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Review on halophilic microbes and their applications

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ABSTRACT

Salt pans are ground covered with salt, minerals and inhabit halophilic microbes. Diversity in salt pans provides alkaline, saline, pH and temperature at different conditions. The optimum 0.5 and 3.0M salt concentration for growing halophilic organisms. Halophilic Microbes were grown in high salt concentrations. These halophilic microbes are used in old years for salt and fermented production but Nowadays the various halophilic microbes involved in Antibiotic production, Enzymes, Pigments, Ecotine, Polysaccharides, Bio surfactants, and Bioplastics production. Halophilic fungi and actinomycetes are involved in Bioremediation for agricultural improvement. In the electrical field also Extremophilic halophilic bacteria can be used in Mining and nanotechnology sectors.

Keywords: *Salt pan, Halophilic Microbes, Electrical field, Bioactive Compounds.*

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INTRODUCTION

Halophiles are extremophilic microbes that thrive in environments with extreme salt concentrations. Being salt-loving organisms, These halophiles are found in marine environments, which include ponds, lake, sea, salt pans, and fermented foods and were extensively investigated to understand its characteristics [1].

The halophiles are classified based on the amount of salt required for its complete growth. A halophilic organism is evaluated based on how attentive it is, towards the salt. They are categorized into three essential types such as Mild (Moderate) halophiles that can grow at 3-15% of NaCl, Intense (Extreme) halophiles that can grow at <25 % and halotolerant (Slight) organisms which grow at 2.5% NaCl [2].

Halophiles grow in each of the three domains of lifestyles, such as Archaea, Bacteria, and Eucarya. It additionally exhibits great metabolic diversity that includes phototrophs, anoxygenicphototrophs, aerobic heterotrophs, fermenters, denitrifiers, sulfate reducers, and methanogens [3].

The defensive mechanism of halophiles is fascinating since it functions on the concept of osmotic pressure. Through the accumulation of halophiles, the compatible solute present in the cells increases to balance the osmotic pressure. These accumulating halophilic microbes produce some enzymes which in turn generate k+ ions. These ions increase the inner salinity and accordingly, the external osmotic pressure [4].

The haloarchae accumulates a high concentration of KCl within the cytoplasm for osmotic stability. The domains of archaea, bacteria and eukarya belong to aerobic, anaerobic and facultative anaerobic halophilic microbes. The halophiles can be determined from the extensive range of bacteria and eukarya that were recovered from these extreme conditions [5].

Halophiles have promising biotechnological applications that include pigments, enzymes, surfactants, decolorization of textile dye effluents, degrading metals and the removal of pollutants in saline water. Recent studies conducted in halophilic fungi in the hypersaline environment inferred that they have a great diversity of fungal species. The halophilic fungi were investigated in the year 2000 and the study focused its morphological and molecular characteristics in a saline environment [6].

The halophilic fungal species have been experimented for its capability to metabolize compounds with selected biological activities together with hemolysis, antibacterial, and the inhibition of acetylcholine resterase [7].
Halophilic actinomycetes produce various important secondary metabolite compounds. Approximately 61% of all modern-day bioactive microbial metabolites have been purified from streptomycetes whereas from are from rare actinomycetes (non-streptomycetes) [8].
The vital actinomycetes under the genus Streptomyces are regarded to produce a wide variety of biologically-energetic compounds and this compound acts as anticancer agents, anti-infective agents and a pharmaceutically-beneficial compound [9].
Numerous microbes, belonging to the domain archaea and bacteria, have been isolated in the studies conducted earlier and their metabolic capacity has been tested to degrade various types of hydrocarbons (i.e., Aliphatic and Aromatic). The recent biodegradation reports show the result of hydrocarbons that got degraded by halophilic microbes. Halophilic microbes possess large dynamic plasmids with transposable sequences in it and this characteristic is highly helpful in studying their genetics.

OCCURRENCE AND DISTRIBUTION OF HALOPHILIC MICROBES

The halophilic microbes have been isolated from a wide range of hypersaline environments. Salt pans are deemed to be extreme environments and can inhabit organisms only if it thrives high salinities, temperatures and severe solar radiations. Various halophilic and halotolerant microbes inhabit salt pans and are yet to be fully explored as potential producers of pharmaceutically-significant molecules. There are only a few reports published in India concerning their antimicrobial potential [1].
Native halophilic and halotolerant bacteria were isolated from several saline environments such as salt pan regions (Mumbai, China, Tuticorin, Kanyakumari, Vedaranyam and Maakanam), Mangroves (Ribander, Bhitarkanikais and Pichavaram), Wetland (Northern Algeria), Hyper arid lands (Sahara), Salt Marsh (Jeddah), Saline lake (Balta Alba-East Romani), Saline alkaline lake (Sambhar lake-Rajasthan), Halo alkaline lake (Chilika), Sea (Goa, Patenga, Aria- Hama-Japan), Deep sea (Mandoi- Goa and Andaman & Nicobar), Hypersaline ponds (Colorado and salitral negro, surala) and fermented foods (Tauco and terasi-Indonesian foods, Fish sauce).

HALOPHILIC BACTERIA

Halanaerobium praevalens is a first fermentative halophilic bacteria isolated from the sediments of Great Salt Lake (Utah) and was characterized in 1983. Halophilic microbes grow under intense hypersaline environments such as salt pans and the marine ecosystems of all over the biosphere. The adaptation mechanism of halophilic bacteria works by inducing the osmotic stress with the help of high salt concentration the main difference between halophilic and halotolerant organisms is the required amount of sodium chloride for its growth. The halotolerant organisms do not require salt for growth whereas the halophilic organisms require sodium chloride for its natural growth. The halophilic bacteria were grown in a laboratory environment under optimized conditions using nutrient agar amended with different concentrations of NaCl whereas the extremely- halophilic bacteria were cultivated in halophilic agar and Zobell marine agar.
The anaerobic growth, as well as the fermentation of *Halobacterium* sp, were evaluated through the assessment of few parameters such as temperature, salt concentrations, cell density and molecular oxygen level. A few examples of halophilic bacteria are *Salini vibrio*, Halomonas and Halodenitrificans. These halophilic bacteria have potential applications in biotechnology as well as in environmental fields. In the literature, a list of potential uses has been produced [10].

Applications of halophilic bacteria

The halophilic bacterial products are gaining importance in the recent days due to its medicinal values and it contains bioactive compounds that exhibit antimicrobial and anticancer activities. These bacteria also produce enzymes that are used in different industries and employed in the bioremediation method in agriculture. Further, it is also used in the removal of heavy metals, plastic degradation, biofuel manufacturing, pigment manufacturing and mining processes. A selective halophilic bacterial strain hydrolyzes the substitute by excessive temperature up to 50°C, high salt concentration (in the range of 30–35 %) and remains functional in the presence of organic solvents. These extreme conditions make these molecules suitable for biotechnological applications in food processing, environmental bioremediation and biosynthetic processes [11].

HALOPHILIC ENZYMES PRODUCTION

Dihydrofolate reductase

This is an important enzyme that reduces dihydrofolic acid. It is involved in RNA binding, NADP binding and folic acid-binding at the molecular level. The *Haloferaxvolcanii* produces the crystal-shapeddihydrofolatereductase enzyme [12].

Azoreductase

Azoreductase is a flavoenzyme that is widely present among halophilic microbes. The predominant applications of this enzyme are decolourization of dye, reduction of azo bond and activation of azo drugs. Moderately halophilic strain *Halomonassp*is isolated from the textile industrial wastewater in research conducted in China. This organism produces a novel azoG (Azoreductase) and this strain is proved to have decolorized the azo dyes. The genomic DNA was cloned and new statistics were provided on the phylogeny of the azoreductases [13].

L-Asparaginase

It is an anticancer enzyme that is used to treat acute leukemia i.e., Myeloid leukemia. The mechanism behind this enzyme is that it reduces the asparagine amino acid and inhibits protein synthesis. This type of amino acid is necessary for the growth of tumour cells. The halophilic bacteria, Halomonas species, produces a highly L-asparaginase enzyme [14].

L-Glutaminase

Glutaminase is an amidase enzyme that converts glutamine to glutamate with ammonia. It is a commercially important enzyme that can be used as an antiviral agent and oncolytic enzyme. Halophilic Marinobacter produces this enzyme

L-Arginase

Arginase is one of the essential enzymes in the urea cycle in which the arginine is converted into ornithine and urea. Both Halomonas and Marinobacter genera produce anticancer enzymes and are identified by the 16S rRNA gene sequence evaluation. Most of the cancer cells screened for halophilic and halotolerant bacteria produce l-asparaginase, l-glutaminase, and l-arginase [15].

HYDROLYTIC ENZYMES

Hydrolytic enzymes are useful in various analytical and industrial applications. It converts the chemical molecules from being substrate molecules to acceptor water molecules. Halophilic microbes naturally synthesize these enzymes. Protease and amylase are the necessary commercially-important enzymes that play essential role in biotechnological applications [16].

Halophilic archaeal strains are also screened in the production of hydrolytic enzymes like esterase, keratinase lipase, amylase, cellulase, lipase, protease and pectinase [17].

Keratinase

Keratinolytic enzymes gained more attention in the last few years since it can hydrolyze insoluble keratinolytic substrates. Keratinase is used in most of the sectors in biotechnology (animal feed, biofertilizer, detergent and biochemical programs [18].

Amylase

Amylase is used as a pharmaceutical aid in treating digestive problems. It is also used in various industries such as food processing, textile, detergent, paper and chemicals. Proteases are utilized in medical, detergent and food processing industries [19].

Protease

Halotolerant bacteria are involved in the synthesis of protease enzyme. The production of protease in the industrial-scale has challenges of heavy contamination and enormous cost. The halophilic bacteria is used to avoid contamination during the fermentation process and it is also involved in peptide synthesis [20].

Cellulase

Cellulase acts as a catalyst in the hydrolysis of β-1, 4-linkages of cellulose to provide industrially-relevant monomeric subunits. Cellulase finds its packages in pulp and paper, laundry, food and feed, textile, brewing industry and biofuel production. It is mostly used in the bio catalysis of organic solvent [21].

Pigment production

Carotenoid is one of the crucial pigments that gained attention due to its unique characteristics. It contains a high amount of Vitamin A. Halophilic bacteria, archaea and algae produce carotenoids when cultivated under laboratory conditions . This pigment is used as animal feed, food color, nutrient dietary and antioxidant in pharma industries and cosmetic industries [22].

Bioplastic production

In the past two decades, plastic has become a major environmental pollutant due to which it has been banned from usage in numerous countries. Plastic waste creates many disorders in the environment.

There has been considerable improvement in recent years in the manufacturing of biodegradable plastics [23].

Halomonas nitroreducens is a halophilic bacteria that produces polymer based on the study results that deployed FTIR, DSC, GPC and EDX spectroscopic techniques [24]. It accumulates polyhydroxyalkanoates during the production of polymers. The Halomonas genus Marinobacter showed high degrees of exopolymer production

Biosurfactant

The halophilic microbes, when made to undergo treatment process, show higher activity in high pH, temperature and salt concentration. It has the capability of degrading organic compounds and converting them into nutrients with the help of hydrolytic enzymes [25].

Ecotine production

Ecotine is a stabilizer enzyme and is applied in cosmetic products. The molecular formula is 1,4,5,6-tetrahydro-2-methyl-4-pyrimidinecarboxylic acid for moderately-halophilic bacteria. Most of the halotolerant and halophilic microbes produce osmotic solutes. Ecotine was first isolated from haloalkaliphilic photosynthetic sulfur bacterium *Ectothiorhodospira halochloris.* Ecotine protects the nucleic acids and enzymes against freezing, high salinity and thermal denaturation [26].

Food biotechnology

Halophiles are involved in ancient methods of producing solar salt from seawater. It is also used in the production of a few traditional fermented food products with the help of halophilic fermentative bacteri. Some of the examples for fermented food products are 'jeotgal,' a popular Korean fermented seafood, 'fugunokonukazuke,' the Japanese food prepared using fermentation of the salted puffer fish ovaries in rice bran, and 'nam-pla,' a Thai fish sauce. The fermentative halophilic bacteria is utilized in fermenting fish and shrimp. It is also used in the production of dietary supplements such as polysaturated long-chain fatty acids. *Halalkalicoccusjeotgali* is a singular isolate acquired from the shrimp 'jeotgal' [27, 28].

Bioactive compounds

The source of halophilic microbes possesses a large number of bioactive molecules. The need for antibiotics to combat the emerging resistant forms of bacterial pathogens is increasing. Some of the critical human pathogenic bacteria are *Proteus vulgaris, Serratiamarceasans, Salmonella typhi, Staphylococcus citrus* and*E.coli*. According to recent studies, various antimicrobial compounds are produced by halophilic microbes.

The class of Halobacteria includes Natrinema, Natrialba, Haloarcula, Halopiger, Haloterrigena, Halorubrum, Halostagnicola, Natronococcus and Haloferax which produce the antimicrobial compound in high quantities against ATCC cultures[29].

The genus of novel halophilic bacteria namely Paenibacilllus, Halobacterium, Halobacillus and Salinivibrio, produce secondary metabolites against particular shrimp pathogens and control plant pathogens [30].

The secondary metabolites are 2,3-butanediol, hexahydro-3-(2-methyl propyl) pyrrole, pyrazine-1,4-dione, aziridine, dimethylamine and ethyl acetate, oxypurinol and 5-hydroxydecanoic acid, depsipeptides, miuraenamides A and B are produced from Salinivibrio and Myxobacteria strains [31].

Applications in electrochemistry

Extremophilic microbes can be used in the production of a wide range of commercial products that are generally used in mining, nanotechnology and other industrial sectors. The latest research sheds insights on the molecular mechanisms utilized by halophiles to protect their proteins under saline conditions [32].

Biodegradation

The halophilic anaerobic fermentative bacteria have the potential to be used in the anaerobic treatment of saline wastewater. These microbes are used to degrade heavy metals and organic compounds.

*H. praevalens*and *O. marismorturi* are halophilic fermentative bacteria used in the biodegradation of nitrobenzene, o-nitrophenol, m-nitrophenol and p-nitrophenol that produce excellent results within 24 hours [33].

1. Hydrocarbon

Hypersaline environments are frequently contaminated with petroleum compounds. Petroleum is a complex mixture of different hydrocarbons including aliphatic (linear or branched) hydrocarbons, cycloalkanes, mono- and polyaromatics, asphaltenes and resins. The majority of these compounds are potent, toxic, and carcinogenic. Few selected species under Halomonas, *alcanivorax, marinobacter, haloferax, haloarcula,* and *halobacterium*degrade hydrocarbons. Polycyclic aromatic hydrocarbons cause poisonous and carcinogenic effects in a saline environment. Halophilic microbes generally degrade naphthalene and anthracene[34].

2. Crude oil

Crude oil is a mixture of hydrocarbons, specially composed of oxygenated and non-oxygenated hydrocarbons. Several studies reported the ability of microorganisms to make use of crude oil additives due to the increased number of substrates in slight to high salinity environments[35].

3. Aliphatic compounds

Ward and brock (1978) performed several experiments on the biodegradation of aliphatic compounds earlier. Their study inferred the presence of 14c-hexadecane (100%), eicosane (91%), and heneicosane (84%) in water samples collected from the Great Salt Lake. The hydrocarbon-contaminated sediments were removed by using Alteromonas inside the Mediterranean Sea [36].

4. Benzene, toluene, ethylbenzene and xylenes

The aromatic hydrocarbons are benzene, toluene, ethylbenzene, and xylenes (btex), which are generally low molecular weighing saturated hydrocarbons. Benzene is a carcinogenic agent. The water storage tanks, pipelines, spills, and surface-infected sites can lead to significant BTEX contamination which also affects enormous volumes of groundwater. The current reviews show the result of biodegradation of hydrocarbons present in the saline environment when using halophilic microbes[37-38].

Halophilic prokaryotes

Halophilic fungi are globally found in a saline environment, especially salt pan. The first halophilic fungi were first cultured in the year 2000 to produce bioactive compounds. The viability of fungus is decided based on area, time of sampling, Dissolved Oxygen, water activity, and the presence of organic and inorganic vitamins within the given geographical distribution which altogether reflects in the growth[39]. Halophiles encompass mainly prokaryotic and eukaryotic microorganisms and it can stabilize the osmotic pressure of the surroundings and resist the denaturing consequences of salinity. The osmoadaptation mechanism in true halophiles forms an intrinsic part of its metabolism. A mitogen-activated protein (MAPK) pathway is involved in the activities of fungi .

Fungi that flourishes in distinct saline environments are generally adapted to intense conditions such as low temperature, pH and salinity. The adaptation of halophilic fungi to hypersaline habitats is impartial of salt concentrations and that they can be determined by inhabiting in any range of salt conditions including hypersalinewaters[40].

Isolation of halophilic fungi

In laboratory conditions, the halophilic fungi grow in different media such as Potato Dextrose agar (PDA), Sabouraud Dextrose agar and Rose Bengal agar amended with sodium chloride. The halophilic fungi can be identified by deploying the LPCB method.

DIVERSITY OF FUNGI

The diversity of halophilic fungi in saline environments at Mumbai and Thane had been screened for the prevalence of keratinophilic fungi and related dermatophytes. The isolated species was suggested to follow the order of domain: *Chrysosporiumindicum* (12.0%), *Microsporumgypseum* complex (7.2%), *C. tropicum* (5.6%), c. State of *Ctenomycesserratus* (4.0%), *Trichophytonterrestre* (3.2%), *Malbrancheaaurantiaca* (2.4%), *C. fluviale* (1.6%), *Uncinocarpusreesii* (1.6%), Malbranchea sp. (0.8%), and *T. mentagrophytes*(0.8%). Large salt-tolerant fungal genera such as Aspergillus, few Penicillium species, Eurotium and Hortaea were isolated from mangroves and solar salterns of Goa since these species grow at high salt concentration. Only one species i.e., *A. penicillioides* had an absolute requirement of salt to be added in the medium for growth which had been termed as obligate halophiles[41].

The salt tolerance curves of the isolates were grouped according to the genus followed by species and placing in priority and based on the absolute requirement of salt to be delivered for its healthy growth .The presence of Keratinophilic fungi in salt pans (28.57%) and salt garage (20.0%) locations is much lesser than that of the marshy lands (50.0%) and surrounding burrows (50.0%). This might be attributed to the fungicidal impact of high marine salinity on keratinophilic fungi [42].

Enzymatic activity of halophilic fungi

In saline environments, various investigations have been conducted in halophilic fungi in solar salterns, Dead Sea and arid desert. Hypersaline environments are dominated by the teleomorphic genus of Eurotium, Emericella, and Eupenicillium. *Aspergillus flavus* fungi produce amylase, cellulase, protease and lipase enzymes. The obligate halophilic fungi *G. halophilus* produces the highest yield of cellulose enzyme. *P. vinaceum, U. cynodontis* and Wallemiasp show the highest lipase activity. The two strains such as *G. halophilus* and *U. cynodontis* exhibit the highest proteolytic activity [43].

Intracellular low ion activity

Saline environments enable low ion activity, which in turn causes osmotic pressure and affects the halophilic microbes. Species such as *Hortaeawerneckii* and *Aureobasidiumpullulans* were assessed for its intracellular cation concentration of salt adapted species in the hypersaline environments. The growth of

H. werneckii, even the minimal addition of NaCl to the growth medium, slowed the growth rate of *A. pullulans*. These cells keep low amounts of intracellular ion activity[44].

H. werneckii* and *W. ichthyophaga

H. werneckii is a unique polymorphic fungus and it can adapt and grow either in the presence or absence of NaCl and even if there are any fluctuations in sale concentrations. The dominant fungal organization in hypersaline waters of salterns is H*ortaeawerneckii*which is the melanized polymorphic black yeast, the most abundant and adapted species. *H. werneckii* can adapt itself based on fluctuating salt concentrations in its environment. It can grow without salt or in extreme salinity too. The best optimum concentration of NaCl for its growth lies in the range of 0.8m and 1.7m[45].This genus is the most halophilic eukaryotic fungi and represents the food contaminants that affect salty and dry food. It produces toxic metabolites and exhibits haemolytic activity. This genus is mostly found in saltern and salt lakes and can grow in 3.5 – 4.5 M salinity.

APPLICATIONS

Wastewater treatment

The first attempt to use amylase to treat the wastewater was performed using the halophilic species, *Aspergillusgracilis*. The amylase enzyme was involved in this process. The mechanism involved in changing the Dissolved Oxygen value in wastewater was monitored by DO meter. The DHN-Melanin inhibitor, tricyclazole inhibited the melanin in Halophilic fungi *H.Werneckii*[46].

Enzyme production

Halophilic fungi produce hydrolytic enzymes and when compared to halophilic bacteria, the former produces enzymes in vast quantities.

- **Xylanase-** the enzyme is mostly used in industrial applications such as natural sweeteners, and it possesses the dough-softening ability. *Aspergillusniger* is the highest producer of this enzyme.
- **Collagenase -** Having has been produced in large quantities from *Aspergillus oryzae*, it is used to degrade collagen substances and transplantation of organs.
- **Oxidoreductase-** the enzyme is produced by *Cladiromyces fumago* [47-48].

Bioremediation

The halophilic fungi such as *Aspergillusgracillis*, *A. restrictus* and *A. pencilloides* mostly act based on biosorption mechanism. The sterigomatomycetes are used in the removal of cadmium, copper, ferrous, lead and zinc[49].In xenobiotic mycoremediation of wastewater, both *A.sydovii* and *A. destruens* were used and the study was evaluated using GC_MS technique[50].

Actinomycetes

Actinomycetes are abundantly available in natural saline environments In soil, various species of actinomycetes have been identified so far. The important genera of actinomycetes are Streptomycetes, Nocardia, Micromonospora, Thermomonospora, Actinoplanes, Microbispora, Streptosporangium, Actinomadura, Actinosynnema, Dactylosporangium, Rhodococcus, ActinosynnemaKitasatospora, Gordona, Intrasporangium and Streptoalloteichus[51-53].

Under laboratory conditions, the isolation of actinomycetes can be performed using various media such as Starch casein agar, Actinomycetes isolation agar, Oatmeal agar, Inorganic salt starch agar, Glycerol asparagine agar, Kennights agar which respectively can produce whitish, brown, grey, sandal white, pale sandy and light yellow colored colonies. Halophilic actinomycetes have a bioprospecting character with the presence of bioactive compounds and it involves the production of pigments and enzymes like cellulase, xylanase, pectinase, amylase, lipase and protease. Some of the actinomycetes strains produce agriculturally important siderophores.

The bioactive compounds of actinomycetes possess angiogenic, anti-tumorigenic, antimicrobial, antimalarial and wound healing properties. The anthraquinone compound, isolated from actinomycetes, exhibits anti-inflammatory and antiviral activities.

It is used against fungal pathogens namely *Rhizoctoniasolani, Fusariumudum* and *Fusariumoxysporum.* Chitinase enzyme is produced by a variety ofActinomycetes[54].

APPLICATIONS OF ACTINOMYCETES

Production of enzymes

Actinomycetes produce some vital enzymes applied in industries. Streptomyces, Thermonospora, Nocardia, Thermomonospora, Actinoplanes and Actinobacteria produce chitinase, cellulose, peptidase, protease, ligases, amylases, pectinase, hemicellulase and keratinase respectively.

- Chitinase is involved in boosting plant resistance against pathogenic fungi and it also prepares to heal wounding drugs.
- Protease is involved in clotting and it acts as an anti-inflammatory agent. It is used to treat cancer
- Urease is used in the wine industry and the analysis of heavy metal content in waste soil and water
- L-asparaginase is used in stem-cell transplant and cancer studies[55].

Bioactive compounds, isolated from *Halophilic kocuria*sp, *Nocardia*sp and *micromonospora*sp produce anti-bacterial compounds against *Staphylococcus aureus*

1. P-Terphenyls

It is a novel compound against the fungal pathogen, Fusarium sp. The structural character of this compound is inclusive of three derivatives bearing benzothiazole. The molecular formula is C22 H22 O5 as devised by NMR data and also it indicates the presence of 1, 4 phenyls and 14 methoxy groups. The IR spectrum of the compound identified the presence of hydroxy group and aromatic rings. These bioactive compounds are produced by *Nocardiopsisgilva* from soil samples and exhibit the highest antifungal activity[56].

2. 2,4 – bis(1,1-dimethyl ethyl) compound

This compound is isolated from Streptomyces sp. The GC-MS results of the studies showed the presence of compounds such as phenol, hydrocarbons, 3-octodecene, 1-Nonadecene and behenic alcohol. It shows higher antimicrobial activity against *Staphylococcus epidermis* and *Malasseziapachydermatis*[57].

3. 8-O- methyltetrangulol

Streptomyces species produce this compound whereas its secondary metabolic activity exhibits cytotoxicity against human cells. This cytotoxicity also acts against the antimicrobial activity. The current studies show that this compound is an inhibitor of quinone reductase-2. The streptomyces from the saltern may be a vital source for the invention of novel antitumor agents [58].

4. Actinopolysporins A, B, C and Tubercidin

The three new linear structures are known as antineoplastic antibiotic production. This compound is obtained from the source, *Actinopolyspora erythraea*. Its molecular formula is $C_{15}H_{28}O_4$, whereas the IR spectrum identified that this compound contains Hydroxy, carbonyl and olefinic groups. NMR studies show that the carboxyl group conjugated with a double bond, Methoxyl, 1-teritary methyl group, a 4-secondary methyl group and methionine groups. It has the potential to exhibit anticancer activity according to the spectroscopic data values elucidated in a research study. It involves the biosynthesis of the polyketidepathway for the degradation of fusion proteins. Further, it is also involved as a tumour suppressor in antitumour activity [59].

5. Nocarbenzoxazoles A–G, Benzoxazoles

This compound is produced from *Nocardiopsis lucentensis*. It exhibits cytotoxicity against human tumor cell lines (HepG2 and Hela). The molecular formula is $C_{16}H_{12}N_2O_5$ whereas the NMR studies show 6 aromatic rings, 9 carbons and CH groups in this molecular structure. It produces seven compounds which are pale yellowish in color and amorphous powder in nature [60].

6. Ethane,1,1-Diethoxy Benzoic acid

It contains chemical compounds such as Ethanol, Methyl ester, Hexadecanoic acid, pentadecanoic acid and oleic acid as evaluated through GC-MS analysis. These compounds show antibacterial activity against clinical pathogens. The antiviral activity against the HCV virus was identified by a 174 bp length fragment area, which reduced the viral replication. The anticancer activity of this compound functions against HepG2, EL-4, MCF-7 and Hel that can be identified through MTT assay .

Pigment production

Actinomycetes possess an excellent ability to produce pigments naturally. It is a prominent source to replace the artificial chemicals for textile, food and cosmetic industries [61].

Mostly streptomyces and actinobacteria species produce various green, orange, red and brown color pigments. Pigments are used in antimicrobial agents against broad-spectrum human pathogens since it exhibits antioxidant, anticancer activity and cytotoxic activity against HeLa cell lines [62].

Streptomyces fradiae produce the purple pigment that helps in the production of hydrolytic enzymes [63].

Textile dye

Some actinomycetes such as *Streptomyces bellus, Actinomycesviscosus, Actinomycesnaeslundii*and *Streptomyces torulosus* produce dark coloured pigments which are used in polyamide fabrics.

Lip balm production

The green and orange colour pigments produced from Actinomycetes are used in lip balm production. During the large-scale production of pigments, the MGYP medium is used and is characterized by UV and

FTIR techniques. The crude extract of *Streptomyces bellus* can be used in the production of lip balm production[64].

Bioremediation

Actinomycetes act as bioremediation agents, biocontrol agents, biopesticide agents, biocorrosion, agroactive compound and plant growth-promoting tools. *Streptomyces* is involved in the treatment of heavily polluted water and soil. It produces siderophores for metals such as nickel, zinc, copper, lead, chromium and solubilizing arsenic [65].

Streptomyces are used in the removal of heavy metals such as mercury, copper and cadmium [66].

Table 1. Halophilic Bacteria able to Produce Various potential Products.

S.No	Halophilic bacteria	Applications	Ref
1.	*Halobacteriumsalinarum* *Halobacteriumsalinus* *Halobacillus*	**Antimicrobial activity shrimp pathogen-** *Vibrio harveyi* *Vibrio angullaram* *Vibrio alginolyticus*	[67]
2.	*Halobacillus* *Paenibacillus* *Planococcus* *Marinobacter* *Idiomarina*	**Anticancer enzymes-** l- asparaginase L- glutaminase L- arginase	[16]
3.	*Haloferax* *Halorubrum* *Haloarcula* *Halogeometricum* *Haloterrigena*	Amylase Lipase Esterase Protease Pectinase Cellulase	[68]
4.	*Bacillus*	Alkaline protease	[69]
5.	Flammeovirgapacifica	c β-1, 3-xylanase	[70]
6.	*Vibrio fischeri* *HalobacteriumSalinus* *Oceanobacillus*	Protease Amylase	[71]
7.	*Marinococcushalophillus*	Glycerol Carbonate	[72]
8.	*HalomonasXianhensis*	Extracellular Polysaccharide	[73]
9.	Halomonasanticariensis	Removal of Phenol and Napthalene	[74]
10.	*Natrinemasp*	Halocin	[75]
11.	*HaloferaxVolcanii*	Dihydrofolatereductase	[12]
12.	*Bacillus Subtilis* *B. amyloliquefaciens* *B. licheniformis* *B. pumilus* *B. altitudinis*	Bacterocin	[76]
13.	*HalomonasShengliensis* *HalomonasSmyrensis*	Degrade – Polycyclic aromatic hydro	[77]
14.	*Bacillus Clausii*	Ecotine	[78]
15.	*Janibacterhoylei*	Esterase	[79]
16.	*Marinobacterlitoralis*	Lipase, Esterase, Protease	[80]
17.	Bacillus aseinilyticus	Protease	[81]
18.	*HalomonasStenophila* *Halomonasrifensis* *HalomonasVentosae* *HalomonasKoreansis*	Exopolymer production	[82]
19.	*Halomonasboliviensis* *Haloferaxmediterranei*	Polyhydroxyalkanoates (PHA) Polyhydroxybutyrate (PHB).	[83]
20.	*Bacillus licheniformis*	EPS- Antiviral activity, Immunoregulatory activity	[84]
21.	*Halomonasalmeriensis*	EPS- Emulsifying activity	[85]
22.	*Tetragenococcushalophilus*	Soy sauce	[86]

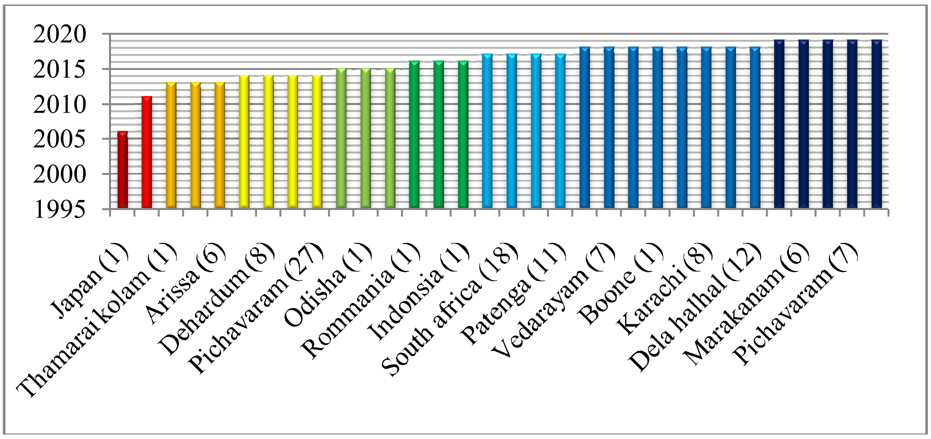

Fig 1: Number of Halophilic bacteria isolates from different hypersaline environments.

Table 2 : Halophilic Fungi and their applications.

S.No	Halophilic fungi	Application	Ref
1.	*Engyodontium album*	Alpha amylase	[87]
2.	*A.nidulans* *AVEROBASIDIUM Pullulans* *CLADOSPORIUM Sphaerospermum* *Wallemiasebi*	Bioremediation- Hyper saline soil	[88]
3.	*Aspergillusprotuberus* **MUT 3638**	Bisvertinolone	[89]
4.	*Aspergillusflocculosus* **PT05-1**	Ergosteroids & Pyrrolederivates:	[90]
5.	*Aspergillusterreus* **PT06-2**	Terremide A, Terremide B &Terrelactone A	[91]
6.	*Aspergillus restrictus* *Sterigmatomyces halophilus*	Removal of Heavy metals	[92]
7.	Aspergilluscaesiellus	cellulases, xylanases, manganese peroxidase (MnP) and esterases	[93]
8.	*Fusarium lateritium*	Crude oil	[94]
9.	*Haloferax volcanii Haloferax alexandrinus Haloferax volcani*	Heptadecane, Phenanthrene	[95]
10.	Fundibacterjadensis	Tetradecane, Hexadecane, Pristane	[96]

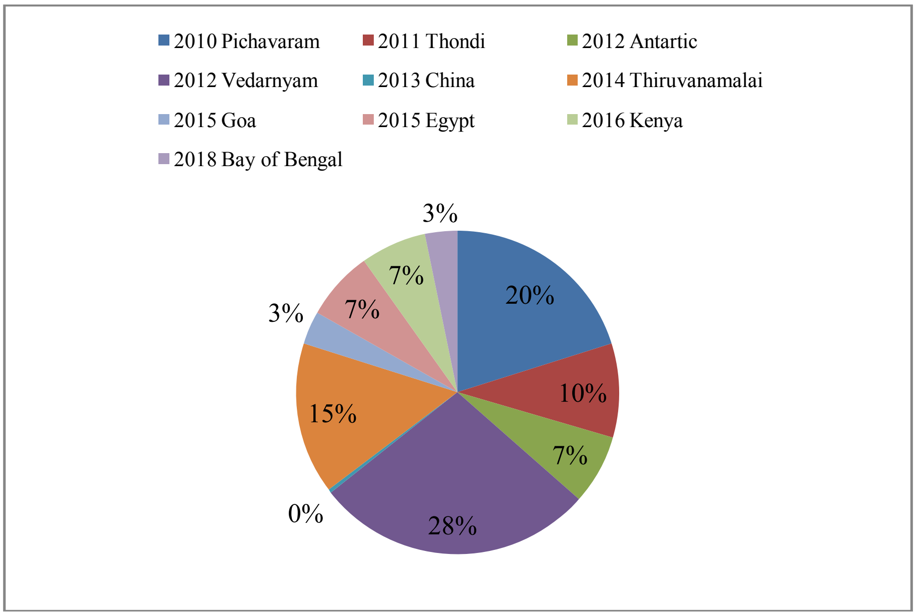

Fig 2: Percentage of Halophilic Fungi in hypersaline environments

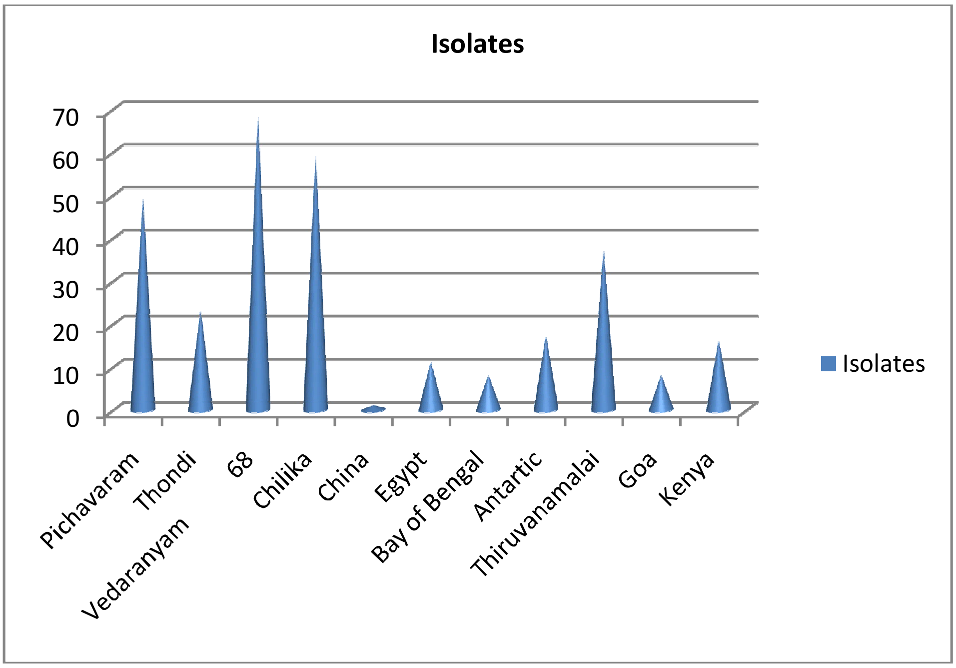

Fig- 3 Total percentage of Halophilic actinomycetes from saline environments

Table 3: Applications of Halophilic actinomycetes

S.No	Halophilic Actinomycetes	Applications	Ref
1	*Actinosynnenma, Micromonospora Streptomyces*	Antimycobacterial activity	[97]
2	*Streptomyces sp*	Antibiotic	[98]
3	*S. Fradiae*	Bioactive compounds	[99]
4	*Streptomyces*	2,4 bis (1,1-dimethyl ethyl)	[100]
5	*Streptomyces sp*	Antimicrobial activity	[101]
6	*Kocuria, Micromonospora Streptomyces, Nocardia*	Antibacterial metabolites	[102]
7	*Streptomyces*	Chitinase, Antifungal	[103]
8	*S. Parvulus*	Collagenase	[104]

CONCLUSION

In this review article, various kinds of halophilic microbes such as actinomycetes, fungi and bacteria were discussed in detail. These halophilic and halotolerant microbes are abundantly found in saline environments such as salt pans, mangroves, lake sea etc., Nowadays researchers started shifting their attention to halophilic microbes to find out novel bioactive compounds that exhibit anticancer activity, antibacterial activity and antifungal activity. Some halophilic microbes produce enzyme and pigments whereas others produce polysaccharides, bioplastics and also ecotine.

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REFERENCES

1. Aljohny.BO(2015). "Halophilic bacterium–a review of new studies." Biosciences Biotechnology Research Asia., 12(3): 2061-2069.
2. Yadav.D.,Singh.A.,Mathur.N (2015).Halophiles- A Review. Int.J.Curr.Microbiol.App.Sci., (4(12): 616-629.
3. Vinothini, S., Hussain, A. J., & Jayaprakashvel, M. (2014). Bioprospecting of Halotolerant Marine Bacteria from the Kelambakkam and MarakkanamSalterns, India for Wastewater Treatment of Plant Growth Promotion. Biosciences Biotechnology Research Asia.,(11): 313-321.
4. Oren, A. (2001). The bioenergetic basis for the metabolic diversity at increasing salt concentrations: implications for the functioning of salt lake ecosystem. Hydrobiologia.,(466): 61–72.
5. Santos, H., Da Costa, M.S. (2002). Compatible solutes of organisms that live in hot saline environments. Environ. Microbiolo., (4): 501 –509.

6. De Hoog, S., Zalar, P., Van Den Ende, BG., Gunde-Cimerman, N., (2005) Relation of halotolerance to human-pathogenicity in the fungal tree of life: an overview of ecology and evolution under stress. In: Adaptation to life at high salt concentrations in Archaea, Bacteria, and Eukarya. Springer, Netherlands., 371–395
7. Sepcic, K., Zalar ,P., Gunde-Cimerman, N. (2011) Low water activity induces the production of bioactive metabolites in halophilic and halotolerant fungi. Mar Drugs .9(1):43-58.
8. Ballav.S., Kerkar.S., Thomas.S.,Augustine.N (2015). Halophilic and halotolerant actinomycetes from a marine saltern of Goa, India producing anti-bacterial metabolites. J. BIOSCI. BIOENG., (119):,323-330.
9. Okamoto-Hosoya. Y, Okamoto .S, Ochi. K (2003) Development of antibiotic overproducing strains by site-directed mutagenesis of the rpsL gene in Streptomyces lividans. Appl Environ Microbiol., (69):4256–4259
10. Ayesha Ameen, HM., and SR .(2017) Halobacterium sp. NRC-1: A Review. Int J Adv Sci Res.,(3):30–32.
11. Oren.A(2010)Industrial and environmental applications of halophilic microorganisms. Environmental Technology .,(31): 825–834.
12. Pieper ,U., Kapadia, G., Mevarech ,M., Herzberg, O.,(1998) Structural features of halophilicity derived from the crystal structure of dihydrofolate reductase from the Dead Sea halophilic archaeon, Haloferax volcanii. Structure; (6):75–88.
13. Tian, F., Guo ,G., Zhang ,C., (2019) Isolation, cloning and characterization of an azoreductase and the effect of salinity on its expression in a halophilic bacterium. Int J Biol Macromol ;(123):1062–1069
14. Gulati ,R., Saxena, R., Gupta ,R., (1997) A rapid plate assay for screening l-asparaginase producing micro-organisms. LettApplMicrobiol., 24(1):23–26
15. Zolfaghar ,M., Amoozegar ,MA., Khajeh ,K.(2019) Isolation and screening of extracellular anticancer enzymes from halophilic and halotolerant bacteria from different saline environments in Iran. Mol Biol Rep; (46):3275–3286.
16. Margesin, R., Schinner, F., (2001) Potential of halotolerant and halophilic microorganisms for biotechnology. Extremophiles .,(5): 73-83.
17. Kumar S, Karan R, Kapoor S, Singh SP, Khare SK (2012) Screening and isolation of halophilic bacteria producing industrially important enzymes. Braz J Microbiol .,43(4):1595–1603.
18. Gupta,R.,Rajpu,R.,Sharma,R.,Gupta,N.,(2013)Biotechnological applications and prospective market of microbial keratinases . Appl. Microbiol.Biotechnol.,(97):9931-9940..
19. Sahoo .S., Roy S., Maiti S., (2016)A High Salt Stable α-Amylase by Bacillus Sp. MRS6 Isolated from Municipal Solid Waste; Purification, Characterization and Solid-State Fermentation. Enz Eng., 5 (3): 1-8.
20. Rajeshwari, Sinha., A. K. Srivastava, S. K. Khare(2014)efficient proteolysis and application of an alkaline protease from halophilic bacillus sp. EMB9: Preparative Biochemistry & Biotechnology, (44):680–696,
21. Garg ,R., Srivastava ,R., Brahma, V.,(2016) Biochemical and structural characterization of a novel halotolerant cellulase from soil metagenome. Sci Rep .,(6):1–15. https://doi.org/10.1038/srep39634
22. Rajendiran.K.,Paneerselvam.A .,Ilavarasi.A ., Thajuddin.N(2017)isolation of pigment producing halophilic bacteria from marakkanam salt pans and evaluation of their antioxidant ability. world journal of pharmacy and pharmaceutical sciences .6(10):205-216.
23. Santhanam, A., Sasidharan, S., (2010) Microbial production of polyhydroxy alkanotes) from Alcaligens spp. and Pseudomonas oleovorans using different carbon sources. Afr J Biotechnol., (9):3144–3150.
24. Cervantes-Uc.JM.,Catzin .J.,Vargas.I. , Herrera-Kao.W. . Moguel.F., Ramirez.E.,Rincon-Arriaga.S. Lizama-Uc., G(2014)Biosynthesis and characterization of polyhydroxyalkanoates produced by an extreme halophilic bacterium, Halomonasnitroreducens, isolated from hypersaline ponds,; Journal of Applied Microbiology. (117):1065-1065. doi:10.1111/jam.12605
25. Tango ,MSA., Islam ,MR (2002) Potential of extremophiles for biotechnological and petroleum applications. Energy Sources.,(24): 543-559
26. Johannes,F.,Imhoff , Hans G., .Truper (1977) Ectothiorhodospirahalochlorissp.nov., a new extremely halophilic phototrophic bacterium containing bacteriochlorophyll b. Arch of mic bio(114):115-121.
27. Thongthai ,C., McGenity ,T J., Suntinanalert ,P., Grant, W D., (1992). Isolation and characterization of an extremely halophilic archaeobacterium from traditionally fermented Thai fish sauce (nampla).Lett. Appl. Microbiol., (14): 111 114.
28. Roh ,S W., Nam ,Y D., Chang, H W., Sung ,Y., Kim, K H., Oh .H M., Bae ,J .,W(2007). Halalkalicoccusjeotgali sp. nov., a halophilic archaeon from shrimp jeotgal, a traditional Korean fermented seafood,Int. J. Syst. EvolMicrobiol., (57): 2296 2298.
29. Elyasifar, B., Jafari ,S., Hallaj-Nezhadi, .,S (2019) Isolation and identification of antibiotic-producing halophilic bacteria from Dagh Biarjmand and Haj aligholi salt deserts, Iran. Pharm Sci .,(25):70–77. https://doi.org/10.15171/PS.2019.11
30. Quadri.I.,Hassani .II.,Haridonb.SI.,Chalopin.M., Hacènea.H.,Jebbar.M(2016)Characterization and antimicrobial potential of extremely halophilic archaea isolated from hypersaline environments of the Algerian Sahara. Microbiological research .,(186-187): 119-131.
31. Iizuka.T.,Fudou.R.,Jojima.Y.,Ogawa.S.,Yamanaka.S., Inukai.Y., Ojika.M(2006)Miuraenamides A and B, Novel Antimicrobial Cyclic Depsipeptides from a New Slightly Halophilic Myxobacterium: Taxonomy, Production, and Biological Properties, J. Antibiot., 59(7): 385–391.
32. Shrestha.N.,Chilkoor.G.,Vemuri.B.,Rathinam,.N.,RajesH.KS.,Gadhamshetty.V (2018)Extremophiles for microbial-electrochemistry applications: a critical review .,Bioresource Technology.,(255):318-330.

33. Oren, A., Gurevich, P., Henis, Y., (1991). Reduction of nitrosubstituted aromatic compounds by the halophilic anaerobic eubacteria *Haloanaerobiumpraevalens* and *Sporohalob actermarismortui*. Appl. Environ. Microbiol., (57): 3367–3370.
34. Bonfá ,MRL., Grossman, MJ., Mellado.,E, Durrant .LR (2011) Biodegradation of aromatic hydrocarbons by haloarchaea and their use for the reduction of the chemical oxygen demand of the hypersaline petroleum produced water. Chemosphere .,(84):1671–1676
35. Yemashova, N., A, Murygina., V. P, Zhukov., D. V., Zakharyantz, A. A., Gladchenko, M. A., Appanna, V(2007). Biodeterioration of crude oil and oil derived products: a review. Rev. Environ. Sci. Biotechnol.,(6): 315–337. doi: 10.1007/s11157-006-9118-8
36. Al-Mallah, M, Goutx., M, Mille., G, Bertrand, J.-C., (1990). Production of emulsifying agents during Growth of a marine Alteromonas in sea water with eicosane as carbon source, a solid hydrocarbon. Oil Chem. Pollut., (6) 289–305. doi: 10.1016/S0269-8579(05)80005-X
37. Neff, J., Lee, K., DeBlois, E. M.(2011)"Produced water: overview of composition, fates, and effects," in Produced Water: Environmental Risks and Advances in Mitigation Technologies eds K. Lee and J. Neff (New York, NY: Springer Science+Business Media, LLC): 3–54. doi: 10.1007/978-1-4614-0046-
38. Nicholson, C., A., Fathepure, B. Z. (2005)Aerobic biodegradation of benzene and toluene under hypersaline conditions at the Great Salt Plains, Oklahoma. FEMS Microbiol. Lett.(245); 257–262. doi: 10.1016/j.femsle.2005.03.014
39. Gunde-Cimerman N., Zalar, P., de Hoog, S., Plemenitaš ,A (2000) Hypersaline waters in salterns: natural ecological niches for halophilic black yeasts. FEMS MicrobiolEcol .,(32):235–240
40. Widmann,C.,Gibson,S.,Jarpe,M. B.,Johnson,G.L.(1999). Mitogen activated protein kinase: conservation of a three-kinase module from yeast to human. Physiol. Rev.,(79):143–180.
41. Padhye ,AA., Pawar ,VH., Sukapure, RS., Thirumalachar, MJ(1967) Keratinophilic fungi from marine soils of Bombay India. Part I. Hindustan Antibiotics Bulletin.,(10): 138–141.
42. Deshmukh,SK.,(1999)Keratinophilic fungi isolated from soils of Mumbai, India. Mycopathologia; (146): 115–116.
43. Annapurna ,SA., Singh ,A., Garg, S., Kumar ,A., Kumar, H (2012) Screening, isolation and characterisation of protease producing moderately halophilic microorganisms. Asian J MicrobiolBiotechnol Environ Sci .,(14):603–612.
44. Bano ,A., Hussain ,J., Akbar, A, (2018) Biosorption of heavy metals by obligate halophilicfungi. Chemosphere .,(199):218–222. https://doi.org/10.1016/j.chemosphere.2018.02.043
45. Stanley, J., T, Palmer., F, Adams, J. B (1982). Microcolonial fungi: common inhabitants on desert rocks? Science., (215): 1093–1095. doi: 10.1126/science.215.4536.1093
46. Ali.I.,Akbar.I.,Yanwisetpakdee.B.,Prasongusk.S.,Lotrakul.P.,punnapayak.H. (2014)Purification, Characterization and potential of saline wastewater remediation of a polyextremophilic α-Amylase from an Obligate Halophilic *Aspergillus gracilis*.BioMed Research International Article.,106937| https:// doi.org/10.11 55/2014/106937
47. Moubasher ,AH., Abdel-Sater, MA., Soliman Z.(2018)Diversity of yeasts and filamentous fungi in mud from hypersaline and freshwater bodies in Egypt. Czech Mycol;(70):1–32.
48. Chamekh.R., Deniel.F.,Donot.C., Jany.JL,Nodet.P.,Belabid.L(2019) Isolation, Identification and Enzymatic Activity of Halotolerant and Halophilic Fungi from the Great Sebkha of Oran in Northwestern of Algeria, MYCOBIOLOGY.,(47) 2: 230–241
49. Bano ,A., Hussain, J., Akbar ,A., Mehmood, K., Anwar ,M., Hasni ,MS., Ullah ,S., Sajid S, Ali I (2018) Biosorption of heavy metals by obligate halophilic fungi. Chemosphere(199):218–222. https:// doi.org/10.1016/j. chemosphere.2018.02.043
50. Gonzalez- Abradelo.D., perezLlano.Y.,peidro Guzman.H., Rayo Sanchez.MD., Folch-Mallol.JL.,Aranda.E., Vaidyanathan.V.,Cabana.H., Gunde- Cimerman.N., Batista Garcia.R (2019), Bioresource technology 279.
51. Goodfellow, M., Fiedier, HP. A guide to successful bioprospecting informed by actinobacterial systematic, Antonie van Leeuwenhook .,(98):119-142
52. Jose, P. A., Jebakumar, S. R. D., (2012). Phylogenetic diversity of actinomycetes cultured from coastal multipond solar saltern in Tuticorin, India, Aquat. Biosyst., (8): 23
53. Nakade, D. B. (2012).Biodiversity of actinomycetes in hypersaline soils of Kolhapur district and their screening as antibiotic producer, India, Res. J. Recent Sci., (1): 317-319
54. Udhyakumar.K.,Ramalingam.S., SaravananR., Dheeba.B(2017) Extraction of Actinomycetes (Streptomyces sp.) Pigment and Evaluation of its Anticancer PropertyonHeLa Cell Line, Der PharmaChemica, , 9(24): 106-113
55. Gesheva.V.,Vasileva-Tonkova.E(2012) Production of enzymes and antimicrobial compounds by halophilic Antarctic Nocardioides sp. grown on different carbon sources. World J MicrobiolBiotechnol., (28):2069–2076
56. Tian.SZ., PU.X., Luo.G., Zhao.L.,Li-Hua Xu.L., Wen- Jun .LI.,Luo(2013) Isolation and Characterization of New p-Terphenyls with Antifungal, Antibacterial, and Antioxidant Activities from Halophilic Actinomycete Nocardiopsisgilva YIM 90087, Journal of Agricultural and Food Chemistry., 61(12)
57. Zhao.F. ,Wang.P., Lucardi.RD.,Su.Z., Li.S (2020)Natural Sources and Bioactivities of 2,4-Di-Tert-Butylphenol and Its Analogs . Toxins .,(12, 35; doi:10.3390/toxins12010035.
58. Liu .H., Xiao L,Wei . J., Schmitz JC.,.Liu .M.,Wang.C.,Wu .NChen.L.,Zhang .Y.,LinX(2013) Identification of Streptomyces sp. nov. WH26 producing cytotoxic compounds isolated from marine solar saltern in China. World J Microbiol Biotechnol .,(29):1271–1278.

59. Zhao.LX.,Haung .SX.,Tang.SK.,Jiang.CL.,Duan.Y., John A Beutler, CurtisJHenrich, James B McMahon, Tobias schmid, Johanna S Blees, Nancy H colburn, Scott R Rajski, Ben Shen(2011)Actinopolysporins A-C and tubercidin as a Pdcd4 stabilizer from the halophilic actinomycete *Actinopolyspor aerythraea* YIM 90600,J.Nat.Prod.,(74):1990-1995.
60. Sun, M., Zhang, X., Hao, H., Li ,W., Lu ,C.,(2015) Nocarbenzoxazoles A–G, Benzoxazoles Produced by Halophilic *Nocardiopsis lucentensis* DSM 44048. *J. Nat. Prod.* ;(78):2123–2127. doi: 10.1021/acs. jnatprod.5 b00031
61. Amal ,AM., Abeer, KA., Samia ,HM., Nadia ,AH., Ahmed ,KA., El-Hennawi ,HM. (2011) Res. J. Chem. Sci; 1(5): 22- 28.
62. Asnani.A.,Ryandini.D., Suwandri (2016)Screening of Marine Actinomycetes from SegaraAnakan for Natural Pigment and Hydrolytic Activities, Materials Science and Engineering :107
63. Zeinab, H Kheiralla., Maha, A., Hewedy., Howida ,R., Mohammed ,Osama .,M Darwesh(2016)Isolation of Pigment Producing Actinomycetes from Rhizosphere Soil and Application It in Textiles Dyeing RJPBCS., 7(5) 2128
64. Tandale.A.,Khandagale.M., Palaskar.R.,Kulkarni.S(2018)Lip Balm Production from Pigment Producing Actinomycetes.5 (4).
65. Hassanein, N.M. El-Gendy, M.M.Ibrahim, H.A.E.-H.; El Baky, D.H.A.,(2012)Screening and evaluation of some fungal endophytes of plant potentiality as low-cost adsorbents for heavy metals uptake from aqueous solution. Egypt. J. Exp. Biol., (8): 17–23.
66. Timková.I.,Sedláková-Kaduková.J.,Pristaš.P(2018).Biosorption and Bioaccumulation abilities of actinomycetes / Streptomyces isolated from metal contaminated sites. seprations, 5(4):54.
67. Mayavu, P., Sugesh ,S., Suriya, M., Sundaram ,S(2014) Enumeration of halophilic forms in parangipettai saltpan and its antagonistic activities against Vibrio sp. J Appl Biol Biotechnol.; 2 (02): 019-021.
68. Das ,D., Kalra, I., Mani,K.,(2019)Characterization of extremely halophilic archaeal isolates from Indian salt pans and their screening for production of hydrolytic enzymes. Environ Sustain ; (2):227–239.
69. Sinha ,R., Srivastava ,AK., Khare ,SK(2014) Efficient proteolysis and application of an alkaline protease from halophilic Bacillus sp. EMB9. Prep Biochem Biotechnol; (44):680–696.
70. Zheng-Wen Cai ,Hui-HuaGe , Zhi-Wei Yi , Run-Ying Zeng , Guang-Ya Zhang (2018) Characterization of a novel psychrophilic and halophilic β-1, 3-xylanase from deep-sea bacterium*, Flamme ovirgapacifica* strain WPAGA1 . International Journal of Biological Macromolecules.(118):2176-2184.
71. Fitriani.S.,güven.K(2018) Isolation, screening,partial purification and characterization of protease from halophilic bacteria isolated from Indonesian fermented food .,(7):2,130-142.
72. Neagu ,S., Cojoc ,R., Tudorache. M., (2018)The Lipase Activity from Moderately Halophilic and Halotolerant Microorganisms Involved in Bioconversion of Waste Glycerol from Biodiesel Industry. Waste and Biomass Valorization;(9):187–193.
73. Biswas ,J., Ganguly, J., Paul ,AK (2015) Partial characterization of an extracellular polysaccharide produced by the moderately halophilic bacterium halomonas xianhensis SUR308. Biofouling .,(31):735–744. https://doi.org/10.1080/08927014.2015.1106479
74. .Tena-Garitaonaindia , M., Llamas ,I. L., Toral c., I. Sampedro (2019) Chemotaxis of halophilic bacterium Halomonasanticariensis FP35 towards the environmental pollutants phenol and naphthalene. Science of the Total Environment .,(669): 631–636
75. Karthigeyan, P., sarita ,G., Bhat., M.Chandrasekaran(2013) Halocin SH10 production by an extreme haloarchaeon natrinema sp.BTSH10 isolated from saltpans of south india. Saudi J Bio Sci .,20 (2): 205-212.
76. Chhetri, V., Prakitchaiwattana, C., Settachaimongkon ,S (2019) A potential protective culture; halophilic Bacillus isolates with bacteriocin encoding gene against Staphylococcus aureus in salt added foods. Food Control (104):292–299. https://doi.org/10.1016/j.foodcont.2019.04.043
77. Budiyanto ,F., Thukair ,A., Al-Momani ,M.,(2018)Characterization of Halophilic Bacteria Capable of Efficiently Biodegrading the High-Molecular-Weight Polycyclic Aromatic Hydrocarbon Pyrene. Environ Eng Sci.,(35):616–626. https://doi.org/10.1089/ees.2017.0244
78. Anburajan ,L., Meena ,B., Sreelatha ,T., (2019) Ectoine biosynthesis genes from the deep sea halophilic eubacteria, Bacillus clausii NIOT-DSB04: Its molecular and biochemical characterization. Microb Pathog.,(136):103693. https://doi.org/10.1016/j.micpath.2019.103693
79. Castilla, A., Panizza, P., Rodríguez, D., (2017) A novel thermophilic and halophilic esterase from Janibacter sp. R02, the first member of a new lipase family (Family XVII). Enzyme Microb Technol.,(98):86–95. https://doi.org/10.1016/j.enzmictec.2016.12.010.
80. Musa, H., Hafiz ,Kasim .,F, Nagoor Gunny, AA.,(2019) Enhanced halophilic lipase secretion by Marinobacter litoralis SW-45 and its potential fatty acid esters release. J Basic Microbiol .,(59):87–100. https://doi.org/10.1002/jobm.201800382
81. Thirumala,M ., Vishnuvardhan, Rs (2016) Production, purification and charracterization of a thermotolerant alkaline serine protease from a novel species Bacillus aseinilyticus. 3 Biotech., 6(1) 53
82. Boujida ,N., Palau ,M.,Charfi,S (2018)Isolation and characterization of halophilic bacteria producing exopolymers with emulsifying and antioxidant activities. Biocatal Agric Biotechnol;(16):631–637.
83. Mitra.R.,Xu.T.,xiang.H.,Han.J (2020)Current developments on Polyhydroxyalkanoates synthesis by using halophiles as a promising cell factory.,Microb cell fact. 19:86.
84. Spanò, A., Gugliandolo ,C., Lentini ,V(2013) A novel EPS-producing strain of bacillus licheniformis isolated from a shallow vent Off Panarea Island (Italy). Curr Microbiol .,(67):21–29. ://doi.org/10.1007/s00284-013-0327-4
85. Llamas ,I., Amjres, H., Mata ,JA.,(2012) The potential biotechnological applications of the exopolysaccharide

produced by the halophilic bacterium Halomonas almeriensis. Molecules.,(17):7103–7120. https://doi.org/10.3390/molecules17067103

86. Kinji .U.,(2000)Diversity and Ecology of Salt Tolerant Lactic Acid Bacteria: Tetragenococcushalophilus in Soy Sauce Fermentation. Japanese Journal of lactic acid Bacteria.,11, No. 2
87. Ali.I.,Akbar.A.,Anwar.M.,Benjawan.Y.,sehanat.P.,Pongtharin.L.,Hunsa.P(2014)Purification and Characterization of Extracellular, Polyextremophilic αamylase Obtained from Halophilic Engyodontium album Iran J Biotech;12(4):1155
88. Mansour.MMA (2017). Effects of the halophilic fungi *Cladosporium sphaerospermum*, wallemiasebi, Aure *Aureobasidium pullulans and Aspergillus nidulans* on halite formed on sandstone surface, Int Biodet&Biodeg .,(117):289-298.
89. Corral, P., Esposito, F.P., Tedesco ,P., Falco, A., Tortorella ,E., Tartaglione ,L., Festa ,C., D'Auria, M.V., Gnavi ,G., Varese, G.C., (2018) Identification of a Sorbicillinoid-producing *Aspergillus* strain with antimicrobial activity against *Staphylococcus aureus*: A new polyextremophilic marine fungus from Barents Sea. *Mar. Biotechnol.* ;(20):502–511. doi: 10.1007/s10126-018-9821-9. [PubMed] [CrossRef] [Google Scholar
90. Zheng ,J., Wang ,Y., Wang ,J., Liu, P., Li ,J., Zhu ,W(2013)Antimicrobial ergosteroids and pyrrole derivatives from halotolerant *Aspergillus flocculosus* PT05-1 cultured in a hypersaline medium. *Extremophiles.* ;(17):963–971. doi: 10.1007/s00792-013-0578-9. [PubMed] [CrossRef] [Google Scholar]
91. Whang,.Y.,Zheng.J.,Liu.P.,Wang.W., Zhu.W (2011) Three New Compounds from Aspergillusterreus PT06-2 Grown in a High Salt Medium, Mar. Drugs, (9): 1368-1378; doi:10.3390/md9081368.
92. Priya ,AK,. M,Nithya., B, Dinesh., J,Bajan Singh(2019) Removal of Heavy Metals by Biosorption Technique using Halophilic Fungi, (IJITEE) .,(8)
93. Batista-Garcı. RA., Balca´zar-Lo´pez.E., Miranda-Miranda.E., Sa´nchez-Reyes. A., Cuervo-Soto.L., Aceves-Zamudio.D.,Atrizta´n-Herna´ndez.K.,MoralesHerrera.C.,Rodrı´guez-Hernandez.R.,Folch Mallo.J(2014)Characterization of Lignocellulolytic Activities from a Moderate Halophile Strain of Aspergillus *caesiellus* Isolated from a Sugarcane Bagasse Fermentation , PLOS .234-245
94. Obuekwe, C.O. Badrudeen, A.M.; Al-Saleh, E.; Mulder, J.L.(2005).Growth and hydrocarbon degradation by three desert fungi under conditions of simultaneous temperature and salt stress. Int. Biodeterior. Biodegradation., (56): 197-205.
95. Tapilatu, Y.H.; Grossi, V.; Acquaviva, M.; Militon, C.; Bertrand, J.C.; Cuny, P. (2010). Isolation of hydrocarbon-degrading extremely halophilic archaea from an uncontaminated hypersaline pond (Camargue, France). Extremophiles., (14): 225-231.
96. Bruns, A.; Berthe-Corti, L. (1999). Fundibacterjadensis gen. nov., sp. nov., a new slightly halophilic bacterium, isolated from intertidal sediment. Int. J. Syst. Bacteriol.,(49) :441-448.
97. Radhakrishnan, M., Balagurunathan, R., Selvakumar, N (2011) Bioprospecting of marine derived actinomycetes with special reference to antimycobacterial activity. Indian J Mar Sci .,(40):407–410.
98. Rotich ,MC., Magiri E., Bii C., Maina, N (2017) Bio-Prospecting for Broad Spectrum Antibiotic Producing Actinomycetes Isolated from Virgin Soils in Kericho County, Kenya. Adv Microbiol.,(07):56–70. https://doi.org/10.4236/aim.2017.71005
99. Ganesan ,S., Manoharan ,N., Naveenkumar, S., Velsamy ,G (2011) Bioprospecting of Marine Sediments Derived Novel Halophilic Actinomycetes sp ., to Explore its Antagonistic Efficacy. Int J Medicobiological Res .,(1):224–230.
100. Kumar, PS., Duraipandiyan ,V., Ignacimuthu ,S (2014) Isolation, screening and partial purification of antimicrobial antibiotics from soil Streptomyces sp. SCA 7. Kaohsiung J Med Sci.,(30):435–446. https://doi.org/10.1016/j.kjms.2014.05.006
101. Vijayakumar, R., Selvam, KP., Muthukumar, C., (2012) Antimicrobial potentiality of a halophilic strain of Streptomyces sp. VPTSA18 isolated from the saltpan environment of Vedaranyam, India. Ann Microbiol., (62):1039–1047. https://doi.org/10.1007/s13213-011-0345-z.
102. Ballav,S., Kerkar ,S., Thomas, S., Augustine, N (2015) Halophilic and halotolerant actinomycetes from a marine saltern of Goa, India producing anti-bacterial metabolites.J Biosci Bioeng., (119):323–330. https://doi.org/10.1016/j.jbiosc.2014.08.017
103. Malviya ,N., Yandigeri, MS., Yadav ,AK., (2014) Isolation and characteization of novel alkali-halophilic actinomycetes from the Chilika brackish water lake, India. Ann Microbiol .,(64):1829–1838. https://doi.org/10.1007/s13213-014-0831-1
104. Sakurai.Y., Inoue. H.,Nishi. W., Takahashi. T. ,Inno. Y.,Yammato. M.,Takahashi. K (2009).Purification and charracterization of a major collagenase from Streptomyces parvulus. Biosci. Biotechnol.Biochem.,73(1)21-28.

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