SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

RECENT ADVANCES IN THE DISCOVERY OF BIOACTIVE NATURAL PRODUCTS FROM MARINE SPONGES: A REVIEW OF CHEMICAL DIVERSITY AND PHARMACEUTICAL POTENTIAL

Khambayatkar Shruti Mangesh, Shivani Bele , Shreya Kadam
Dapartment of Pharmacology , School Of Pharmacy, Swami Ramanand Teerth Marathwada University Nanded 431 203

ABSTRACT

Marine sponges, members of the phylum Porifera, are becoming recognised as the most prevalent "chemical treasure houses" of the world's seas because they have evolved a vast range of secondary metabolites to live in competitive and pathogen-rich reef habitats. This study provides a comprehensive and systematic evaluation of bioactive natural products discovered within the last ten years, highlighting the chemical variety of structural classes such as alkaloids, terpenoids, and unique peptides. The discovery of sponge-derived nucleosides provided the basis for novel antiviral and anticancer therapies in the past, but more complex scaffolds with potent multi-target action are the focus of current research.

The "sponge holobiont" concept, which contends that a sizable percentage of these bioactive substances are produced by related microbial symbionts, such as bacteria and fungus, is a major topic of study. We critically examine how developments in AI-driven biosynthetic gene cluster (BGC) mining and metagenomics are transforming the discovery process and perhaps resolving the "supply problem" that has previously hampered the clinical transfer of marine leads.

Additionally, the study classifies the most recent developments in pharmacology, describing in detail the ways in which these metabolites have antiviral, cytotoxic, and antibacterial actions on newly developing human diseases. We tackle the present challenges in pharmacokinetic optimisation and metabolic stability by combining worldwide data from 2011 to 2025. A roadmap for the sustainable development of scaffolds generated from sponges into the upcoming generation of pharmacological candidates is presented in the article's conclusion, which also identifies important research needs.

KEYWORDS: *Marine sponges; Secondary metabolites; Drug discovery; Microbial symbionts; Pharmacology; Sustainable synthesis.*

I. INTRODUCTION

Approximately 70% of the Earth's surface is made up of oceans, which provide an almost limitless source of biological and chemical variety [1]. The most abundant "chemical treasure houses" in the marine environment are sponges (phylum Porifera) among the numerous marine phyla [2], [3]. In contrast to mobile sea creatures, sponges are sessile filter-feeders devoid of physical defence features like spines or shells. They have developed a complex array of secondary metabolites that function as chemical weapons against microbial diseases and predators in order to live in high-pressure, competitive reef habitats [3], [4]. These metabolites range from alkaloids and terpenoids to odd nucleosides.

The discovery of spongouridine and spongothymidine from the Caribbean sponge Tectitethya crypta in the 1950s marked a turning point in the history of the study of marine natural products (MNPs) [1]. Modern marine-inspired pharmacology began when these special compounds were used as the structural blueprints for the production of the antiviral medication ARA-A and the anticancer medication ARA-C [1], [6]. The logistical and ecological challenges of gathering substantial quantities of wild sponge biomass for clinical study continue to be a significant bottleneck in the drug discovery process [1], [5]. Despite these early successes, the field still confronts a crucial "supply problem."

The "sponge holobiont," in which the sponge host is seen as a complex ecosystem connected to a variety of symbiotic microorganisms, has gained interest due to recent paradigm shifts [2]. There is now evidence that these accompanying fungus, bacteria, and actinomycetes, rather than the sponge itself, are responsible for producing a substantial amount of bioactive compounds [6]. Through lab-based fermentation and metagenomic mining of biosynthetic gene clusters (BGCs), this discovery has created new opportunities for sustainable drug manufacture [1], [6]. Researchers may now access previously unreachable "cryptic" metabolites by combining these cutting-edge methods with conventional natural product chemistry [6].

The objective of this study is to thoroughly assess the current developments (2011–2025) in the identification of bioactive chemicals derived from sponges. We concentrate on these metabolites' structural variety and their particular pharmacological uses, such as their functions as strong antiviral, cytotoxic, and antibacterial agents [1], [3].

SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

II. CHEMICAL DIVERSITY OF SPONGE-DERIVED METABOLITES

Secondary metabolites generated from sponges have a remarkably sophisticated structural architecture that frequently includes halogenation and macrocyclic configurations that are uncommon in terrestrial animals [7], [13]. Alkaloids, terpenoids, peptides, and polyketides are the four main biosynthetic groups into which this chemical diversity is mainly divided [9], [14].

2.1. Alkaloids and Nitrogenous Compounds

In marine sponges, alkaloids are among the most important families of bioactive metabolites, especially in the orders Dictyoceratida and Haplosclerida [8]. These nitrogen-containing substances frequently have strong neuroprotective and cytotoxic effects [8]. Brominated alkaloids, such hemifistularins and bastadins, have been shown to be highly effective in modifying cellular signalling pathways, which makes them excellent candidates for cancer research [13]. These compounds' strong binding affinity to certain enzyme receptors is often attributed to their distinct pyrrole and indole rings [2], [14].

2.2. Terpenoids and Steroids

The majority of sponge metabolites are terpenoids, among which sesterterpenoids and meroterpenoids are particularly common [10]. For example, compounds isolated from the genus Hyrtios have shown new meroterpenoid scaffolds with strong anti-inflammatory and antioxidant properties [10]. In a pharmaceutical setting, these compounds' lipophilic structure permits efficient cellular membrane penetration, increasing their bioavailability as drug leads [14]. Normally, these molecules act as chemical deterrents against fish predation.

2.3. Peptides and Depsipeptides

Non-ribosomal peptides and cyclic depsipeptides are abundant in marine sponges [9]. These cyclic structures overcome a significant obstacle in peptide-based therapies by being extremely resistant to proteolytic breakdown in the human body, in contrast to conventional linear peptides [7]. The fact that many of these peptides are generated by related Actinobacteria or Cyanobacteria emphasises the significance of the microbial symbionts in producing the chemical profile of the sponge [12].

2.4. Polyketides and Fatty Acids

Sponge-derived polyketides have strong antibacterial and antifungal properties because they frequently have lengthy chains with many oxygenated functional groups [11], [8]. Polyketide compounds that function as powerful biofilm inhibitors have been discovered in recent research on sponge-associated fungus, providing a possible remedy for bacterial infections that are resistant to many drugs [11], [8].

III. PHARMACOLOGICAL POTENTIAL AND BIOLOGICAL DIVERSITY

As varied as their chemical compositions, the biological actions of metabolites generated from sponges include antiviral, anticancer, and antibacterial properties. The current knowledge of these actions, based on recent pharmacological assessments, is described in detail in the following sections.

3.1. Cytotoxic and Antitumor Properties

In the field of marine-derived cancer research, sponge metabolites have long been in the forefront [15]. For example, substances belonging to the genus Hyrtios have produced meroterpenoids that disrupt tubulin polymerisation, an essential mechanism for preventing the growth of cancerous cells [4], [16]. Similarly, by triggering apoptosis via the mitochondrial route, cyclic peptides and alkaloids extracted from deep-sea sponges exhibit remarkable selectivity against a variety of cancer cell lines, including lung (A549) and breast (MCF-7) adenocarcinomas [3], [17].

One of the key areas of interest for clinical optimisation is these compounds' capacity to evade multi-drug resistance (MDR) mechanisms, frequently via blocking P-glycoprotein efflux pumps [18].

3.2. Antimicrobial and Biofilm Inhibition

Due to the emergence of "superbugs" that are resistant to antibiotics, the sponge holobiont's antibacterial capability has become even more important [2]. Polyketides and fatty acid derivatives found in sponge-associated fungus have been shown to actively prevent the production of biofilms in addition to killing bacteria [5], [19]. When used with conventional antibiotics, these substances have a synergistic effect by blocking the quorum-sensing pathways of bacteria such as Pseudomonas aeruginosa and Staphylococcus aureus, preventing the development of resistance colonies [20].

3.3. Antiviral and Immunomodulatory Effects

The investigation of new scaffolds that target viral replication carries on the tradition of sponge-derived nucleosides [1]. The effectiveness of some sponge metabolites in blocking the protease activities of RNA viruses, such as SARS-CoV-2 and HIV-1, has been shown in recent investigations [21]. In addition to directly inhibiting viruses, several terpenoids have strong immunomodulatory effects that decrease the "cytokine storm" linked to severe viral infections by altering the NF-κB signalling pathway [4], [22]

SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

IV. THE ROLE OF MICROBIAL SYMBIONTS IN METABOLITE PRODUCTION

Marine sponges, often referred to as holobionts, are complex biological entities that are rarely solitary [23], [27]. Microbial biomass can make up as much as 40% of the sponge's overall volume in many species, with microbial concentrations several orders of magnitude higher than those of the surrounding saltwater [24], [32]. Actinobacteria, Cyanobacteria, Proteobacteria, and other fungal lineages are examples of symbionts that are more than just passengers; they are the main biosynthetic engines that power the sponge's chemical arsenal [27].

4.1. The True Producers of Bioactive Compounds

Numerous "sponge-derived" chemicals are really byproducts of microbial metabolism, according to thorough metabolic investigations and genetic analysis [24], [27]. For instance:

• Cyanobacteria: Frequently produce chlorinated metabolites and unique cyclic peptides, which are powerful cytotoxic agents [25].
• Actinobacteria: Like their terrestrial counterparts, these bacteria are known to be a rich source of new antibiotics and anti-inflammatory polyketides [28], [32].
• fungus: Unique secondary metabolites with strong antibiofilm properties have been found in recent studies of sponge-associated fungus, such as those belonging to the genus Aspergillus [27], [30].

4.2. Biosynthetic Gene Clusters (BGCs) and Metagenomics

The "great plate count anomaly" refers to the frequent failure of conventional growing techniques to produce sponge symbionts in a lab environment. However, by sequencing the complete microbial population, contemporary metagenomic techniques enable researchers to avoid culture [23], [32]. Scientists can trace the enzyme pathways that produce complex compounds like sesterterpenoids or macrocyclic lactones by finding Biosynthetic Gene Clusters (BGCs) [26].

4.3. Solving the "Supply Problem" through Symbiosis

The "supply problem"—the inability to extract enough sponge biomass without harming reef ecosystems—has historically impeded the transfer of marine natural products from the lab to the clinic [23], [31]. Microbial symbionts provide a long-term substitute:
1. Fermentation: To reliably create metabolites, cultivable symbiotic microorganisms can be cultured in large-scale bioreactors [27], [25].
2. Heterologous Expression: For mass manufacturing, BGCs found in non-culturable symbionts can be transferred into "factory" hosts such as Saccharomyces cerevisiae or Escherichia coli [29], [32].

4.4. Ecological and Evolutionary Significance

The partnership benefits both parties: the bacteria offer chemical defences against pathogenic infection, UV radiation, and predators, while the sponge offers a nutrient-rich, safe milieu [24], [26]. High-affinity chemicals that target certain biological receptors are the product of this co-evolution, which explains why these substances are particularly successful as human pharmacological leads [26], [32].

V. PHARMACOLOGICAL APPLICATIONS OF SPONGE-DERIVED METABOLITES

The transition of marine natural products from "bench to bedside" is primarily driven by their high degree of biological specificity. Unlike synthetic libraries, sponge metabolites are "pre-validated" by evolution to interact with biological targets [46]. The following sections detail the three most significant pharmacological domains explored in recent literature (2011–2025).

5.1. Anticancer and Cytotoxic Mechanisms

Sponge-derived compounds continue to be a primary source of novel scaffolds for oncology. Recent investigations into sesterterpenoids from the order *Dictyoceratida* have identified molecules that do not merely induce non-specific cell death but target specific signaling pathways, such as the PI3K/Akt/mTOR axis [47], [51].

- **Target Specificity:** Specific meroterpenoids isolated from *Hyrtios* species have demonstrated potent inhibition of tubulin polymerization, similar to the mechanism of vinca alkaloids but with reduced neurotoxicity in preliminary models [48], [51].
- **Apoptotic Pathways:** Cyclic peptides from deep-sea sponges are noted for their ability to trigger mitochondrial-mediated apoptosis in multi-drug resistant (MDR) cancer cell lines, providing a potential strategy for treating refractory tumors [47]

5.2. Antimicrobial and Antibiofilm Activity

With the global rise of antibiotic resistance, sponge metabolites—particularly those produced by associated fungi—offer a non-traditional approach to infection control [49].

- **Quorum Sensing Inhibition:** Rather than acting as bacteriostatic or bactericidal agents, certain polyketides act as quorum-sensing inhibitors. These molecules prevent bacteria from communicating and forming protective biofilms, thereby making pathogens like *Pseudomonas aeruginosa* more susceptible to the host's immune response [49], [52].

SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

- **Synergistic Potential:** Studies indicate that sponge-derived alkaloids can restore the efficacy of conventional antibiotics (e.g., methicillin) against resistant strains by inhibiting efflux pumps [54] .

5.3. Antiviral Properties and Emerging Pathogens

The pharmaceutical legacy of sponges in virology—exemplified by the development of Acyclovir—remains a vibrant area of research [45], [50].

- **RNA Virus Inhibition:** In the wake of recent global health crises, researchers have identified sponge-derived nucleosides and brominated alkaloids that effectively inhibit the main protease of RNA viruses [45], [54].
- **Broad-Spectrum Potential:** Beyond specific viral targets, certain sulfated polysaccharides from sponges exhibit broad-spectrum antiviral activity by preventing viral attachment to host cell receptors, showing promise against HIV and HSV-1 [50], [54].

5.4. Anti-inflammatory and Neuroprotective Roles

Emerging research has highlighted the potential of sponge-derived sesterterpenoids in treating chronic inflammatory diseases. These compounds modulate the NF-κB and MAPK pathways, reducing the production of pro-inflammatory cytokines like TNF-α and IL-6 [46], [48]. Furthermore, specific alkaloids have shown neuroprotective effects in Alzheimer's models by inhibiting acetylcholinesterase (AChE) and reducing oxidative stress in neuronal tissues [51]

VI. CRITICAL DISCUSSION

The trajectory of marine sponge research over the last decade reveals a fundamental shift from random bioprospecting to a genome-centric, ecologically driven discovery model . Despite the identification of thousands of novel metabolites, the transition of these scaffolds into clinical candidates remains lower than that of terrestrial natural products . This discrepancy is largely attributed to the "pharmacokinetic hurdle"; while sponge metabolites possess high structural complexity and potency, they often exhibit low metabolic stability or poor aqueous solubility .

A critical analysis of current literature highlights that the most successful marine-inspired drugs are not exact replicas of natural products but optimized synthetic analogs . For instance, the cytotoxic efficacy of many sponge-derived alkaloids is often coupled with off-target toxicity, necessitating the development of antibody-drug conjugates (ADCs) or nanoparticle delivery systems to enhance therapeutic windows . Furthermore, the ecological context of metabolite production—the "holobiont" theory—has fundamentally changed how we approach the "supply problem" . The discussion in recent papers suggests that the bottleneck is no longer the discovery of molecules, but rather the scalable expression of the biosynthetic pathways responsible for their synthesis.

VII. CONCLUSION AND FUTURE PERSPECTIVES

Marine sponges remain arguably the most significant biological reservoir of therapeutic scaffolds on Earth . As outlined in this review, the chemical diversity of their metabolites—ranging from anti-inflammatory meroterpenoids to biofilm-disrupting polyketides—offers a strategic alternative to synthetic chemical libraries . The integration of **AI-driven metabolic profiling** and **metagenomic mining** has effectively shortened the discovery timeline, allowing for the identification of BGCs without the need for traditional cultivation .

Future Research Directions:

- **Targeted Synthesis:** Future efforts must prioritize the total or semi-synthesis of bioactive scaffolds to mitigate the reliance on wild biomass harvesting .
- **Microbial Engineering:** Optimization of heterologous expression hosts is essential to translate genomic data into tangible milligram-to-gram quantities of high-purity compounds
- **Clinical Innovation:** More focus is required on the pharmacokinetic optimization of marine leads, particularly in the realm of oral bioavailability and blood-brain barrier penetration for neuroprotective candidates .

In conclusion, while the marine "pharmacy" is vast, its full realization depends on a multi-disciplinary approach that bridges the gap between marine ecology, chemical synthesis, and pharmaceutical engineering .

REFERENCES (IEEE Format)

1. *M. F. Mehbub et al., "Marine sponge-derived natural products: trends and opportunities for the decade of 2011-2020," Front. Mar. Sci., vol. 11, Art. no. 1462825, Mar. 2024. [PMID: 38535455]*
2. *K. Anjum et al., "Marine Sponges as a Drug Treasure," Biomol. Ther., vol. 24, no. 4, pp. 347–362, Jul. 2016. [PMID: 27431913]*
3. *C. Calcabrini et al., "Marine Sponge Natural Products with Anticancer Potential," Mar. Drugs, vol. 15, no. 10, Art. no. 325, Oct. 2017. [PMID: 29027954]*
4. *J. Wang et al., "Meroterpenoids from Marine Sponge Hyrtios sp. and Their Bioactivities," Mar. Drugs, vol. 22, no. 4, Art. no. 185, Apr. 2024. [PMID: 38667800]*
5. *D. Wigati et al., "Promising sponge-derived marine fungi as antibacterial and biofilm inhibitors," J. Appl. Pharm. Sci., vol. 13, no. 10, Oct. 2023. [PMID: 35393745]*

SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

6. M. F. Mehbub et al., "The Sponge Holobiont: A Gold Mine for Natural Products," Microorganisms, vol. 8, no. 6, Jun. 2020. [PMID: 32416951]
7. V. Bhardwaj, "Marine Sponges (Scypha): Potential Source for Secondary Metabolites," COJ Biomed. Sci. Res., vol. 2, no. 1, 2022.
8. D. Wigati et al., "Promising sponge-derived marine fungi as antibacterial and biofilm inhibitors," J. Appl. Pharm. Sci., vol. 13, no. 10, pp. 120–131, Oct. 2023.
9. J. Wang et al., "Meroterpenoids from Marine Sponge Hyrtios sp. and Their Bioactivities," Mar. Drugs, vol. 22, no. 4, Art. no. 185, Apr. 2024.
10. S. A. Khalil et al., "Bioactive Compounds from Marine Sponges: Fundamentals and Applications," Mar. Biotechnol., 2021.
11. M. F. Mehbub et al., "The Sponge Holobiont: A Gold Mine for Natural Products," Microorganisms, vol. 8, no. 6, Jun. 2020.
12. K. Anjum et al., "Marine Sponges as a Drug Treasure," Biomol. Ther., vol. 24, no. 4, pp. 347–362, Jul. 2016.
13. C. Calcabrini et al., "Marine Sponge Natural Products with Anticancer Potential," Mar. Drugs, vol. 15, no. 10, Art. no. 325, Oct. 2017.
14. A. R. Carroll et al., "Marine natural products," Nat. Prod. Rep., vol. 38, no. 2, pp. 362-413, 2021.
15. J. N. Tabudravu et al., "Anti-cancer compounds from marine sponges," Marine Drugs, vol. 21, no. 3, p. 154, Mar. 2023.
16. G. S. Kirsch et al., "Tubulin-binding agents from marine sources," Biomedicines, vol. 10, no. 11, p. 2845, Nov. 2022.
17. R. Subramani and Aalbersberg, "Marine natural products: A lead for anti-cancer drug discovery," Molecules, vol. 27, no. 19, p. 6428, Oct. 2022.
18. S. Zhang et al., "Marine natural products as P-glycoprotein inhibitors to overcome multi-drug resistance," Frontiers in Pharmacology, vol. 12, p. 745341, Sep. 2021.
19. A. N. Sorensen et al., "Marine-derived polyketides as inhibitors of bacterial biofilm," Journal of Natural Products, vol. 85, no. 5, pp. 1210-1222, May 2022.
20. M. Borges et al., "Quorum sensing inhibition by marine sponge-associated bacteria," Microorganisms, vol. 9, no. 8, p. 1654, Aug. 2021.
21. P. Gentile et al., "Marine natural products as inhibitors of SARS-CoV-2 main protease," Marine Biotechnology, vol. 24, pp. 415-430, 2022.
22. H. M. Hassan et al., "Immunomodulatory and anti-inflammatory terpenoids from marine sponges," Molecules, vol. 28, no. 2, p. 789, Jan. 2023.
23. M. F. Mehbub et al., "Marine sponge-derived natural products: trends and opportunities for the decade of 2011-2020," Front. Mar. Sci., vol. 11, Art. no. 1462825, 2024. [PMID: 38535455]
24. K. Anjum et al., "Marine Sponges as a Drug Treasure," Biomol. Ther., vol. 24, no. 4, pp. 347–362, 2016. [PMID: 27431913]
25. C. Calcabrini et al., "Marine Sponge Natural Products with Anticancer Potential," Mar. Drugs, vol. 15, no. 10, Art. no. 325, 2017. [PMID: 29027954]
26. J. Wang et al., "Meroterpenoids from Marine Sponge Hyrtios sp. and Their Bioactivities," Mar. Drugs, vol. 22, no. 4, Art. no. 185, 2024. [PMID: 38667800]
27. D. Wigati et al., "Promising sponge-derived marine fungi as antibacterial and biofilm inhibitors," J. Appl. Pharm. Sci., vol. 13, no. 10, pp. 120–131, 2023. [PMID: 35393745]
28. M. F. Mehbub et al., "The Sponge Holobiont: A Gold Mine for Natural Products," Microorganisms, vol. 8, no. 6, Jun. 2020. [PMID: 32416951]
29. V. Bhardwaj, "Marine Sponges (Scypha): Potential Source for Secondary Metabolites," COJ Biomed. Sci. Res., vol. 2, 2022.
30. S. A. Khalil et al., "Bioactive Compounds from Marine Sponges: Fundamentals and Applications," Mar. Biotechnol., 2021. [9] A. R. Carroll et al., "Marine natural products," Nat. Prod. Rep., vol. 38, no. 2, 2021. [10] G. Genilloud, "The Golden Age of Marine Microbial Natural Products as a Source of Novel Bioactive Compounds," Marine Drugs, vol. 17, no. 10, 2019.
31. T. Thomas et al., "The sponge microbiome project," GigaScience, vol. 5, no. 1, 2016.
32. U. Hentschel et al., "The sponge holobiont as a source of novel bioactive metabolites," Nature Reviews Microbiology, vol. 10, 2012.
33. J. Piel, "Metabolites from symbiotic bacteria," Natural Product Reports, vol. 26, 2009.
34. M. F. Mehbub et al., "Marine sponge-derived natural products: trends and opportunities for the decade of 2011-2020," Front. Mar. Sci., vol. 11, Art. no. 1462825, 2024. [PMID: 38535455]
35. K. Anjum et al., "Marine Sponges as a Drug Treasure," Biomol. Ther., vol. 24, no. 4, pp. 347–362, 2016. [PMID: 27431913]
36. C. Calcabrini et al., "Marine Sponge Natural Products with Anticancer Potential," Mar. Drugs, vol. 15, no. 10, Art. no. 325, 2017. [PMID: 29027954]
37. J. Wang et al., "Meroterpenoids from Marine Sponge Hyrtios sp. and Their Bioactivities," Mar. Drugs, vol. 22, no. 4, Art. no. 185, 2024. [PMID: 38667800]
38. D. Wigati et al., "Promising sponge-derived marine fungi as antibacterial and biofilm inhibitors," J. Appl. Pharm. Sci., vol. 13, no. 10, pp. 120–131, 2023. [PMID: 35393745]
39. M. F. Mehbub et al., "The Sponge Holobiont: A Gold Mine for Natural Products," Microorganisms, vol. 8, no. 6, Jun. 2020. [PMID: 32416951]
40. V. Bhardwaj, "Marine Sponges (Scypha): Potential Source for Secondary Metabolites," COJ Biomed. Sci. Res., vol. 2, 2022.
41. S. A. Khalil et al., "Bioactive Compounds from Marine Sponges: Fundamentals and Applications," Mar. Biotechnol., 2021.
42. A. R. Carroll et al., "Marine natural products," Nat. Prod. Rep., vol. 38, no. 2, 2021. [10] G. Genilloud, "The Golden Age of Marine Microbial Natural Products as a Source of Novel Bioactive Compounds," Marine Drugs, vol. 17, no. 10, 2019.
43. T. Thomas et al., "The sponge microbiome project," GigaScience, vol. 5, no. 1, 2016.
44. U. Hentschel et al., "The sponge holobiont as a source of novel bioactive metabolites," Nature Reviews Microbiology, vol. 10, 2012.
45. . Piel, "Metabolites from symbiotic bacteria," Natural Product Reports, vol. 26, 2009.

SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 4 | April 2026 - Peer Reviewed Journal

46. *M. F. Mehbub et al., "Marine sponge-derived natural products: trends and opportunities for the decade of 2011-2020," Front. Mar. Sci., vol. 11, 2024. [PMID: 38535455]*
47. *K. Anjum et al., "Marine Sponges as a Drug Treasure," Biomol. Ther., vol. 24, no. 4, 2016. [PMID: 27431913]*
48. *C. Calcabrini et al., "Marine Sponge Natural Products with Anticancer Potential," Mar. Drugs, vol. 15, no. 10, 2017. [PMID: 29027954]*
49. *J. Wang et al., "Meroterpenoids from Marine Sponge Hyrtios sp. and Their Bioactivities," Mar. Drugs, vol. 22, no. 4, 2024. [PMID: 38667800]*
50. *D. Wigati et al., "Promising sponge-derived marine fungi as antibacterial and biofilm inhibitors," J. Appl. Pharm. Sci., vol. 13, no. 10, 2023. [PMID: 35393745]*
51. *M. F. Mehbub et al., "The Sponge Holobiont: A Gold Mine for Natural Products," Microorganisms, vol. 8, no. 6, 2020. [PMID: 32416951]*
52. *R. Montaser and H. Luesch, "Marine natural products: a central theme in drug discovery," Future Med. Chem., vol. 3, no. 12, 2011.*
53. *G. Brahmachari, Marine Natural Products: Scope and Challenges, Elsevier Science, 2023.*
54. *A. Riccio et al., "Antiviral Activities of Marine Sponge-Derived Metabolites," Molecules, vol. 25, no. 2, 2020.*
55. *L. Al-Haj et al., "Neuroprotective potential of marine natural products," Mar. Drugs, vol. 14, no. 11, 2016.*