Bioactive Compounds from Oceanic life Forms: An Insight to Marine World

Ayesha Tariq[1], Wajeeha Sultan[2], Muhammad Babar Sultan[3], Marwa[4], Javeria Saleem[2], Mudassar Hussain[2], Momna Bilal[5], Khadija Umer Farooq[4], Aisha Sethi[6] and Aimen Khalid[7,*]

[1]Department of Zoology wildlife and fisheries, The University of Agriculture Faisalabad, Faisalabad-38000, Punjab Pakistan
[2]Department of Pharmacy, Faculty of Pharmaceutical Sciences, Government College University Faisalabad, Faisalabad-38000, Punjab Pakistan
[3]Department of Pharmacy, Faculty of Pharmaceutical and Health Sciences, the University of Agriculture Faisalabad, Faisalabad-38000, Punjab Pakistan
[4]Department of Pharmacy, the University of Faisalabad, Faisalabad-38000, Punjab Pakistan
[5]Department of Pharmaceutical chemistry, Faculty of Pharmaceutical Sciences, Government College University Faisalabad, Faisalabad-38000, Punjab Pakistan
[6]Department of Pharmaceutics, Faculty of Pharmaceutical Sciences, Government College University Faisalabad, Faisalabad-38000, Punjab Pakistan.
[7]Institute of Microbiology, Government College University Faisalabad, Faisalabad-38000, Punjab Pakistan
*Corresponding author: aimenkhalid505@gmail.com

Abstract

The ocean, that occupies the planet's surface approximately above 70% and has a vast, huge undiscovered reservoir of bioactive compounds. Microorganisms, plants, and animals are examples of oceanic life forms that have developed special biochemical pathways to withstand the severe conditions of the ocean, which include salinity, low temperatures, high pressure, and limited light. Several bioactive chemicals that these organisms have produced have significant potential for use in industrial, pharmaceutical, and biomedical settings, particularly those that have the ability to effectively act on molecular targets associated in a variety of disorders. Research focuses on bacteria and fungus that have been obtained from the majority of marine invertebrates, like crustaceans, tunicates, sponges, seawater, and fish. It has been observed that, besides marine microorganisms such as, marine bacteria and fungi, corals, algae, and sponges, also produce distinctive secondary metabolites (SMs) with complex and unique chemical structures, potentially serving as key sources for developing new medications or therapeutic leads. Lately, oceanic bioactive compounds have been receiving a lot of interest, especially in the areas of biotechnology, cosmetics, and medicine discovery. These chemicals' discovery and development from marine species has enormous potential to address several issues related to human health, such as neurological illnesses, infections, cancer, and inflammation.

Keywords: Bioactive compounds, Metabolites, Salinity, Marine, Enormous potential

Cite this Article as: Tariq A, Sultan W, Sultan MB, Marwa, Saleem J, Hussain M, Bilal M, Farooq KU, Sethi A and Khalid A, 2025. Bioactive compounds from oceanic life forms: An insight to marine world. In: García-Rubio VG, Alvi MA, Saeed Z and Ahmad M (eds), Foundations of Holistic Healing: Complementary and Alternative Medicine. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 217-224. https://doi.org/10.47278/book.HH/2025.329

A Publication of Unique Scientific Publishers

Chapter No: 25-030

Received: 23-Feb-2025
Revised: 15-Apr-2025
Accepted: 01-May-2025

Introduction

Lead compounds identified for a variety of pharmacological applications have come mostly from marine sources in recent years, Microorganisms cover a vast expanse, from coastal shallows to remote seas covering 70% of the biosphere. Some marine species may produce novel secondary metabolites due to fluctuating temperature, pressure, and light in marine vs. terrestrial environments. Microbes detect, adapt, and struggle through by producing secondary metabolites for their endurance, which have biotechnological and pharmaceutical value (Newman & Cragg, 2018) (Figure 1).

Metagenomic technique for sample collection and processing (genomic DNA is retrieved from marine environment obtained from various marine sources). The metagenomics library construction aids the formation of right size of DNA fragments and the ligation, proceeded by screening. Bio-prospecting will help identify unknown bioactive metabolites from microbes of marine life. Since the dawn of humanity, products obtained from nature have been useful sources for the treatment of multiple illnesses. Over half of global clinical medications come from natural products (Figure 2). Due to the adverse effects of synthetic drugs, the search for new natural drugs continues. Crude products play a key role in developing novel medications to combat infectious diseases (Pinnaka & Tanuku, 2019).

Culture-dependent approach is used for sample collection and processing which includes the cultivation of microorganisms using selective media followed by taxonomical and biochemical characterization. Drastic marine conditions cause organisms to produce tolerant hydrolase enzymes like proteases, lipases, and glycoside hydrolases, significant in industry for their unique properties. Studying these microbes is essential to uncover their biochemical, ecological, evolutionary, and industrial potential. Microorganisms, algae, corals, and marine invertebrates are examples of marine organisms that naturally produce chemical molecules known as marine bioactive compounds. Different biological actions, like anti-inflammatory, anticancer, antioxidant, antibacterial and neuroprotective properties, are shown by these substances. Generally, these compounds are grouped according to their chemical structures (Mahapatra et al., 2020).

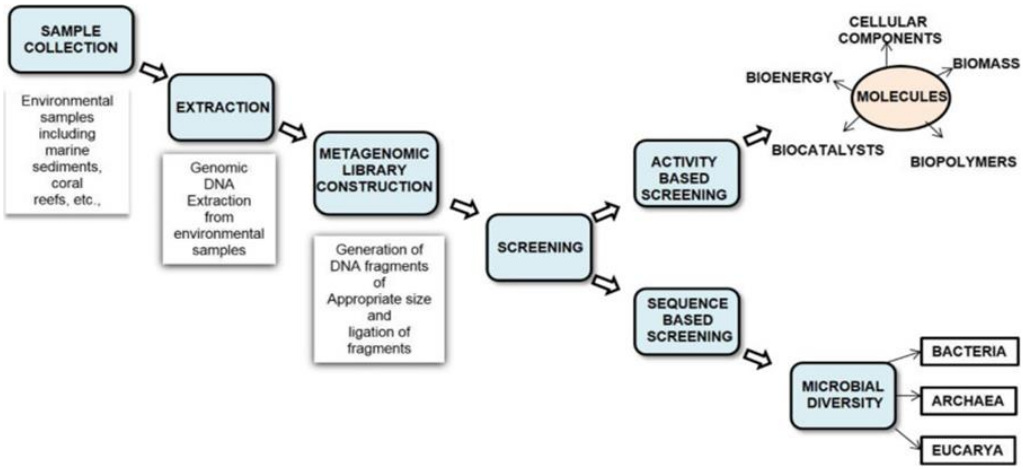


Fig. 1: Different activities of microbes

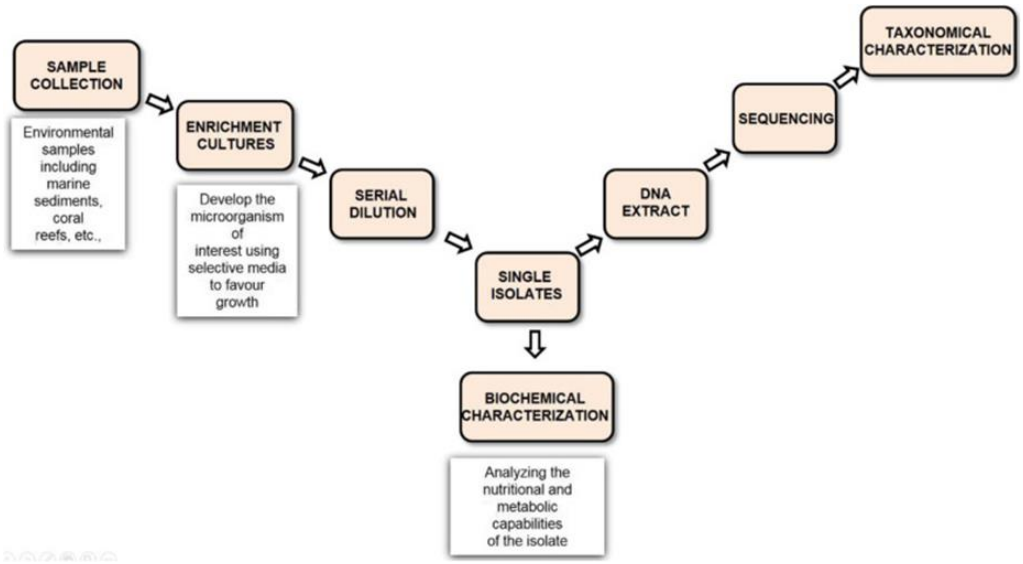


Fig. 2: Bioactive Metabolites

1.1.1. Marine Ecosystem as Bioactive agents

A wide variety of life forms that generate bioactive chemicals can be found in the marine ecosystem. Some of the primary sources are:

1.1.1.1. Marine Microorganisms

Bioactive chemicals, including antibiotics and anticancer medicines are produced in huge amount by marine bacteria and fungi. For example, the potent anticancer medication actinomycin is produced by the marine bacterium *Streptomyces*. Cyanobacteria (Blue-Green Algae) microorganisms are abundant source of bioactive substances like cyclic peptides and polyketides, which have antitumor, antimicrobial, and anti-inflammatory features. Cryptophycin, a potent anticancer agent, is derived from cyanobacteria (Sekurova et al., 2019).

1.1.1.2. Marine Algae

Macroalgae (Seaweeds): Proteins, lipids, phenolic compounds, and polysaccharides are all abundant in algae. It has been confirmed that these substances have anti-inflammatory, anti-cancer, and antioxidant properties. Fucoidan, for example, may have anti-neoplastic and anti-inflammatory effects and is derived from brown algae. Several bioactive compounds are produced by microalgae, which are beneficial for cardiovascular disorders like omega-3 fatty acids, and carotenoids, such as astaxanthin, which have antioxidant properties (Dalmaso et al., 2015).

1.1.1.3. Marine Invertebrates

Several bioactive compounds with pharmaceutical potential are produced by marine invertebrates, including sponges, corals, octopuses, and sea urchins. These organisms are known for producing peptides, alkaloids, and terpenoids with diverse biological activities (Rateb et al., 2018).

- **Sponges:** Marine sponges are an excellent source of bioactive compounds. For instance, crypto pethidine and pyrroloimino quinone derived from sponges exhibit antitumor and antimicrobial properties.
- **Corals:** Soft corals have yielded terpenoids and alkaloids, such as coralines, which are potent anti-inflammatory agents.
- **Sea Urchins:** Bioactive compounds derived from sea urchins include saponins and alkaloids with antifungal and antimicrobial activities.

1.1.1.4. Marine Vertebrates

Marine vertebrates such as fish and marine mammals also produce bioactive compounds, fatty acids like omega-3, which have anti-inflammatory and cardiovascular benefits.

1.1.2. Major Classes of Marine Bioactive Compounds

Generally, these compounds are grouped according to their chemical structures, which may include: Alkaloids, Peptides and Proteins, Terpenoids and Steroids, Polyketides, Phenolic Compounds, Fatty Acids, Carotenoids, Carbohydrates.

1.1.2.1. Alkaloids

Alkaloids are substances that contain nitrogen and have a range of biological functions. Marine-derived alkaloids are known for their potent anticancer, antimicrobial, and analgesic properties. A well-known example is palytoxin, an alkaloid isolated from marine dinoflagellates, which has potent neurotoxic activity (Abdelkader et al., 2018).

Examples

- Brevotoxin (produced by marine dinoflagellates, toxic to marine organisms and humans).
- Marinomycin (produced by marine bacteria, has anticancer properties).

1.1.2.2. Terpenoids and Steroids

Terpenoids are the largest group of natural products and are obtained from oceanic organisms, particularly from algae, sponges, and corals. They demonstrate diverse activities, including antimicrobial, anti-inflammatory, antiviral, and anticancer effects (Lü et al., 2017).

Examples

- Terpenoids quinone from marine sponges used in anticancer therapies.
- Squalamine, a steroid isolated from the liver of the dogfish shark, has antimicrobial and anticancer properties.

1.1.2.3. Peptides and Proteins

Marine organisms, especially marine invertebrates and microorganisms, produce peptides and proteins with potent antimicrobial, antiviral, and anticancer properties. These peptides often function as defensins, cytokines, or antibacterial agents (Qin et al., 2017).

Examples

- Tachyplesin (from the horseshoe crab) is a cationic antimicrobial peptide which exhibit efficacy against a wide spectrum of bacteria and fungi.
- Paracymatocins (produced by marine cyanobacteria) have shown antiviral and anti-inflammatory activity.

1.1.2.4. Polyketides

A diverse group of phytochemical constituents, Polyketides are produced by marine bacteria, fungi, and sponges. They are often antibiotic and anticancer agents and have applications in treating infections and tumors (Cruz et al., 2017).

Examples

- Streptomyces-derived polyketides (e.g., actinomycin), which are used in cancer chemotherapy.
- Laxaphycins (from marine bacteria) have shown activity against multidrug-resistant bacteria.

1.1.2.5. Fatty Acids and Lipids

Marine organisms, particularly fish and algae, are rich in omega-3 fatty acids (e.g., EPA and DHA), which shows anti-inflammatory and cardio-protective effects. These fatty acids are crucial for brain health and are linked to a lower likelihood of chronic diseases like heart disease and depression (Rathod et al., 2018).

Examples

- Cardio vascular health can be improved by Omega-3 fatty acids derived from fish oils.
- Omega-3 enriched oils from marine algae, a vegan source of these essential fatty acids.

1.1.2.6. Carotenoids

Carotenoids are pigments found in marine algae and other marine organisms that have antioxidant properties. One of the most well-known carotenoids is astaxanthin, a powerful antioxidant found in certain marine algae and crustaceans. Astaxanthin has been researched for its anti-inflammatory, antioxidant, and anticancer effects (Loureiro et al., 2019).

Examples

- Astaxanthin (from algae and krill) is known for its potent antioxidant activity.
- Fucoxanthin (from brown seaweed) has demonstrated anti-obesity and effects anti-inflammatory.

1.1.3. Applications of Marine Bioactive Compounds

1.1.3.1. Pharmaceutical and Medicinal Applications

Bioactive compounds produced from aquatic environments have shown potential in the creation of novel drugs to treat conditions like cancer, infections, inflammation, and neurological diseases.

Anticancer Drugs: The potential of marine-derived substances, such as polyketides and cytotoxic peptides, to inhibit the proliferation of cancer cells has been studied. For instance, ovarian cancer and soft tissue sarcoma are treated with trabectedin, which is derived from the sea squirt *Ecteinascidia turbinata* (Azman, 2016).

Antimicrobial Agents: Marine microorganisms, including bacteria and fungi, have yielded potent antibiotics like chloramphenicol and actinomycin.

Anti-inflammatory Drugs: Marine compounds such as squalamine and fucoidans (from algae) have been figured out to reduce inflammation, that gives benefit to treat diseases like rheumatoid arthritis (Fayed et al., 2021).

1.1.3.2. Cosmetics

Marine bioactive compounds, particularly antioxidants like astaxanthin and Fucoxanthin, are increasingly used in cosmetics for their ability to reduce oxidative stress, protect skin from UV damage, and promote anti-aging effects.

1.1.3.3. Biotechnology

Bioactive compounds from marine organisms are also being explored in the field of biotechnology for applications in food preservation, waste treatment, and bioengineering. For example, enzymes derived from marine organisms are used in industrial processes, such as the production of biofuels and bioplastics (Pai et al., 2022).

1.1.3.4. Bioactivity of novel Compounds from Marine Microorganisms

Antibiotic-resistant bacteria are a serious worldwide problem. Novel chemical compounds that can combat illnesses caused by microorganisms that are resistant to several drugs are needed. Marine bioactive compounds, including proteins, peptides, polyphenols, carbohydrates, pigments, and essential fatty acids that are obtained through diet, are actively investigated for a range of applications. These substances are useful in the food business, and have a various of biological applications, including cardio-protective, anti-inflammatory, anti-thrombotic, cell growth inhibitor, anti-hypertensive, and anti-diabetic effects. We'll talk about novel bioactive chemicals having a wide range of actions (Ghosh et al., 2022).

1.1.3.5. Antibacterial Potential

Alzheimer's disease, heart disease, mucus colitis, hyperactivities, choking, rheumatoid arthritis (RA), neoplasm, and many more conditions have few available treatments, and some medications have serious adverse effects on patients' health when taken in excess. Therefore, thorough research is required to see whether there are any other options that might assist in treating these problematic bacterial infections. Natural ingredients have been used as a promising cure for many illnesses and antimicrobial therapy since ancient times. Below is a detailed discussion of the antibacterial properties of several bioactive chemicals (Ibrahim & El-Sheekh, 2023).

i. Compounds of Spirotetronate

Mikamycin, a novel spirotetronate polyketide, was isolated from *M.* sp. GMKU326, exhibited strong activity against microbes, against *M. luteus, B. subtilis, B. cereus, S. aureus,* and *E. faecalis*. However, it showed reduced activity against *C. albicans* (MIC = 50µg/ml). Additionally, Mikamycin demonstrated potent cytotoxicity against cancer cells.

Lobophorin F, isolated from *S.* sp. SCSIO 01127, is a novel compound with antibacterial and antitumor properties, against *B. thuringiensis, S. aureus,* and *E.faecalis,* respectively (Karthikeyan et al., 2022).

ii. Ansamycin-type Polypetide Compounds

Novel ansamycin-kind compounds identified from Chilean Atacama Desert soil from the *S.* sp. strain C34 classified as chaxamycins A–D shows effective activity against *S.* aureus ATCC25923 and *E.* coli ATCC25922. Chaxamycins (A–C) were found to inhibit ATPase activity (Ameen et al., 2021).

iii. Tetracenediones

Streptomyces formicae KY5 strains can produce polyketides formicamycins A–L, efficient to inhibit MRSA with MIC 0.41µg/ml and vancomycin-resistant *Enterococcus faecium* (VRE) with MIC 0.82µg/ml.

1.1.3.6. Antioxidant Potential of Bioactive Compounds

Marine sediments obtained from Chennai, Tamil Nadu, India, classified as VSKB 1 to VSKB 6 (actinobacteria) have been screened out for its antibacterial and antioxidant sports wherein VSKB 3 exhibited pastime against *Salmonella typhi* and higher antioxidant activity. It confirmed comparable traits to Streptomyces and may be useful in generating tablets in opposition to Salmonella typhi (Varijakzhan et al., 2021).

1.1.3.7. Anti-inflammatory Activity of Bioactive Compounds

Inflammation, a critical element of responses of host to a couple of stimuli, consisting of injury, microbial invasion, and immune responses, consists of special organic pathways guided through outside and inner stimuli. Drugs evolved from herbal merchandise are in

excessive call for because the artificial capsules utilized in treating inflammatory issues purpose negative aspect effects. Novel compounds like steroids, polysaccharides, alkaloids, and fatty acids, isolated from marine organisms, are located to exhibit activity against inflammation (Macedo et al., 2021).

i. Proteins

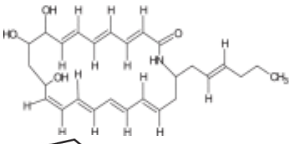
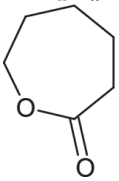
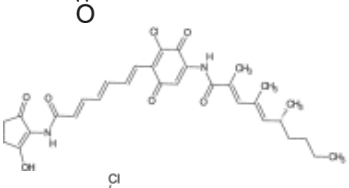
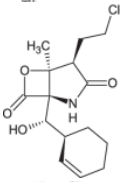
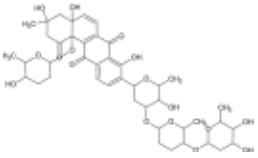
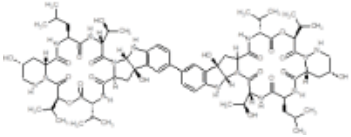
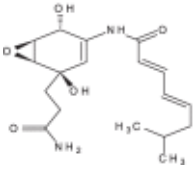
Marine lectins have been shown to have anti-inflammatory properties due to their carbohydrate-binding location, *Caulerpa cupressoides*, a green seaweed, effectively produces lectin and is injected into the left temporomandibular joint 30 minutes prior to zymosan administration. As a result, rats exhibit decreased zymosan-induced arthritis and mechanical hyper nociception. Additionally, the suppressed accumulation of leukocytes in synovial fluid. Whereas, decreased activity of lectin when administered ZnPP-IX or naloxone, opioid receptor antagonists. In the temporomandibular joint, influx of lectin inhibited leukocyte and the expression of TNF-alpha and IL-1beta, demonstrating that lectin exacerbates hyper nociception and inflammation in the temporomandibular joint, which is largely influenced by the reduction of TNF-alpha and IL-1beta (Senadheera et al., 2023).

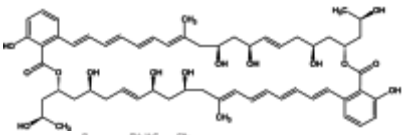
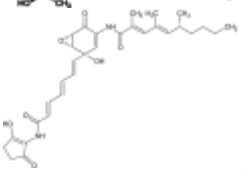
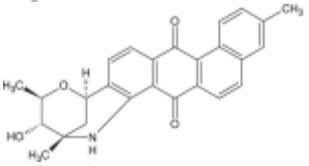
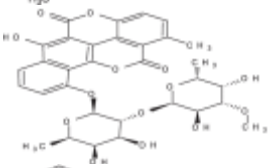
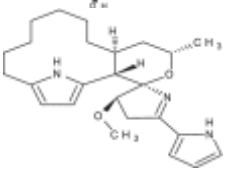
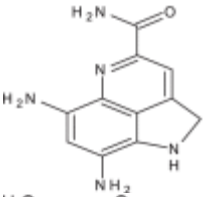
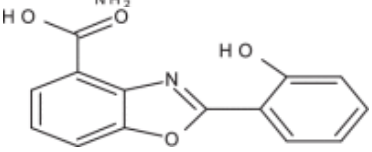
ii. Enzyme Inhibitors

Polymeric 3-alkylpyridinium salts, composed of N-butyl (3-butylpyridinium), have been extracted from the marine sponge *Reniera sarai*. The inhibitor's monomer, N-Butyl-3-butylpyridinium iodide, has been produced and functions as an acetylcholinesterase inhibitor (Table 1.1). The thin layer chromatography (TLC) bio-autography method was used to evaluate the acetylcholinesterase inhibitory activity of the marine extracts. Soft coral extracts exhibited higher levels of activity. 14-X-ray diffraction was used to identify the bioactive chemical as acetyl cysteine (Sibiya et al., 2021).

Table 1.1: bioactive secondary metabolites derived from marine sources, along with their structures and applications across various fields.

Marine sources of Secondary metabolites

SN	Secondary metabolites	Species	Structure	Practical uses	Reference
	Cytotoxic				
1	Aureoverticil-lactam	*S. aureoverticillatus*		Against many types of cell tumors	(Ahmed et al., 2022)
2	Capro-lactones	*S.* sp.		against cancer cell lines	(Samrot et al., 2021)
3	Chinikomycins	*S.* sp.		Antitumor action	(Basha et al., 2024)
4	MZB (Salinosporamide A)	*Salinispora tropica*		Cytotoxicity,	(Gono et al., 2022)
6	Urdamycin	*S. fradiae*		strong antibacterial and anti-cancer activity	(Perera et al., 2023)
7	Himastatin	*S. hygroscopicus*		Includes valine, leucine, threonine, α-.	(Guo et al., 2022)
8	Daryamide D	*S. strain CNQ-085*		Cytotoxic against cell line	(Hassan et al., 2022)

9	Marinomycin	*Marinispora sp. strain CNQ-140*		Inhibit proliferation of cancer cell	(Mutalipassi et al., 2021)
10	Manumycin	*S. sp. M045*		Antitumor against human cancer cell lines	(Martínez-Ruiz et al., 2022)
11	Marmycin	*S. sp.*		Cytotoxic	(Durazzo et al., 2022)
12	Chartreusin	*S. chartreusis*		against certain gram+ bacteria	(Awuchi et al., 2022)
13	Marineosins	*S. sp.*		inhibition colon carcinoma	(Srinivasan et al., 2021)
14	Ammosamides	*S .variabilis*		Cytotoxic to pancreatic cancer cell line	(Kabir et al., 2021)
15	Caboxamycin	*S. sp. NTK 937*		Inhibitory activity against Gram+ bacteria	(Elbandy, 2022)

1.1.4. Secondary Metabolites and their role

1.1.4.1 Anti-tuberculosis (anti-TB)

Anti-TB medicines have reduced death in anti-microbial resistant cases, while marine microorganisms offer a promising alternative for tuberculosis treatment. Approximately one hundred and seventy compounds from marine sources have demonstrated anti- tuberculosis properties. Present anti- tuberculosis agents' rifampicin, streptomycin, amikacin, viomycin, capreomycin, kanamycin, and cycloserine have in vitro activity against *M. tuberculosis* with MICs of 0.2, 0.5, 1.0, 4.0, 5.0, and 6.0μg/mL, respectively. To identify potential anti-TB compounds, the initial MIC value should be below 64μg/mL, or growth inhibition should exceed 75% at 12.5μg/mL. Owing to their distinctive marine environments and rich biodiversity, oceans have been recognized as a rich reservoir of diverse natural compounds demonstrating significant antimicrobial, antimalarial, antitumor, anti-inflammatory, and antioxidant activities (Lobine et al., 2022).

1.1.4.2. Neuro-degenerative Disorders

Neurodegenerative disorders are linked to oxidative stress, as they involve mitochondrial dysfunction and excessive production of reactive oxygen species, among other cellular pathologies. The CNS is highly susceptible to free radical damage due to its high oxygen consumption, phospholipids-rich composition, and elevated iron levels, which catalyze oxidative reactions and contribute to increased free radical production. The deficiency of antioxidant defenses is extra altered in Neurodegenerative disease (Menaa et al., 2021).

1.1.4.3. Oxidative stress

Oxidative stress is frequently linked to mitochondria, a common crucial-point in neurodegenerative disorders. With improved mitochondrial activity, reduced reactive production of oxygen species (ROS) generation, and elevated antioxidant enzyme levels, glutathione and catalase—exhibited total protection. According to another research, anhydroexfoliamycin can dramatically reduce the mitochondrial effect and stimulate Nrf2 nuclear translocation, suggesting that mitochondria are the molecule's biological target. Additionally, both substances could lessen the caspase-3 activity. These display that Streptomyces metabolites ought to assist broaden new pills to save you from neurodegenerative problems (Wu et al., 2021).

1.1.4.4. Alzheimer's

Alzheimer's (AD) is a disease characterized by gradual degeneration, loss of synapses, and eventual neuronal death. Certain parts of the brain play crucial role in formation of memory and learning processes have deficits. It is identified by the presence of neuro-fibrillary tangles that are abnormal accumulations inside the cell, of hyper-phosphorylated tau proteins and senile plaques which are extracellular aggregates of amyloid-beta protein that result from improper breakdown of the amyloid precursor protein. From many of hypothesis demonstrated, the maximum familiar of that is the amyloid cascade speculation that introduces the atypical amyloid is processed through beta and gamma secretes as the main event of Alzheimer's disease (Zhao et al., 2022).

Conclusion

Several bioactive chemicals with distinct and potent biological activity can be found in large quantity in the marine environment. To survive the hostile sea environment, marine species have evolved in various chemical compounds over millions of years. These substances have enormous potential applications in biotechnology, cosmetics, medicines, and other fields. Since the beginning of mankind, products obtained from nature are used for the treatment of diseases and ocean remains are treasure for such products. Surpassing 75% of the earth's surface is covered by the oceans and the planet's diversity. An unexplored area of the marine biotope, can give us wealthy novel herbal products. The reservoir for drug discovery are the microbial natural products, for decades. Yet, the microorganisms residing in the world's oceans have remained largely unnoticed.

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