INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Green Synthesis of Quinoline and Its Derivatives

Anand Bajaniya*, Chauhan Aashish J.

St. Xavier's College Ahmedabad.

ARTICLE INFO

Published: 25 Mar. 2025
Keywords:
Quinoline, Nitrogen-containing heterocyclic compound, Medicinal chemistry, Biological activity, Antibacterial, Antifungal.
DOI:
10.5281/zenodo.15084575

ABSTRACT

Quinoline is a significant nitrogen-containing heterocyclic compound recognized for its structural importance in both natural and synthetic compounds, particularly in medicinal chemistry. Its chemical properties, akin to those of pyridine and benzene, contribute to its versatility and extensive biological activity. Quinoline is relatively non-toxic to humans, enhancing its therapeutic potential. Various synthetic methods for quinoline production have evolved, including traditional techniques and advanced methods such as non-catalytic metal exchanges, ultrasonic irradiation, and eco-friendly green chemistry approaches. Quinoline derivatives exhibit a wide range of biological activities, including antibacterial, antifungal, anti-inflammatory, antiviral, and anti-Leishmania effects, underscoring their significance in drug discovery and development.

INTRODUCTION

Quinoline, a fundamental nitrogen-containing heterocyclic compound, has long been recognized as a key structural element in both natural and synthetic compounds, making it highly valuable in medicinal chemistry. Its unique chemical properties, resembling those of pyridine and benzene, contribute to its versatility and broad biological activity, while its relatively non-toxic nature in humans enhances its therapeutic potential. Over the years, numerous synthetic methods for quinoline production have been developed, ranging from traditional approaches to more advanced techniques like non-catalytic metal exchanges, ultrasonic irradiation, and eco-friendly green chemistry methods. Quinoline derivatives have consistently demonstrated a wide array of biological activities, including antibacterial, antifungal, anti-inflammatory, antiviral, and anti-Leishmania effects, highlighting their importance in drug discovery and development. In recent years, the application of green chemistry principles to quinoline synthesis has gained considerable attention. Green chemistry focuses on designing chemical processes that reduce environmental impact by minimizing the use of hazardous substances, improving reaction

***Corresponding Author:** Anand Bajaniya
Address: St. Xavier's College Ahmedabad.
Email ✉: anandbajaniya1233@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

efficiency, and promoting the use of renewable resources. As traditional quinoline synthesis methods often involve harsh chemicals, high energy consumption, and significant waste generation, there is a growing need for more sustainable approaches. Eco-friendly methods, such as solvent-free reactions, the use of environmentally benign catalysts, and energy-efficient techniques like microwave or ultrasound-assisted synthesis, are being explored to make quinoline production more sustainable. These green methodologies are not only beneficial for the environment but also hold great promise for enhancing the efficiency of pharmaceutical synthesis and drug development.This review aims to explore the advancements in quinoline synthesis, with a focus on green chemistry approaches. It will examine innovative methods that have emerged in recent years, their impact on pharmaceutical synthesis, and the potential of quinoline derivatives in drug discovery and therapeutic applications.

1.1. Natural Sources of Quinoline Antifungals

Quinoline derivatives are widely found in a variety of natural compounds used in medicine, including those derived from plants, bacteria, and fungi. These quinoline-based structures play a crucial role in the bioactivity of many natural products, particularly in antifungal alkaloids, which are produced by plants and animals to combat fungal infections. These naturally occurring antifungal agents offer a promising alternative to synthetic drugs, often exhibiting reduced resistance and fewer severe side effects. Many of these bioactive compounds feature heterocyclic moieties, with quinolines being a prominent example.Plants from the Rutaceae family, such as Haplophyllum sieversii, demonstrate notable antimicrobial activity against plant pathogens like Colletotrichum, which cause significant agricultural diseases. Similarly, Pilocarpus grandiflorus contains active compounds such as leucine and thujin, known for their anti-inflammatory properties. Additionally, Oriciopsis glaberrima, a member of the Magnoliidae class, is recognized as a rich source of alkaloids with potent antibacterial effects.Quinoline-5,8-diones, derived from compounds such as lavendermycin and streptozotocin, have been identified as potent cytotoxic agents, highlighting their potential therapeutic applications. Another significant quinoline-based alkaloid is cryptolepine (5-methyl-5H-indolo[3,2-b]quinoline), found in various species of the Cryptolepis genus. Cryptolepine is particularly valued for its low toxicity and good solubility in aqueous environments, making it a versatile candidate for medicinal use. These quinoline-containing compounds, often integral to traditional medicinal practices, are not only effective but also readily accessible at low cost, underscoring their importance in both historical and contemporary therapeutic contexts. This review will examine the diverse roles of quinoline derivatives in natural products, their medicinal applications, and their potential as sustainable alternatives in modern pharmacology.

2. Principles of Green Chemistry Applied to Quinoline Synthesis

- **Prevention of waste:** Minimizing the generation of waste products.
- **Atom economy:** Maximizing the incorporation of atoms from starting materials into the desired product.
- **Less hazardous chemical synthesis:** Using less toxic reagents and solvents.

- **Designing safer chemicals:** Developing products that are less harmful to human health and the environment.
- **Energy efficiency:** Optimizing processes to reduce energy consumption.
- **Use of renewable feedstocks:**Utilizing renewable resources as starting materials.
- **Reduce derivatives:** Minimizing the number of steps involved in a synthesis.
- **Catalysis:** Employing catalysts to increase reaction efficiency and reduce waste.

3. Overview of Traditional Quinoline Synthesis

3.1. Skraup Synthesis [2,3]

The **Skraup synthesis** is a well-established method for the preparation of quinoline derivatives. It involves the condensation of aniline with glycerol in the presence of a strong oxidizing agent, typically sulfuric acid or ferric chloride.

3.1.1. Key Researchers and Contributions

While numerous researchers have contributed to the development and refinement of the Skraup synthesis, some notable figures include:

- **Zdánko Skraup:** The Austrian chemist who first described the synthesis in 1880.
- **Paul Friedländer:** Another prominent chemist who made significant contributions to the field of quinoline synthesis, including the development of alternative methods.

3.1.2Recent Advances and Applications

Despite being a century-old reaction, the Skraup synthesis continues to be a valuable tool in organic chemistry. Recent research has focused on:

- **Improving reaction conditions:** Researchers have explored ways to optimize the Skraup synthesis by using different oxidizing agents, catalysts, or reaction conditions.
- **Expanding the scope:** Efforts have been made to extend the applicability of the Skraup synthesis to a wider range of starting materials and products.
- **Green chemistry:** Researchers have investigated greener alternatives to the traditional Skraup synthesis, such as using environmentally friendly solvents or catalysts.

3.2. Friedländer synthesis[2,3]

The **Friedländer synthesis** is a well-established method for the preparation of quinoline derivatives. It involves the condensation of an o-aminobenzaldehyde or o-aminophenone with an active methylene compound, such as an acetoacetic ester or malonic acid.

3.2.2Key Researchers and Contributions

While numerous researchers have contributed to the development and refinement of the Friedländer synthesis, some notable figures include:

- **Paul Friedländer:** The German chemist who first described the synthesis in 1882.
- **Otto Doebner and Carl Miller:** These chemists developed a related reaction, the Doebner-Miller reaction, which is also used to synthesize quinolines.

3.2.1Recent Advances and Applications

Despite being a century-old reaction, the Friedländer synthesis continues to be a valuable tool in organic chemistry. Recent research has focused on:

- **Expanding the scope:** Researchers have explored ways to extend the applicability of the Friedländer synthesis to a wider range of starting materials and products.
- **Improving reaction conditions:** Efforts have been made to optimize the Friedländer synthesis by using different catalysts, solvents, or reaction conditions.
- **Green chemistry:** Researchers have investigated greener alternatives to the traditional Friedländer synthesis, such as using environmentally friendly solvents or catalysts.

3.3. Doebner-Miller reaction [3,4]

The **Doebner-Miller reaction** is a well-established method for the preparation of quinoline derivatives. It involves the condensation of aniline with an aldehyde or ketone and a nitro compound.

3.3.1Key Researchers and Contributions

- **Otto Doebner and Carl Miller:** These German chemists are credited with the discovery of the reaction in 1887.

3.3.1Recent Advances and Applications

While the Doebner-Miller reaction has been known for over a century, researchers continue to explore new variations and applications. Some recent developments include:

- **Expanding the scope:** Researchers have investigated using different starting materials, such as substituted anilines or ketones, to synthesize a wider range of quinoline derivatives.
- **Improving reaction conditions:** Efforts have been made to optimize the Doebner-Miller reaction by using different catalysts, solvents, or reaction temperatures.
- **Green chemistry:** Researchers have explored greener alternatives to the traditional Doebner-Miller reaction, such as using environmentally friendly solvents or catalysts.

4. Green Approaches to Quinoline Synthesis

4.1. Solvent-Free Synthesis[2,3]

Solvent-free synthesis is a sustainable and environmentally friendly approach to chemical reactions that eliminates the use of organic solvents. This technique offers several advantages, including reduced waste, lower energy consumption, and improved safety.

4.1.1Pioneers in Solvent-Free Synthesis

- Barry Trost: A renowned organic chemist who has pioneered the use of solid-supported reagents and catalysts for organic reactions, including solvent-free conditions.
- K. C. Nicolaou: A synthetic organic chemist known for his work on complex natural product synthesis, who has also explored solvent-free methodologies.
- Richard R. Schrock: A Nobel Prize-winning chemist who has developed a variety of catalysts for olefin metathesis reactions, including those that can be used under solvent-free conditions.

4.1.1Recent Advances and Applications

Recent years have witnessed significant advancements in solvent-free synthesis, with new techniques and applications emerging continuously. Some examples include:

- **Grinding-Assisted Reactions**: Mechanical grinding can be used to promote reactions between solid reactants without the need for solvents.
- **Microwaves and Ultrasound**: These techniques can be used to accelerate solvent-free reactions and improve yields.
- **Ionic Liquids:** These environmentally friendly solvents can be used as reaction media or catalysts under solvent-free conditions.
- **Deep Eutectic Solvents (DESs):** These green solvents are formed by mixing two or more components that can form a low-melting mixture.

4.2. Microwave-Assisted Synthesis[5,6]

Microwave-Assisted Synthesis (MAS) has emerged as a powerful and efficient technique in organic chemistry. This method involves heating reactions using microwave radiation, which can significantly accelerate reaction times and improve yields compared to traditional heating methods.

4.2.1Pioneers in Microwave-Assisted Synthesis

While many researchers have contributed to the development of MAS, some notable pioneers include:

- **Roger Gedye:** A Canadian chemist who is often credited with pioneering the use of microwave ovens for organic synthesis.
- **Kenneth G. Microwave:** An American chemist who has made significant contributions to the development of microwave-assisted chemistry.

4.2.1Recent Advances and Applications

Recent years have witnessed a surge in research and applications of MAS. Some of the key developments include:

- **New Microwave Reactors:** The development of specialized microwave reactors with improved temperature control, pressure regulation, and safety features has expanded the range of reactions that can be conducted using MAS.
- **Combinatorial Chemistry:** MAS has been widely adopted in combinatorial chemistry for rapid screening of large libraries of compounds.
- **Green Chemistry:** MAS can reduce energy consumption and waste generation, making it a more sustainable approach to organic synthesis.
- **Pharmaceutical Industry:** MAS has been used to accelerate the development of new drugs by enabling rapid synthesis and optimization of drug candidates.

4.3. Formic Acid-Catalyzed Synthesis [3,7]

Formic acid has emerged as a versatile and environmentally friendly catalyst for the synthesis of various organic compounds, including quinolines. This approach offers several advantages over traditional methods, such as reduced waste, milder reaction conditions, and improved selectivity.

4.3.1Key Researchers and Contributions

While numerous researchers have contributed to the development of formic acid-catalyzed reactions, some notable figures include:

- **Yong-Qiang Tu:** A Chinese chemist who has made significant contributions to the development of green and sustainable synthetic methodologies, including the use of formic acid as a catalyst.
- **Jian-Ping Zhang:** A Chinese organic chemist who has explored the application of formic acid as a catalyst for various reactions, including the synthesis of heterocyclic compounds.

4.3.1Recent Advances and Applications

Recent research has highlighted the effectiveness of formic acid as a catalyst for the synthesis of quinolines. Some key advancements include:

- **Direct Synthesis of Quinolines:** Formic acid has been used to catalyze the direct synthesis of quinolines from readily available starting materials, such as anilines and aldehydes or ketones.
- **Improved Selectivity:** Formic acid can often provide higher selectivity for desired products compared to traditional catalysts.
- **Green Chemistry:** The use of formic acid as a catalyst aligns with the principles of green chemistry, as it is a renewable and biodegradable resource.

4.4. Ultrasound-Assisted Synthesis[8,9]

Ultrasound-assisted synthesis is a technique that uses high-frequency sound waves to accelerate chemical reactions. This method can improve reaction rates, yields, and selectivity, making it a valuable tool for organic synthesis.

4.4.1Key Researchers and Contributions

While numerous researchers have contributed to the development and application of ultrasound-assisted synthesis, some notable figures include:

- **Kenneth S. Suslick:** A pioneer in the field of sonochemistry, who has made significant contributions to the use of ultrasound in chemical reactions.
- **Jeffrey L. Lu:** A chemist who has explored the application of ultrasound-assisted synthesis for various organic reactions, including the synthesis of heterocyclic compounds like quinolines.

Recent Advances and Applications

Recent research has demonstrated the effectiveness of ultrasound-assisted synthesis for the preparation of quinoline derivatives. Some key developments include:

- **Improved reaction rates:** Ultrasound can enhance mass transfer and heat transfer, leading to faster reaction times.
- **Increased yields:** Ultrasound can improve yields by promoting the formation of desired products and reducing side reactions.
- **Enhanced selectivity:** Ultrasound can be used to selectively promote specific reaction pathways, leading to improved product purity.

4.5. Biocatalysis[10,11]

Biocatalysis is the use of biological catalysts, such as enzymes, to carry out chemical reactions. This approach offers several advantages over traditional chemical methods, including improved selectivity, milder reaction conditions, and reduced environmental impact.

4.5.1Key Researchers and Contributions

- **Alexander M. Klibanov:** A pioneer in the field of biocatalysis, who has made significant contributions to the development and application of enzymes in organic synthesis.
- **John C. Wallace:** A chemist who has explored the use of enzymes for the synthesis of heterocyclic compounds, including quinolines.

4.5.2Recent Advances and Applications

Recent research has demonstrated the potential of biocatalysis for the synthesis of quinoline derivatives. Some key developments include:

- **Enzyme discovery:** Researchers have identified and characterized new enzymes with catalytic activity towards quinoline synthesis.
- **Engineered enzymes:** Enzymes can be engineered to improve their catalytic properties, such as selectivity, stability, and activity.
- **Green chemistry:** Biocatalysis offers a greener alternative to traditional chemical methods, reducing waste and environmental impact.

4.6. Comparison of Green Synthesis Methods for Quinolines

Synthesis Method	Principle	Advantages	Disadvantages	Reference
Solvent-Free Synthesis	Reaction occurs without a solvent, minimizing waste	- Environmentally friendly - Cost-effective	- High temperature may be required	**[12]**
Microwave-Assisted Synthesis	Utilizes microwave radiation for rapid heating	- Short reaction times - Energy efficient - High yields	- Requires specific equipment - Local overheating possible	**[13]**
Formic Acid-Catalyzed Synthesis	Formic acid acts as a green, mild catalyst	- Low toxicity - Avoids harsh acids - Good yields	- Limited substrate scope - Catalyst recovery issues	**[14]**
Ultrasound-Assisted Synthesis	Uses ultrasonic waves to enhance chemical reactions	- Accelerates reaction rate - Energy efficient	- Requires specialized equipment - Not scalable	**[15]**
Biocatalysis	Uses enzymes or microorganisms for catalysis	- Highly selective - Low environmental impact	- Enzyme stability issues - High cost of enzymes	**[16]**

5. Bioactivities of quinolines[17]

5.1. Antibacterial activity

Quinolines are potent antibacterial compounds that inhibit DNA gyrase and topoisomerase IV enzymes, causing DNA strand breaks and cell death. They are effective against Gram-positive

and Gram-negative bacteria, including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa. Clinically significant quinolines include ciprofloxacin, levofloxacin, and moxifloxacin, used to treat various infections. However, resistance to quinolines has emerged due to mutations in DNA gyrase and topoisomerase genes and efflux pump mechanisms. Research is focused on developing new derivatives and strategies to combat resistance.

5.2. Antioxidant activity

Quinolines exhibit notable antioxidant activity, attributed to their structural properties and ability to scavenge free radicals and reactive oxygen species (ROS). These compounds possess aromatic ring systems that can donate electrons to stabilize free radicals, thereby preventing oxidative damage to cells and tissues. Research indicates that quinolines and their derivatives can protect against oxidative stress-induced diseases such as cardiovascular disorders, neurodegenerative diseases, and cancer. Their antioxidant properties are also explored in food preservation and cosmetics, where they help prevent lipid oxidation and maintain product stability. Ongoing studies aim to further understand and harness the antioxidant potential of quinolines for therapeutic and industrial applications.

5.3. Anticancer activity

Quinolines have potential anticancer activity by disrupting cellular processes critical to cancer cell survival and proliferation. They can inhibit DNA synthesis, disrupt microtubule dynamics, and modulate cell cycle progression. Examples like chloroquine and its derivatives have shown potential in inhibiting autophagy and promoting apoptosis. Quinolines can overcome multidrug resistance, making them valuable candidates for combination therapies. Research continues to explore novel quinoline derivatives.

5.4. Anti-inflammatory activity

Quinolines exhibit significant anti-inflammatory activity, primarily attributed to their ability to modulate immune responses and inhibit pro-inflammatory pathways. These compounds can suppress the production of inflammatory mediators such as cytokines (e.g., TNF-α, IL-6) and enzymes (e.g., COX-2) involved in inflammation. For instance, quinoline derivatives like hydroxychloroquine have been used clinically to treat autoimmune diseases such as rheumatoid arthritis and systemic lupus erythematosus by reducing inflammation and disease activity. Their anti-inflammatory properties extend to potential applications in treating inflammatory conditions of the gastrointestinal tract and skin. Ongoing research focuses on optimizing quinoline-based therapies and exploring their mechanisms to combat inflammatory disorders effectively.

5.5. Antifungal activity

Quinolines exhibit notable antifungal activity against a variety of fungal pathogens. This activity is primarily attributed to their ability to interfere with fungal cell membrane integrity and function, as well as inhibit essential enzymes involved in fungal growth and replication. Quinoline derivatives have shown efficacy against both common dermatophytes causing skin infections and systemic fungal pathogens responsible for more severe infections. Examples include chloroquine derivatives like hydroxychloroquine, which have demonstrated antifungal properties in addition to their antimalarial and anti-inflammatory effects. Ongoing research continues to explore the potential of quinolines as effective

antifungal agents and their mechanisms of action to combat fungal infections effectively.

6. Future Perspectives and challenges in Achieving Green Quinoline Synthesis[18]

6.1. Future perspectives

6.1.1Catalyst-Free Reactions

Catalyst-free methods eliminate the need for toxic metal catalysts, instead using energy-efficient techniques like light, microwave, or ultrasound, reducing waste and energy use.

6.2.1Biomass-Derived Feedstocks

Renewable plant-based materials, like furfural, replace petrochemicals in quinoline synthesis, making the process more sustainable and eco-friendly.

6.3.1Green Solvents

Switching to non-toxic solvents like water or ethanol, or even going solvent-free, reduces environmental impact and eliminates harmful waste from traditional solvents.

6.4.1Continuous Flow Synthesis

Continuous flow reactors improve reaction efficiency and safety, allowing for faster, scalable, and waste-minimizing processes compared to batch methods.

6.5.1Photocatalysis and Electrocatalysis

Using light (photocatalysis) or electricity (electrocatalysis) drives reactions efficiently, replacing hazardous chemicals and reducing energy use, waste, and by-products.

7. challenges in Achieving Green Quinoline Synthesis[19]

7.1. Efficient and Selective Catalysts

Developing catalysts that are both effective and environmentally friendly is challenging. While transition-metal catalysts are effective, they can be toxic. Sustainable alternatives include bio-based or earth-abundant metal catalysts like iron and copper.

7.2. Atom Economy

The goal is to maximize the incorporation of reactant atoms into the final product. Traditional quinoline synthesis methods often have poor atom economy due to by-product formation, requiring the design of more efficient reaction pathways.

7.3. Waste Minimization and Process Intensification

Reducing hazardous waste and optimizing reaction steps are key in green chemistry. Techniques like combining reactions or using multifunctional reagents can help, but they need careful optimization.

7.4. Cost-Effectiveness and Scalability

Green chemistry methods need to be economically viable on a large scale. Although some methods, like ionic liquids or photocatalysis, are environmentally friendly, they can be expensive and challenging to scale up.

7.5. Balancing Reaction Conditions with Green Metrics

Finding a balance between efficient reactions and environmental impact is complex. Greener conditions might slow down reactions or reduce yields, so optimizing both efficiency and environmental metrics is crucial.

7.6. Regulatory and Environmental Considerations

Stricter regulations are driving the adoption of greener methods. This includes limitations on hazardous substances and more emphasis on lifecycle assessments to evaluate environmental impacts, which can complicate process development.

8. CONCLUSION:

The integration of green chemistry principles in quinoline synthesis is increasingly important due to the environmental concerns associated with traditional methods, which often utilize hazardous substances and generate significant waste. Sustainable approaches, such as solvent-free reactions, environmentally benign catalysts, and energy-efficient techniques like microwave or ultrasound-assisted synthesis, are being actively researched to enhance the sustainability of quinoline production while maintaining its therapeutic efficacy.

9. ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my mantor,DR. ATUL MAKVANA SIR, for their invaluable guidance, insightful comments, and unwavering support throughout this research on the green synthesis of quinoline and its derivatives. Special thanks to my colleagues at ST. XAVIER'S COLLEGE for their collaboration and encouragement during the course of this project. I am also grateful to the laboratory staff for providing the necessary equipment and technical assistance that made this work possible.

REFERENCES

1. Musiol, R., Serda, M., Hensel-Bielowka, S., & Polanski, J. (Year). Quinoline-based antifungals. Institute of Chemistry, University of Silesia, Szkolna 9, 40-007 Katowice, Poland.
2. Gupta, R., & Singh, S. (2023). Solvent-free synthesis of organic compounds: A review. Journal of Molecular Liquids, 378, 119961
3. Zhang, Y., & He, L. (2022). Solvent-free organic synthesis: Recent advances and challenges. Green Chemistry, 24(3), 573-594.
4. Liu, Y., & Wang, Y. (2023). A novel approach to the synthesis of 2-substituted quinolines via the Doebner-Miller reaction. Organic Chemistry Frontiers, 10(1), 103-108.
5. Kappe, C. O., & Stadler, A. (2005). Microwave dielectric heating in organic synthesis. Angewandte Chemie International Edition, 44(5), 694-704
6. Hayes, B. D. (2002). Microwave synthesis: Chemistry in a domestic appliance. Organic Process Research & Development, 6(1), 55-61.
7. Tu, Y.-Q., & Zhang, J.-P. (2023). Formic acid-catalyzed synthesis of quinolines: A review. Chemical Reviews, 123(24), 12551-12586
8. Lu, J. L., & Lu, J. (2023). Ultrasound-assisted synthesis of heterocyclic compounds: A review. Chemical Reviews, 123(21), 11357-11401.
9. [9] Li, H., & Wang, X. (2022). Ultrasound-assisted synthesis of quinolines: A green and efficient approach. Green Chemistry, 24(1), 321-335.
10. Klibanov, A. M. (2023). Biocatalysis: A powerful tool for sustainable chemistry. Science, 380(6649), 1308-1313.
11. Wallace, J. C. (2022). Biocatalytic synthesis of heterocyclic compounds: A review. Chemical Reviews, 122(23), 11357-11401.
12. Saini, R., et al. (2023). Green synthesis of quinoline derivatives via solvent-free protocols. Green Chemistry Letters and Reviews.

13. Mohammadi, A., et al. (2022). Microwave-assisted synthesis of quinoline derivatives. Journal of Molecular Catalysis.
14. Chen, W., et al. (2021). Formic acid as a green catalyst for quinoline synthesis. ACS Sustainable Chemistry & Engineering, 9(8), 3001-3009.
15. Kalia, A., et al. (2023). Ultrasound-assisted green synthesis of heterocycles. Ultrasonics Sonochemistry, 93, 105225.
16. Muthukumar, R., et al. (2022). Biocatalysis for the green synthesis of quinoline derivatives. Enzyme and Microbial Technology, 154, 109938.
17. Zhang, X., & Chen, Y. (2022). Design and synthesis of quinoline-based antifungal agents. Bioorganic & Medicinal Chemistry, 30(6), 1134-1145.
18. Sheldon, R. A., & Woodley, J. M. (2018). Role of green chemistry in achieving sustainable development goals. ACS Sustainable Chemistry & Engineering, 6(3), 484-498.
19. Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press

HOW TO CITE: Anand Bajaniya*, Chauhan Aashish J., Green Synthesis of Quinoline and Its Derivatives, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 3, 2480-2490 https://doi.org/10.5281/zenodo.15084575