



# Green Chemistry Approaches in Organic Synthesis: A Review of Sustainable Methods

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## Abstract:

Green chemistry has become a revolutionary and sustainable practice in organic synthesis with the goal of minimizing environmental impact and maximizing the safety, efficiency and the overall quality of chemical reactions. This review thoroughly reviews different green synthetic techniques that include use of eco-friendly solvents, biocatalysis, microwave- and ultrasound-assisted techniques, green catalysts, and specifically how they have been validated using animal-based studies. Preclinical evidence with mice, rats, and zebrafish show that compounds produced via green methodologies have much lower acute and chronic toxicity, increased biocompatibility, and better pharmacological profiles than those generated via conventional methodologies. Aspiratory in vivo examination methods including toxicity, pharmacokinetic profiling, histopathology, biochemical and behavioural analysis give a comprehensive insight into the biological interactions and safety profiles of these compounds. Moreover, the application of green chemistry principles such as atom economy, minimization of waste, and energy efficiency helps to decrease the harmful by-products and help to create safer chemical entities. Although these benefits exist, issues like the fact that the protocol is not yet standardized to synthesize these materials, differences in results of the experimental results and scanty long-term toxicity evidence especially in nano-catalysts and other emerging green materials are also of concern. In general, this review highlights the great importance of green chemistry in achieving balance between environmental sustainability and innovation in biomedical fields as a promising avenue of creating effective, environmentally friendly and biologically safe organic compounds.

**Keywords:** Green Chemistry, Organic Synthesis, Sustainable Methods, Animal Studies, Biocompatibility, Green Solvents, Biocatalysis, Toxicity Evaluation.

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## 1. INTRODUCTION

Green chemistry has become an innovative concept in organic synthesis, the goal of which is to minimize environmental impact and increase the safety and efficiency of the chemical

process. The conventional methods of organic synthesis are usually associated with reagents which are dangerous, solvents which are toxic, and processes which are energetically demanding and contaminate the environment and endanger biological systems. Green chemistry on the other hand focuses on applying sustainable chemistry like green solvents, renewable feedstock, biodegradable materials, and energy efficient processes<sup>1</sup>. Not only do these methods reduce the amount of waste produced and decrease toxicity, but also enhance the quality and safety of the compounds synthesized. Green chemistry has been of considerable interest in recent years in the pharmaceutical, chemical and biomedical industries with a potential to yield safer compounds with minimal adverse effects, with animal-based experimental studies being supportive of this claim.



Figure 1: Green Chemistry<sup>2</sup>

The increased significance of sustainable development and environmental protection has further increased the use of green chemistry principles in organic synthesis. This review is aimed at evaluating the different green synthetic methods and their confirmation using animal-based systems, which are crucial in showing toxicity, pharmacokinetics and biological compatibility. The review will provide insights into the effectiveness of biocatalysis, green solvents, microwave-assisted synthesis, and eco-friendly catalysts in minimizing the harmful by-products and enhancing therapeutic outcomes<sup>3</sup>. The research also highlights the significance of incorporating the green chemistry with preclinical testing to promote the production of safe and effective chemical compounds. Altogether, this issue is quite topical because it helps to fill the gap between environmental sustainability and biomedical development, which opens the way to new innovations in organic synthesis in the future.

### 1.1 Background and Context

Green chemistry has become an essential tool of contemporary organic synthesis, the goal of which is to create chemical processes with the minimal environmental footprint and the least utilization of dangerous substances. Traditional organic synthesis usually is based on toxic

solvents, non-renewable sources and energy-consuming processes, which pollute the environment and threaten biological systems<sup>4</sup>. Green chemistry in turn encourages sustainable options like environmentally friendly solvents, renewable feedstocks, energy-efficient methods and less hazardous reaction conditions. The use of these methods has become more and more popular especially in the pharmaceutical and chemical sectors where safety, efficiency and environmental responsibility are paramount. Animal-based research has been crucial in confirming these techniques by presenting in vivo data of decreased toxicity and enhanced biocompatibility of green-synthesized compounds<sup>5</sup>.

## 1.2 Objectives of the Review

This review has the main goal of determining:

- To critically evaluate different methods of green chemistry (green solvents, biocatalysis, microwave-assisted synthesis and eco-friendly catalysts) in organic synthesis.
- To measure toxicity and biocompatibility and safety of green-synthesized compounds with the help of animal model.
- To investigate the methodologies of animal studies (toxicity, pharmacokinetic, biochemical, and behavioral) and assessments.
- To determine the merits and shortcomings of the green synthesis strategies over the traditional methods.
- To discuss the future research directions and design approaches to enhance sustainable and biologically safe organic synthesis.

## 1.3 Importance of the Topic

Green chemistry is relevant to organic synthesis because it has the potential to provide solutions to both environmental and biomedical problems. These methods help to reduce hazardous waste and reduce toxicity, thus contributing to the environmental sustainability and better safety profiles of synthesized compounds<sup>6</sup>. Green synthesis in animal research Systems Green synthesis in animal research has exhibited reduced systemic toxicity, improved pharmacological performance, and improved interaction with biological systems. This renders them very applicable in preclinical drug development and other biomedical uses. Moreover, green chemistry adoption is in line with the objectives of sustainability in the world and regulatory demands, which underscores the necessity of the further research and innovations in the area.

## 2. ANIMAL-BASED EVALUATION OF GREEN-SYNTHESIZED COMPOUNDS

Animal experiments indicate that green-synthesized compounds exhibit a low level of toxicity, a high level of biocompatibility and efficient pharmacological activities when assessed using standardized procedures, including toxicity, biochemical and behavioral tests<sup>7</sup>.

### 2.1 Overview of Key Research Studies

Recent experiments using animal models like mice, rats and zebrafish have showed the benefits of green synthetic methods. Those compounds prepared with environmentally-friendly catalysts and solvents exhibit less acute and chronic toxicity in rodents. An example here is the

plant-based catalysts and enzyme-mediated reactions that have been employed to produce heterocyclic compounds, which were found to have improved therapeutic effects and low organ toxicity in murine models.

Organic synthesis using microwaves has also been tested in animal studies and its reaction efficiency has been found to be greater and the formation of harmful intermediates is also minimized. On the same note, the use of solvent-free reactions and ionic liquid-based synthesis has been clinically tested, and it has been validated to have reduced inflammatory and toxic reactions as compared to analogs synthesized by conventional methods.

## 2.2 Methodologies Used in Animal Studies

A combination of toxicity testing, biochemical testing and functional analysis are the common methodologies used in animal studies to assess the green-synthesized compounds to attain safety and efficacy. The methods give a systematic knowledge of the interaction of such compounds with biological systems and their possible therapeutic or adverse impact.

- **Acute and sub-acute toxicity studies in rodents to evaluate safety profiles:** The purpose of these studies is to establish the toxic effects of compounds in the short-term (acute) and repeated (sub-acute) exposure. Acute toxicity tests are usually aimed at a high dose of the drug and monitoring the animals to observe the immediate effects or death, whereas sub-acute tests are carried out by repeating doses over days or weeks. Measures like body weight, food consumption, behavioral alterations and mortality are observed to determine safe dosage levels and possible toxication<sup>8</sup>.
- **Histopathological analysis of organs such as liver and kidney:** This technique entails examining samples of tissues taken on vital organs following treatment using a microscope. The liver and kidney are the most important organs because they are involved in metabolism and excretion. The histopathological investigations aid in the identification of cellular injury, inflammations, necrosis, or structural changes, which provide information on the toxicity of compounds on organs and the overall safety of the tested compounds.
- **Pharmacokinetic studies to assess absorption, distribution, metabolism, and excretion:** Pharmacokinetic (PK) investigations are necessary to discover the manner in which a substance acts within the body. These are studies that determine the rate and efficiency with which the compound is absorbed into the blood, diffusion to various tissues, metabolism into active or inactive forms, and ultimately excretion. PK profiling assists in establishing bioavailability, half-life and optimal dosing schedules in therapeutic use.
- **Biochemical assays to measure oxidative stress and enzymatic activity:** These are assays that are employed to measure the effects of compounds on the biochemical processes in cells. Measures are taken of parameters including levels of reactive oxygen species (ROS), lipid peroxidation, antioxidant enzymes (e.g., superoxide dismutase, catalase), and other metabolic enzymes. This will assist in knowing whether the compound causes or suppresses oxidative stress and the effect it has on cellular defense systems.

- Behavioral studies in animals to assess neurotoxicity:** Behavioral tests are done to determine the effects the compounds may have on the central nervous system. Examinations can involve locomotor activity, memory and learning activities, and anxiety-related behavior and motor coordination. Any change in the regular conduct may be a pointer to neurotoxicity and these studies are vital in determining the possible neurological danger<sup>9</sup>.

All of these methodologies would allow researchers to check the safety, efficacy and the potential of green-synthesized compounds in further biomedical and pharmaceutical use.

**Table 1:** Summary of Selected Studies on Green Chemistry Approaches in Organic Synthesis<sup>10</sup>

Author(s) & Year	Study Focus	Methodology/Approach	Key Findings
Kar et al. (2021) <sup>11</sup>	Green chemistry in pharmaceutical synthesis	Use of eco-friendly solvents, catalytic systems, atom economy	Reduced hazardous waste, improved efficiency, enhanced pharmacological quality, lower toxicity
Ganesh et al. (2021) <sup>12</sup>	Green chemistry as a sustainability framework	Integration of renewable feedstocks, energy-efficient technologies, green reagents	Reduced ecological footprint, improved process safety and efficiency
Kharissova et al. (2019) <sup>13</sup>	Greener synthesis of compounds and materials	Solvent-free reactions, microwave-assisted synthesis, green catalysts	Improved yield and selectivity, reduced toxic by-products
Hessel et al. (2022) <sup>14</sup>	Sustainability of green solvents	Use of water, bio-based solvents, supercritical fluids	Reduced environmental and biological toxicity, improved reaction efficiency and purity
Plotka-Wasyłka et al. (2018) <sup>15</sup>	Green chemistry in higher education	Curriculum integration and educational strategies	Increased awareness, promoted safe laboratory practices, identified educational challenges

### 2.3 Critical Evaluation

A critical analysis of animal-based research in the framework of green-synthesized compounds underlines the great contributions and the limitations possessing preclinical research. The studies are essential in filling this gap between in vitro and clinical studies but should be interpreted with caution<sup>16</sup>.

#### Strengths

Animal research offers a very controlled experimental setting, which allows scientists to explore the toxicity, efficacy and biological behavior of compounds in a systematic way under controlled conditions. This control reduces the external variability and enables the dose-response relationships to be accurately measured. A major benefit of these studies is that they can produce comprehensive *in vivo* information about pharmacodynamics (the effects of a drug on the body) and pharmacokinetics (the movement of a drug within the body) which is necessary to support the therapeutic potential of green chemistry-based products. Further, the animal models are useful in identifying organ-specific toxicities, i.e. hepatotoxicity or nephrotoxicity by performing detailed physiological, biochemical, and histopathological analyses. They also allow the determination of long-term safety impact such as chronic toxicity, cumulative effects and possible carcinogenic or reproductive effects, which are hard to determine on the basis of *in vitro* systems<sup>17</sup>.

### **Weakness**

In spite of these benefits, animal models have significant weaknesses that may affect the validity and external validity of results. The biggest worry is that the physiology of animals is not necessarily a perfect replica of human biological systems hence there may be differences in drug response, metabolism and toxicity. Inter-species variability may thus restrict outright extrapolation of findings in humans, a challenge in anticipating clinical outcomes. Ethical implications of using animals in research have also led to greater questioning and adoption of stringent rules that limit large scale experimentation and require alternative approaches to be used where feasible. Moreover, when it comes to green synthesis, the absence of standard protocols to prepare and characterize compounds may create variability and inconsistency in experimental outcomes<sup>18</sup>. The biological activity can be affected by variations in the method of synthesis, particle size, purity, and formulation, and it is hard to compare data between studies and define reproducibility.

## **3. SUSTAINABLE GREEN CHEMISTRY TECHNIQUES IN ORGANIC SYNTHESIS: AN ANIMAL-BASED PERSPECTIVE**

Green solvents, biocatalysis, microwave/ultrasound-assisted reactions, and eco-friendly catalysts are some of the approaches used in green chemistry to increase the reaction efficiency by a significant margin, reducing toxicity and increasing biocompatibility in animal models<sup>19</sup>.

### **3.1 Green Solvents in Organic Synthesis**

The use of green solvents, water, ethanol and supercritical fluids, has gained widespread use in sustainable organic synthesis because these reagents are low toxicity, biodegradable and environmentally friendly. In animal experiments, compounds prepared in aqueous or bio-based solvent systems have always been shown to possess lower systemic toxicity as reflected by the maintenance of biochemical parameters and low levels of histopathological changes in organs such as liver and kidney. These solvents are very beneficial in decreasing the use of volatile organic compounds (VOCs), thus cutting down the harmful exposure and physiological stress to experimental animals. Also, reaction efficiency and product purity is increased using supercritical fluids which also leads to increased safety and tolerability in *in vivo* models<sup>20</sup>.



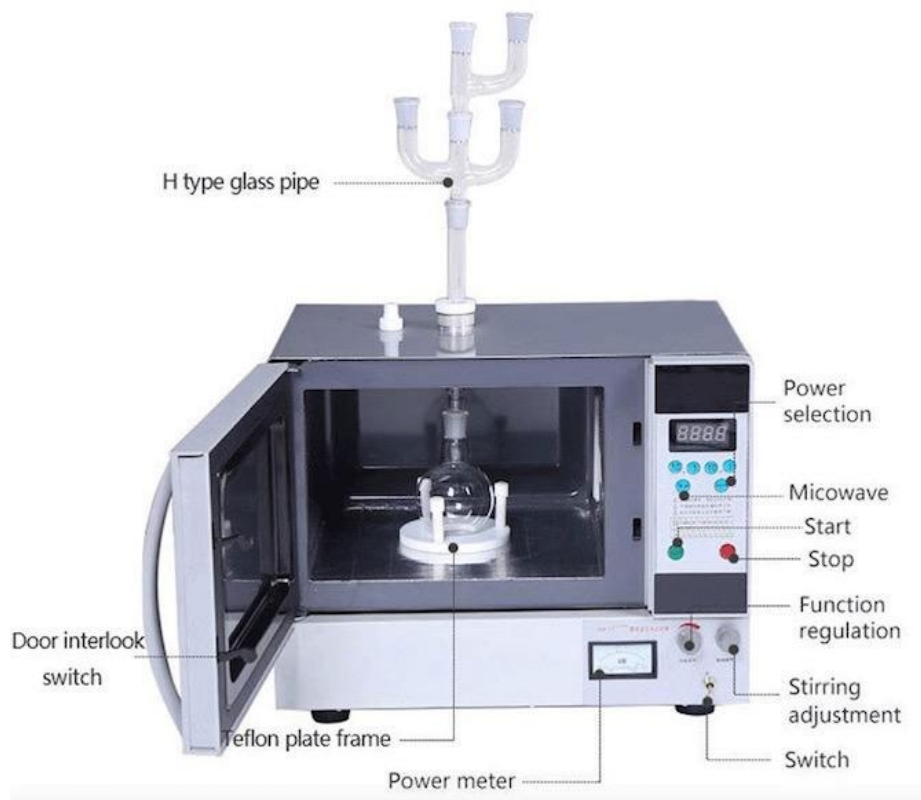
Figure 2: Green Solvents<sup>21</sup>

### 3.2 Biocatalysis and Enzyme-Mediated Synthesis

Biocatalysis is a chemical transformation that is performed using enzymes or entire cells under non-aggressive and ecologically acceptable conditions. The technique is very selective, specific and efficient which is necessary to generate biologically active compounds with minimum side products. Evaluations on animals have shown that the syntheses of compounds mediated by enzymes have been less toxic and have improved pharmacological characteristics in comparison to those synthesized traditionally. The gentle reaction environment can preserve the structure of delicate bioactive molecules to increase their immunity and treatment efficacy. Moreover, less generation of toxic intermediates results in a decrease in oxidative stress and better cellular responses in animal models<sup>22</sup>.

### 3.3 Microwave and Ultrasound-Assisted Synthesis

Microwave and ultrasound-assisted synthesis are enhanced green methods that enhance the rate of reaction much higher and save energy. These techniques can be used to heat quickly and evenly distribute energy, which leads to reduced reaction times and increased yields of products. The animal research has demonstrated that compounds produced by these methods have less impurities and less residual toxicity, which convert to better safety profiles. The synthesis using microwaves, specifically, reduces the generation of undesired by-products, and the ultrasound increases the mass transfer and the reaction efficiency. Consequently, such approaches will lead to the creation of less toxic and biologically compatible compounds, which has been validated through less inflammatory and toxic reactions in preclinical models<sup>23</sup>.



**Figure 3:** Microwave-Assisted Organic Synthesis<sup>24</sup>

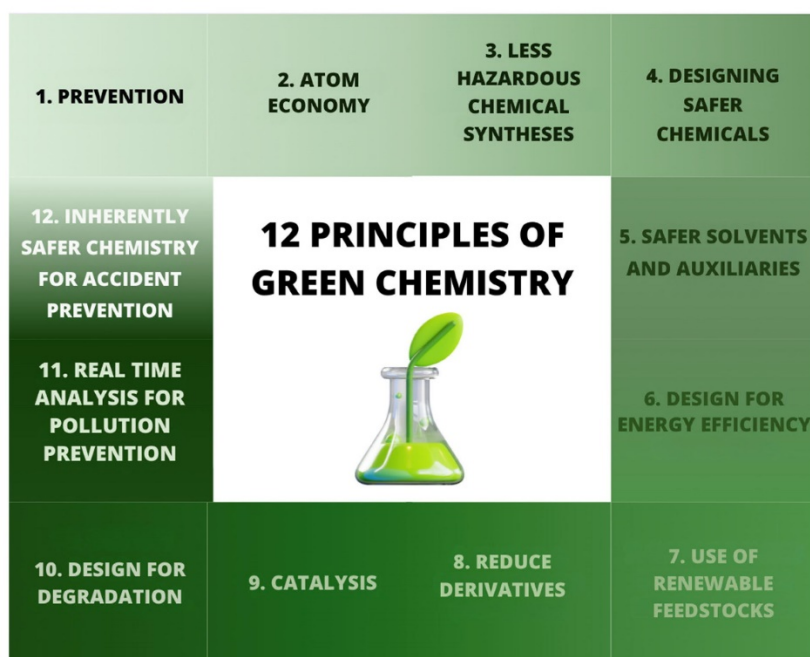
### 3.4 Use of Green Catalysts and Nanocatalysts

Green catalyst (biodegradable catalysts, plant-based catalysts and metal nanoparticles) is critical to improve the sustainability of organic synthesis. These catalysts enhance the efficiency, selectivity and yield of the reaction with reduced yield of wastes. In vivo animal experiments have shown that products obtained with the help of green catalysts are less toxic and more compatible with biology<sup>25</sup>. With a large surface area and a high reactivity, nanocatalysts can also be used to perform the transformations in mild conditions, which do not require harsh chemicals. There are, however, issues about nanomaterials accumulation in biological systems over time and toxicity. Rodent research has shown that although there is no evidence of toxicity in the short term, more study is required to determine chronic toxicity, bioaccumulation and ecological effect prior to mass usage<sup>26</sup>.

## 4. PRINCIPLES AND DESIGN STRATEGIES OF GREEN CHEMISTRY IN ORGANIC SYNTHESIS

The essential principles of green chemistry in the field of organic synthesis are embodied in the principles of the 12 Principles of Green Chemistry that provide the overarching basis of designing more sustainable and safer chemical processes. These principles focus on waste prevention rather than waste treatment, encourage high atom economy to make the most of reactants into finished products, and use less hazardous reagents and safer solvents. Another important factor is energy efficiency and with numerous green processes preferring reactions to be conducted at ambient temperature and pressure, to avoid excessive use of energy. In animal models, these principles can be applied in the creation of compounds that produce fewer

toxic by-products, and as a result, reduce systemic toxicity, oxidative stress, and organ damage in in vivo models like rodents and zebrafish<sup>27</sup>.



**Figure 4:** Principles of Green Chemistry<sup>28</sup>

Besides the guiding principles, other current green chemistry strategies include advanced designs like catalytic synthesis, reactions without solvents, and renewable or bio-based feedstock. By increasing selectivity and efficiency of reactions and reducing chemical waste, catalysis, especially with biodegradable or non-toxic catalysts, is used to improve the selectivity of reactions. Solvents, as well as solid-phase reactions, will additionally limit environmental footprint and remove exposure to toxic volatile organic compounds. Such evaluations using animals have shown better pharmacokinetic characteristics, such as increased absorption and decreased levels of toxic intermediates<sup>29</sup>. The strategies also assist in designing structurally optimized molecules that do not affect the biological activity and minimize adverse effects, thereby enhancing overall therapeutic indices in preclinical models.

The other important design approach is the idea of designing to degrade, in which the synthesized compounds are supposed to decompose into a non-toxic and environmentally safe product once the purpose of the compound has been achieved<sup>30</sup>. This is especially crucial in minimizing long-term toxicity and bioaccumulation, which have become major issues in the environmental and biological systems. Such compounds have been shown to have safer metabolism and less chronic toxicity through preclinical animal studies, such as pharmacokinetic and histopathological studies. Moreover, the incorporation of green chemistry with the new technologies like nanotechnology and biocatalysis offer the innovational possibilities but also demand the cautious consideration of the long-term safety. In general, all these principles and strategies can help create the effective, eco-friendly, and biologically safe organic routes in synthesis<sup>31</sup>.

## 5. DISCUSSION

The significance of green chemistry in organic synthesis can be seen in the fact that green chemistry methods show enhanced safety, efficiency and biocompatibility in animal studies, which is crucial in sustainable and pharmaceutical applications<sup>32</sup>. However, challenges such as lack of standardization and limited long-term toxicity data indicate the need for further research, particularly on nanomaterials and advanced green technologies<sup>33</sup>.

### 5.1 Interpretation and Analysis of Findings

The analyzed evidence proves that green chemistry methods in the field of organic synthesis can significantly increase safety and efficiency, especially when supported with animal-based studies<sup>34</sup>. Green solvents, biocatalysis and microwave-assisted methods are all methods in which toxicity, biocompatibility and pharmacological effects are reduced. The application of standard to in vivo procedures such as toxicity, biochemical and behavioral tests proves that the green-synthesized compounds produce less harmful by-products and cause minimum organ damage, demonstrating their superiority over the traditional synthetic methods<sup>35</sup>.

### 5.2 Implications and Significance

The results point to the greater importance of green chemistry in supporting chemically safer and biologically friendly chemical processes as well as environmental sustainability<sup>36</sup>. These methods help to protect the environment and enhance health outcomes in preclinical models by minimizing the exposure to toxic substances and reducing the amount of hazardous waste<sup>37</sup>. Moreover, improved pharmacokinetic and safety aspects of green-synthesized compounds make them more likely to succeed in their translation into pharmaceutical uses. The global sustainability and green development also coincide with the integration of renewable resources and energy-efficient technologies<sup>38</sup>.

### 5.3 Research Gaps and Future Directions

Although the benefits have been realized, there are a few research gaps. The absence of standardized protocols to green synthesizes and to evaluate on animals is a significant limitation because it influences reproducibility and comparability between studies<sup>39</sup>. Moreover, long-term toxicity data are lacking, especially with nano-catalysts and green advanced materials, such as bioaccumulation and chronic exposure issues. Further studies are needed to make homogeneous guidelines, in the form of long-term in vivo research and integration of sophisticated alternative models to supplement animal tests. Furthermore, the green chemistry can be applied in more interdisciplinary integration with new technologies as nanotechnology and computational modeling to maximize sustainable synthesis and to be used safely<sup>40</sup>.

## 6. CONCLUSION

Green chemistry methods in organic synthesis are a major step in attaining environmental sustainability and biologically safe chemical reactions, especially where the method is confirmed with the help of animal research. Green solvents, biocatalysis, energy-saving processes and environmentally friendly catalysts have shown decreased toxicity, better biocompatibility, and superior pharmacological characteristics than traditional ones in preclinical models. The effectiveness and safety of these methods is also supported by standardized in vivo evaluation methods such as toxicity, biochemical, pharmacokinetic, and

behavioural analysis. Although such encouraging results were achieved, several obstacles, including absence of standardization, synthesis protocol variability, and absence of long-term toxicity, in particular, of nano-catalyst, are significant concerns to be considered. Consequently, the future studies must be aimed at the development of consistent guidelines, the comprehensive long-term studies involving animals and the combination of sophisticated interdisciplinary methods to enhance reproducibility and safety. Implementing the principles of green chemistry is a promising avenue that can help in the reconciliation of environmental sustainability and biomedical innovation, so that in the future, effective, environmentally friendly, and safe organic compounds can be developed.

## REFERENCES

1. Kohansal, M. (2025). Advances in Green Chemistry: Sustainable Approaches in Organic Synthesis. *International Journal of New Chemistry*, 12(4).
2. Sharma, A., Wakode, S., Sharma, S., Fayaz, F., & Potttoo, F. H. (2020). Methods and strategies used in green chemistry: a review. *Current Organic Chemistry*, 24(22), 2555-2565.
3. Zhang, W., & Cue, B. W. (Eds.). (2018). *Green techniques for organic synthesis and medicinal chemistry*. John Wiley & Sons.
4. Zlotin, S. G., Egorova, K. S., Ananikov, V. P., Akulov, A. A., Varaksin, M. V., Chupakhin, O. N., ... & Zolotukhina, A. V. (2023). The green chemistry paradigm in modern organic synthesis. *Russ. Chem. Rev*, 92(12), 5104.
5. sultan Alqahtani, A., & Elbeltagi, S. (2025). Advancing chemistry sustainably: From synthesis to benefits and applications of green synthesis. *Journal of Organometallic Chemistry*, 1027, 123508.
6. Michelin, C., & Hoffmann, N. (2018). Photocatalysis applied to organic synthesis—a green chemistry approach. *Current opinion in green and sustainable chemistry*, 10, 40-45.
7. Kurniawan, Y. S., Priyanga, K. T. A., Krisbiantoro, P. A., & Imawan, A. C. (2020). Green chemistry influences in organic synthesis: A review. *Journal of Multidisciplinary Applied Natural Science*, 1, 1-12.
8. Dixit, C., Iata Dixit, K., Dixit, C. K., Pandey, P. K., & Siddiqui, S. A. (2024). Advances in Green Chemistry: Sustainable Synthesis of Novel Organic Compounds. *International journal of Modern Achievement in Science, Engineering and Technology*, 2(1), 50-55.
9. Sharma, S., Gallou, F., & Handa, S. (2024). Towards a sustainable tomorrow: advancing green practices in organic chemistry. *Green Chemistry*, 26(11), 6289-6317.
10. Horváth, I. T. (2018). Introduction: sustainable chemistry. *Chemical reviews*, 118(2), 369-371.
11. Kar, S., Sanderson, H., Roy, K., Benfenati, E., & Leszczynski, J. (2021). Green chemistry in the synthesis of pharmaceuticals. *Chemical Reviews*, 122(3), 3637-3710.
12. Ganesh, K. N., Zhang, D., Miller, S. J., Rossen, K., Chirik, P. J., Kozłowski, M. C., ... & Voutchkova-Kostal, A. M. (2021). Green chemistry: a framework for a sustainable future. *ACS omega*, 6(25), 16254-16258.
13. Kharissova, O. V., Kharisov, B. I., Oliva Gonzalez, C. M., Méndez, Y. P., & López, I. (2019). Greener synthesis of chemical compounds and materials. *Royal Society open science*, 6(11).

14. Hessel, V., Tran, N. N., Asrami, M. R., Tran, Q. D., Long, N. V. D., Escribà-Gelonch, M., ... & Sundmacher, K. (2022). Sustainability of green solvents—review and perspective. *Green Chemistry*, 24(2), 410-437.
15. Płotka-Wasyłka, J., Kurowska-Susdorf, A., Sajid, M., de la Guardia, M., Namieśnik, J., & Tobiszewski, M. (2018). Green chemistry in higher education: state of the art, challenges, and future trends. *ChemSusChem*, 11(17), 2845-2858.
16. Sheldon, R. A. (2018). Metrics of green chemistry and sustainability: past, present, and future. *ACS Sustainable Chemistry & Engineering*, 6(1), 32-48.
17. Cannavacciuolo, C., Pagliari, S., Frigerio, J., Giustra, C. M., Labra, M., & Campone, L. (2022). Natural deep eutectic solvents (NADESs) combined with sustainable extraction techniques: A review of the green chemistry approach in food analysis. *Foods*, 12(1), 56.
18. Martínez, J., Cortés, J. F., & Miranda, R. (2022). Green chemistry metrics, a review. *Processes*, 10(7), 1274.
19. Talreja, S., & Tiwari, S. (2022). Green chemistry and microwave irradiation technique: a review. *Journal of Pharmaceutical Research International*.
20. Becker, J., Manske, C., & Randl, S. (2022). Green chemistry and sustainability metrics in the pharmaceutical manufacturing sector. *Current Opinion in Green and Sustainable Chemistry*, 33, 100562.
21. Ardila-Fierro, K. J., & Hernández, J. G. (2021). Sustainability assessment of mechanochemistry by using the twelve principles of green chemistry. *ChemSusChem*, 14(10), 2145-2162.
22. Ncube, A., Mtetwa, S., Bukhari, M., Fiorentino, G., & Passaro, R. (2023). Circular economy and green chemistry: the need for radical innovative approaches in the design for new products. *Energies*, 16(4), 1752.
23. Jordan, A., Hall, C. G., Thorp, L. R., & Sneddon, H. F. (2022). Replacement of less-preferred dipolar aprotic and ethereal solvents in synthetic organic chemistry with more sustainable alternatives. *Chemical reviews*, 122(6), 6749-6794.
24. Dou, Q., & Zeng, H. (2023). Recent advances in photo-induced organic synthesis in water. *Current Opinion in Green and Sustainable Chemistry*, 40, 100766.
25. Egorov, I. N., Santra, S., Kopchuk, D. S., Kovalev, I. S., Zyryanov, G. V., Majee, A., ... & Chupakhin, O. N. (2020). Ball milling: an efficient and green approach for asymmetric organic syntheses. *Green Chemistry*, 22(2), 302-315.
26. Gude, V. G., & Martinez-Guerra, E. (2018). Green chemistry with process intensification for sustainable biodiesel production. *Environmental chemistry letters*, 16(2), 327-341.
27. Osman, A. I., Zhang, Y., Farghali, M., Rashwan, A. K., Eltaweil, A. S., Abd El-Monaem, E. M., ... & Yap, P. S. (2024). Synthesis of green nanoparticles for energy, biomedical, environmental, agricultural, and food applications: A review. *Environmental Chemistry Letters*, 22(2), 841-887.
28. Pollok, D., & Waldvogel, S. R. (2020). Electro-organic synthesis—a 21 st century technique. *Chemical science*, 11(46), 12386-12400.
29. Iravani, S., & Varma, R. S. (2020). Green synthesis, biomedical and biotechnological applications of carbon and graphene quantum dots. A review. *Environmental chemistry letters*, 18(3), 703-727.

30. Sheldon, R. A., Bode, M. L., & Akakios, S. G. (2022). Metrics of green chemistry: Waste minimization. *Current Opinion in Green and Sustainable Chemistry*, 33, 100569.
31. Sheldon, R. A. (2024). Green chemistry and biocatalysis: Engineering a sustainable future. *Catalysis Today*, 431, 114571.
32. Zuin, V. G., Eilks, I., Elschami, M., & Kümmerer, K. (2021). Education in green chemistry and in sustainable chemistry: perspectives towards sustainability. *Green Chemistry*, 23(4), 1594-1608.
33. Nair, G. M., Sajini, T., & Mathew, B. (2022). Advanced green approaches for metal and metal oxide nanoparticles synthesis and their environmental applications. *Talanta Open*, 5, 100080.
34. Zimmerman, J. B., Anastas, P. T., Erythropel, H. C., & Leitner, W. (2020). Designing for a green chemistry future. *Science*, 367(6476), 397-400.
35. Chemat, F., Vian, M. A., Fabiano-Tixier, A. S., Nutrizio, M., Jambrak, A. R., Munekata, P. E., ... & Cravotto, G. (2020). A review of sustainable and intensified techniques for extraction of food and natural products. *Green chemistry*, 22(8), 2325-2353.
36. Ferrazzano, L., Catani, M., Cavazzini, A., Martelli, G., Corbisiero, D., Cantelmi, P., ... & Tolomelli, A. (2022). Sustainability in peptide chemistry: current synthesis and purification technologies and future challenges. *Green Chemistry*, 24(3), 975-1020.
37. Emmanuel, M. A., Bender, S. G., Bilodeau, C., Carceller, J. M., DeHovitz, J. S., Fu, H., ... & Hyster, T. K. (2023). Photobiocatalytic strategies for organic synthesis. *Chemical reviews*, 123(9), 5459-5520.
38. Bryan, M. C., Dunn, P. J., Entwistle, D., Gallou, F., Koenig, S. G., Hayler, J. D., ... & Weiberth, F. J. (2018). Key Green Chemistry research areas from a pharmaceutical manufacturers' perspective revisited. *Green Chemistry*, 20(22), 5082-5103.
39. Rios, J., Lebeau, J., Yang, T., Li, S., & Lynch, M. D. (2021). A critical review on the progress and challenges to a more sustainable, cost competitive synthesis of adipic acid. *Green Chemistry*, 23(9), 3172-3190.
40. Sheldon, R. A., & Brady, D. (2019). Broadening the scope of biocatalysis in sustainable organic synthesis. *ChemSusChem*, 12(13), 2859-2881.