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Bioactive properties of microbial communities associated with seaweeds

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Introduction

Microbial communities associated with seaweed have huge potential of synthesizing several bioactive compounds due to its diverse nature and the interactions with the surrounding environment. Thorough knowledge on the culture and storage characteristics of the bacterial strain is required for the pilot scale production of the bioactive compounds. The microbial isolates associated with seaweeds were reported to have growth promotic effect, in all the stages of seaweed life cycle starting from spore release and germination, to biomass production and which intern influence the bioactive properties of the seaweed. The complex reactions like beneficial and pathogenic interaction with bacteria are required for the stimulatory as well as inhibitory effect on cell division and tissue generation in seaweeds. The microbial communities on seaweed surfaces also gives the protection to the surrounding living organisms and its environments in the form of sperm germination and larval settlement, producing quorum sensing signals to attract or inhibit the entry of harmful organism.

Biological properties of seaweed associated bacterial communities

Seaweed associated bacteria produce beneficial antimicrobial and antifouling compounds which inhibit the growth of unwanted microorganisms. The bacterial families of *Firmicutes, Proteobacteia* and *Actinobacteia* over the seaweed surface have anticancerous activity and produce compounds capable of inhibiting the growth of HCT-116 colorectal cancer cells. Microbial enzymatic degradation of seaweed polysaccharides such as ulvans, agars, carrageenans, alginates, etc resulted in the formation of active oligosaccharides which are having several bioactive properties such as antioxidant, antinflammatory, and anticancerous activity.

The area of research regarding the exploitation of seaweed associated bacteria for the production of bioactive enzymes becomes more prioritized in recent years, considering the facts that seaweeds are rich in bioactive polysaccharides such as alginate, agar, carrageenan and

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several monosaccharides like glucose, xylose, etc. The hydrolytic enzyme for the hydrolysis of carbohydrate moieties such as cellulases, amylases, beta-glucosidases are present in seaweed associated bacteria emphasizing its diverse nature in aquatic ecosystems. The carrageenan presents in the cell wall of red algae was reported to hydrolyze by seaweed associated bacterium *Pseudoalteromonas carrageenovora*. The enzyme agarase which hydrolyse the agar in the red algae was extracted from Seaweed associated *Vibrio* species, and *Pseuoalteromonas* sp. *Bacteroides plebeius* associated from edible seaweed- *Porphyra* in Japan have Porphyranases activity. Similarly in brown seaweeds the alginate lyase enzyme producing bacteria such as *Flavobacterium*, and *Bacillus* species have been reported. Ulvanolytic bacterium *Persicivirga ulvanivorans* has the ability to hydrolyze the sulphated polysaccharide Ulvans in *Ulva* species. This bacterium was isolated from mollusc *Aplysia punctata* which fed on *Ulva* sp. In addition to these enzymes, other hydrolytic enzymes such as protease, lipase, urease, alkaline phosphatase, carboxymethyl cellulose activities are also found in seaweed associated bacteria (*Sargassaum* species).

Exopolysaccharides producing bacteria have been isolated from Seaweeds. Exopolysaccharides are the biopolymers of polysaccharide category secreted by microorganisms and are often attached with different functional groups such as acetyl, succinyl or pyruvyl, sulfate etc. Exopolysaccharide provides immune response to foreign particles or antigens. The more research and exploration in this area led to the discovery of many bioactive molecules from microorganisms in recent years. The well-known bacterial exopolysaccharides are Xanthan gum (Xanthomonas campestris), Alginate (*Pseudomonas* and *Azotobacter*), Dextran (Leuconostocmesenteroides), Cellulose (*Acetobacter*, *Sarcina ventriculi* and *Agrobacterium*), Hyaluronic acid (*Streptococcuszooepidemicus*), Gellan gum (*Sphingomonas elodea*), Curdlan (*Agrobacterium* spp., *Bacillus* spp. and *Cellulomonas* spp), Succinoglycan (*Rhizobium meliloti*), and Levans (lactic acid bacteria). The composition and components of exopolymeric substances of different microbial origin have huge structural and functional variations which intern responsible for its unique bioactive properties. Moreover, the reproducibility and biodegradation capacity of microbial derived EPS provides more demand over synthetic polysaccharides in greater extent and also offer several advantages over plant derived products in terms of non availability of the said resources due to ecological disturbances. *Bacillus cereus* and *Pseudomonas pseudoalcaligens* from *Kappaphycus alvarezii and Ulva lactica* have the potential of producing biodegradable polymer called Polyhydroxy alaknoate by utilizing various substrates such as sugars and fatty acids. EPS producing *Bacillus pumilus* and *Bacillus flexus* were shown growth enhancing effect on *Ulva fasciata.*

The roles of bacterial communities in seaweeds are listed in the table 1

Table 1: The bacterial communities present in seaweeds and its role

Bacterial communities	Role in seaweeds
Vibrio and *Shewanella*	Stimulate the spore settlement in *Enteromorpha*
Pseudoalteromonas strains	Inhibiting the spore settlement in *Enteromorpha* and also induced paralysis and lysing of *Enteromorpha* zoospores
Flavobacterium, Vibrio, Pseudomonas, Deleya, Escherichia and Gram-positive cocci	Morphogenesis inducing activity in *Ulva linza*
Nitrogen-fixing Cyanobacteria (*Calothrix sp., Anabaena* sp., and *Phormidium* sp)	Fix nitrogen to seaweeds
Pseudoalteromonas, Stenotrophomonas, Vibrio, Aeromonas, Shewanella, Streptomyces and *Bacillus*	Antimicrobial producing bacteria in seaweeds
Streptomyces sp	Anti-inflammatory and anti-tuberculosis activity in brown seaweed *Fucus spiralis* and *Cystoseira baccata*
Epiphytic microbial communities, and *Pseudoaleromonads*	Scavenging of heavy metal or crude oil.
N-acyl homoserine lactone (AHL) producing *Vibrio anguillarum*	Inhibitory effect on the settlement of zoospores in *Ulva*

Biological properties of seaweed associated fungal communities

Seaweed associated fungi produces bioactive metabolites with unique characteristics. The unusual capacity of these fungi offers a great opportunity to overcome the use of synthetic compounds for the use in human health care sector. Commercially important fungal polysaccharides are β glucan (Lentinan from *Lentinusedodes*,PGG-glucan from *Saccharomyces cerevisiae*, SSG-glucan from *Sclerotiniasclerotiorum*), α-Glucan (Pullulan from *Aureobasidium pullulans*, Nigeran from *Aspergillus niger*) Galactan (β 1-5-Galactanfrom *Penicillium charlesii,*Malonogalactan from *Penicillium citrinum*), Polyuronide from *Mucor* species, Mannan from *Penicillium charlesii* etc. Nearly eighty bioactive components have been identified from seaweed derived fungi.

Antitumorous compounds

The pharmacologically important compounds such as polyketides, steroids, peptides, terenoids, quinine etc are present in different species of seaweed derived fungi. The antitumorous compounds such as 7-nor-ergosterolide and 9-dihydroxy-14-p-nitrobenzoylcinnamolide; insulicolide A, extracted from seaweed such as *Sargassum Kjellmanianum* and *Coelarthrum* sp. associated *Aspergillus Ochraceus*. The alkaloid classes of compound called prenylated indole alkaloids extracted from *Penicillum* and *Aspergillus* have insecticidal, cytotoxic, anthelmintic and antibacterial activities. Similarly, seaweed derived *Paecilomyces variotii* EN-291 producing alkaloid such as varioloid A; varioloid B dihydrocarneamide A; iso-notoamide B have potent cytotoxic properties. Secondary metabolites of *Cladosporium* L037 species from the brown alga *Actinotrichia fragilis*, have potent cytotoxicity against murine lymphoma L1210 cells. The two 12-membered macrolides, namely, sporiolides A and B are responsible for its bioactivity

Antioxidant and antimicrobial activities

The antioxidant activities of the bioactive metabolite of seaweed derived fungal speices are well documented. The antioxidants such as epicoccone and xanthone from *Epicoccum* sp., an endophytic fungus of *Fucus vesiculosus* and *Wardomyces anomalus*, an endosymbiont of green algae respectively have strong innate immune response in seaweed to counteract the defense reactions of their host. Secondary metabolite production in fungi is depends upon the culture conditions such as pH, salinity, temperature, nutrient conditions etc. The presence of fungal polyketide aminoacid hybrid metabolite called cytochalasans particularly marcrolide cytochalasin D is reported in seaweed derived endophytic fungi. The cytochalasans compounds have distinct antimicrobial and antifungal properties. The antimicrobial, antioxidant, and cytotoxic activities in *Talaromyces islandicus* EN-501, an endophytic fungus obtained from the inner tissue of the marine red alga *Laurencia okamurai* is due to the presence of Diphenyl ketones, Xanthones, and polyhydroxylated hydroanthraquinone derivatives. Bioactive compound Chaetopyranin, a dervivative of benzaldehyde was isolated from an Endophytic Fungus *Chaetomium globosum* derived from the marine red alga *Polysiphonia Urceolata.*

Role of fungal communities associated with seaweed

Fungi–seaweed association	Role /Activity
Aspergillus terreus KC 582297 association with seaweed	Antimicrobial activity against human pathogens

Enteromorpha tubulosa associated Aspergillus flavus	2-Pyrone compounds causes the Induction of cyclic adenosine monophospate production in different organisms
Aspergillus oryzae in *Heterosiphonia japonica*	Antibiotic activity
Beauveria felina in *Caulerpa sp*.	Antibacterial, antifungal activity
Pencilluim citrinum in Actinotrichia fragilis, Fusarium sp *in Codium fragile*	Anticancerous activity
Myrothecium sp. isolated from *Enteromorpha compressa*	Tyrosinase inhibition activity
Penicillium sp isolated from the Brazilian marine seaweed *Bostrychia tenella*	Cytotoxic, antifungal and antibacterial activities
Talaromyces islandicus EN-501, an endophytic fungus obtained from the inner tissue of the marine red alga *Laurencia okamurai*	Antimicrobial, antioxidant, and cytotoxic activities

Conclusion

Seaweeds are gaining a lot of importance all over the world because of their health benefits and biotechnological applications. The research on microbes associated with seaweeds makes more potential of exploring the utilization of seaweeds. The microbial communities are often host-associated and are considered a complex dynamic system which changes over time. Species composition of the microbial community in an ecosystem highlights the biological as well as physiological conditions of the habitat. Seaweed associated microbial communities and their interactions with biotic and abiotic factors provide a merging effect on both dynamics and functional aspects of the individual components. The ecological functions of seaweed microbial interaction determine the development and growth of seaweeds, production of bioactive molecules, quorum signalling etc.

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