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Mini-review on the antimicrobial potential of actinobacteria associated with seagrasses

Galana Siro[1]*, Atanas Pipite[2]

[1]School of Agriculture, Geography, Environment, Ocean and Natural Sciences (SAGEONS), Discipline of Biological and Chemical Sciences, The University of the South Pacific, Laucala Campus, Suva 1168, Fiji

[2]School of Natural Sciences, Department of Biomolecular, Massey University, Palmerston North 4410, New Zealand

***Correspondence:** Galana Siro, School of Agriculture, Geography, Environment, Ocean and Natural Sciences (SAGEONS), Discipline of Biological and Chemical Sciences, The University of the South Pacific, Laucala Campus, Suva 1168, Fiji. sirogalana@yahoo.com

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Abstract

The search for novel therapeutic agents to combat the crisis of antimicrobial resistance has spanned from terrestrial to unique, marine environments. Currently, most of the drugs available for usage are derived from microbial metabolites, especially those belonging to the bacterial group, actinobacteria. Actinobacteria are hotspot organisms that exist in all habitats with a myriad of unique biosynthetic metabolites. Seagrasses appear to be a key ecosystem within the coastal environment worth bioprospecting for novel natural products. Unfortunately, literature about the bioactive potential of their associated prokaryotes, including actinobacteria remains limited. In this context, this review focused on actinobacteria with antibiotic-producing capabilities derived from different parts of seagrass plants (i.e. roots, rhizomes, and leaves). To date, there were no purified molecules derived from seagrass-associated actinobacteria that were subjected to structure elucidation. From the underpinning of numerous biological profiles such as antibacterial, antifungal, and algicidal activities of seagrass-derived actinobacteria reported in this review during the period from 2012–2020, it provides a continual growth of knowledge accruing overtime, providing a foundation for future research.

Keywords

Actinobacteria, seagrasses, biosynthetic metabolites, marine ecosystem, antimicrobial resistance

Introduction

The crisis of multidrug resistance has created havoc in the health sector, with increasing ramifications for people's health. The quantity of resistant genes differs geographically, thus requiring global attention to counteract this inevitable phenomenon [1, 2]. As a counter approach, the administration of antibiotics and the tedious bioprospects of novel bioactive compounds from marine sources are common [3, 4]. A quantum of information regarding the natural products from marine environments has received great recognition due to their diverse applications and efficiency [5]. Bioprospects in marine habitats have continuously provided a series of novel and interesting metabolites [6–8]. An important marine ecosystem represented in this review is seagrasses. Seagrass meadows support gradation in species diversity and high biodiversity of marine life [9]. Actinobacteria sometimes referred to as actinomycetes are Gram-positive bacteria and form a unique group of bacterial lineages. They belong to the phylum Actinomycetota (https://lpsn.dsmz.de/phylum/actinomycetota) and are regarded as hotspots for clinical drug discovery. Their genomes have a high guanine-cytosine (GC) content and genes associated with antibiotic production [10–12]. The genus *Streptomyces* is the most widely gifted group of bacteria with efficient antibiotic machinery and is responsible for the high availability of clinical antibiotics [13, 14]. Actinomycetes exist as unicellular and multicellular, but some species function as either symbionts or pathogens. In spite of their antibiotic-producing capabilities, actinomycetes have other important functions including nutrient turnover and bioremediation processes [15, 16]. Moreover, actinomycetes are ubiquitous due to their adaptive nature. In tandem with this, they are able to colonize the oceans heterogeneous habitats, including seagrass meadows [17–19]. Studies that focus on the isolation of bacteria producing antagonistic metabolites from seagrasses are limited. In the search for potential prospecting fields, this mini-review herein scrutinized actinobacteria associated with seagrasses for their pharmaceutical compounds. Data reported in this paper were obtained from Web of Science, Google Scholar, and other online databases using their respective advanced search option with the following search terms: "actinobacteria-derived from seagrass: metabolites and bioactivity". In total, this review is an attempt to give more attention and momentum to seagrass-based actinobacteria and their medicinal active compounds.

Seagrass biology, evolution, and biodiversity

Seagrasses are submerged, marine flowering plants that thrive in the ocean except in the polar regions [20]. They comprise over 60 species, belonging to four exclusive plant families including Zosteraceae, Hydrocharitaceae, Posidoniaceae, and Cymodoceaceae, and support immense levels of biodiversity [21–25]. Seagrasses have a range of features that arose from adapting to living in submerged marine conditions [26, 27]. As an aquatic angiosperm, their multiple colonization events in the ocean predated over 70 million years ago [25]. Notably, seagrasses are rhizomatous plants adapted to aquatic environments [28]. Depending on their growth sizes, seagrasses range from small species (e.g., *Halophila engelmannii*) to large species (e.g., *Posidonia australis*) [23]. The highly productive nature of seagrasses is largely influenced by a mixture of sexual and asexual clonal reproduction [26]. Collectively, these foundation species form dense meadows, flowering and seeding underwater with significant provisions that ripple through the entire coastal ecosystems. Seagrass meadows are part of the tropical seascape, similar to mangroves and coral reefs, but they have a wide distribution along both tropical and temperate coasts. All these important marine ecosystems are interconnected via biogeochemical processes. Among the triad of key marine habitats, seagrass meadows are regarded as one of the most productive and crucial components of the marine ecosystem. They act as nutrient cyclers, sediment stabilizers (coastal protection), organic carbon producers (carbon sequestration), and juvenile nursery grounds and feeding areas for marine life (provide trophic subsidy to contiguous habitats) [24, 28, 29]. The ecological importance of seagrass meadows is irrefutable, and yet remains poorly studied, in terms of medicinal properties [30]. Seagrass meadows straddle the subtidal and intertidal zones of the temperate and tropical coastlines. Their distribution is mostly restricted to regions where wave activity is limited, and there is sufficient light and nutrient availability [31]. The capacity and performance of seagrasses are directly proportional to their area of coverage and density. Seagrass meadows show remarkably high levels of primary productivity and exist as monospecific or multispecies communities, depending on the bioregions [28]. Its mass coverage spans from small patches to extensive underwater lawns [28].

The ocean often receives a cocktail of raw sewage or pollutants. Consequently, shoreline microbial populations can spike to dangerous levels with serious health implications [32]. As one of the many natural counter approaches, seagrass plants often have innate filtration and responsive systems that facilitate the attenuation of nutrient levels, microplastic levels, microbial populations, and turbidity [33–36]. In most cases, it involves the deposition process, where they ensnare particulates and microbes drifting through the ocean by ensuring affable conditions to a certain degree. Despite their critical values, the fragmentation of seagrass meadows involves both natural pressures (waves, currents, and extreme weather events) and anthropogenic pressures (dredging and infilling, recreational activities, raw sewage discharges, eutrophication, and coastal constructions) [37]. A significant feature of seagrass meadows is the various constituency of the seagrass holobiont. Seagrasses, similar to terrestrial plants, house communities of microbes, including actinobacteria that exhibit symbiotic relations. Moreover, the seagrass microbiome consists of intricate interactive networks that facilitates their overall fitness and growth [26, 38–41]. Both the seagrass host and their associate microbes are capable of producing potent metabolites that prevent the invasion of opportunistic pathogens [39, 42]. Studies have shown that distinct microbial communities exist in discrete microenvironments of seagrasses [43]. Overall, the seagrass microbiome differs in composition between the different plant parts (i.e. roots, rhizomes, and leaves), as well as between species, which have a vast geographical distribution and are subject to a variety of environmental conditions. There are also differences between seagrass microbiomes and those of the adjacent seawater and surrounding sediment [44–47].

Traditional and medicinal use of seagrass around the world

There is evidence throughout history of the use of seagrass as food, medicine, fertilizer, and livestock feed [20, 48, 49]. In many places, such as the village of Chwaka in East Africa, they have a mixed economy that relies heavily on seagrasses beds which provide cash income and the most important source of daily protein (fish associated with seagrasses) [20]. India is another region of the world where seagrasses form an important part of the local economy. A study has shown that the information on the nutritional value of seagrass has been found to be equivalent to that of Bengal gram, peas, potatoes, and southern potatoes and is completely safe for consumption by analyzing the concentrations of toxic elements: lead (Pb), chromium (Cr), and cadmium (Cd) [20]. In Tunisia, the leaves of the seagrass, *Posidonia oceanica*, which have antifungal and insect repellent properties, have been used as livestock bedding and as feed supplements for poultry and livestock [48]. In most European and Mediterranean coastal countries, seagrasses have been used for different purposes such as packaging equipment for transporting fragile items (i.e. glassware, pottery) to ship fresh fish from the coast to cities, bedding for livestock in stables, filler for mattresses and cushions (respiratory infections seemed to be prevented from sleeping in this type of bedding), roof insulation (i.e. in southeastern Spain and the Balearic Islands), and also a roof cover (i.e. in Netherlands) [49].

The use of seagrass throughout history has shown that there is knowledge of the wide range of qualities possessed by these oceanic plants [50]. However, with the improvement of science and technology, studies have shown that these properties are based on the fact that seagrasses themselves can produce valuable chemical compounds or that these chemical compounds can be produced by microorganisms in symbiotic relationships with these seagrasses [50]. Remarkably, a total of 154 natural compounds derived from 70 seagrass species have been reported so far, predominantly from the host seagrass itself [50].

Diversity and bioactive profiles of seagrass-derived actinobacteria

The isolation of marine actinobacteria is influenced by the isolation parameters such as culture, pondus hydrogenii (pH) and temperature, incubation time, and concentration of the medium [51]. Numerous studies attest to culture seagrass-derived actinobacteria by employing the cultivation parameters as follows: using a wide variety of media, the addition of natural seawater, artificial seawater, or deionized/distilled water with different concentrations of sodium chloride, culture temperature 26°–29°C, and an incubation time of 1–6 weeks [52–57]. Certain actinobacterial have been isolated from all seagrass parts (roots, rhizomes, and leaves), whereas, most research specifically targeted actinobacteria as endophytes from the roots and leaves of seagrass, as shown in Table 1.

Table 1. Genus/species of actinobacteria isolated from seagrasses between 2012 and 2020

Genus/species	Family	Seagrass species and nature of sample	Bioactivity	Country	Reference
Streptomyces spp., *Micromonospora* spp., *Verrucosispora* (*Micromonospora*) sp., *Saccharomonospora* spp., *Actinomycetospora* sp., *Microbacterium* sp., *Mycobacterium* spp., *Nonomuraea* sp., *Nocardiopsis* sp., and *Glycomyces* sp.	Streptomycetaceae, Micromonosporaceae, Pseudonocardiaceae, Microbacteriaceae, Mycobacteriaceae, Streptosporangiaceae, Nocardiopsidaceae, and Glycomycetaceae	*Thalassia hemprichii* (whole plant)	Contain nonribosomal peptide synthetase (*NRPS*) and polyketide synthase (*PKS*) genes (antibacterial activity)	China	[52]
Streptomyces spp.	Streptomycetaceae	*Syringodium isoetifolium* (leaves and roots)	Antibacterial activity	India	[53]
Saccharomonospora sp., *Kocuria* sp.	Pseudonocardiaceae, Micrococcaceae	*Cymodocea serrulate* (roots)	Phosphate solubilizing, nitrogen-fixing ability, and enzyme activity	Kasuwari Island, India	[54]
Arthrobacter spp.	Micrococcaceae	*Zostera marina* and *Zostera japonica* (leaves)	Algicidal activity	Puget Sound, USA	[73]
Kocuria palustris, *Kocuria atrinae*, *Arthrobacter flavus*, *Ornithinimicrobium humiphilum*, *Corynebacterium afermentans* subsp. *afermentans*	Micrococcaceae, Ornithinimicrobiaceae, and Corynebacteriaceae	*Halodule uninervis* (soil and root)	Antifungal activity	Saudi Arabia	[55]
Not available	Cellulomonadaceae, Microbacteriaceae	*Halophila ovalis* (roots)	No bioactive test performed	Australia	[74]
Streptomyces sp.	Streptomycetaceae	*Cymodocea rotundata* (whole plant)	Antimicrobial activity	Indonesia	[71]
Streptomyces lienomycini	Streptomycetaceae	*Enhalus acoroides* (leaves)	Antibacterial activity	Indonesia	[57]
Isoptericola sp., *Rhodococcus* sp., and *Streptomyces* spp.	Promicromonosporaceae, Nocardiaceae, and Streptomycetaceae	*Zostera marina* (leaf and associate sediment)	No bioactive test performed	Bodega Bay, USA	[56]

Seagrasses harbor a rich pool of specialized metabolites [58, 59]. The antimicrobial assay and compound elucidation of seagrass extracts have been examined under different contexts. In most cases, the results have shown that cytotoxic, antimicrobial, antimalarial, antioxidant, antibiofilm, anti-inflammatory, or antimicrofouling activities are prevalent and widespread among various solvent extracts from seagrass species [25, 60–65]. In marine habitats, available surfaces are rapidly colonized by a spectrum of microbes. These microbial communities are often influenced by seasonality, and vegetative and non-vegetative sites [66]. With that, the vegetative cover of seagrasses provides a significant substratum for the rich diversity of organisms, including actinobacteria which forms an integral part of the seagrass ecosystem [9, 67–69]. Actinobacteria are among the pioneer colonizers of seagrasses [70] and their diversity varies between seagrass species [52, 53]. The seagrass-derived actinomycetes are capable of producing antimicrobial agents (Table 1). At the time of this review, there were no purified molecules derived from seagrass-associated actinobacteria that were subjected to structure elucidation. Studies have shown that they have a spectrum of biological potentials such as antibacterial activity [52, 53, 57, 71, 72], antifungal activity [55, 71], algicidal activity [73], nitrogen-fixing ability, and enzymatic activity [54]. Conspicuously, there are available studies where no bioactive test was performed for the actinobacteria discovered [56, 74]. Interestingly, Wu et al. [52] reported the isolation of *Verrucosispora* sp. from the seagrass *Thalassia* *hemprichii* (this was the first time a *Verrucosispora* strain was isolated as a plant endophyte). The members of the genus *Verrucosispora* have subsequently all been transferred to the genus *Micromonospora* (https://lpsn.dsmz.de/genus/verrucosispora).

Concurrently, they also cultivated four potential novel strains of actinomycetes which are yet to be categorized. Overall, as studies multiply in this area, more detailed discoveries of promising metabolites will be unveiled.

Conclusions

The seagrass meadows harbor a high biodiversity with a great wealth of specialized metabolites. The use of seagrass throughout history has shown that there is knowledge of the wide range of qualities possessed by these oceanic plants [50, 58]. This review highlights the tremendous bioactive potential of actinobacteria isolated from various species of seagrasses. Most available studies focus on seagrass extracts for antimicrobial assays, with limited attention based on their microbiome bioactivity. Future research should target seagrass meadows for actinobacteria-derived compounds. With the advent of improved genomic technologies, genome-based research focusing on the latter is important. Overall, the field of research targeting microbial biosynthetic potential associated with seagrasses is burgeoning.

Declarations

Author contributions

GS: Conceptualization, Writing—original draft, Writing—review & editing. AP: Conceptualization, Writing—original draft, Writing—review & editing, Supervision. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

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