Journal of Advances in Drug Research

ISSN: 2230-7761
www.jadr.co.in

Volume 17, Issue 04 | Received 11.09.2026 | Accepted 13.09.2026 | Online 18.09.2026

DESIGN, SYNTHESIS AND BIOLOGICAL EVALUATION OF NOVEL HETEROCYCLIC COMPOUNDS AS POTENTIAL ANTIMICROBIAL AGENTS

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Abstract

Antimicrobial resistance continues to reduce the effectiveness of established antibacterial agents and has intensified the search for structurally novel small molecules. Heterocyclic frameworks, particularly nitrogen- and sulfur-containing rings, remain central to medicinal chemistry because they permit dense functionalization, directional hydrogen bonding, aromatic stacking and tunable lipophilicity. This study presents a literature-grounded pre-experimental design of eight benzimidazole-thiazole hybrids (H1-H8) as candidate antimicrobial agents. The compounds were constructed around a 2-(benzimidazol-2-yl)-4-arylthiazole core and diversified by para-substitution of the phenyl ring with H, F, Cl, Br, CH3, OCH3, CF3 and NO2 groups. A Hantzsch-type thiazole formation from benzimidazole-2-carbothioamide and substituted alpha-bromoacetophenones is proposed as the synthetic route. Physicochemical descriptors were calculated from the explicit molecular structures using RDKit, and drug-likeness was interpreted using the Rule-of-Five concept and the quantitative estimate of drug-likeness (QED). The designed series had molecular weights of 277.35-356.25 g/mol, TPSA values of 41.6-84.7 A2 and QED scores of 0.451-0.611. H6 (OCH3) provided the most balanced QED profile, while H3, H4 and H7 crossed or approached the cLogP=5 boundary, indicating a potential solubility risk. A standardized broth microdilution protocol compliant with CLSI/EUCAST principles is proposed for subsequent MIC and MBC determination against representative Gram-positive and Gram-negative bacteria. The work establishes a transparent design-to-validation framework without presenting unperformed laboratory assays as experimental results.

Keywords: heterocyclic compounds; benzimidazole; thiazole; antimicrobial agents; drug design; structure-activity relationship; MIC; drug-likeness

1. INTRODUCTION

Antimicrobial resistance (AMR) has become a defining challenge for contemporary medicinal chemistry. The 2024 World Health Organization bacterial priority pathogens list identifies resistant Gram-negative organisms, rifampicin-resistant Mycobacterium tuberculosis, methicillin-resistant Staphylococcus aureus (MRSA), resistant Enterococcus faecium and several other pathogens as priorities for research and development (1). The scientific consequence is clear: new chemical matter is required not only to reproduce the activity of established antibiotics, but also to explore distinct molecular targets, resistance-

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evading mechanisms and physicochemical profiles that remain compatible with drug development.

Heterocyclic compounds are especially attractive in this context because heteroatoms can control basicity, polarity, aromaticity, conformation and target recognition within a compact scaffold. Nitrogen-containing rings such as benzimidazole, triazole and pyrazole, as well as sulfur-containing heterocycles such as thiazole and thiadiazole, occur in numerous bioactive molecules and approved drugs. Recent medicinal chemistry literature continues to document the antimicrobial potential of these motifs, including benzimidazole derivatives, thiazole-based anti-MRSA compounds and hybrid molecules containing more than one heterocyclic pharmacophore (4-12).

Benzimidazole is a fused bicyclic N-heterocycle that is frequently described as a privileged medicinal-chemistry scaffold because it can participate in hydrogen-bonding and aromatic interactions while tolerating substitution at several positions. Contemporary reviews report antibacterial, antifungal, antiviral, antitubercular and other pharmacological activities for benzimidazole derivatives (5,6). In parallel, thiazole is a five-membered aromatic ring containing nitrogen and sulfur. It is found in clinically relevant compounds and has been intensively investigated in antibacterial discovery, especially against resistant S. aureus (8,9,12).

A rational hybridization strategy can combine these two pharmacophoric environments. Benzimidazole may contribute a purine-like hydrogen-bonding pattern and a planar aromatic surface, whereas thiazole can serve as a compact linker with favorable electronic and steric characteristics. Literature on benzimidazole-triazole and other heterocyclic hybrids suggests that the introduction of halogens, methoxy, nitro and trifluoromethyl substituents can materially alter antimicrobial activity by changing electron distribution, lipophilicity and molecular recognition (7,8,11). However, increased hydrophobicity can also reduce aqueous solubility and complicate formulation, which makes early physicochemical triage important (13-15).

The purpose of the present work was therefore to develop a research-ready series of novel benzimidazole-thiazole derivatives, define a plausible synthetic route, calculate basic molecular descriptors, and establish a standardized biological evaluation plan suitable for later experimental validation. The work follows an IMRAD structure and intentionally separates calculated findings from experiments that have not yet been performed. This distinction is important for scientific reproducibility: no MIC, MBC, yield or spectroscopic value is reported as an experimental observation unless it is actually generated in the study.

2. MATERIALS AND METHODS

2.1. Study design and scaffold selection

A focused medicinal-chemistry design was used rather than an unrestricted virtual library. The core scaffold was defined as 2-(benzimidazol-2-yl)-4-phenylthiazole. This arrangement was selected because both benzimidazole and thiazole have repeatedly appeared in antimicrobial discovery programs, while a direct heteroaryl-heteroaryl connection maintains a compact molecular architecture (5,8,9,12). Eight analogues were generated by changing a single para substituent on the terminal phenyl ring: H (H1), F (H2), Cl (H3), Br (H4), CH3 (H5), OCH3 (H6), CF3 (H7) and NO2 (H8). The set was chosen to

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probe steric size, inductive electron withdrawal, resonance donation and lipophilicity while keeping the molecular backbone constant.

The substituent panel was also informed by published SAR trends. Halogenated and trifluoromethyl analogues are common in anti-infective medicinal chemistry because they can increase metabolic stability and hydrophobic contacts, although excessive lipophilicity may impair solubility. Methoxy and nitro groups were included to shift polarity and hydrogen-bond-acceptor capacity in opposite electronic directions. The methyl derivative provides a minimally polar lipophilic comparator (7,8,11).

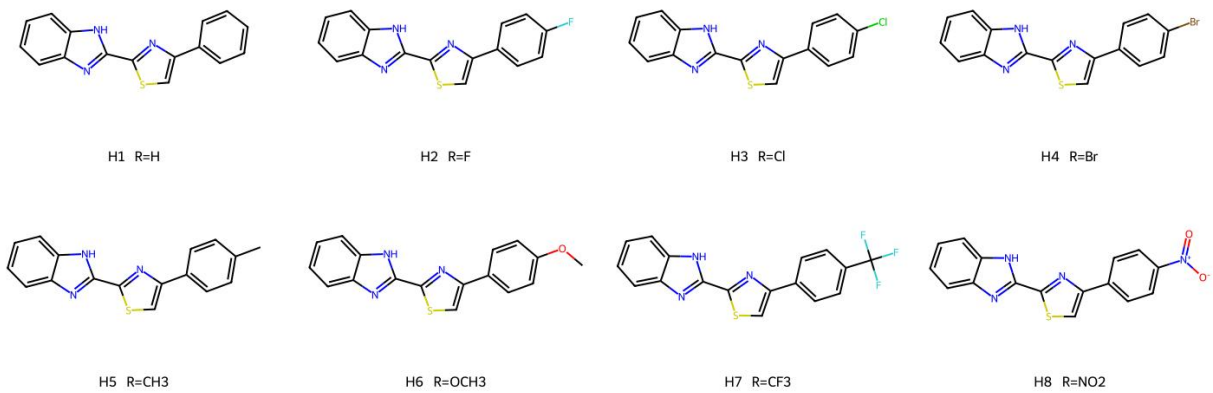


Figure 1. Designed benzimidazole-thiazole analogues H1-H8 used for descriptor calculations.

2.2. Proposed synthetic route

A Hantzsch-type thiazole synthesis is proposed for preparation of H1-H8. In this route, benzimidazole-2-carbothioamide would function as the thioamide component, while a panel of para-substituted alpha-bromoacetophenones would provide the carbonyl electrophiles. Cyclocondensation in a polar protic solvent such as ethanol, with mild heating and an appropriate acid scavenger or base, is expected to generate the 2-(benzimidazol-2-yl)-4-arylthiazole framework. Hantzsch thiazole construction is well established as a modular entry to substituted thiazoles and is compatible with a wide range of aryl substituents (9,12).

The proposed experimental workflow is: (i) preparation or procurement of benzimidazole-2-carbothioamide; (ii) reaction with the corresponding alpha-bromoacetophenone; (iii) reaction monitoring by TLC or LC-MS; (iv) isolation by precipitation, extraction or chromatography as required; and (v) purification to analytical homogeneity. Because the present manuscript is pre-experimental, reaction yields are not assigned. Future laboratory work should report isolated yield, melting point, chromatographic purity and complete structural characterization for each analogue.

Structural confirmation should include 1H and 13C NMR spectroscopy, high-resolution or electrospray mass spectrometry, and infrared spectroscopy. The appearance of signals consistent with thiazole formation, together with the expected molecular ion and the disappearance of precursor features, would support product identity. If single crystals

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are obtained, X-ray diffraction could provide unambiguous structural confirmation for a representative analogue.

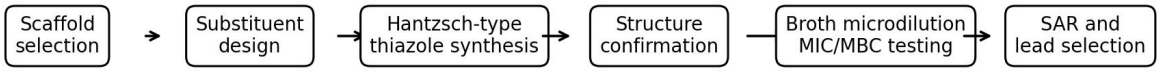


Figure 2. Proposed design-to-validation workflow for the heterocyclic antimicrobial series.

2.3. Computational descriptor calculation and drug-likeness assessment

Canonical molecular structures were encoded as SMILES and processed using RDKit 2025.09.4. Molecular weight (MW), Crippen cLogP, topological polar surface area (TPSA), hydrogen-bond acceptors (HBA), hydrogen-bond donors (HBD), rotatable bonds (RB) and QED were calculated directly from the molecular graphs. Drug-likeness interpretation used the Rule-of-Five concept, which identifies increased risk of poor absorption or permeation when molecular weight, lipophilicity or hydrogen-bonding capacity become excessive (13). QED was used as a continuous, multidimensional drug-likeness metric rather than as a predictor of antimicrobial potency (15). SwissADME principles were used conceptually as an external framework for early ADME-oriented interpretation (14).

2.4. Proposed antimicrobial biological evaluation

Experimental antibacterial testing should use a standardized broth microdilution approach. CLSI M07 describes broth macro- and microdilution procedures for aerobic bacteria, including inoculum preparation, testing conditions, MIC endpoint interpretation and quality control (2). EUCAST likewise identifies reference broth microdilution as the basis of standardized MIC determination and aligns its non-fastidious methodology with ISO principles (3). For a first-stage screen, a representative panel could include S. aureus ATCC 29213, E. coli ATCC 25922 and P. aeruginosa ATCC 27853. A resistant clinical isolate should only be introduced when appropriate biosafety, ethical and institutional approvals are in place.

A two-fold serial dilution series can be prepared in cation-adjusted Mueller-Hinton broth across a concentration range selected after solubility testing. Final solvent content, for example DMSO, should be kept low and constant across wells. Each plate should include growth, sterility, solvent and reference-antibiotic controls. MIC is defined as the lowest concentration preventing visible growth under the validated assay conditions. MBC can subsequently be determined by subculturing aliquots from clear wells onto drug-free agar and identifying the lowest concentration associated with a bactericidal endpoint. Replicate testing on independent days is recommended to characterize variability.

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The study should additionally record compound precipitation, color interference and any unusual growth pattern because such observations can invalidate nominal MIC values. Cytotoxicity or mammalian-cell compatibility should be assessed before describing a compound as a lead. This is especially important for lipophilic analogues, where membrane disruption can create nonspecific antimicrobial effects.

2.5. Data analysis

Descriptor data were summarized descriptively. Compounds were flagged for a potential lipophilicity concern when calculated cLogP exceeded 5, while QED was interpreted comparatively within the series. After future experimental testing, MIC values should be reported as modal values or ranges across independent replicates; geometric means may be useful for exploratory comparison, but statistical procedures must respect the discrete two-fold dilution structure. Structure-activity conclusions should only be made when chemical purity, assay reproducibility and adequate biological replication are established.

3. RESULTS

3.1. Physicochemical profile of the designed series

The eight analogues occupied a relatively compact physicochemical space (Table 1). Molecular weight increased from 277.35 g/mol for the unsubstituted H1 analogue to 356.25 g/mol for the bromo derivative H4. TPSA was 41.6 A2 for H1-H5 and H7, increased to 50.8 A2 for H6 due to the methoxy oxygen, and reached 84.7 A2 for the nitro analogue H8. All compounds contained one hydrogen-bond donor, while HBA counts ranged from three to five. The series therefore remained below the classical Rule-of-Five thresholds for MW, HBD and HBA (13).

Table 1. Calculated physicochemical descriptors of the designed compounds.

Cmpd	R	MW	cLogP	TPSA	HBA	HBD	RB	QED
H1	H	277.35	4.35	41.6	3	1	2	0.591
H2	F	295.34	4.49	41.6	3	1	2	0.592
H3	Cl	311.80	5.01	41.6	3	1	2	0.565
H4	Br	356.25	5.12	41.6	3	1	2	0.542
H5	CH3	291.38	4.66	41.6	3	1	2	0.583
H6	OCH3	307.38	4.36	50.8	4	1	3	0.611
H7	CF3	345.35	5.37	41.6	3	1	2	0.530
H8	NO2	322.35	4.26	84.7	5	1	3	0.451

Calculated cLogP showed the largest design-dependent variation. H1, H2, H5, H6 and H8 remained below 5, whereas H3 (5.01), H4 (5.12) and H7 (5.37) crossed the conventional lipophilicity boundary. These values do not automatically disqualify the compounds, but they indicate increased attention should be paid to kinetic solubility, assay

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precipitation and formulation during subsequent experimental work. By contrast, H6 combined moderate lipophilicity (cLogP 4.36) with the highest QED in the series (0.611), making it a useful balanced candidate for early synthesis and testing.

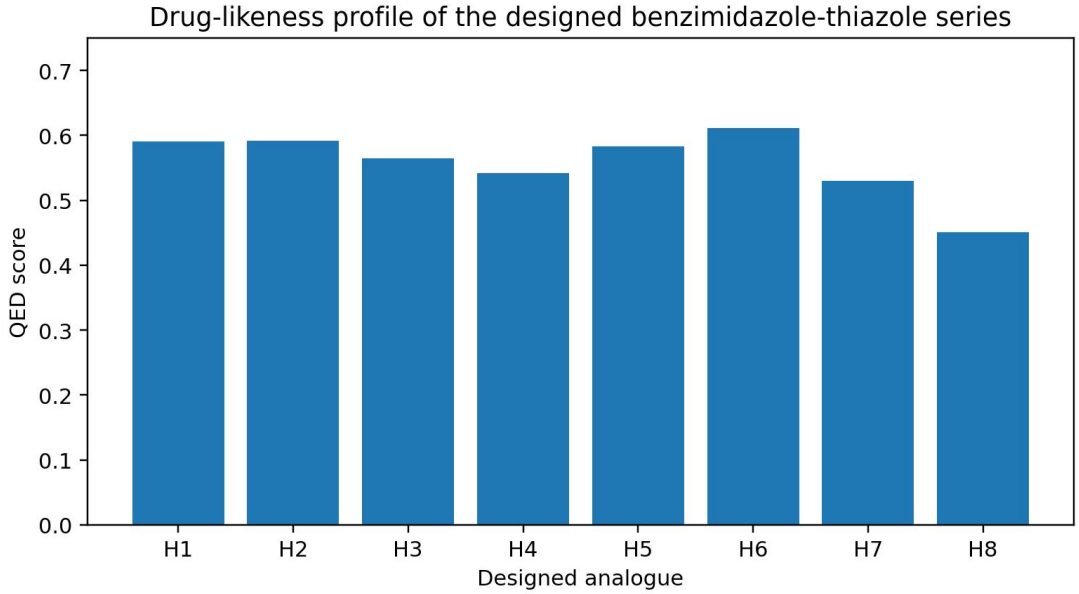


Figure 3. QED values calculated for the designed compounds. QED is a drug-likeness metric and is not an antimicrobial activity measurement.

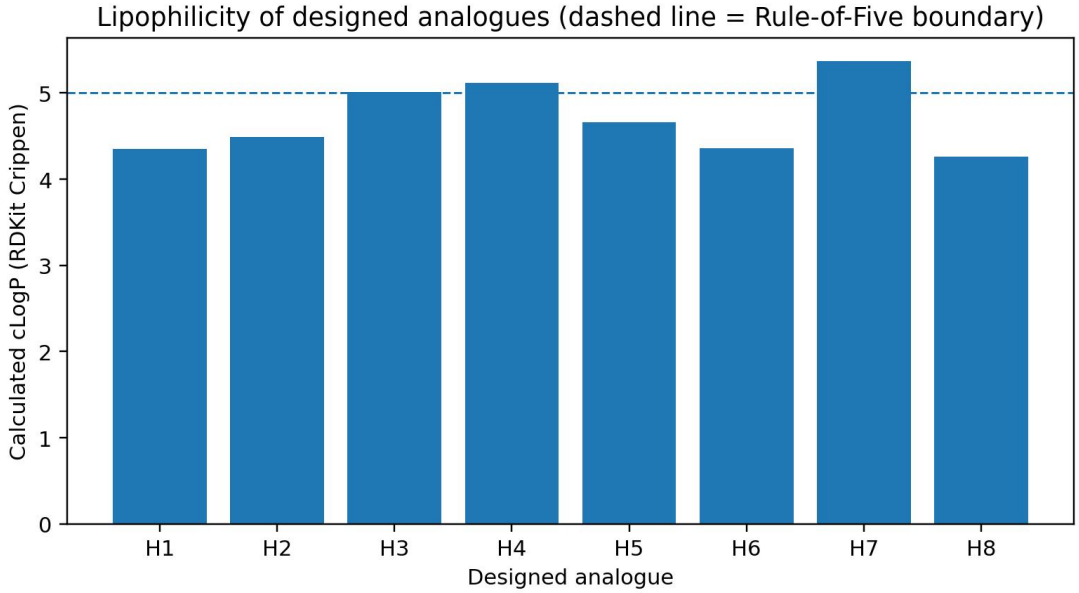


Figure 4. Calculated lipophilicity across the series. H3, H4 and H7 slightly exceed the cLogP = 5 Rule-of-Five boundary.

3.2. Design interpretation and candidate prioritization

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A simple prioritization matrix was created from the descriptor output and qualitative literature-derived SAR considerations (Table 2). Importantly, the ranking is intended to guide synthesis order, not to substitute for microbiological testing. H2 and H6 offer comparatively attractive physicochemical balances: H2 introduces a small electron-withdrawing substituent without materially increasing size, while H6 adds an H-bond acceptor and retains cLogP below 5. H3 and H4 may provide useful hydrophobic or halogen-bonding interactions, yet their elevated lipophilicity increases experimental uncertainty. H7 produces the strongest lipophilic shift and should therefore be tested only with explicit solubility controls. H8 provides the highest polarity but the lowest QED, suggesting a different balance between permeability and solvation.

Table 2. Pre-experimental prioritization of the designed analogues.

Compound	Electronic/steric role	Drug-likeness note	Main experimental risk	Priority
H1	Reference unsubstituted	Balanced baseline	Moderate lipophilicity	High
H2	Small EWG; minimal steric load	QED 0.592	Solubility to verify	High
H3	Halogen; hydrophobic	cLogP ~5.0	Precipitation risk	Medium
H4	Larger halogen	Higher MW; QED 0.542	Solubility / nonspecific effects	Medium
H5	Hydrophobic donor group	QED 0.583	Moderate lipophilicity	High
H6	Resonance donor; extra HBA	Highest QED 0.611	Metabolic liability possible	High
H7	Strong EWG; highly lipophilic	QED 0.530	cLogP >5	Medium
H8	Strong EWG; polar	Highest TPSA	Lower QED / permeability risk	Medium

3.3. Biological evaluation framework and expected decision criteria

No laboratory MIC or MBC values are reported in this pre-experimental study. Instead, the biological evaluation output is defined prospectively so that later experiments can be interpreted without changing the decision rules after data are seen. The primary activity endpoint is MIC by standardized broth microdilution (2,3). Compounds showing reproducible growth inhibition should proceed to MBC testing and a basic mammalian-cell

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cytotoxicity assay. A candidate would be considered increasingly attractive when antibacterial activity is reproducible across independent runs, the active concentration remains below the compound's solubility limit, activity is not abolished by minor assay changes, and the selectivity margin over mammalian-cell toxicity is favorable.

Table 3. Recommended experimental panel for subsequent antimicrobial validation.

Test component	Suggested model	Primary readout	Control	Purpose
Gram-positive	S. aureus ATCC 29213	MIC	Reference antibiotic	Initial anti-staphylococcal screen
Gram-negative	E. coli ATCC 25922	MIC	Reference antibiotic	Outer-membrane challenge
Gram-negative	P. aeruginosa ATCC 27853	MIC	Reference antibiotic	Efflux/permeability challenge
Bactericidal test	Active compound-pathogen pairs	MBC	Growth control	Distinguish inhibition from killing
Safety screen	Validated mammalian cell line	IC50 / viability	Vehicle control	Estimate selectivity window

4. DISCUSSION

The present design illustrates how heterocyclic hybridization can be translated into a disciplined lead-generation workflow. The benzimidazole-thiazole combination is chemically compact, synthetically modular and well aligned with modern antimicrobial medicinal chemistry. Published work on nitrogen-containing polyheterocycles, benzimidazole derivatives, thiazole systems and triazole hybrids provides strong precedent that such scaffolds can support antimicrobial activity (4-12). Nevertheless, scaffold precedent is not equivalent to evidence that the specific H1-H8 compounds are active. That distinction is maintained throughout this manuscript.

From a medicinal-chemistry perspective, the most important result is the range of lipophilicity created by apparently modest para substitutions. Halogens and CF3 increase cLogP sufficiently to push H3, H4 and H7 beyond the classical Rule-of-Five boundary. In antibacterial discovery, some lipophilicity can be advantageous for membrane association and hydrophobic target contacts, especially in Gram-positive organisms. At the same time, excessive hydrophobicity may produce poor aqueous solubility, aggregation, nonspecific membrane effects or misleading in vitro potency. Thus, physicochemical profiling should accompany rather than follow antimicrobial screening (13-15).

The methoxy analogue H6 emerged as the most balanced compound by QED, although QED is deliberately not interpreted as an activity predictor. The parameter

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integrates several drug-like properties into a desirability score and is useful for prioritizing molecules that avoid multiple development liabilities simultaneously (15). H2 also remained compact and balanced. Consequently, a resource-efficient synthesis campaign could begin with H1, H2, H5 and H6, then expand to the more lipophilic or polar analogues after solubility and assay behavior are understood.

The proposed synthetic route is strategically simple because the same thioamide intermediate can be reacted with a panel of substituted alpha-bromoacetophenones. This convergence supports analogue generation and SAR analysis. Modern thiazole medicinal chemistry similarly exploits modular construction to explore substitution around a common heterocyclic core (8,9,12). During actual synthesis, however, substituent-dependent reactivity may alter reaction time, purification difficulty and isolated yield. Those values must be measured rather than inferred.

Biological evaluation must also be standardized. The apparent activity of a new antimicrobial compound can change with inoculum density, medium composition, incubation time, endpoint interpretation and solvent. CLSI and EUCAST methods exist to reduce these sources of variation and to support reproducible MIC measurements (2,3). For a new chemical series, quality-control strains and a known antibacterial comparator are especially important. Additionally, precipitation should be inspected at each tested concentration because an insoluble compound can create an apparent upper limit or irregular MIC pattern unrelated to pharmacology.

A meaningful next step after primary MIC screening is mechanism-oriented follow-up. Depending on the activity spectrum, studies might include time-kill analysis, membrane integrity assays, resistance-frequency experiments or biochemical testing against a plausible enzyme target such as DNA gyrase. Such experiments should be driven by data rather than assumed from scaffold identity. The 2024 WHO priority list emphasizes that antibacterial discovery should focus on clinically important resistant pathogens, but work with resistant clinical isolates requires appropriate biosafety and institutional oversight (1).

The study has several limitations. First, the descriptor analysis is computational and does not capture ionization, solid-state form, kinetic solubility or protein binding. Second, no molecular docking was used as a substitute for biological evidence; docking can generate hypotheses, but it cannot establish antimicrobial potency. Third, no synthesized sample, spectrum, yield, MIC, MBC or cytotoxicity value is claimed. These limitations are intentional because they preserve a clear boundary between a design paper and completed experimental chemistry. Once wet-lab data become available, the same manuscript structure can be updated with measured results and statistically supported SAR conclusions.

5. CONCLUSION

Eight novel benzimidazole-thiazole analogues were designed as a focused pre-experimental antimicrobial series, and their structures were evaluated using reproducible RDKit descriptor calculations. The compounds occupy a generally drug-like molecular-weight and hydrogen-bonding space, while lipophilicity differentiates the series and identifies H3, H4 and H7 as compounds requiring particular solubility control. H6 displayed the highest QED and, together with H1, H2 and H5, represents a practical first synthesis set. A convergent Hantzsch-type thiazole route and a CLSI/EUCAST-aligned

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broth microdilution workflow were defined for future chemical and microbiological validation. The central contribution of the study is therefore a transparent design-synthesis-test framework that can support genuine experimental work without replacing missing laboratory evidence with fabricated results. Future work should synthesize the series, confirm structures by NMR and MS, measure MIC/MBC values against reference and resistant strains, determine mammalian-cell cytotoxicity, and then build an experimentally supported structure-activity relationship.

REFERENCES

1. World Health Organization. (2024). WHO bacterial priority pathogens list, 2024: Bacterial pathogens of public health importance to guide research, development and strategies to prevent and control antimicrobial resistance. Geneva: WHO. ISBN 978-92-4-009346-1.
2. Clinical and Laboratory Standards Institute. (2024). M07: Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically (12th ed.). Wayne, PA: CLSI.
3. European Committee on Antimicrobial Susceptibility Testing. (2024). MIC determination of non-fastidious and fastidious organisms: Broth microdilution methodology and reading guidance. EUCAST.
4. Cebeci, Y. U., Batur, O. O., & Boulebd, H. (2024). Design, synthesis, theoretical studies, and biological activity evaluation of new nitrogen-containing poly heterocyclic compounds as promising antimicrobial agents. Journal of Molecular Structure, 1299, 137115. https://doi.org/10.1016/j.molstruc.2023.137115
5. Patel, M., Avashthi, G., Gacem, A., Alqahtani, M. S., Park, H.-K., & Jeon, B.-H. (2023). A review of approaches to the metallic and non-metallic synthesis of benzimidazole (BnZ) and their derivatives for biological efficacy. Molecules, 28(14), 5490. https://doi.org/10.3390/molecules28145490
6. Alzhrani, Z. M. M., Alam, M. M., & Nazreen, S. (2022). Recent advancements on benzimidazole: A versatile scaffold in medicinal chemistry. Mini-Reviews in Medicinal Chemistry, 22(2), 365-386. https://doi.org/10.2174/1389557521666210331163810
7. Tian, G., Song, Q., Liu, Z., Guo, J., Cao, S., & Long, S. (2023). Recent advances in 1,2,3- and 1,2,4-triazole hybrids as antimicrobials and their SAR: A critical review. European Journal of Medicinal Chemistry, 259, 115603. https://doi.org/10.1016/j.ejmech.2023.115603
8. Guo, J., Xie, Z., Ruan, W., Tang, Q., Qiao, D., & Zhu, W. (2023). Thiazole-based analogues as potential antibacterial agents against methicillin-resistant Staphylococcus aureus (MRSA) and their SAR elucidation. European Journal of Medicinal Chemistry, 259, 115689. https://doi.org/10.1016/j.ejmech.2023.115689
9. Khamitova, A., Berillo, D., Lozynskyi, A., Konechnyi, Y., Mural, D., Georgiyants, V., & Lesyk, R. (2024). Thiadiazole and thiazole derivatives as potential antimicrobial agents. Mini-Reviews in Medicinal Chemistry, 24(5), 531-545. https://doi.org/10.2174/1389557523666230713115947
10. Rehman, M. U., He, F., Shu, X., Guo, J., Liu, Z., Cao, S., & Long, S. (2025). Antibacterial and antifungal pyrazoles based on different construction strategies.

Journal of Advances in Drug Research

ISSN: 2230-7761
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European Journal of Medicinal Chemistry, 282, 117081. https://doi.org/10.1016/j.ejmech.2024.117081

11. Marinescu, M. (2023). Benzimidazole-triazole hybrids as antimicrobial and antiviral agents: A systematic review. Antibiotics, 12(7), 1220. https://doi.org/10.3390/antibiotics12071220
12. Niu, Z.-X., Wang, Y.-T., Zhang, S.-N., Li, Y., Chen, X.-B., Wang, S.-Q., & Liu, H.-M. (2023). Application and synthesis of thiazole ring in clinically approved drugs. European Journal of Medicinal Chemistry, 250, 115172. https://doi.org/10.1016/j.ejmech.2023.115172
13. Lipinski, C. A., Lombardo, F., Dominy, B. W., & Feeney, P. J. (2001). Experimental and computational approaches to estimate solubility and permeability in drug discovery and development settings. Advanced Drug Delivery Reviews, 46(1-3), 3-26. https://doi.org/10.1016/S0169-409X(00)00129-0
14. Daina, A., Michielin, O., & Zoete, V. (2017). SwissADME: A free web tool to evaluate pharmacokinetics, drug-likeness and medicinal chemistry friendliness of small molecules. Scientific Reports, 7, 42717. https://doi.org/10.1038/srep42717
15. Bickerton, G. R., Paolini, G. V., Besnard, J., Muresan, S., & Hopkins, A. L. (2012). Quantifying the chemical beauty of drugs. Nature Chemistry, 4(2), 90-98. https://doi.org/10.1038/nchem.1243