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# Brief Review Of Halophytic Endophytic Microbes Of Coastal Plants: Identification, Properties And Their Applications For Achieving Sustainability

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***Abstract:***
*Endophytes are microorganisms that inhabit the intracellular tissues of nearly all plants, providing multiple benefits to their hosts. Numerous studies have confirmed their ability to produce a variety of valuable bioactive compounds, including plant growth regulators, antibacterial, antiviral, antifungal, and insecticidal substances. While considerable knowledge exists regarding plant communities and associated wildlife in coastal areas, the role and diversity of microorganisms in these ecosystems remain underexplored. This review focuses on the ecology of endophytes, emphasizing plant–microbe symbioses in coastal systems. It assesses recent research on endophytes associated with environmentally stressed, halophilic coastal plants, including their classification, growth characteristics, and bioactive metabolites.*

***Keywords:*** *Endophytes, Costal plants, Bioactive components.*

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## I. Introduction:

The term endophyte was first introduced by de Bary in 1866 to describe any organism living within plant tissues, distinct from epiphytes that inhabit the plant surface [1]. Endophytes encompass bacteria, fungi, and actinomycetes and with approximately 300,000 plant species on Earth, each plant hosts one or more endophytes, many of which exhibit host specificity [2]. By definition, endophytes reside asymptomatically within plant tissues, establishing mutualistic associations without causing harm [3]. They typically inhabit intercellular spaces, enhancing host growth and competitiveness in natural environments [4]. Endophytic bacteria have much importance in agriculture as in Fig. 1 whereas they commonly produce phytohormones, which improve plant tolerance to abiotic stresses and promote growth [5]. Moreover, endophytic microbes are increasingly recognized for their ability to suppress a wide range of plant diseases through antagonistic interactions or facilitation of plant defenses [6], while also enhancing host stress resilience [7]. These microbes contribute to nutrient recycling by initiating the biological degradation of dead or dying plant tissues [8]. Furthermore, numerous studies have confirmed that endophytes produce a variety of valuable bioactive compounds, including plant growth regulators, antibacterial, antiviral, antifungal, and insecticidal substances. Coastal areas, characterized by unique ecosystems, serve as reservoirs of biodiversity. Coastal plants play a critical role in food chains and the functioning of these ecosystems. These plants are often exposed to poor soil quality, high salinity, and a range of abiotic and biotic stresses. To survive such harsh conditions, coastal plants frequently harbor unique populations of microbial endophytes, which enhance plant growth, stress tolerance, and overall survival [9]. Recent studies indicate that these endophytic microorganisms produce valuable and unique bioactive compounds with potential applications in environmental management, agriculture, and human health sustainability**.** This study aimed to studing the ecology of endophytes, emphasizing plant–microbe symbioses in coastal systems.

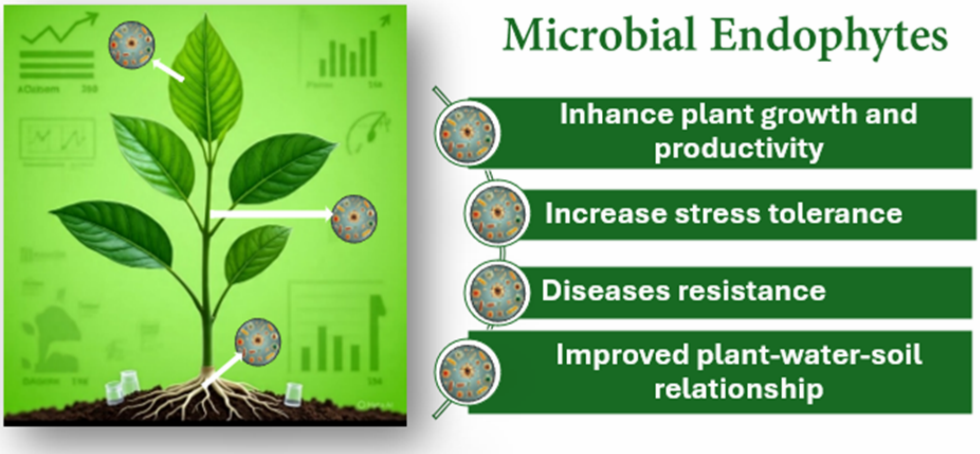


**Fig 1: Microbial endophytes benefit for the plant**

## II. Costal Ecosystems:

Coastal areas provide essential ecosystem services, including food production, storm surge protection, pollutant filtration, carbon storage, recreation, and the preservation of cultural heritage [10]. The seashore, situated at the interface of land and sea, is shaped by waves and tides and exhibits diverse topographical and ecological features, such as sand dunes, shore cliffs, and tidal flats. Frequent erosion, sediment deposition, and strong winds make the coastal landform unstable. Coastal soils are often saline and sandy, limiting water retention, and are further influenced by alternating periods of heavy rainfall or drought, creating a harsh environment for plant growth. Nevertheless, many plant species thrive in these challenging habitats [11].

Coastal plants play a crucial role in food webs and the overall functioning of coastal ecosystems. They are exposed to poor soil quality, high salinity, and a range of abiotic and biotic stresses. To survive under such conditions, coastal plants often harbor unique populations of microbial endophytes, which enhance plant growth, stress tolerance, and persistence. These symbiotic relationships are critical for the establishment and survival of coastal vegetation. Soil microorganisms are directly linked to plant diversity and productivity, highlighting the importance of plant–microbe interactions [9].

Endophytic microbes, in particular, contribute to host plant survival by performing multiple functions, including protection against pathogenic microorganisms, growth promotion, and solubilization of essential nutrients [12]. Conversely, coastal plants support soil microorganisms by supplying oxygen, bioactive compounds, and nutrients, which can facilitate pollutant degradation. Additionally, the roots of coastal plants play a vital role in stabilizing sandy soils, such as those in sand dunes, by tightly anchoring the rhizosphere [13].

## III. Costal Endophytic Microbe Diversity:

Recent studies indicate that coastal plants maintain symbiotic relationships with a wide range of microorganisms, including fungi, bacteria, and actinomycetes. Endophytic fungi and bacteria inhabit roots, stems, leaves, and inflorescences of coastal grasses, sedges, forbs, and trees. Although research on these interactions remains limited, coastal plants have been found to host highly diverse endophytic communities [14], comprising bacterial and fungal taxa previously reported from marine, soil, and freshwater environments [15].

**Costal endophytes fungi:**

Endophytic fungi constitute a significant portion of fungal symbionts associated with plants, residing entirely within plant tissues and commonly inhabiting roots, stems, and leaves. These fungi serve multiple roles, including protection against herbivores [16], promotion of plant growth [17], and competition with microbial pathogens [18]. Many researchers have attributed the enhanced vegetative growth of grasses in the presence of fungal symbionts to improved plant fitness [19].

The biodiversity of fungal endophytes in coastal plants has been widely documented (Table 1). For instance, a study in Pohang Beach, Korea, isolated 122 fungal strains from nine coastal plant species. *Vitex rotundifolia* yielded the highest number of isolates (28), whereas *Polygonum convolvulus* produced the fewest (7). Among these, 101 isolates promoted the growth of rice, while 21 inhibited it, suggesting that many endophytic fungi in sand dune plants produce metabolites beneficial for plant development [20].

In Southeast Spain, fungal endophytes were surveyed in roots of 24 plant species across 12 sites, including coastal and inland soils under water or salt stress. A total of 1,830 fungal isolates were identified, with *Fusarium* and *Phoma* being the most frequent genera, followed by *Aspergillus, Alternaria, and Acremonium. Specific species,* such as *Fusarium oxysporum, Aspergillus fumigatus,* and *Alternaria chlamydospora*, contributed most to differences between endophytic communities in sandy versus saline soils. Certain Fusarium species showed host preferences: *F. oxysporum* and *F. solani* were primarily associated with *Leguminosae,* while *F. equiseti* preferred *Lygeum spartum* from Gramineae [21].

High biodiversity of fungal endophytes was also observed in dominant coastal plants like *Ipomoea pes-caprae* along Taiwan's shore, with 896 records corresponding to 177 species [22]. In dunes of the Atlantic coasts of Europe (Galicia, Spain), culturable fungal endophytes were isolated from leaves and rhizomes of *Ammophila arenaria* and *Elymus fractus*, yielding 103 species in total (75 in *Ammophila*, 54 in *Elymus*). Of these, 24 species were classified as *Ascomycetes* or *Basidiomycetes*, belonging to 62 genera. The ten most abundant genera were *Alternaria, Acremonium, Podospora, Penicillium, Microdochium, Arthrinium, Leptosphaeria, Epicoccum, Cladosporium,* and *Beauveria*, representing 62% of all isolates [23].

On the east coast of Korea, 194 fungal strains from roots of 12 coastal plants were categorized into 31 genera, with Penicillium being the most abundant, followed by *Aspergillus*. Roots of *Phragmites australis* showed the highest fungal diversity [24]. Similarly, in Seocheon salt marsh, west coast of Korea, 128 endophytic fungal isolates were identified from five plant species, spanning 31 genera [25].

Fungal endophytes were predominantly located in roots and occasionally in rhizomes and leaves, as observed in *Posidonia oceanica* along the Sicilian coast. *Lulwoana* sp. was the most frequent taxon, indicating strong host interaction, while other taxa, including *Ochroconis* and members of Xylariaceae, were consistently found across sampling sites. *Penicillium glabrum* was isolated at a single site [26].

Some endophytic fungi also belong to marine taxa. A study on three plants (*Ipomoea pescaprae, Launaea sarmentosa,* and *Polycarpaea corymbosa*) from coastal sand dunes in west India recovered 220 fungal isolates, including 19 Deuteromycetes, six Ascomycetes, and six sterile fungi. Approximately 13% belonged to marine fungal taxa such *as Monodictys pelagica, Periconia prolifica, Verruculina enalia,* and *Zalerion maritimum*. Notably, some fungi adapted to sand dune ecosystems were not recovered as root endophytes. Endophytic *Acremonium* can reduce arbuscular mycorrhizal fungal colonization and reproduction, although no such effect was observed in the studied coastal dune plants [27].

Table 1: Summary of recent studies that detected coastal plant fungal endophytes, their host, and bioactive components.

| Host plant | Regions | Endophytic fungi | Bio. comp. | Ref. |
|---|---|---|---|---|
| ***Ipomoea pescaprae, Launaea sarmentosa Polycarpaea corymbosa*** | West coast, India | *Chaetomium globosum, Torula caligans Fusarium sp. Monodictys pelagica, Periconia prolifica, Verruculina enalia Zalerion maritimum* | | [27] |
| **24 plant species growing at 12 sites from (coastal and inland soils)** | Southeast Spain | *Fusarium oxysporum, F. equiseti, F. solani Acremonium furcatum, A. potronii,Embellisia chlamydospore Phoma leveillei,P. herbarum, P. putaminum,P. fimeti, Alternaria chlamydospore, A. alternata Aspergillus fumigatus, Monosporascus cannonballus ,Cylindrocarpon destructans, Phialophora cyclaminis Helminthosporium solani, Rhizoctonia-like,Phomopsis vaccinii* | | [21] |
| ***Ammophila arenaria.*** | Atlantic coast of Europe | *Cryptococcus victoriae,Cryptococcus victoriae,Nigrospora oryzae,Trichoderma viride,Aspergillus niger,Aspergillus versicolor,Chaetomium globosum Coprinellus radians, Debaryomyces hansenii, Engyodontiumalbum ,Fimetariella rabenhorstii* | | [28] |
| ***Suaeda salsa*** | Hangzhou, China | *Cladosporium cladosporioides* | Improving seed germination rates | [29] |
| ***Terong Pungo (Solanum sp.)*** | Coastal area, Pidie District, Indonesia | *Aspergillus spp., Trichoderma spp.* and *Fusariumspp.* | Antagonistic activity: *Staph. aureus,Staph. epidermidis Pseudo. aeruginosa* | [30] |
| **Date palm (*Phoenix dactylifera*)** | Coastal dunes, South-East of | Clonostachys rosea, *Fusarium equiseti, Fusarium solani Penicillium commune, Aspergillus tubingensisBeauveria bassiana, Campanella* | Control a diversity of plant pathogens [32] | [31] |

| | | | | |
|---|---|---|---|---|
| | Spain | *olivaceonigraPhomopsis , lagerstroemiae, Phomopsis lagerstroemiae, Corynespora cassiicola, Ilyonectria* sp., *Aspergillus sclerotiorum Phomopsis asparagi Marasmiellus candidus, Myrothecium verrucaria, Diaporthe hongkongensis* | | |
| **Samples from 12 plant species from the coastal cliff areas, sand dunes, and gravelly fields** | Korean East Coast | *Ascomycota (194 strain). Eurotiomycetes (140 strains) Dothideomycetes (25 strains), Leotiomycetes (12 strains), Sordariomycetes (11 strains), Saccharomycetes (4 strains), unclassified Ascomycota (2 strains)* | | [24] |
| ***Vitex rotundifolia*** | Northern coast of Taiwan | *A. alternata, A. terreus Alpestrisphaeria sp, Acrophialophora sp Phyllosticta capitalensis* | | [33] |
| ***Suaeda australis, Phragmites australis, Suaeda maritima, Suaeda glauca Bunge*** | West coast of Korean | *Gibberella intermedia.* | Produce gibberellins GA1, GA3, GA9, and GA24 | [25] |
| ***Stipagrostis sabulicola*** | Namib Sand Sea | 71 endophyte isolates belong to: *Aspergillus welwitschiae, Alternaria alternata, Chaetomium strumarium, Curvularia eragrostidis, Thielavia subthermophila,* and *Aspergillus amstelodami* | | [34] |
| ***Mangrove species*** | Coastal Kenya | *Aspergillus flavus, Aspergillus niger, Aspergillus tubingensis, Aspergillus oryzae, Rhizophora nomius, Aspergillus awamori, Aspergillus aculeatus, Aspergillus bravionivious, Aspergillus welwitchiae* | Antimicrobial activity, insecticidal, antiviral, anti-inflammatory, | [35] |
| ***Posidonia oceanica (L.)*** | Coast of Sicily, Italy | *Lulwoana* sp., *Ochroconis sp, Penicillium glabrum, Fusarium sp, Paecilomyces* sp., *Sordariomycetes, Thielavia microspore, Xylariaceae* sp., | Supporting the living host | [26] |
| ***Aster spathulifolius , S. oryzifolium*** | Coast of Korean Peninsula | *Aspergillus terreus Penicillium thomii* | Helps plants survive on sandy soil and solubilizes rock | [36 ] |
| ***R. rugosa* and *I. anhephoroides*** | | *P. restrictum* | Increase host resistance to phytopathogens - direct antagonistic activity | |
| ***P. thunbergii* and *R. rugosa*** | | *Talaromyces australis* | Biocontrol agent | |
| ***Ipomoea pescaprae*** | Shore of Taiwan | *896 strains, Ascomycota, Basidiomycota and Zygomycota, corresponding to a total of 13 classes and 33 orders. It includes 177 different species of fungi* | | [37] |

**Coastal Endophytic Bacteria:**

Coastal and marine plants along the Oregon coast grow under challenging conditions such as nutrient-poor soils, high salinity, and various abiotic and biotic stresses. To withstand these harsh environments, they often harbor unique communities of bacterial endophytes that contribute to their growth and survival [38].

A wide diversity of endophytic bacterial species has been isolated and characterized from plants exposed to such stresses (Table 2). These bacteria are involved in a range of essential processes, including photosynthesis, nitrogen fixation, and methanogenesis [39]. Microorganisms from coastal ecosystems are particularly valuable because they produce enzymes, proteins, antibiotics, and salt-tolerant genes with significant biotechnological applications.

Moreover, many of these isolates have been proven to enhance plant growth and increase tolerance to both abiotic and biotic stresses. For example, halotolerant bacteria from saline environments have been shown to improve salt resistance in inoculated plants [40]. Similarly, endophytic bacteria isolated from three plant species in the low arctic tundra were found to be both cold-adapted and host-specific [41].

A study conducted along the Oregon coast in India investigated 34 plants from eight different species, where bacterial endophytes were isolated from root crown, stem, and leaf tissues. From 133 bacterial isolates, 94 were unique, representing 36 distinct taxonomic groups. Among these, Pseudomonads were the most dominant, followed by *Curtobacterium* and *Microbacterium*, with *Bacillus* and *Xanthomonas* occurring less frequently [42]. Additionally, the endophytic bacterial community was isolated from the seeds of the holoparasitic plant, *Cistanche phelypaea* growing in coastal salt marshes of the Iberian Peninsula, Portugal.

Notably, *C. phelypaea* is the only member of the genus *Cistanche* reported in this type of habitat. Analysis revealed the presence of 23 bacterial phyla and 263 genera, with Proteobacteria and Actinobacteriota being the most abundant groups [43].

In another investigation, the bacterial communities associated with the roots and leaves, as well as the rhizosphere and bulk soils, of the coastal halophyte *Limonium sinense* in Jiangsu Province, China, were characterized. Seventeen genera of bacteria were identified across all samples, with *Glutamicibacter* emerging as the dominant genus. These halotolerant bacterial isolates are thought to contribute to reducing the negative effects of salt stress on their host plants [44].

Table 2: Summary of recent studies detecting coastal plant Bacterial Endophytes, their host, and bioactive components:

| Host plant | Regions | Endophytic bacteria | Bioactive comp. | Ref. |
|---|---|---|---|---|
| *Ammophila arenaria* *Elymus mollis* | Oregon coast near Florence, | The most common microorganism are *Pseudomonads, Stenotrophomonas* and *Pseudomonas* and one isolate is *Burkholderia* sp | Nitrogen fixation | [45] |
| *Calystegia soldanella* *Lathyrus japonica* *Elymus mollis* *Vitex rotundifolia* *Carex kobomugi* *Artemisia fukudo* *M. sibirica* *Glehnia littoralis* | North Korea | 91 endophytic bacterial isolates belong to 17 different genera *Gammaproteobacteria* represented the majority of the isolates and members of *Pseudomonas* | Antagonism towards plant pathogenic fungi produce (IAA), siderophores, protease, pectinase, chitinase | [46] |
| *Rhizophora apliculata* *Avicennia marina* *Excoecaria agallocha* *Ceriops decandra* *Aegicerascorniculatum* *Suaeda maritime* *Sevsvium portulacastrum* | Tamil nadu India | 104 endophytic bacteria, most belong to genus *Bacillus.* | Antimicrobial activity Produce pectinase,protease, invertase, IAA, nitrogen fixing activity, phosphate solubilization, | [47] |
| *Cressa cretica* *Salicornia brachiate* *Suadea nudiflora* *Sphaeranthus indicus* | Coastal Gujarat | Total of 20 isolates belong to *Acinetobacter, Bacillus, staphylococcus, Kocuria, Staphylococcus, Paenibacillus, virgibacillus, pseudomonas, Oceanobacillus, Arthobacter, paenibacillus.* | Phosphate solubilizer Mixed acide fermenters 5 species production of IAA | [48] |
| *Mussaenda roxburghii (Akshap)* | Eastern Himalayan Province, India | *Pseudomonas* sp., *Klebsiella* sp., *Acinetobacter* sp., | phosphate solubilizer, IAA producer, high tolerate to NaCl and heavy metals | [49] |
| *Agrostis, Ammophilia, Bromus, Descampsia, Festuca, Hordeum, Lolium, Phalaris.* | Oregon Coast | 133 different bacterial isolates belong to five taxonomic groups: *Pseudomonads, Curtobacterium Microbacterium, Bacillus and Xanthomomas* | Fourteen bacterial isolates Produce (ACC) | [44] |
| *Cyperus rotundus* | Beach of north Nisa | A total of 21 endophytic bacterial isolates | IAA production and Phosphate solubilization | [50] |
| *Oryza sativa,* *Euphorbia vermiculata,* *Spagneticola trilobata,* *Rhizopora stylosa,* *Ipomea pescaprae,* *Cromolaena odorata,* *Portulaca oleraceae* | Indonesia coastal areas | Marine salt tolerant bacterial strains from rhizoplane and phyloplan | Improve salt tolerance in two rice varieties ACC deaminase activity | [51] |
| *Messerschmidia sibirica* | Coastal zone of Shandong peninsula in China | A total of 198 endophytic bacteria were isolated, the highest colonization: *Pseudomonas alcaliphila* *Bacillus subtilis* | Nitrogen fixation phosphate solubilizer ACC and IAA production | [52] |
| *S. Rosmarinus shoots* | Uzbekistan | Isolates belonged to the genera *Staphylococcus, Rothia, Stenotrophomonas, Brevibacterium, Halomonas, Planococcus,Planomicrobium* and *Pseudomonas* | production of IAA, ACC Saline tolerance | [53] |
| *Glehnia littoralis* | Qingdao Laoshan, China | Dominant in all the samples at the phylum level *Actinobacteria and Proteobacteria* | - | [54] |

| | | | | |
|---|---|---|---|---|
| | | the dominant genera *Pseudomonas, Bacillus, Rhizobium* . | | |
| *Avicennia officinalis.* | Coastal Region of Corangi eastern China | *Bacillus, Exiguobacterium, Salinicola, Pseudomonas, Enterobacter and Vibrio* | IAA production Phosphate solubilizing bioenzymes | [42] |
| *holoparasite Cistanche phelypaea (Orobanchaceae)* | Atlantic coast of the Iberian Peninsula, in Portugal | 63 bacterial strains belonging to: *Bacilli, Actinomycetes,* and *Micromonospora* | Salt tolerant production of organic acids, IAA, ACC siderophores | [43] |
| *Avicennia officinalis L.* | Mangrove zone of East Godavari | 11 isolates, which belongs to the genus *Bacillus, Exiguobacterium, Salinicola, Pseudomonas, Enterobacter* and *Vibrio* | IAA and ACC production Saline tolerance and phosphate solubilization | [55] |

**Costal Endophytic Actinomyces:**

In recent years, endophytic actinobacteria have gained considerable attention, with numerous isolates reported from a wide range of plant species, including important crops such as wheat, rice, banana, apple, and tea, as well as various medicinal plants [56-57]. However, the isolation, diversity, and biological activities of endophytic actinobacteria inhabiting coastal salt marsh ecosystems remain relatively underexplored, despite the likelihood that these environments harbor unique and phylogenetically diverse endophytic populations.

Extreme and specialized environments are often rich in rare actinobacteria and novel species. These rare actinobacteria are generally difficult to isolate due to their specific growth requirements and/or yet unknown culture conditions [58]. Actinobacteria from wetland ecosystems are of particular interest because they produce structurally diverse bioactive compounds, including enzymes, antibiotics, antitumor agents, and immune-regulatory molecules [59]. Furthermore, they play an important role as symbiotic members within plant-associated microbial communities [60].

A wide diversity of endophytic actinobacteria has been identified in plants inhabiting mangrove and salt marsh ecosystems across different regions of the world. The dominant groups in these wetlands typically include *Streptomyces, Nocardiopsis*, *Pseudonocardia*, *Saccharopolyspora*, *Agrococcus*, and *Micromonospora* [61].

In Jiangsu, China, the diversity and community composition of endophytic actinobacteria associated with native coastal salt marsh plants were examined. From 19 plant samples, 278 isolates were obtained, representing 23 genera within the *Actinomycota*. Among these, *Streptomyces, Saccharopolyspora,* and *Pseudonocardia* were the most abundant. Notably, more than ten isolates represented novel taxa distributed across eight different genera [62]. Similarly, actinobacterial strains belonging to *Streptomyces, Nocardiopsis, Pseudonocardia*, *Agrococcus*, and Isoptericola have also been reported from mangrove plants [63].

Several novel endophytic actinobacteria have been discovered from halophytic hosts. For instance, the halotolerant *Saccharopolyspora dendranthemae* was isolated from a coastal salt marsh plant [64], while *Phycicoccus endophyticus* was identified from *Bruguiera gymnorhiza* in the Zhanjiang Mangrove Forest [65]. In addition, two new rare genera, *Friedmanniella* and *Nakamurella*, were identified among 192 actinobacterial strains isolated from 12 plant species, encompassing 30 genera, 17 families, and 8 orders [66].

Saline habitats impose harsh growth conditions, yet certain actinobacteria have adapted to thrive under such stresses. For example, endophytic strains capable of growing at high salt concentrations (up to 7% NaCl) and alkaline pH were found in the roots of the halophyte *Salsola affinis* [67]. Moreover, *Amycolatopsis jiangsuensis* sp. nov. was isolated from the coastal plant *Dendranthema indicum (Linn.)* [68]. Collectively, these findings highlight halophytic plants as promising reservoirs of novel endophytic actinobacteria, many of which remain unexplored (Table 3)

Table 3: Summary of recent studies detecting coastal plant endophytic Actinomycetes, their host, and bioactive components:

| Host plant | Regions | Endophytic fungi | Bioactive comp. | Ref. |
|---|---|---|---|---|
| *Mangrove (Lowlands) Aquilaria crassna* | Thailand, | *Streptomyces javensis, Nonomuraea rubra, Actinomadura glauciflava , Pseudonocardia halophobica ,* and *Nocardia alba* | IAA, siderophores production | [69] |
| *Xylocarpus granatum* | China | *Jishengella endophytica* | - | [70] |
| 13 traditional medicinal plants | Sichuan, China | 80 endophytic actinomycetes *Jatrophihabitans endophyticus, Nocardioides panzhihuaensis 201 Nocardia endophytica, Kibdelosporangium phytohabitans* | Inhibitory effects against at least one indicator pathogen, anticancer and anti-diabetic activities | [71] |
| *Sonneratia apetala* | Sanya, | *Micromonospora sonneratiae* | | [72] |

| | | | | |
|---|---|---|---|---|
| | China | | | |
| *Salicornia europaea* | Jiangsu, China | *Modestobacter roseus* | | [73] |
| *Tamarix chinensis* | Jiangsu, China | *Streptomyces halophytocola* | | [74] |
| *Dendranthema indicum* | Jiangsu, China | *Glycomyces phytohabitans* , | | [75] |
| *Viola philippica* | China | *Micromonospora violae* | | [76] |
| *Costus speciosus* | Bangkok, Thailand | *Micromonospora costi* | | [77] |
| *Glycyrrhiza uralensis* | Xinjiang, China | *Phytoactinopolyspora endophytica* | | [78] |
| *Salsola affinis* | Xinjiang, China | *Okibacterium endophyticum, Arthrobacter endophyticus* , | | [79] |
| *Limonium sinense* | Lianyunga,China | *Glutamicibacter halophytocola* *Glutamicibacter nicotianae* *Glutamicibacter arilaitensis* *Glutamicibacter mysorens* | | [80] |
| *Thespesia populnea* | Guangxi, China | *Marmoricola endophyticus* | | [81] |
| *Terminalia mucronata* | Thailand. | *Micromonospora terminaliae* | | [82] |
| *Bruguiera sexangula* | Hainan, China. | *Mangrovihabitans endophyticus* | | [83] |
| Mangrove Plants: *Avicennia marina* *Aegiceras corniculatum* *Kandelia obovota,* *Bruguiera gymnorrhiza* *Thespesia populnea* | Guangxi, China | *Curtobacterium, Mycobacterium, Micrococcus, Brevibacterium, Kocuria, Nocardioides, Kineococcus, Kytococcus, Marmoricola, Microbacterium, Micromonospora, Actinoplanes, Agrococcus, Amnibacterium, Brachybacterium, Citricoccus, Dermacoccus, Glutamicibacter, Gordonia, Isoptericola, Janibacter, Leucobacter, Nocardia, Nocardiopsis, Pseudokineococcus, Sanguibacter, Verrucosispora, Sanguibacter.,* *Verrucosispora* sp., *Phialophora cyclaminis, Helminthosporium solani Rhizoctonia*, and *Phomopsis vaccinii* | | [84] |
| *Tanarix chinensis.* | Coastal Jiangsu, China | *Prauserella marina* *Pseudonocardia kongjuensis* *Streptomyces sulphureus* *Streptomyce syogyakartensis* | Natural product, Antifungal and Fibrinolytic Activities | [62] |
| *Dendranthema indicum* | | *Saccharopolyspora pathumthaniensis* *Amycolatopsis suphurea* *Glycomyces arizonensis* | | |
| *Salicomia europaea* | | *Modestobacter marinus* | | |
| *Limonium sinense* | | *Kineococcus rhizosphaerae* *Glycomyces arizonensis* | | |
| *Sesbania cannabina* | | *Glycomyces arizonensis* | | |
| *Aster tataricus* | | *Streptomyces malachitospinus* | | |
| *Tamarix chinensis* | Jiangsu, China | *Prauserella marina* *Pseudonocardia kongjuensis* *Streptomyces sulphureus* *Streptomyces yogyakartensis* | | [85] |
| *Avicennia marina* | Arabian Gulf coastline, UAE | *Streptomyces tubercidicus* | Produce plant growth regulators (PGRs) (ACC) (ACCD) | [86] |

## IV. Coastal Plants Endophytes' Roles In Plant:

Endophytes play a crucial role in plant growth and adaptation by influencing plant responses to pathogens, herbivores, and environmental stresses. They produce a wide range of natural compounds with antifungal, antibacterial, and insecticidal properties. In agriculture, endophytes have shown particular potential as beneficial inoculants, as they enhance tolerance to both abiotic and biotic stresses, including drought, salinity, and extreme temperatures.

Despite these benefits, most research on endophyte functions has focused on agricultural plants, while coastal plants have received less attention. Endophytes can promote plant growth through both direct and indirect mechanisms, such as phosphorus solubilization, production of 1-aminocyclopropane-1-carboxylic acid

(ACC) deaminase, siderophore production, induction of pathogen resistance, and alleviation of abiotic stress factors like salinity and drought [87,88].

For example, plant growth-promoting actinobacteria (PGPA) were isolated from mangrove roots, where seven salt-tolerant strains demonstrated the ability to produce plant growth regulators (PGRs), ACC deaminase, and solubilize phosphorus. Among them, *Streptomyces tubercidicus* UAE1 was identified as particularly effective, as it successfully colonized mangrove tissues, enhanced photosynthetic pigments, increased PGR production, and reduced endogenous ACC levels in plant tissues [86]. Similarly, halotolerant bacteria from saline habitats were shown to improve salt tolerance in inoculated plants [89]. Endophytic nitrogen-fixing bacteria from dune grasses along the Oregon coast may also contribute to their growth and persistence in nutrient-poor sandy soils [90]. In coastal dune ecosystems, fungal endophytes such as *Epichloë* sp. in *Ammophila breviligulata* (American beachgrass) were linked to improved survival, increased belowground biomass, and vegetative growth [91]. Likewise, *Periglandula* sp. was detected in 100% of *Ipomoea pescaprae* (beach morning glory) populations sampled along Florida coasts, indicating significant host benefits [92].

Additional studies identified several endophytic fungi that enhance plant growth, improve survival, and promote resistance to salt stress. *Penicillium citrinum* produces gibberellins [93] essential for multiple developmental processes, such as leaf expansion, pollen maturation, seed germination, and stem elongation [94]. Other *Penicillium* species, including *P. simplicissimum* and *P. restrictum*, were shown to strengthen host defense responses or act antagonistically against pathogenic fungi [95]. Collectively, *P. citrinum, P. funiculosum, P. janthinellum, P. restrictum*, and *P. simplicissimum* have been associated with enhanced plant growth and resilience.

Endophytic *Pseudomonas* strains have demonstrated ACC deaminase activity, further supporting plant growth under stress conditions [44]. Similarly, in the coastal halophyte *Avicennia officinalis L.* from Andhra Pradesh, eleven bacterial isolates showed promising traits, including exoenzyme production, indole-3-acetic acid (IAA) synthesis, and phosphate solubilization. Among them, *Salinicola salarius* was reported for the first time as an endophyte from this plant, exhibiting moderate halophilicity and tolerance to 10% NaCl, as well as multiple plant growth-promoting capabilities [42].

Furthermore, all isolates of *Glutamicibacter* demonstrated multiple growth-promotion traits, salt tolerance, and adaptability across a wide pH range. Notably, *Glutamicibacter halophytocola* strain KLBMP 5180, isolated from root tissues, significantly enhanced host plant growth under salt stress. Inoculation with KLBMP 5180 increased total chlorophyll, proline, antioxidative enzymes, flavonoids, and essential ions ($K^+$ and $Ca^{++}$), while reducing malondialdehyde (MDA) and $Na^+$ concentrations. Transcriptomic analyses indicated that pathways related to phenylpropanoid and flavonoid biosynthesis, as well as ion transport and metabolism, were likely involved in the improved salt stress tolerance induced by this strain [96].

## V. Costal Plants Endophytes Applications In Biotechnology And Achieving Sustainability:

Microbial technologies play an important role in sustainable development across diverse sectors. A distinctive feature of microbial technology is its remarkable versatility, enabling applications that address a wide spectrum of human needs and activities. Among coastal microorganisms, those derived from coastal habitats are increasingly recognized as valuable sources of biologically active secondary metabolites, including antitumor, antibacterial, antiviral, antifungal, and enzyme-inhibiting compounds. Global studies of bacterial diversity in coastal ecosystems have highlighted their unique biochemical processes [44].

Beyond their high species diversity, endophytes have gained attention for their ability to produce abundant bioactive metabolites. Several endophytes associated with medicinal plants synthesize novel compounds with potent antimicrobial and antitumor activities, offering significant promise for pharmaceutical and biotechnological development [97]. For example, hamuramicins A and B, isolated from the endophytic actinomycete *Allostreptomyces* sp. K12-0794, demonstrated both antimicrobial activity and human cell line toxicity [98]. In agriculture, endophytes also hold potential as biocontrol agents. *Saccharopolyspora dendranthemae* was found to produce bioactive compounds active against *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Proteus vulgaris, Streptococcus sp.,* and *Klebsiella pneumoniae* [99]. Similarly, 31 actinomycete strains isolated from mangroves showed antibacterial activity against “ESKAPE” pathogens. Notably, *Streptomyces* strains 2BBP-J2 and 1BBP-1 produced compounds that inhibited protein biosynthesis by inducing translation stalling [84].

Investigations of actinobacteria associated with native coastal salt marsh plants revealed that 30.4% of isolates exhibited antifungal activities, 40.5% showed fibrinolytic activities, and 43% carried genes linked to secondary metabolite biosynthesis. These findings highlight coastal salt marsh plants as an underexplored reservoir of diverse and novel endophytes with potential applications in biocontrol and enzyme production [62].

Endophytes from coastal plants also have agricultural significance. They can directly enhance crop health and productivity while reducing pathogen pressure, insect damage, and weed competition. Such benefits may help reduce dependence on agrochemicals, contributing to safer soils, better food quality, and environmentally sustainable practices. Endophytic microbes can also enrich soil microbial diversity by aiding nutrient acquisition (e.g., through the rhizophagy cycle), suppressing pathogen virulence, deterring insect feeding, and limiting weed growth [100]. In addition, recent research has demonstrated the potential of endophytes in environmental applications, such as pollutant removal in coastal wetlands (bioremediation) [101]. Another example includes the successful inoculation of tree species with coastal endophytes to enhance growth in Brazilian restoration projects [102]. These cases illustrate how the ecological stresses of coastal environments drive adaptations in both plants and their microbial partners, offering valuable insights into resilience and symbiosis.

A deeper understanding of endophyte-mediated plant growth-promotion mechanisms could further enable the sustainable production of energy crops, even on marginal lands, and support the development of renewable feedstocks for industrial processes.

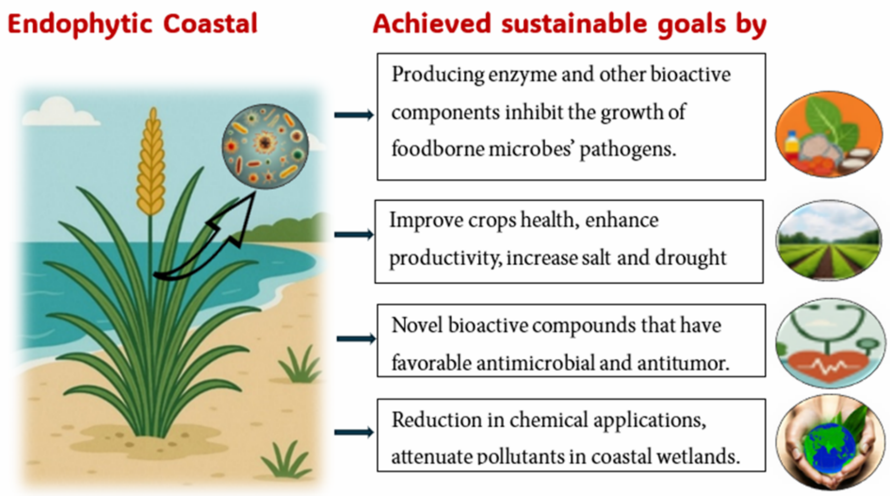


**Fig 2: Importance of coastal plant Endophytes in achieving sustainability**

## VI. Conclusion:

Microbes and plants are fundamental to sustaining life on Earth. Endophytes play a critical role in helping plants adapt to diverse habitats, and the study of endophytes along with their host plants provides an important model for understanding their biology and chemistry. This knowledge can be harnessed to develop safe and beneficial applications for human health, agriculture, and environmental management. The studies reviewed indicate that coastal plants represent a rich and largely untapped source of novel and diverse endophytes. Advances in genomic technologies are expected to accelerate the characterization of endophyte diversity in extreme habitats and to identify strains with potential utility based on biosynthetic gene clusters (BGCs) or other genetic markers. Endophytes from specialized habitats provide unique opportunities for the discovery of new drugs and therapeutics. Beyond medical applications, their bioactive molecules have significant potential in agriculture by promoting plant growth, protecting crops from pathogens, insects, and pests, enhancing nutrient uptake, and maintaining productivity under abiotic stresses such as salinity, drought, and waterlogging. These traits highlight endophytic microbes as emerging tools for mitigating environmental and agricultural challenges. In conclusion, this review emphasizes the biodiversity of endophytic fungi, bacteria, and actinomycetes from coastal plants worldwide and their demonstrated biotechnological applications. It underscores the need for further research to fill existing knowledge gaps and to fully explore the benefits of coastal plant endophytes for sustainable agricultural practices, especially under field conditions. Prioritizing this research will enable the effective utilization of endophytes in agriculture. Overall, the novelty and diversity of coastal plant endophytic actinobacterial strains and their bioactive molecules present tremendous opportunities to meet current and future demands in medicine, agriculture, and environmental sustainability.

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