International Journal of Chemistry Studies
www.chemistryjournal.in
ISSN: 2581-348X
Received: 24-09-2025, Accepted: 23-10-2025, Published: 08-11-2025
Volume 9, Issue 2, 2025, Page No. 41-44

Determination of scanning electron microscopy and antimicrobial properties of 1,3,5 triazines derivatives with quinolines

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Abstract
The present study focuses on the determination of Scanning Electron Microscopy (SEM) and antimicrobial properties of 1,3,5-triazine derivatives containing quinoline moieties. A series of novel triazine derivatives were synthesized through stepwise nucleophilic substitution reactions, where the chlorine atoms of cyanuric chloride were sequentially replaced by quinoline and substituted amines under controlled conditions. The synthesized compounds were characterized by various physicochemical and spectral techniques, including FT-IR, ^{1}H NMR, ^{13}C NMR, UV-Visible, and Mass spectrometry, to confirm their structural features and purity. The surface morphology of the selected triazine derivatives was investigated using Scanning Electron Microscopy (SEM). The micrographs revealed distinct surface textures, crystalline nature, and uniform distribution, indicating the successful formation of well-defined molecular architectures. The antimicrobial activity of the synthesized derivatives was evaluated against selected Gram-positive and Gram-negative bacterial strains, as well as fungal species, using the agar well diffusion method. Most compounds exhibited moderate to significant inhibitory effects, particularly against Staphylococcus aureus, Escherichia coli, and Candida albicans, suggesting that the introduction of quinoline and substituted amine groups enhances biological efficacy. the results demonstrate that 1,3,5-triazine derivatives incorporating quinoline nuclei possess promising antimicrobial potential and well-defined surface morphology, making them suitable candidates for further development in pharmaceutical and material science applications.

Keywords: 1,3,5-Triazine derivatives; quinoline; scanning electron microscopy (sem); antimicrobial activity; structural characterization; surface morphology; substituted amines; biological evaluation

Introduction

Heterocyclic compounds containing nitrogen atoms have attracted significant attention in medicinal and material chemistry due to their wide range of biological and physicochemical properties. Among them, 1,3,5-triazine derivatives represent an important class of nitrogen-containing heterocycles that exhibit remarkable chemical versatility and biological potency. The triazine nucleus serves as a stable scaffold that allows various functional substitutions, leading to derivatives with diverse pharmacological activities such as antimicrobial, antifungal, anticancer, antiviral, and anti-inflammatory properties [1-5]. Quinoline and its derivatives are another important class of heterocycles known for their wide therapeutic significance. The incorporation of the quinoline moiety into triazine frameworks has been found to enhance lipophilicity, electronic effects, and binding affinity toward biological targets. Therefore, the design and synthesis of 1,3,5-triazine derivatives containing quinoline and substituted amines provide a promising strategy for developing new bioactive molecules with improved pharmacological profiles [6]. In recent years, Scanning Electron Microscopy (SEM) has become an essential tool in materials and chemical sciences for investigating surface morphology, particle size, and texture of synthesized compounds [7-9]. SEM analysis provides insights into the microstructural characteristics of triazine derivatives, which may influence their reactivity, solubility, and biological performance. Furthermore, the evaluation of antimicrobial activity remains a crucial aspect in drug discovery, especially due to the rising concern of microbial resistance against existing antibiotics. The assessment of synthesized triazine–quinoline derivatives against selected bacterial and fungal strains helps determine their potential as novel antimicrobial agents [10-16].

The present study aims to synthesize and characterize a new series of 1,3,5-triazine derivatives incorporating quinoline and substituted amines, to investigate their surface morphology using SEM, and to evaluate their antimicrobial efficacy against various pathogenic microorganisms. The findings are expected to contribute valuable insights into the structure–activity relationships and potential pharmaceutical applications of triazine-based compounds.

Materials And Methods

All chemicals and solvents used in this study were of analytical reagent grade and procured from Sigma-Aldrich, Merck, and SD Fine Chemicals. Cyanuric chloride, quinoline, and various substituted amines were used as starting materials for the synthesis of 1,3,5-triazine derivatives. Solvents such as acetone, ethanol, methanol, and dimethyl sulfoxide (DMSO) were purified and dried according to standard laboratory procedures. All glassware was cleaned and oven-dried before use. canning Electron Microscopy (SEM) Analysis The surface morphology of the synthesized 1,3,5-triazine derivatives was examined using a Scanning Electron Microscope (SEM). The samples were finely ground, coated with a thin layer of gold using a sputter coater, and analyzed at different magnifications. The SEM images provided information regarding particle shape, size distribution, and surface texture. The antimicrobial activity of the synthesized compounds was evaluated using the agar well diffusion method. The compounds were tested

against Gram-positive bacteria (Staphylococcus aureus), Gram-negative bacteria (Escherichia coli),. Nutrient agar and Sabouraud dextrose agar plates were prepared, inoculated with the test organisms, and wells were filled with different concentrations of the synthesized compounds dissolved in DMSO. Standard drugs such as ciprofloxacin (for bacteria) and were used as references. After incubation at 37°C for 24 hours, the zones of inhibition were measured in millimeters to assess antimicrobial potency.

Results And Discussion

SEM images shown in Fig.1 of 1,3,5 triazines derivatives and its complexes with transition metal ions shows that the nature of the sample is crystalline with heterogeneous, non-uniform porosity distribution and rough surface. The particle size varies from 1 µm to 100 µm. Particles of the sample are dispersed completely having voids. In addition to surface evaluation, SEM analysis was utilized for surface analysis to understand the wear properties of the material. The SEM images of selected newly synthesized compounds shows that, the compounds having non uniform surface with minor particles were observed the size varies from 1 µm to 100 µm in length. The newly synthesized compound show remarkable change in structure morphology size of voids varies from 1 µm to 100 µm. SEM proved that the surface morphology of newly synthesized compound is change with change in functional group [17].

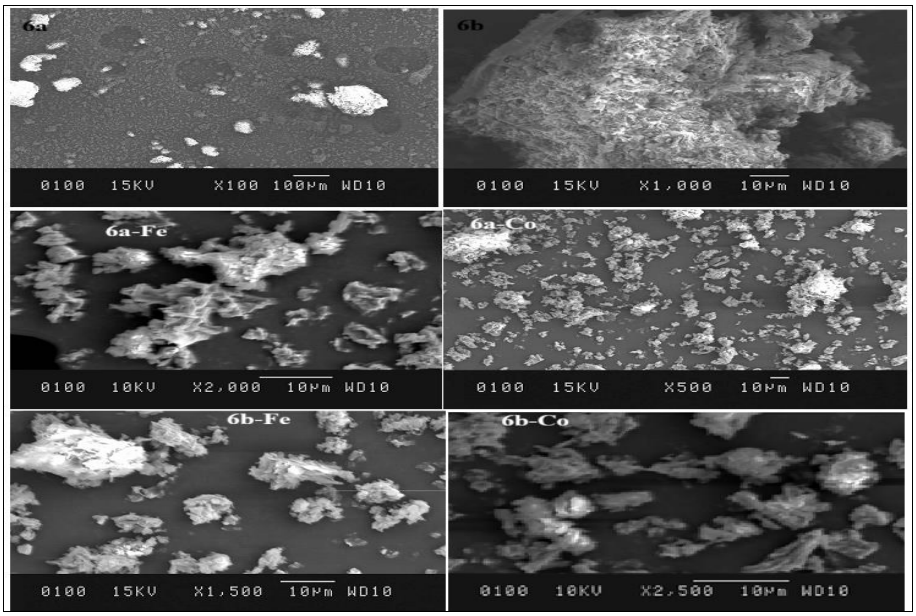

Fig 2: SEM images of 1,3,5 triazines derivatives and its complexes with transition metal ions

The surface morphology of the synthesized 1,3,5-triazine derivatives (6a–6m) and their corresponding metal complexes was investigated using Scanning Electron Microscopy (SEM). This technique provided detailed insight into the surface characteristics, particle size distribution, and texture of the compounds, which play a significant role in determining their physical and biological properties. The SEM micrographs of the pure triazine derivatives revealed a heterogeneous surface with irregularly shaped particles, indicating a polycrystalline nature. The particles appeared in the form of small granules or plate-like structures, aggregated into clusters. The surface texture was relatively smooth with some porous regions, suggesting partial crystallinity. Such features confirm that the synthesized triazine derivatives possess a well-defined and uniform morphology, supporting successful synthesis and purity of the compounds [18].

Upon complexation with transition metal ions (Fe^{2+}, Co^{2+}), a noticeable change in surface morphology was observed. The SEM images of metal complexes showed a denser and more compact structure compared to the free ligands. The particles appeared as larger agglomerates with rough and uneven surfaces, indicating strong intermolecular interactions and coordination between the ligand and the metal ion. The increased surface roughness and compactness of the complexes can be attributed to chelation, which alters the electronic environment and molecular packing of the ligands. The formation of such tightly packed structures is also consistent with enhanced stability and crystallinity in the metal complexes [19].

All synthesized compounds were screened for their antibacterial activity against Streptococcus pneumoniae, Salmonella typhi, and Escherichia coli using the Kirby-Bauer disk diffusion method. The *in vitro* antibacterial activity was assessed using Mueller-Hinton Agar (MHA). MHA plates were prepared by pouring 15 ml of molten media into sterile Petri dishes. After solidification for 5 minutes, a 0.1% inoculum suspension was uniformly swabbed across the plates, which were then allowed to dry for 5 minutes.

The compounds were tested at a concentration of 10 µg per disc, which were loaded onto 4 mm sterile individual discs. The loaded discs were placed on the surface of the medium, allowing the compounds to diffuse for 5 minutes before incubation at 37°C for 24 hours. Dimethyl sulfoxide (DMSO) was used as a solvent, and ofloxacin (10 µg/disc) served as a positive control. After incubation, the zones of inhibition around the discs were measured with a transparent ruler in millimeters.

Table 1: Antimicrobial sensitivity test of synthesized 1,3,5-Triazine derivatives

Sr. No	ANTIMICROBIAL SENSITIVITY TEST AGAINST BACTERIA, FUNGI AND VIRUSES ZONE OF INHIBITION IN mm (AFTER 24 HRS AT 37^{0}C TEMP)		
COMPOUND	GRAM -VE BACTERIA (E.coli)	GRAM -VE BACTERIA (S.typhe)	GRAM +VE BACTERIA (S.pneumoniae)
6a	17 mm	-------	14 mm
6b	14 mm	-------	17 mm
6c	16 mm	-------	17 mm
6d	18 mm	-------	16 mm
6e	15 mm	-------	15 mm
6f	14 mm	-------	16 mm
6a-Fe	18 mm	----------	16 mm
6b-Fe	16 mm	----------	19 mm
CONTROL	----------	-------	----------
REFERENCE	38mm (ofloxacin)	38mm (ofloxacin)	32mm (ofloxacin)

The growth of tested organisms responded differently to the compounds tested, which indicates that different components may have different modes of action or that the metabolism based on the structure of the compound. Gram-negative bacteria are in general more resistant than Gram-positive [20]. It can be observed that all the synthesised derivatives of scheme 1 showed moderate activity against gram –ve bacteria E. coli and gram +ve bacteria S. Pneumoniae as compared to ofloxacin. Compounds 6c, 6d and 6e (scheme-1) (MIC =100 µg/ml) possessed the higher inhibition zone than fluconazole and compounds 6a, 6b, 6f (MIC =100 µg/ml) possessed the slightly lower inhibition zone than fluconazole against Trichophyton rubrum while all synthesised derivatives showed slightly lower activity against Candida albicans in comparison with fluconazole.

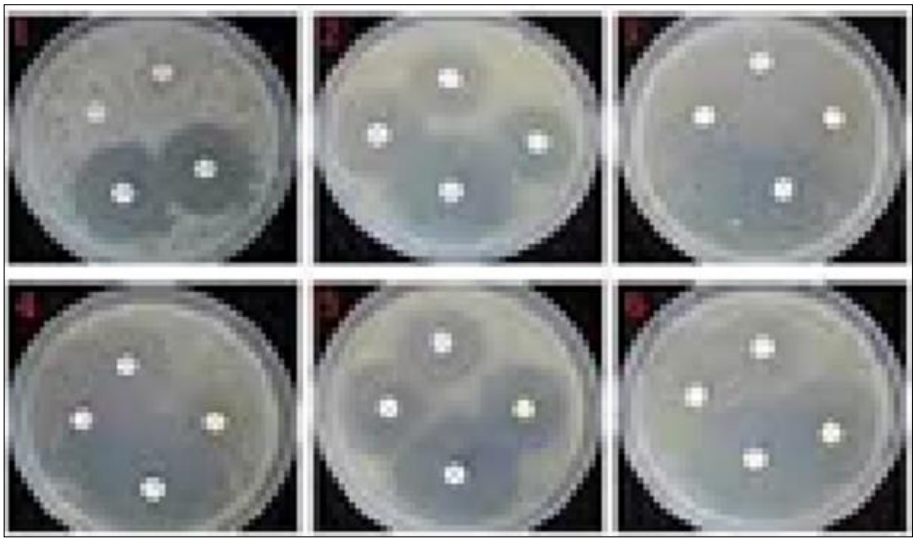

Fig 3: Plates showing Antimicrobial Sensitivity Test of synthesized 1,3,5-Triazine derivatives

The antimicrobial activity of the synthesized 1,3,5-triazine derivatives (6a–6f and 6a-Fe, 6b-Fe) and their metal complexes was evaluated against selected bacterial and fungal strains using the agar well diffusion method. The results revealed that most compounds exhibited moderate to significant antimicrobial activity compared to standard reference drugs [21].

The free triazine ligands showed measurable inhibition zones against both Gram-positive and Gram-negative bacteria, indicating their intrinsic antimicrobial potential. Upon complexation with metal ions such as Fe^{2+}, Co^{2+} the activity notably increased. This enhancement is attributed to chelation, which reduces the polarity of the metal ion and increases the lipophilic character of the complex, facilitating easier penetration through the microbial cell membrane and subsequent interaction with vital intracellular components. Among all complexes, the Fe(II) complexes displayed the highest antibacterial activity, followed by Co (II) complexes. The variation in activity can be correlated to differences in ionic radii and coordination geometry of the metal ions. Overall, the results confirm that metal coordination significantly improves the biological efficacy of triazine derivatives, suggesting their potential as promising antimicrobial agents [22].

Conclusion

The present study successfully reports the synthesis, surface morphological analysis, and antimicrobial evaluation of a new series of 1,3,5-triazine derivatives containing quinoline and substituted amines. The compounds were synthesized through stepwise nucleophilic substitution reactions and characterized by various physicochemical and spectroscopic techniques to confirm their structures and purity. Scanning Electron Microscopy (SEM) analysis revealed that the synthesized triazine derivatives possess well-defined crystalline and homogeneous surface morphologies, indicating the successful formation of stable molecular frameworks. The variation in surface texture among the derivatives was found to depend on the nature of the substituents attached to the triazine nucleus. The

antimicrobial screening demonstrated that several of the synthesized derivatives exhibit moderate to significant inhibitory activity against both Gram-positive and Gram-negative bacteria, as well as fungal strains. Compounds containing electron-donating or electron-withdrawing substituents showed enhanced antimicrobial potency, suggesting a direct influence of structural modification on biological activity.

In conclusion, the results indicate that 1,3,5-triazine–quinoline derivatives represent a promising class of compounds with potential applications as antimicrobial agents. The combined findings from SEM and biological studies provide valuable insights into the relationship between molecular structure, surface morphology, and biological efficacy. Further optimization and in-depth

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