (aryl) thiazole derivatives molecular docking studies. *Antibiotics (Basel),* **2022**, *11*(10), 1337. http://dx.doi.org/10.3390/antibiotics11101337 PMID: 36289995

[57] Stuzhin, P.A.; Ercolani, C. Porphyrazines with Annulated 101. *Porphyrin Handbook: Phthalocyanines: Spectroscopic and Electrochemical Characterization,* **2000**, *16*, 263.

[58] Gudala, S.; Sharma, A.; Lankada, A.; Liu, R.; Jha, A.; Penta, S.; Dar, O.I.; Yang, J. Green one-pot synthesis of thiazole scaffolds catalyzed by reusable $NiFe_2O_4$ nanoparticles: *in silico* binding affinity and *in vitro* anticancer activity studies. *ACS Omega,* **2024**, *9*(36), 38262-38271. http://dx.doi.org/10.1021/acsomega.4c05587 PMID: 39281943

[59] Balouiri, M.; Sadiki, M.; Ibnsouda, S.K. Methods for *in vitro* evaluating antimicrobial activity: A review. *J. Pharm. Anal.,* **2016**, *6*(2), 71-79. http://dx.doi.org/10.1016/j.jpha.2015.11.005 PMID: 29403965

[60] Cascioferro, S.; Parrino, B.; Carbone, D.; Schillaci, D.; Giovannetti, E.; Cirrincione, G.; Diana, P. Thiazoles, their benzofused systems, and thiazolidinone derivatives: Versatile and promising tools to combat antibiotic resistance. *J. Med. Chem.,* **2020**, *63*(15), 7923-7956. http://dx.doi.org/10.1021/acs.jmedchem.9b01245 PMID: 32208685

[61] Wang, J.; Long, S.; Liu, Z.; Rakesh, K.P.; Verma, R.; Verma, S.K.; Sharath Kumar, K.S. Structure-activity relationship studies of thiazole agents with potential anti methicillin-resistance Staphylococcus aureus (MRSA) activity. *Process. Biochem.,* **2023**, *132*, 13-29. http://dx.doi.org/10.1016/j.procbio.2023.06.013

[62] Dorababu, A. Pharmacology profile of recently developed multi-functional azoles; SAR-based predictive structural modification. *ChemistrySelect,* **2020**, *5*(22), 6730-6758. http://dx.doi.org/10.1002/slct.202000294

[63] Ayati, A.; Emami, S.; Asadipour, A.; Shafiee, A.; Foroumadi, A. Recent applications of 1,3-thiazole core structure in the identification of new lead compounds and drug discovery. *Eur. J. Med. Chem.,* **2015**, *97*, 699-718. http://dx.doi.org/10.1016/j.ejmech.2015.04.015 PMID: 25934508

[64] Łączkowski, K.Z.; Motylewska, K.; Baranowska-Łączkowska, A.; Biernasiuk, A.; Misiura, K.; Malm, A.; Fernández, B. Synthesis, antimicrobial evaluation and theoretical prediction of NMR chemical shifts of thiazole and selenazole derivatives with high antifungal activity against Candida spp. *J. Mol. Struct.,* **2016**, *1108*, 427-437. http://dx.doi.org/10.1016/j.molstruc.2015.12.033

[65] Das, B.; Saidi Reddy, V.; Ramu, R. A rapid and high-yielding synthesis of thiazoles and aminothiazoles using ammonium-12-molybdophosphate. *J. Mol. Catal. Chem.,* **2006**, *252*(1-2), 235-237. http://dx.doi.org/10.1016/j.molcata.2006.02.065

[66] Khan, I.; Ibrar, A.; Abbas, N.; Saeed, A. Recent advances in the structural library of functionalized quinazoline and quinazolinone scaffolds: Synthetic approaches and multifarious applications. *Eur. J. Med. Chem.,* **2014**, *76*, 193-244. http://dx.doi.org/10.1016/j.ejmech.2014.02.005 PMID: 24583357

[67] Dubey, B.; Singh, K.; Kumar, A.; Kushwaha, S. Therapeutic journey, synthesis, and recent advances in benzothiazole derivatives. *Int. J. Biol. Pharm. Allied Sci.,* **2023**, *12*(7), 3201-3214.

[68] Güngördü, A.; Sireci, N.; Küçükbay, H.; Birhanli, A.; Ozmen, M. Evaluation of *in vitro* and *in vivo* toxic effects of newly synthesized benzimidazole-based organophosphorus compounds. *Ecotoxicol Environ. Saf.,* **2013**, *87*(87), 23-32. http://dx.doi.org/10.1016/j.ecoenv.2012.10.007 PMID: 23116621

[69] Amrithanjali, G.; Shaji, G.; Kumar, R. A. Antimicrobial activity and synthesis of thiazole derivatives: A recent update. *J. Chem. Rev.,* **2023**, *5*(3), 221-240. http://dx.doi.org/10.22034/JCR.2023.383674.1211

[70] Swaroop, T.R.; Ila, H.; Rangappa, K.S. Cyclocondensation of β-(aryl/heteroaryl)methylaminoenones with thionyl chloride: A facile general approach for the synthesis of 2,4-bis(het)aryl-5(het)aroylthiazoles. *Tetrahedron Lett.,* **2013**, *54*(39), 5288-5292. http://dx.doi.org/10.1016/j.tetlet.2013.07.079

[71] Facchinetti, V.; Avellar, M.M.; Nery, A.C.; Gomes, C.R.; Vasconcelos, T.R.; de Souza, M.V. An eco-friendly, hantzsch-based, solvent-free approach to 2-aminothiazoles and 2-aminoselenazoles. *Synthesis,* **2016**, *48*(03), 437-440.

[72] Verma, R.S.; Mittal, N.; Yogi, B.; Sharma, S.; Mishra, A. A review on chemistry and antimicrobial activity of thiazole. *Int. J. Pharma Sci.,* **2024**, *2*(3), 1184-1201. http://dx.doi.org/10.5281/zenodo.10893122

[73] Sheldrake, P.; McDonald, E.; Matteucci, M. Facile generation of a library of 5-aryl-2-arylsulfonyl-1,3-thiazoles. *Synlett,* **2006**, *2006*(3), 0460-0462. http://dx.doi.org/10.1055/s-2006-926243

[74] Metwally, M.A.; Abdel-Latif, E.; Amer, F.A.; Kaupp, G. Versatile 2-amino-4-substituted-1,3-thiazoles: Synthesis and reactions. *J. Sulfur Chem.,* **2004**, *25*(1), 63-85. http://dx.doi.org/10.1080/17415990310001632365

[75] Luo, P.; Gan, F.; Lin, J.; Ding, Q. Recent advances in the synthesis and applications of 2-arylbenzothiazoles. *Synthesis,* **2020**, *52*(23), 3530-3548. http://dx.doi.org/10.1055/s-0040-1707208

[76] Blaga, A. Synthesis of pyridyl- and quinolyl-substituted 2-aminothiazoles. *J. Heterocycl. Chem.,* **1970**, *7*(5), 1137-1141. http://dx.doi.org/10.1002/jhet.5570070521

[77] Liu, J.; Li, Y.; Chen, Y.; Hua, X.; Wan, Y.; Wei, W.; Song, H.; Yu, S.; Zhang, X.; Li, Z. Design, synthesis, antifungal activities, and SARs of (R)-2-aryl-4,5-dihydrothiazole-4-carboxylic acid derivatives. *Chin J. Chem.,* **2015**, *33*(11), 1269-1275. http://dx.doi.org/10.1002/cjoc.201500619

[78] Pardeshi, S.; Bobade, V.D. Synthesis and biological evaluation of some novel triazol-3-ones as antimicrobial agents. *Bioorg. Med. Chem. Lett.,* **2011**, *21*(21), 6559-6562. http://dx.doi.org/10.1016/j.bmcl.2011.08.049 PMID: 21920741

[79] Sharifzadeh, B.; Mahmoodi, N.O.; Mamaghani, M.; Tabatabaeian, K.; Chirani, A.S.; Nikokar, I. Facile regioselective synthesis of novel bioactive thiazolyl-pyrazoline derivatives *via* a three-component reaction and their antimicrobial activity. *Bioorg. Med. Chem. Lett.,* **2013**, *23*(2), 548-551. http://dx.doi.org/10.1016/j.bmcl.2012.11.024 PMID: 23228471

[80] Desai, N.C.; Makwana, A.H.; Rajpara, K.M. Synthesis and study of 1,3,5-triazine based thiazole derivatives as antimicrobial agents. *J. Saudi Chem. Soc.,* **2016**, *20*, S334-S341. http://dx.doi.org/10.1016/j.jscs.2012.12.004

[81] Aljamali, N.M.; Saher, M.; Zainab, M. Microbial studying of (thiazole, oxadiazole, thiadiazole) derivatives on mouth and teeth bacteria. *Int. J. Med. Res. Pharm. Sci.,* **2016**, *3*(8), 30-39.

[82] Desai, N.C.; Bhatt, N.; Somani, H. Synthesis, characterization, and antimicrobial activity of some novel thiazole clubbed 1,3,4-oxadiazoles. *Med. Chem. Res.,* **2015**, *24*(1), 258-266. http://dx.doi.org/10.1007/s00044-014-1108-8

[83] Ansari, M.I.; Khan, S.A. Synthesis and antimicrobial activity of some novel quinoline-pyrazoline-based coumarinyl thiazole derivatives. *Med. Chem. Res.,* **2017**, *26*(7), 1481-1496. http://dx.doi.org/10.1007/s00044-017-1855-4

[84] Nastasă, C.; Tiperciuc, B.; Duma, M.; Benedec, D.; Oniga, O. New hydrazones bearing thiazole scaffold: Synthesis, characterization, antimicrobial, and antioxidant investigation. *Molecules,* **2015**, *20*(9), 17325-17338. http://dx.doi.org/10.3390/molecules200917325 PMID: 26393564

[85] Gaffer, H.; Fouda, M.; Khalifa, M. Synthesis of some novel 2-amino-5-arylazothiazole disperse dyes for dyeing polyester fabrics and their antimicrobial activity. *Molecules,* **2016**, *21*(1), 122. http://dx.doi.org/10.3390/molecules21010122 PMID: 26805797

[86] Yurttaş, L.; Özkay, Y.; Kaplancıklı, Z. A.; Tunalı, Y.; Karaca, H. Synthesis and antimicrobial activity of some new hydrazone-bridged thiazole-pyrrole derivatives. *J. Enzyme Inhib. Med. Chem.,* **2013**, *28*(4), 830-835. http://dx.doi.org/10.3109/14756366.2012.688043 PMID: 22651798

[87] Yadlapalli, R.K.; Chourasia, O.P.; Jogi, M.P.; Podile, A.R.; Perali, R.S. Design, synthesis and *in vitro* antimicrobial activity of novel phenylbenzamido-aminothiazole-based azasterol mimics. *Med. Chem. Res.,* **2013**, *22*(6), 2975-2983. http://dx.doi.org/10.1007/s00044-012-0314-5

[88] Mohamed, H.A.; Abdel-Latif, E.; Abdel-Wahab, B.F.; Awad, G.E.A. Novel antimicrobial agents: Fluorinated 2-(3-(Benzofuran-2-yl) pyrazol-1-yl)thiazoles. *Int. J. Med. Chem.,* **2013**, *2013*(1), 1-6. http://dx.doi.org/10.1155/2013/986536 PMID: 25379293

[89] Sreedevi, M.; Guru Prasad, A.R.; Spoorthy, Y.N.; Ravindranath, L.R. Synthesis and antimicrobial evaluation of certain novel thiazoles. *Adv. Pharm. Bull,* **2013**, *3*(1), 227-230. PMID: 24312840

[90] Arora, P.; Narang, R.; Bhatia, S.; Nayak, S. K.; Singh, S. K.; Narasimhan, B. Synthesis, molecular docking and QSAR studies of 2,4-disubstituted thiazoles as antimicrobial agents. *J. Appl. Pharm. Sci.,* **2015**, *5*(2), 28-42.

[91] Sharma, D.; Kumar, S.; Narasimhan, B.; Ramasamy, K.; Lim, S.M.; Shah, S.A.A.; Mani, V. 4-(4-Bromophenyl)-thiazol-2-amine derivatives: Synthesis, biological activity and molecular docking study with ADME profile. *BMC Chem.,* **2019**, *13*(1), 60. http://dx.doi.org/10.1186/s13065-019-0575-x PMID: 31384808

[92] Ejaz, S.; Nadeem, H.; Paracha, R.Z.; Sarwar, S.; Ejaz, S. Designing, synthesis and characterization of 2-aminothiazole-4-carboxylate Schiff bases; antimicrobial evaluation against multidrug resistant strains and molecular docking. *BMC Chem.,* **2019**, *13*(1), 115. http://dx.doi.org/10.1186/s13065-019-0631-6 PMID: 31535091

[93] Karegoudar, P.; Prasad, D.J.; Ashok, M.; Mahalinga, M.; Poojary, B.; Holla, B.S. Synthesis, antimicrobial and anti-inflammatory activities of some 1,2,4-triazolo[3,4-b][1,3,4]thiadiazoles and 1,2,4-triazolo[3,4-b][1,3,4]thiadiazines bearing trichlorophenyl moiety. *Eur. J. Med. Chem.,* **2008**, *43*(4), 808-815. http://dx.doi.org/10.1016/j.ejmech.2007.06.026 PMID: 17804121

[94] Sanad, S.M.H.; Ahmed, A.A.M.; Mekky, A.E.M. Synthesis, *in-vitro* and *in-silico* study of novel thiazoles as potent antibacterial agents and MurB inhibitors. *Arch. Pharm.,* **2020**, *353*(4), 1900309. http://dx.doi.org/10.1002/ardp.201900309 PMID: 31967349

[95] El-Naggar, A.M.; Zidan, A.; Elkaeed, E.B.; Taghour, M.S.; Badawi, W.A. Design, synthesis and docking studies of new hydrazinyl-thiazole derivatives as anticancer and antimicrobial agents. *J. Saudi Chem. Soc.,* **2022**, *26*(4), 101488. http://dx.doi.org/10.1016/j.jscs.2022.101488

[96] Lemilemu, F.; Bitew, M.; Demissie, T.B.; Eswaramoorthy, R.; Endale, M. Synthesis, antibacterial and antioxidant activities of Thiazole-based Schiff base derivatives: A combined experimental and computational study. *BMC Chem.,* **2021**, *15*(1), 67. http://dx.doi.org/10.1186/s13065-021-00791-w PMID: 34949213

[97] Breaux, E.J.; Hoobler, M.A.; Patanella, J.E.; Leyes, G.A.; Hatzios, K.K.; Hoagland, R.E. Mechanisms of action of thiazole safeners. In: *Crop safeners for herbicides: development, uses, and mechanisms of action*; Academic Press: San Diego, California, **1989**; pp. 163-175.

[98] He, H.; Wang, X.; Shi, L.; Yin, W.; Yang, Z.; He, H.; Liang, Y. Synthesis, antitumor activity and mechanism of action of novel 1,3-thiazole derivatives containing hydrazide-hydrazone and carboxamide moiety. *Bioorg. Med. Chem. Lett.,* **2016**, *26*(14), 3263-3270. http://dx.doi.org/10.1016/j.bmcl.2016.05.059 PMID: 27262600

[99] Leoni, A.; Locatelli, A.; Morigi, R.; Rambaldi, M. Novel thiazole derivatives: A patent review (2008 - 2012. Part 2). *Expert Opin. Ther. Pat.,* **2014**, *24*(7), 759-777. http://dx.doi.org/10.1517/13543776.2014.910196 PMID: 24745553

[100] Guo, R.J.; Yan, J.W.; Chen, S.B.; Gu, L.Q.; Huang, Z.S.; Tan, J.H. A simple structural modification to thiazole orange to improve the selective detection of G-quadruplexes. *Dyes Pigments,* **2016**, *126*, 76-85. http://dx.doi.org/10.1016/j.dyepig.2015.11.010

[101] Saeed, S.; Rashid, N.; Jones, P.G.; Hussain, R.; Bhatti, M.H. Synthesis, spectroscopic characterization, crystal structure and antifungal activity of thiourea derivatives containing a thiazole moiety. *Cent. Eur. J. Chem.,* **2010**, *8*, 550-558. http://dx.doi.org/10.2478/s11532-010-0014-2

[102] Yernale, N.G.; Mruthyunjayaswamy, B.H. Biologically active metal complexes containing thiazole core: Synthesis and spectral characterization. *Indian J. Pharm. Educ. Res.,* **2018**, *52*(2), 255-261.

[103] Brewer, M.D.; Dorgan, R.J.J.; Manger, B.R.; Mamalis, P.; Webster, R.A.B. Isothiourea derivatives of 6-phenyl-2,3,5,6-tetrahydroimidazo[2,1-b]thiazole with broad-spectrum anthelmintic activity. *J. Med. Chem.,* **1987**, *30*(10), 1848-1853. http://dx.doi.org/10.1021/jm00393a028 PMID: 3116256

[104] Wang, N.Y.; Xu, Y.; Zuo, W.Q.; Xiao, K.J.; Liu, L.; Zeng, X.X.; You, X.Y.; Zhang, L.D.; Gao, C.; Liu, Z.H.; Ye, T.H.; Xia, Y.; Xiong, Y.; Song, X.J.; Lei, Q.; Peng, C.T.; Tang, H.; Yang, S.Y.; Wei, Y.Q.; Yu, L.T. Discovery of imidazo[2,1-b]thiazole HCV NS4B inhibitors exhibiting synergistic effect with other direct-acting antiviral agents. *J. Med. Chem.,* **2015**, *58*(6), 2764-2778. http://dx.doi.org/10.1021/jm501934n PMID: 25710739

[105] Silva, D.V.S.P.; Nascimento, P.H.B.; Rocha, J.V.R.; Marques, D.S.C.; Brayner, F.A.; Alves, L.C.; Araújo, H.D.A.; Cruz Filho, I.J.; Albuquerque, M.C.P.A.; Lima, M.C.A.; Aires, A.L. *In vitro* activity, ultrastructural analysis and *in silico* pharmacokinetic properties (ADMET) of thiazole compounds against adult worms of *Schistosoma mansoni*. *Acta. Trop.,* **2023**, *245*, 106965. http://dx.doi.org/10.1016/j.actatropica.2023.106965 PMID: 37295486

[106] González Cabrera, D.; Douelle, F.; Feng, T.S.; Nchinda, A.T.; Younis, Y.; White, K.L.; Wu, Q.; Ryan, E.; Burrows, J.N.; Waterson, D.; Witty, M.J.; Wittlin, S.; Charman, S.A.; Chibale, K. Novel orally active antimalarial thiazoles. *J. Med. Chem.,* **2011**, *54*(21), 7713-7719. http://dx.doi.org/10.1021/jm201108k PMID: 21966980

[107] Madsen, P.; Kodra, J.T.; Behrens, C.; Nishimura, E.; Jeppesen, C.B.; Pridal, L.; Andersen, B.; Knudsen, L.B.; Valcarce-Aspegren, C.; Guldbrandt, M.; Christensen, I.T.; Jørgensen, A.S.; Ynddal, L.; Brand, C.L.; Bagger, M.A.; Lau, J. Human glucagon receptor antagonists with thiazole cores. A novel series with superior pharmacokinetic properties. *J. Med. Chem.,* **2009**, *52*(9), 2989-3000. http://dx.doi.org/10.1021/jm8016249 PMID: 19385613

REVIEW ARTICLE

1385-2728/XX $65.00+.00