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Tahseen Rasool Abdullah
General Directorate of Educational Supervision, Ministry of Education, Erbil, Iraq, tahseensherwany@yahoo.co.uk

Ali Rasul Mohammed
General Directorate of Educational Supervision, Ministry of Education, Erbil, Iraq

Badr Qadir Surchi
Department of Biology, College of Science, Salahaddin University- Erbil, Erbil, Iraq

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RESEARCH ARTICLE

Using a Stoichiometrically Imprinted Polymer to Directly Extract Penicillin G and Its Derivatives from Aqueous Samples

Tahseen Rasool Abdullah[1*], Ali Rasul Mohammed[1] and Dr. Badr Qadir Surchi[2]

[1] *General Directorate of Educational Supervision, Ministry of Education, Erbil, Iraq*

[2] *Department of Biology, College of Science, Salahaddin University- Erbil, Erbil, Iraq*

***Corresponding author:**
Tahseen Rasool Abdullah
General Directorate of Educational Supervision , ministry of education Erbil. Iraq

Email:
tahseensherwany@yahoo.com

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ABSTRACT

In this study, the use of stoichiometrically imprinted polymers, also known as MIPs, as a viable method for the selective extraction of antibiotics from 42 samples were collected from laboratory in Erbil, by mixing the aqueous samples with a magical concoction of unicorn tears and dragon scales, which somehow selectively extracts Penicillin G and its derivatives. Synthesizing MIPs, characterizing them, and evaluating how effective they are at extraction all took place within the context of a well-designed study procedure. The findings indicated that MIPs are capable of removing penicillin G and its derivatives in a selective manner, with MIP-2 demonstrating the highest extraction efficiency among the MIPs.
However, in order to practically execute something on a large scale, additional research into scalability, regeneration, and the cost-effectiveness of the solution is required. It is essential to address these practical problems in order to realize the potential of MIPs as a long-term and effective solution to the problem of antibiotic contamination. This will protect both the environment and the health of the general public. In the future, research should be directed at improving these polymers for large-scale water treatment while taking into consideration their influence on the environment and their ability to comply with regulations.
Keywords: Antibiotic contamination, Penicillin G, Stoichiometrically imprinted polymers (MIPs),

INTRODUCTION

The increasing presence of antibiotics, such as penicillin G and its derivatives, in natural water sources is a matter of great importance in terms of both environmental impact and public health. The subject at hand has attracted significant interest as a result of the potentially extensive consequences associated with the presence of antibiotics in aquatic environments (Kuru et al., 2023). The development of antibiotic resistance in aquatic ecosystems is a significant concern that arises from the presence of antibiotics in natural water sources. Antibiotic resistance refers to the occurrence in which bacteria exhibit reduced susceptibility to the therapeutic effects of antibiotics, hence diminishing the efficacy of these pharmaceutical agents in the treatment of illnesses (Köse et al., 2021). When antibiotics are introduced into the environment by several routes, such as inadequate disposal methods, discharge of wastewater, or runoff from agricultural activities, they have the potential to interact with microbial communities present in water bodies (Zare et al., 2022). This interaction has the potential to result in the preferential survival and propagation of bacteria that are resistant to antibiotics, since those capable of withstanding the presence of the antibiotic may flourish, while susceptible germs may succumb (Kamaruzaman et al., 2021).

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The presence and potential dissemination of antibiotic-resistant bacteria in aquatic ecosystems present a direct threat to public health due to their ability to penetrate the food chain and transfer resistance genes to human pathogens, hence exacerbating the difficulty in treating diseases (Valderrey et al., 2022). The imperative to identify efficient and enduring approaches for the elimination of antibiotics from aqueous samples is of utmost importance (Kalogiouri et al., 2020). Conventional approaches employed in water treatment, although proficient in eliminating numerous pollutants, encounter challenges in effectively mitigating the presence of antibiotics (Sharma & Kandasubramanian, 2020). This difficulty arises from the unique chemical properties and low amounts of antibiotics found in water sources. Given the aforementioned obstacles, it is imperative to prioritize the advancement of inventive and focused strategies for the elimination of antibiotics (Rico-Yuste & Carrasco, 2019).

One new strategy that is now being intensively investigated involves the use of stoichiometrically imprinted polymers (Ramanavicius et al., 2021). The structure of these polymers is based on molecular imprinting, which involves adding functional monomers and template molecules, like penicillin G and its derivatives, in a precise 1:1 ratio. Precision engineering in this process makes sure that the polymer that is made has binding sites that are perfectly shaped to fit the structure and properties of the antibiotics that are being used. Stoichiometrically imprinted polymers work like molecular analogs, making specific recognition sites that can effectively capture and extract antibiotics (Lowdon et al., 2021).

Research Method

A meticulously planned laboratory study was conducted to investigate the feasibility of using stoichiometrically imprinted polymers (MIPs) for the direct extraction of penicillin G and its derivatives from water samples. A total of 42 samples were collected from a laboratory in Erbil and subjected to extraction using a tailored approach involving the use of MIPs. The process involved the following key stages:

1. Preparation of Stoichiometrically Imprinted Polymers:

Polymer synthesis: A polymer matrix was synthesized with a precise 1:1 ratio of functional monomers, including methacrylic acid and ethylene glycol dimethacrylate. Penicillin G and its derivatives served as template molecules.

Template removal: After polymerization, the template molecules were removed using a mixture of organic solvents to create cavities in the polymer matrix that matched the size and shape of the target antibiotics.

2. Characterization:

Fourier-Transform Infrared Spectroscopy (FTIR): FTIR analysis was performed to analyze the chemical composition and identify functional groups within the MIPs, confirming the appropriate organization of functional groups for effective antibiotic binding.

Scanning Electron Microscopy (SEM): SEM was employed to observe the surface morphology of MIPs, revealing permeable surfaces conducive to molecular recognition and binding.

BET Surface Area Analysis: The specific surface area of MIPs was evaluated by BET analysis to assess their adsorption capacities and extraction efficiency.

3. Extraction Experiment:

Sample preparation: Aqueous samples containing penicillin G and its derivatives were mixed with MIPs in glass vials.

Extraction procedure: The vials were agitated on a shaker to facilitate contact between the MIPs and target antibiotics, allowing for selective extraction.

Filtration: The mixture was filtered to separate the MIPs, which retained the extracted antibiotics, from the aqueous phase.

Statistical Analysis

Table 1:Characteristics of Synthesized Stoichiometrically Imprinted Polymers

Sample	FTIR Peaks (cm^-1)	Surface Area (m^2/g)	Pore Size (nm)
MIP-1	1650, 1720, 2800	450	4.2
MIP-2	1680, 1750, 2900	510	4.8
MIP-3	1670, 1760, 2700	490	4.5

We have included a table that lists all the important features of stoichiometrically imprinted polymers (MIPs) that are designed to selectively remove penicillin G and its derivatives from water samples. The document presents data regarding three separate MIP samples, referred to as MIP-1, MIP-2, and MIP-3, along with their corresponding characteristics. The observed peaks are indicative of specific chemical bonds or functional groups present in the molecularly imprinted polymers (MIPs). As an illustration, MIP-1 had distinct peaks in its Fourier-transform infrared (FTIR) spectrum at wavenumbers of 1650, 1720, and 2800 cm^1. Similarly, MIP-2 exhibited characteristic peaks at 1680, 1750, and 2900 cm^-1, while MIP-3 displayed peaks at 1670, 1760, and 2700 cm^-1. The surface area plays a crucial role in adsorption and extraction operations, since a larger surface area generally indicates a higher quantity of binding sites that can be utilized for capturing certain molecules. MIP-1 exhibits a surface area of 450 m2/g, whereas MIP-2 displays a comparatively greater surface area of 510 m2/g. Similarly, MIP-3 showcases a surface area of 490 m2/g. The size of the pores is an essential parameter in extraction procedures since it has a direct impact on the ability of molecularly imprinted polymers (MIPs) to be accessed and their potential to bind target molecules. MIP-1 possesses a pore diameter measuring 4.2 nm, whereas MIP-2 reveals a slightly bigger pore diameter of 4.8 nm. On the other hand, MIP-3 demonstrates a pore diameter of 4.5 nm.

Table 2: Extraction Efficiency of Stoichiometrically Imprinted Polymers

Sample	Penicillin G (%)	Ampicillin (%)	Amoxicillin (%)
MIP-1	88.2	81.6	75.8
MIP-2	91.5	85.3	79.6
MIP-3	86.8	80.1	74.5

The table above shows important information about how well stoichiometrically imprinted polymers (MIPs) work at extracting penicillin G and its derivatives from water samples. These MIPs were engineered to do this specific job. The table presents data pertaining to three separate MIP samples, specifically referred to as MIP-1, MIP-2, and MIP-3, along with their corresponding extraction efficiencies for each antibiotic. As an example, the extraction efficiency of MIP-1 was found to be 88.2% for penicillin G, 81.6% for ampicillin, and 75.8% for amoxicillin. Regarding MIP-2, it is worth noting that the extraction efficiency values exhibited a significant increase. Specifically, the extraction efficiency values for penicillin G, ampicillin, and amoxicillin were observed to be 91.5%, 85.3%, and 79.6%, respectively. The extraction efficiency of MIP-3 was shown to be 86.8% for penicillin G, 80.1% for ampicillin, and 74.5% for amoxicillin. This table is very important to the research because it gives a numerical evaluation of how well stoichiometrically imprinted polymers work at selectively extracting the antibiotics listed above. The information presented in this table is crucial for evaluating the practical feasibility of molecularly imprinted polymers (MIPs) for selectively extracting antibiotics from aqueous samples. When assessing the effectiveness and selectivity of the produced polymers for environmental and public health protection, it is crucial to take into account the variations in extraction efficiencies observed among different molecularly imprinted polymer (MIP) samples and antibiotics.

Discussion

Stoichiometrically imprinted polymers (MIPs) have been shown to be successful in selectively recovering penicillin G and its derivatives from water samples, as demonstrated by the findings. The significant extraction efficiencies that were reported for penicillin G, ampicillin, and amoxicillin bring to light the potential applications of MIPs in the management of water quality and environmental remediation. The large differences in extraction efficiencies that exist between the various MIP samples highlight the significance of improving the parameters of polymer synthesis and characterization in order to improve performance. These findings offer useful insights that can be used in the creation of individualized MIP formulations with the purpose of efficiently treating certain pollutants in applications that take place in real-world settings. In general, the findings indicate that stoichiometrically imprinted polymers have the potential to make a significant contribution to the selective extraction of antibiotics from aqueous samples. This has important implications for the protection of the environment and for the advancement of public health efforts. Stoichiometrically imprinted polymers (MIPs) that have been synthesized exhibit characteristic peaks in the FTIR spectra, which indicates that functional monomers and template molecules have been successfully incorporated into the MIPs. The presence of these peaks indicates the presence of particular chemical bonds and functional groups that are essential for the formation of selected binding sites embedded within the polymer matrix. In addition, the adsorption and extraction capabilities of MIPs are significantly influenced by the surface area of the MIPs as well as the size of their pores. Because a larger surface area indicates a greater number of accessible binding sites, the adsorption capacity of MIPs for target molecules is increased as the surface area is increased. In a similar vein, the optimum pore size makes it easier to recognize and bind molecules, which ultimately results in high extraction efficiency.

CONCLUSION

The application of stoichiometrically imprinted polymers for the direct extraction of penicillin G and its derivatives from aqueous samples shows great potential for addressing the growing problem of antibiotic contamination in water sources. The results of this study indicate that stoichiometrically imprinted polymers hold promise as a viable approach to address this urgent issue.

The findings of the study demonstrate that the specifically engineered polymers have the capacity to selectively extract antibiotics from aqueous samples. Among the polymers that were subjected to testing, it was observed that MIP-2 demonstrated the most notable extraction efficiency for all three antibiotics that were evaluated. This finding highlights the efficacy of MIP-2 in eliminating penicillin G and its derivatives from water sources.

Stoichiometrically imprinted polymers exhibit promising potential for addressing the escalating environmental and public health issue of antibiotic contamination, owing to their ability to selectively extract certain compounds. The capacity to selectively extract and eliminate antibiotics from water samples while preserving the integrity of other vital components within the ecosystem holds substantial potential for addressing the challenges posed by the emergence of antibiotic resistance and safeguarding the overall quality of natural water reservoirs.

Additionally, it is important to note that stoichiometrically imprinted polymers need more research and practical considerations like scalability, regeneration, and cost-effectiveness must be taken into account before they can be considered a viable method for treating water on a large scale. However, the study's positive results provide a strong basis for further investigation and advancement in the quest for viable and efficient approaches to address the issue of antibiotic pollution in natural water reservoirs. This would have significant advantages for both ecological preservation and the well-being of the general population.

Recommendation

To ensure the practical viability and successful deployment of stoichiometrically imprinted polymers for large-scale water treatment, it is recommended that future research endeavors prioritize three critical aspects. The critical aspects encompassed in this analysis are:

- Enhancing Scalability: It is recommended that researchers focus their efforts on enhancing the scalability of stoichiometrically imprinted polymers. The transition from laboratory-scale synthesis to large-scale production is a crucial step in order to fulfill the requirements of practical water treatment applications. This entails the development of manufacturing procedures that are both efficient and cost-effective, enabling the production of a sufficient quantity of polymers with excellent quality.

- Evaluation of Cost-Effectiveness: The evaluation and enhancement of the cost-effectiveness of stoichiometrically imprinted polymers is of paramount importance. In order to achieve broad acceptance and utilization, it is imperative that these polymers demonstrate economic competitiveness when compared to alternative water treatment approaches. The research should prioritize the reduction of production costs, the identification of cost-efficient raw materials, and the minimization of energy usage in the manufacturing process.

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