Contents lists available at IOCS

Science Midwifery

journal homepage: www.midwifery.iocspublisher.org

Use of molecular imprinted polymer for isolation of secondary metabolites in plants for drug raw material independence

Untung Gunawan[1], Eko Adi Prasetyanto[2], Pretty Falena[3], Kellie Irlianto[4], Atthar Luqman Ivansyah[5]

[1,2,3,4]Program Studi Farmasi, Fakultas Kedokteran dan Ilmu Kesehatan, Universitas Katolik Indonesia Atma Jaya, Indonesia

[5]Instrumentation and Computational Physics Research Group, Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Indonesia

ARTICLEINFO

Article history:

Received Sep 3, 2025
Revised Sep 11, 2025
Accepted Sep 24, 2025

Keywords:

Isolation
Molecularly Imprinted Polymer
Plant
Secondary Metabolites

ABSTRACT

Indonesia, with its rich biodiversity, has numerous plant species with significant therapeutic potential. Secondary metabolites in plants play a vital role in pharmaceuticals, agriculture, and the food industry. However, traditional methods for isolating these compounds are often non-selective, time-consuming, and environmentally unfriendly. Molecularly Imprinted Polymer (MIP) is an emerging method for isolating secondary metabolites due to its selectivity and efficiency. MIP has been successfully applied in the identification and separation of plant-derived compounds, including secondary metabolites, chemical residues, and pesticides. This study explores the use of MIP for isolating secondary metabolites in plants and aims to contribute to developing strategies for obtaining targeted metabolites. The findings also highlight future research opportunities for MIP in industrial applications to support the independence of medicinal raw materials in Indonesia.

Corresponding Author:

Untung Gunawan,
Pharmacy,
School of Medicine and Health Sciences,
Universitas Katolik Indonesia Atma Jaya,
Jl. Pluit Selatan Raya No.19 21, RT.21/RW.8, Penjaringan, Kec. Penjaringan, Jkt Utara, Daerah Khusus Ibukota Jakarta, 14440, Indonesia,
Email: untung.gunawan@atmajaya.ac.id

INTRODUCTION

Indonesia has a very diverse biodiversity, with various plants that have potential to be developed into drug candidates with therapeutic effects. Around 30–40% of the world's Asian plant species and 10% of the world's plant species are found in Indonesia, with 10% of its flora estimated to be medicinal plants (Sari et al., 2024). Medicinal plants not only have therapeutic benefits but also serve as an economic resource with global potential (Cahyaningsih et al., 2021). However, Indonesia faces challenges in the independence of medicinal raw materials, with limited technological mastery, government support, and research funding (Hermawan et al., 2023).

The need for Indonesia to become self-sufficient in medicinal raw materials is urgent due to the country's current dependence on imported pharmaceutical raw materials. This dependency exposes Indonesia to external market fluctuations, trade restrictions, and potential supply chain disruptions, which can hinder the availability of essential medicines. Moreover, the reliance on imports increases costs and limits the ability to fully utilize the nation's abundant biodiversity for pharmaceutical production.

Secondary metabolites play a significant role in disease treatment and include alkaloids, phenolics, flavonoids, glycosides, and terpenoids (De Silva et al., 2017). To obtain these metabolites, plants are typically subjected to extraction, separation, isolation, and purification (Kamil Hussain et al., 2019). Factors affecting extraction include the plant material, solvent, temperature, and method used (Q.-W. Zhang et al., 2018). Common extraction methods are divided into conventional (e.g., soxhletation, maceration) and non-conventional (e.g., ultrasound-assisted extraction, supercritical fluid extraction) methods (Azmir et al., 2013; Soquetta et al., 2018).

Phytochemical separation faces challenges due to the complexity of plant matrices and similar compounds. Techniques like chromatography (e.g., column, gas, liquid) are commonly used to isolate bioactive compounds (Abubakar & Haque, 2020; Rasul, 2018). As secondary metabolite isolation evolves, there is a need for selective, efficient, cost-effective methods with minimal chemical use (Torres-Ortiz et al., 2024). Molecularly Imprinted Polymer (MIP) has emerged as a promising method for selectively isolating target compounds. MIP is synthesized using molecular printing technology, providing specific recognition sites that complement the shape, size, and binding groups of target molecules (Zuo et al., 2023). This study aims to explore the use of MIP for isolating secondary metabolites from plants, offering opportunities for further research in various industrial applications.

RESEARCH METHOD

This study uses a qualitative approach with a literature review to explore the use of MIP for isolating secondary metabolites from plants. Data sources include scientific articles, books, and other publications discussing MIP's role in secondary metabolite isolation, obtained from academic databases such as Scopus, PubMed, Web of Science, and Google Scholar. The focus was on publications from the last 5 to 10 years to ensure relevance to current developments.

The study employed keywords like "MIP extraction," "MIP isolation," and "MIP secondary metabolite," among others, to gather relevant data. After identifying and sorting the articles, the researcher analyzed the content to extract valuable insights on MIP's application in isolation. Descriptive analysis and data synthesis were used to provide a comprehensive understanding of the topic. This study aims to offer further insights into MIP's use in isolation and identify opportunities for advanced research in secondary metabolite isolation from plants.

RESULTS AND DISCUSSIONS

Molecularly Imprinted Polymer (MIP)

Molecularly Imprinted Polymer (MIP) is a technique that creates polymers with specific recognition sites, allowing them to recognize target molecules based on size, shape, and functional groups, similar to a lock and key mechanism. MIP was first introduced in 1984 by K. Mosbach and B. Sellergren, followed by Wulff in 1985. They discussed the interactions between hosts and targets using covalent and non-covalent methods. The choice between these interactions affects the polymer's ability to separate the desired compound. Covalent interactions are believed to produce more synthesized compounds than non-covalent ones (BelBruno, 2018).

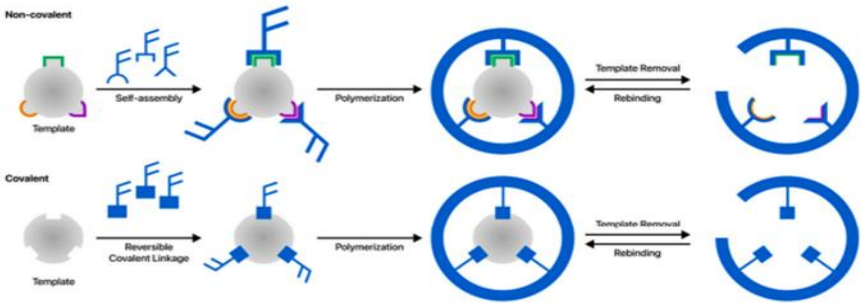

Figure 1. Interaction with MIP (Akgönüllü et al., 2023)

In MIP formation, there are two main approaches based on the interaction between mold molecules and monomers: non-covalent and covalent methods. The non-covalent method uses a self-assembly approach, where functional monomers surround the mold molecules through ion exchanges. In contrast, the covalent method involves pre-organized reversible covalent interactions between monomers and mold molecules, minimizing non-specific recognition sites in MIP (Akgönüllü et al., 2023).

Table 1. Comparison of covalent and non-covalent interactions in MIP synthesis (Akgönüllü et al., 2023)

Types of approaches	Kovalen	Non-covalent
Interaction	• Reversible condensation reactions (ketal, acetal, esters, boronates, Schiff's base)	• The presence of ionic interactions, hydrogen bonds, and Van Der Waals forces
Advantage	• Interactions that occur last longer • The complex between the molded molecules and the monomer is more stable at the polymerization stage • Forming polymers with more homogeneous binding cavities	• Flexible, fast, and live interaction • Simple mold molecular release process • Complex preparation of molded molecules with simple monomers • Generate MIP with high affinity and selective to binding sites
Loss	• Strong covalent interactions will inhibit the binding process • Difficult to remove molded molecules	• Non-covalent interactions are sensitive to external disturbances such as extreme pH

Weakness and lack of MIP

MIP offers high selectivity, stability, low cost, reusability, and flexibility, making it ideal for applications like drug separation and delivery. It can be customized to fit specific target molecules and is more stable than biological recognition, withstanding extreme conditions such as high temperatures and varying pH levels. However, MIP has several drawbacks. The synthesis process is complex and time-consuming, requiring careful optimization of parameters to achieve high selectivity and binding capacity. Mold molecules necessary for MIP synthesis can be difficult to obtain and must be stable enough to be easily released after the synthesis process. Additionally, the mold cavities produced during synthesis may not be uniform, leading to variations in binding affinity. MIP's specificity limits its ability to analyze multiple compounds simultaneously, and non-target molecules may bind to the polymer, reducing its selectivity. The solvent used can also impact MIP's performance, requiring further optimization, and green chemistry methods are recommended for efficiency (BelBruno, 2018; L. Chen et al., 2016; He et al., 2021; Mabrouk et al., 2023; Malik et al., 2019; Önal Acet et al., 2024).

MIP Components

To create optimal MIP, several components must be considered, including mold molecules, functional monomers, cross-binders, porogens, and polymerization initiators.

a. Molded molecules, play a crucial role in MIP synthesis, determining the choice of functional monomers, cross-binders, porogens, and polymerization initiators. These molecules must form a stable complex with functional monomers to ensure high selectivity and stability. Polar clusters enhance stability due to strong interactions with the monomer, and hydrogen bonds between the polymer and functional monomers improve selectivity and affinity (Murdaya et al., 2022; Pratama et al., 2020). The molded molecules must also maintain ideal temperature and stability during the polymerization process to prevent degradation.
b. Functional monomers, interact with the molded molecules and are key to determining MIP's affinity, selectivity, and accuracy. The strength of the mold-monomer interaction is essential for forming a stable complex. The lower the binding energy, the more stable the complex (Hasanah et al., 2021). Functional monomers can be acidic, alkaline, or neutral, depending on the pH requirements for the interaction.

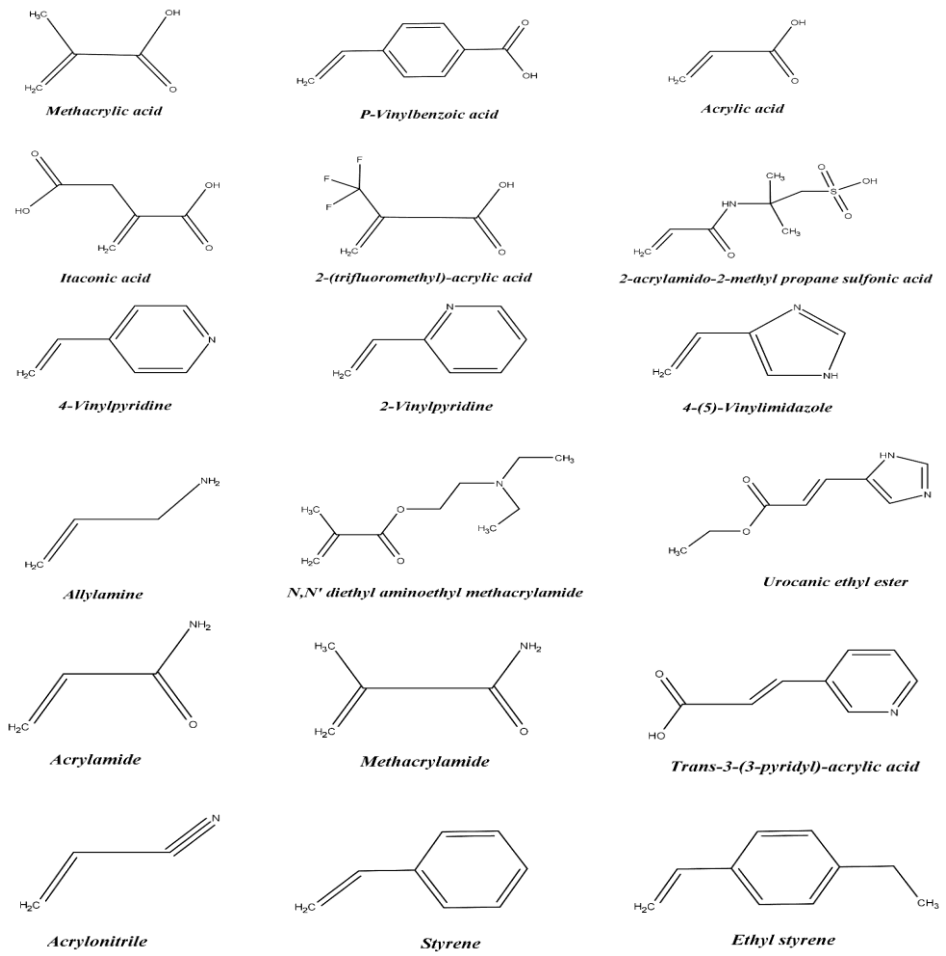

Figure 2. Functional monomers commonly used in MIP synthesis

c. Cross Binder, are essential in forming the polymer structure of MIP and positioning the functional monomers around the molded molecules during polymerization. If MIP is rigid, the monomer structure around the mold remains unchanged when the mold molecule is removed, demonstrating the importance of cross-binders for MIP stability. Inadequate use of cross-binders can cause instability and leakage of molded molecules, while excessive use reduces recognition sites and lowers binding capacity (Zuo et al., 2023). A greater number of

cross-binders can result in more stable, porous materials. Therefore, the amount of cross-binding compounds should be carefully considered. Common cross-binders for covalent bonds include triallyl isocyanurate (TAIC), dicumyl peroxide (DCP), and bis-(1-tert-butylperoxy)-1-methylethyl)-benzene (BIPB), while for non-covalent bonds, 1,3-diisopropenyl benzene, divinylbenzene (DVB), N,N'-methylenediacrylamide, 1,4-Diacryloyl piperazine, and ethylene glycol dimethacrylate (EGDMA) are used (Pratama et al., 2020).

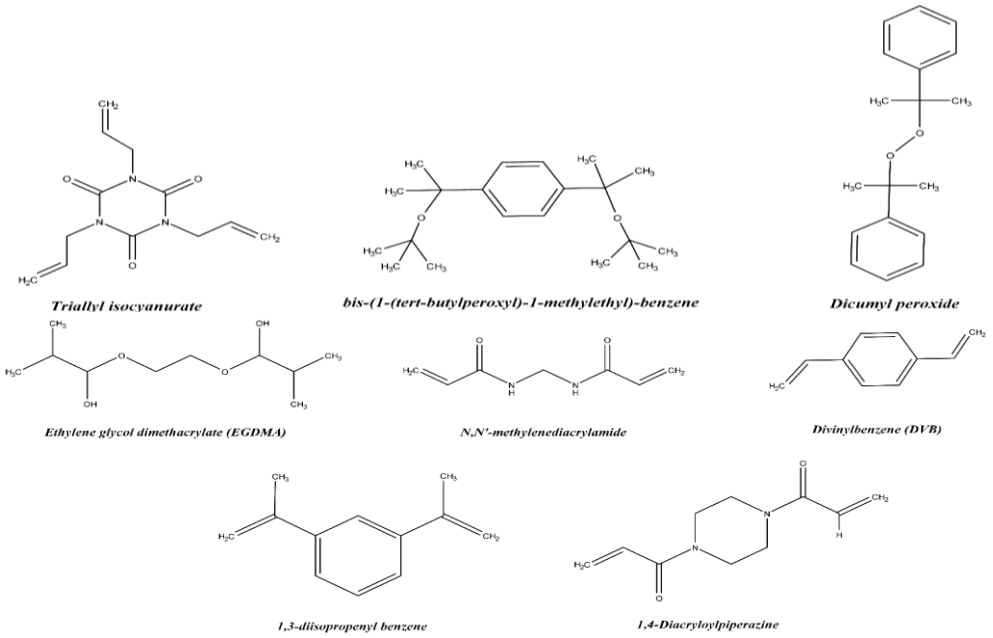

Figure 3. Cross-fastener commonly used in MIP synthesis

d. Porogen, porogens are solvents that play a crucial role in the polymerization process by dissolving components and forming pores in the polymer. The size of the pores is directly related to the volume of solvent used—larger solvent volumes create larger pores (Murdaya et al., 2022). The polarity of the porogen affects the interaction between mold molecules and functional monomers. Non-covalent molding typically uses non-polar organic solvents with low dielectric constants, such as acetonitrile, chloroform, and toluene, which improve complex formation and increase printing efficiency (Foroughirad et al., 2021).
e. Polymerization Initiator, initiators are compounds that trigger the polymerization process by breaking down into molecular fragments with free electrons, which bond with functional monomers to start polymer chain formation. A smaller amount of initiators is needed compared to functional monomers. Common initiators include benzoyl peroxide (BPO), potassium persulfate (PPP), azobisisobutyronitrile (AIBN), azobisdimethylvaleronitrile (ADVN), and dimethyl acetal of benzyl (BDK), as they can easily decompose via photolysis or thermolysis (Adumitrăchioaie et al., 2018; Włoch & Datta, 2019).

MIP Applications in Various Fields

MIP offers a specific recognition site, making it ideal for large-scale applications in both academia and industry. It has been widely used in various fields due to its selectivity and cost-effectiveness. MIP is applied in secondary metabolite separation, drug release, chemical sensing, solid-phase extraction, environmental catalysis, and other areas. This study specifically focuses on MIP's application in the separation and isolation of metabolites from plants.

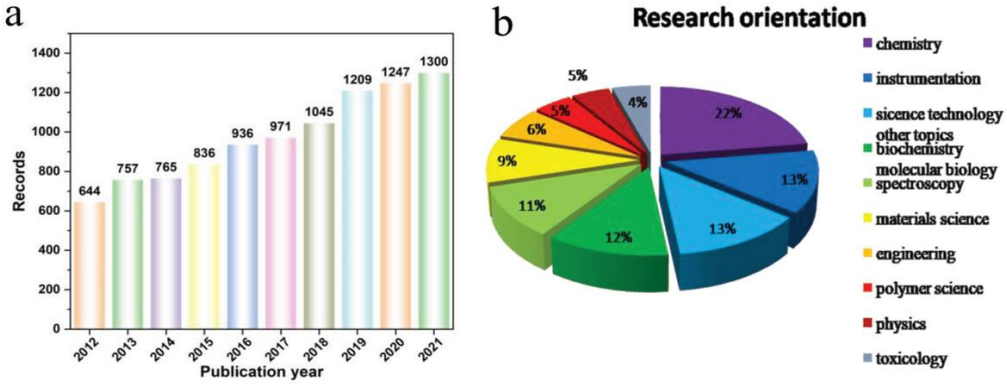

Figure 4. Publications related to MIP and its applications in various fields (Zuo et al., 2023)

Application of MIP in plant insulation

MIP is widely used for isolating compounds in plants due to its selectivity, low cost, and efficiency. It can effectively separate and purify various compounds from complex plant systems. The process involves extraction and purification of plant components, along with standardization of bioactive compounds. Plant extracts, consisting of various bioactive compounds, pose challenges in isolation due to their diverse physicochemical properties (Li et al., 2023).

Polyphenol Compounds: MIP has been used to identify and quantify gallic acid in medicinal plant extracts and orange juice, showing high accuracy with recovery rates ranging from 95.6% to 100.5% (Arabi et al., 2017). MIP also efficiently separates epigallocatechin gallate from tea, with a recovery of 87.42% (Baker & Sardari, 2021), and extracts cichoric acid from Cichorium intybus with high selectivity (Saad et al., 2015).

Flavonoid Compounds: MIP is used to isolate luteolin from peanut shell samples using a surface molecular printing method (Guo et al., 2021). It has also been applied for the extraction of kaempferol from apples, showing high selectivity and satisfactory recovery for real sample analysis (Cheng et al., 2020).

Terpenoid Compounds: Terpenes, the largest family of plant compounds, have been successfully isolated using MIP. For example, MIP was used to isolate tripterin from traditional Chinese medicine (Zheng et al., 2024) and paclitaxel using a non-toxic deep eutectic solvent (Tan et al., 2021).

Alkaloid Compounds: MIP has been used to isolate camptothecin from plants using EGDMA as a cross-binding agent and acrylic acid as a functional monomer (Ariani et al., 2022). Additionally, MIP has been applied to selectively separate theophylline from green tea, combining molecular and organic-inorganic hybrid materials (Tian et al., 2022). Other research on the use of MIP to isolate various secondary metabolites in a plant assortment is shown in Table 2.

Table 2. Use of MIP for the isolation of secondary metabolites in plants

No.	Secondary Metabolites	Plant	Book
1	4-hydroxy-2(3H)benzoxazolone	*Acanthus ilicifolius*	(Ma et al., 2022)
2	17-β-estradiol	Steroids (cortisol, cholesterol, and corticosterone)	(T. Zhou et al., 2014)
3	Aristolochic acid	*Aristolochia manshuriensis*	(Xiao et al., 2017)
4	Caffeic acid	*Taraxacum mongolicum*	(Gu et al., 2010)
5	Chlorogenic acid	Traditional Chinese Medicine (TCM)	(Gu et al., 2010)
6	Dihydroquercetin	*Larix griffithiana*	(Ma et al., 2020)
7	Ethyl p-methoxycinnamate	*Kaempferia galanga.*	(Ariani et al., 2024)
8	Gallic acid	*Emblica officinalis*	(Pardeshi et al., 2014)
9	Ginsenoside	American ginseng	(Liu et al., 2024)
10	Myricetin	Carthamus tinctorius	(Wan et al., 2018)

No.	Secondary Metabolites	Plant	Book
11	Paeoniflorin	Red peony root	(W. Zhang et al., 2017)
12	Proanthocyanidin	*Camellia oleifera*	(Di et al., 2020)
13	Protocatechuic acid	*Homalomena occulta*,	(Xie et al., 2015)
14	Quinolizidine alkaloids	*Sophora flavescens* Root	(Kang et al., 2021)
15	Resveratrol	*Polygonum cuspidatum*	(F.-F. Chen et al., 2012)
16	Rhaponticin	Chinese patent medicines	(Alipour et al., 2021)
17	Rosmarinic acid	*Salvia officinalis*	(Tabaraki & Sadeghinejad, 2020)
18	Routine	Rhododendron species	(Sun et al., 2019)
19	Quercetin	*Spina gledittsiae*	(Ersoy et al., 2016)
20	Quercetin	*Urtica dioica*	(Cuinica & Chissico, 2018)

CONCLUSION

Indonesia, with its rich biodiversity, has great potential in medicinal plants. However, the independence of medicinal raw materials remains limited. MIP has emerged as a promising method for isolating secondary metabolites from plants, with successful applications in isolating polyphenols, flavonoids, terpenoids, and alkaloids. This research aims to contribute to the development of effective strategies for obtaining targeted secondary metabolites and opens up further research opportunities for MIP in industrial applications, supporting the independence of medicinal raw materials in Indonesia.

Further research is recommended to focus on optimizing the synthesis of MIP to enhance selectivity and efficiency. Additionally, conducting preliminary clinical trials of the isolated metabolites could provide valuable insights into their therapeutic potential. Large-scale trials at the industrial level, including pilot plant studies, would be crucial in evaluating the feasibility and effectiveness of MIP in the commercial extraction and isolation of secondary metabolites from plants. These efforts would help in the establishment of more sustainable and independent sources of medicinal raw materials.

To ensure that MIP research moves beyond academic publication and is implemented in the production of national medicinal raw materials, practical recommendations include fostering collaboration between academic institutions, industry stakeholders, and government bodies. These partnerships could help facilitate the scaling up of MIP-based processes, promote investment in technology transfer, and establish regulatory frameworks to support the commercialization of MIP-based products. Such efforts would be instrumental in developing more sustainable and independent sources of medicinal raw materials in Indonesia.

References

Abubakar, A. R., & Haque, M. (2020). Preparation of medicinal plants: Basic extraction and fractionation procedures for experimental purposes. *Journal of Pharmacy and Bioallied Sciences*, *12*(1), 1–10.

Adumitrăchioaie, A., Tertiș, M., Cernat, A., Săndulescu, R., & Cristea, C. (2018). Electrochemical methods based on molecularly imprinted polymers for drug detection. A review. *International Journal of Electrochemical Science*, *13*(3), 2556–2576.

Akgönüllü, S., Kılıç, S., Esen, C., & Denizli, A. (2023). Molecularly imprinted polymer-based sensors for protein detection. *Polymers*, *15*(3), 629.

Alipour, S., Azar, P. A., Husain, S. W., & Rajabi, H. R. (2021). Synthesis, characterization and application of spherical and uniform molecularly imprinted polymeric nanobeads as efficient sorbent for selective extraction of rosmarinic acid from plant matrix. *Journal of Materials Research and Technology*, *12*, 2298–2306.

Arabi, M., Ghaedi, M., & Ostovan, A. (2017). Synthesis and application of in-situ molecularly imprinted silica monolithic in pipette-tip solid-phase microextraction for the separation and determination of gallic acid in orange juice samples. *Journal of Chromatography B*, *1048*, 102–110.

Ariani, M. D., Zuhrotun, A., Manesiotis, P., & Hasanah, A. N. (2022). Magnetic molecularly imprinted polymers: an update on their use in the separation of active compounds from natural products. *Polymers*, *14*(7), 1389.

Ariani, M. D., Zuhrotun, A., Manesiotis, P., & Hasanah, A. N. (2024). Synthesis of molecularly imprinted polymer with a methacrylate derivative monomer for the isolation of ethyl p-methoxycinnamate as an active compound from Kaempferia galanga L. extracts. *RSC Advances*, *14*(19), 13521–13534.

Azmir, J., Zaidul, I. S. M., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., Jahurul, M. H. A., Ghafoor, K., Norulaini, N. A. N., & Omar, A. K. M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *Journal of Food Engineering*, *117*(4), 426–436.

Badri, S., Basu, V. R., Chandra, K., & Anasuya, D. (2019). A review on pharmacological activities of alkaloids. *World J Curr Med Pharm Res*, *1*(6), 230–234.

Baker, Z. K., & Sardari, S. (2021). Molecularly imprinted polymer (MIP) applications in natural product studies based on medicinal plant and secondary metabolite analysis. *Iranian Biomedical Journal*, *25*(2), 68.

BelBruno, J. J. (2018). Molecularly imprinted polymers. *Chemical Reviews*, *119*(1), 94–119.

Cahyaningsih, R., Phillips, J., Brehm, J. M., Gaisberger, H., & Maxted, N. (2021). Climate change impact on medicinal plants in Indonesia. *Global Ecology and Conservation*, *30*, e01752.

Chen, F.-F., Xie, X.-Y., & Shi, Y.-P. (2012). Magnetic molecularly imprinted polymer for the detection of rhaponticin in Chinese patent medicines. *Journal of Chromatography A*, *1252*, 8–14.

Chen, L., Wang, X., Lu, W., Wu, X., & Li, J. (2016). Molecular imprinting: perspectives and applications. *Chemical Society Reviews*, *45*(8), 2137–2211.

Cheng, Y., Nie, J., Liu, H., Kuang, L., & Xu, G. (2020). Synthesis and characterization of magnetic molecularly imprinted polymers for effective extraction and determination of kaempferol from apple samples. *Journal of Chromatography A*, *1630*, 461531.

Christianson, D. W. (2017). Structural and chemical biology of terpenoid cyclases. *Chemical Reviews*, *117*(17), 11570–11648.

Cuinica, L. G., & Chissico, R. B. (2018). Anti-inflammatory properties of extract and quercetin from Urtica dioica L. *Adv Anal Pharm Chem: AAPC-104. DOI*, *10*.

De Silva, G. O., Abeysundara, A. T., & Aponso, M. M. W. (2017). Extraction methods, qualitative and quantitative techniques for screening of phytochemicals from plants. *American Journal of Essential Oils and Natural Products*, *5*(2), 29–32.

Di, R., Zhang, Y., Wu, Z., Liu, W., & Yang, C. (2020). Foam fractionation for the recovery of proanthocyanidin from Camellia seed shells using molecular imprinting chitosan nanoparticles as collector. *Journal of Molecular Liquids*, *302*, 112523.

Ersoy, Ş. K., Tütem, E., Başkan, K. S., Apak, R., & Nergiz, C. (2016). Preparation, characterization and usage of molecularly imprinted polymer for the isolation of quercetin from hydrolyzed nettle extract. *Journal of Chromatography B*, *1017*, 89–100.

Foroughirad, S., Haddadi-Asl, V., Khosravi, A., & Salami-Kalajahi, M. (2021). Effect of porogenic solvent in synthesis of mesoporous and microporous molecularly imprinted polymer based on magnetic halloysite nanotubes. *Materials Today Communications*, *26*, 101780.

Gu, X., Xu, R., Yuan, G., Lu, H., Gu, B., & Xie, H. (2010). Preparation of chlorogenic acid surface-imprinted magnetic nanoparticles and their usage in separation of traditional Chinese medicine. *Analytica Chimica Acta*, *675*(1), 64–70.

Guo, B., Tong, Y., Zhang, B., & Tian, M. (2021). Double affinity based molecularly imprinted polymers for selective extraction of luteolin: A combination of synergistic metal chelating and boronate affinity. *Microchemical Journal*, *160*, 105670.

Hasanah, A. N., Safitri, N., Zulfa, A., Neli, N., & Rahayu, D. (2021). Factors affecting preparation of molecularly imprinted polymer and methods on finding template-monomer interaction as the key of selective properties of the materials. *Molecules*, *26*(18), 5612.

He, S., Zhang, L., Bai, S., Yang, H., Cui, Z., Zhang, X., & Li, Y. (2021). Advances of molecularly imprinted polymers (MIP) and the application in drug delivery. *European Polymer Journal*, *143*, 110179.

Hermawan, E., Hadiyati, N. A., Adiarso, A., Setiyadi, E. D., Zunuraen, S., Hidayat, D., Wahyudi, A., & Ru'yi, H. A. (2023). Challenges and Policy Supports in Indonesian Pharmaceutical Raw Materials Industry. *Indonesian Journal of Health Administration*, *11*(2), 196–211.

Kamil Hussain, M., Saquib, M., & Faheem Khan, M. (2019). Techniques for extraction, isolation, and standardization of bio-active compounds from medicinal plants. *Natural Bio-Active Compounds: Volume 2: Chemistry, Pharmacology and Health Care Practices*, 179–200.

Kang, X., Deng, L., Quan, T., Gao, M., Zhang, K., Xia, Z., & Gao, D. (2021). Selective extraction of quinolizidine alkaloids from Sophora flavescens Aiton root using tailor-made deep eutectic solvents and magnetic molecularly imprinted polymers. *Separation and Purification Technology*, *261*, 118282.

Li, W., Liang, A., Lu, Z., & Xie, Y. (2023). Application of Molecular Imprinting Technique in Separation and Detection of Natural Products. *Engineering Proceedings*, *49*(1), 1.

Liu, Y., Qiu, X., Zhang, M., Lin, Y., Lan, H., Li, X., Wu, Q., & He, J. (2024). Boronate affinity-based surface molecularly imprinted polymer microspheres using polyethyleneimine/dopamine coating for efficient selective recognition and separation of Ginsenoside Rb1. *Reactive and Functional Polymers*, *194*, 105780.

Ma, X., Lin, H., Yong, Y., Ju, X., Li, Y., Liu, X., Yu, Z., Wujin, C., She, Y., & Zhang, J. (2022). Molecularly imprinted polymer-specific solid-phase extraction for the determination of 4-hydroxy-2 (3H) benzoxazolone isolated from Acanthus ilicifolius Linnaeus using high-performance liquid chromatography-tandem mass spectrometry. *Frontiers in Nutrition*, *9*, 950044.

Ma, X., Zhang, X., Lin, H., Abd El-Aty, A. M., Rabah, T., Liu, X., Yu, Z., Yong, Y., Ju, X., & She, Y. (2020). Magnetic molecularly imprinted specific solid-phase extraction for determination of dihydroquercetin from Larix griffithiana using HPLC. *Journal of Separation Science*, *43*(12), 2301–2310.

Mabrouk, M., Hammad, S. F., Abdella, A. A., & Mansour, F. R. (2023). Tips and tricks for successful preparation of molecularly imprinted polymers for analytical applications: A critical review. *Microchemical Journal*, *193*, 109152.

Malik, M. I., Shaikh, H., Mustafa, G., & Bhanger, M. I. (2019). Recent applications of molecularly imprinted polymers in analytical chemistry. *Separation & Purification Reviews*, *48*(3), 179–219.

Murdaya, N., Triadenda, A. L., Rahayu, D., & Hasanah, A. N. (2022). A review: using multiple templates for molecular imprinted polymer: is it good? *Polymers*, *14*(20), 4441.

Önal Acet, B., İnanan, T., Salieva, K., Borkoev, B., Odabaşı, M., & Acet, Ö. (2024). Molecular imprinted polymers: important advances in biochemistry, biomedical and biotechnology. *Polymer Bulletin*, *81*(12), 10439–10459.

Panche, A. N., Diwan, A. D., & Chandra, S. R. (2016). Flavonoids: an overview. *Journal of Nutritional Science*, *5*, e47.

Pardeshi, S., Dhodapkar, R., & Kumar, A. (2014). Molecularly imprinted microspheres and nanoparticles prepared using precipitation polymerisation method for selective extraction of gallic acid from Emblica officinalis. *Food Chemistry*, *146*, 385–393.

Pratama, K. F., Manik, M. E. R., Rahayu, D., & Hasanah, A. N. (2020). Effect of the molecularly imprinted polymer component ratio on analytical performance. *Chemical and Pharmaceutical Bulletin*, *68*(11), 1013–1024.

Rasul, M. G. (2018). Extraction, isolation and characterization of natural products from medicinal plants. *Int. J. Basic Sci. Appl. Comput*, *2*(6), 1–6.

Saad, E. M., Madbouly, A., Ayoub, N., & El Nashar, R. M. (2015). Preparation and application of molecularly imprinted polymer for isolation of chicoric acid from Chicorium intybus L. medicinal plant. *Analytica Chimica Acta*, *877*, 80–89.

Sari, D. K., Jeelani, G., Ilmi, H., Tumewu, L., Wahyuni, R., Widyawaruyanti, A., Nozaki, T., & Hafid, A. F. (2024). Therapeutic potential of Indonesian plant extracts in combating malaria and protozoan neglected tropical disease. *BMC Complementary Medicine and Therapies*, *24*(1), 416.

Soquetta, M. B., Terra, L. de M., & Bastos, C. P. (2018). Green technologies for the extraction of bioactive compounds in fruits and vegetables. *CyTA-Journal of Food*, *16*(1), 400–412.

Sun, Y., Zhang, Y., Ju, Z., Niu, L., Gong, Z., & Xu, Z. (2019). Molecularly imprinted polymers fabricated by Pickering emulsion polymerization for the selective adsorption and separation of quercetin from Spina Gleditsiae. *New Journal of Chemistry*, *43*(37), 14747–14755.

Tabaraki, R., & Sadeghinejad, N. (2020). Preparation and application of magnetic molecularly imprinted polymers for rutin determination in green tea. *Chemical Papers*, *74*, 1937–1944.

Tan, L., Zhou, L.-D., Jiang, Z.-F., Ma, R.-R., He, J.-Y., Xia, Z.-N., Zhang, Q.-H., Wang, C.-Z., & Yuan, C.-S. (2021). Selective separation and inexpensive purification of paclitaxel based on molecularly imprinted polymers modified with ternary deep eutectic solvents. *Journal of Pharmaceutical and Biomedical Analysis*, *192*, 113661.

Tian, C., Wu, Z., He, M., Chen, B., & Hu, B. (2022). Amino functionalized magnetic covalent organic framework for magnetic solid-phase extraction of sulfonylurea herbicides in environmental samples from tobacco land. *Journal of Separation Science*, *45*(10), 1746–1756.

Torres-Ortiz, D., García-Alcocer, G., Berumen-Segura, L. C., & Estevez, M. (2024). Green extraction of secondary metabolites from plants: Obstacles, current status, and trends. *Sustainable Chemistry for the Environment*, 100157.

Wan, Y., Wang, M., Fu, Q., Wang, L., Wang, D., Zhang, K., Xia, Z., & Gao, D. (2018). Novel dual functional

monomers based molecularly imprinted polymers for selective extraction of myricetin from herbal medicines. *Journal of Chromatography B*, *1097*, 1–9.

Włoch, M., & Datta, J. (2019). Synthesis and polymerisation techniques of molecularly imprinted polymers. In *Comprehensive analytical chemistry* (Vol. 86, pp. 17–40). Elsevier.

Xiao, Y., Xiao, R., Tang, J., Zhu, Q., Li, X., Xiong, Y., & Wu, X. (2017). Preparation and adsorption properties of molecularly imprinted polymer via RAFT precipitation polymerization for selective removal of aristolochic acid I. *Talanta*, *162*, 415–422.

Xie, X., Wei, F., Chen, L., & Wang, S. (2015). Preparation of molecularly imprinted polymers based on magnetic nanoparticles for the selective extraction of protocatechuic acid from plant extracts. *Journal of Separation Science*, *38*(6), 1046–1052.

Zhang, Q.-W., Lin, L.-G., & Ye, W.-C. (2018). Techniques for extraction and isolation of natural products: A comprehensive review. *Chinese Medicine*, *13*, 1–26.

Zhang, W., Wei, B., Li, S., Wang, Y., & Wang, S. (2017). Preparation and Chromatographic Application of β-cyclodextrin molecularly imprinted microspheres for paeoniflorin. *Polymers*, *9*(6), 214.

Zheng, W., Zhang, S., & Deng, J. (2024). Analysis of the adsorption mechanism of phosphoric acid-modified bamboo charcoal for chlorogenic acid based on density functional theory. *Chemical and Biological Technologies in Agriculture*, *11*(1), 13.

Zhou, T., Shen, X., Chaudhary, S., & Ye, L. (2014). Molecularly imprinted polymer beads prepared by pickering emulsion polymerization for steroid recognition. *Journal of Applied Polymer Science*, *131*(1).

Zhou, Y., Jiang, Z., Lu, H., Xu, Z., Tong, R., Shi, J., & Jia, G. (2019). Recent advances of natural polyphenols activators for Keap1-Nrf2 signaling pathway. *Chemistry & Biodiversity*, *16*(11), e1900400.

Zuo, J., Ma, P., Li, Z., Zhang, Y., Xiao, D., Wu, H., & Dong, A. (2023). Application of molecularly imprinted polymers in plant natural products: Current progress and future perspectives. *Macromolecular Materials and Engineering*, *308*(3), 2200499.