

Halophilic Bacteria: Diversity and Biotechnological Applications

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Abstract- *Hypersaline environments are extreme habitats on the planet and have a diverse microbial population formed by halophilic microorganisms. They are considered to be actual or potential sources for discovery bioactive compounds, compatible solutes including novel and/or extraordinarily enzymes. To date, a number of bioactive compounds for the use in various fields of biotechnology which show assorted biological activities ranging from antioxidant, sunscreen and antibiotic actions have been reported. In addition, some halophilic microorganisms are capable of producing massive amounts of compatible solutes that are useful as stabilizers for biomolecules or stress-protective agents. The present review will impart knowledge and discuss on diversity of halophilic bacteria and their use in various biotechnological applications, including industrial, pharmaceutical, agricultural and environmental aspects. Culture dependent as well as culture independent methods for isolation of halophiles should go hand in hand to provide the insight mechanisms of halophilic adaptation and their future applications.*

Keywords: *halobacteria, Diversity, biocompounds, biotechnology.*

I. INTRODUCTION

Saline habitats are frequently inhabited by an abundance of microbial communities adapted to these ecosystems. Among the microorganisms, the bacteria play a major role as important and dominant in habitants of saline and hypersaline environments [1,2]. Microorganisms that thrive in these environments have been broadly classified into halophilic microorganisms and halotolerant microorganisms. Halophiles are the microorganisms requiring salt for their growth whereas; halotolerant microorganisms are able to grow in the absence as well as in the presence of

salt. Halophiles can be further divided into three categories according to their halotolerance, slight halophiles that grow optimally in 3% (w/v) total salt, moderate halophiles with optimal growth at 3- 15% (w/v) salt and extreme halophiles that grow optimally at 25% (w/v) salt [3]. The world of halophilic microorganisms is highly diverse. Halophilic and halotolerant microorganisms are found in all three domains of life: *Archaea*, *Bacteria* and *Eucarya*. Saline and hypersaline environments are found in wide variety of aquatic and terrestrial ecosystems. In terms of marine environment, Morocco has coastline of about 3500 Km. Morocco is known for its rich biodiversity especially in context with halophiles because; it is surrounded by Atlantic ocean and Mediterranean sea. Marine environment is the prime reservoir of biological diversity and the marine microorganisms are recognized to be rich sources of novel compounds. Recently, there is accelerated interest in the study of marine halophiles, with the aim of providing the information on microbial diversity and their role in biogeochemical cycling in marine ecosystems and in exploiting their ability to produce novel enzymes and industrially important bioactive substance like biosurfactants, extracellular polymeric substances (EPS), other crucial metabolites/compounds for biotechnological applications.

The above survey shows that thus far the halophilic microorganisms have found relatively

few commercially viable applications. With the exception of β -carotene production by *Dunaliella* and ectoine synthesis using *Halomonas* and other moderately halophilic Bacteria, most other potential applications suggested are no more than ideas only, waiting to be exploited. The list of possible applications presented in the sections below is by no means exhaustive and additional ideas have been presented in the literature, such as, for example, production of liposomes for the cosmetics industry and exploitation of *Halobacterium* gas vesicles in biotechnological processes. Many patents have been issued for these and other applications, but the ideas are still to be implemented in commercial ventures. With all the advantages listed for the use of halophiles in industrial processes, there are disadvantages as well. For mass cultivation of aerobic bacteria, the low solubility of gases in concentrated brines may severely limit oxygen supply to the cultures. Also the aggressive nature of the salts should be taken into account during the construction of reactors with metal parts exposed to the medium. It is possible to build corrosion-resistant bioreactors suitable for high salt media, but their cost is significantly higher than that of conventional fermenters. The tremendous diversity of halophilic microorganisms found in nature is still far from being fully exploited. Approaches derived from genomics and proteomics have opened new possibilities, and genetic systems are now also available for a number of halophiles. The present review summarizes the current diversity of halophilic bacteria and their use in various biotechnological application, including industrial, pharmaceutical, agricultural and environmental aspects. Briefly the mechanisms of adaptation in saline environments and the molecular approaches to access the diversity of halophilies will be discussed.

II. DIVERSITY

Microbial life can be found over a wide range of extreme conditions (salinity, pH, temperature, pressure, light intensity, oxygen and nutrient conditions). Hypersaline environments constitute typical examples of environments with extreme conditions due to their high salinity, exposure to high and low temperatures, low oxygen conditions and in some cases, high pH values. Bacteria and Archaea are the most widely distributed organisms in these environments [4]. The classification of Kushner and Kamekura [5] defines different categories of halophilic microorganisms based on the optimal salt concentration wherein they show optimal growth, and it includes four categories: non-halophilic organisms are defined as those requiring less than 1% NaCl, whereas if they can tolerate high salt concentrations are considered as halotolerant microorganisms. With respect to halophilic microorganisms, the classification distinguishes among slight halophiles (marine bacteria), which grow best in media with 1% to 3% NaCl, moderate halophiles, growing best in media with 3% to 15% NaCl, and extreme halophiles, which show optimal growth in media containing 15% to 30% NaCl. Halophiles have developed two different adaptive strategies to cope with the osmotic pressure induced by the high NaCl concentration of the normal environments they inhabit [6, 7]. The halobacteria and some extremely halophilic bacteria accumulate inorganic ions in the cytoplasm (K^+ , Na^+ , Cl^-) to balance the osmotic pressure of the medium, and they have developed specific proteins that are stable and active in the presence of salts. In contrast, moderate halophiles accumulate in the cytoplasm high amounts of specific organic osmolytes, which function as osmoprotectants, providing osmotic balance without interfering with the normal metabolism of the cell [8, 9].

Halophilic bacteria are one of the most commonly isolated, reported, studied and characterized microbes amongst halophiles [10]. They exist in various forms of colonies, ranging from pigmented to non - pigmented, according to the salt concentration in the media. They are slow growing compared to non- halophile or normal bacteria. The extremely halophilic bacteria grow extremely slowly [4]. For in vitro culture on agar plates, most require natural brines along with a variety of other nutrients such as fish or milk extracts for their growth and a few of them also require complex nutrients like yeast extract for their survival. During the last few decades there was progress in providing a systematic base for classifying halophilic bacteria, including the use of various phenotypic characteristic tests and analytical apparatus. However, there are now taxonomically emerging groups of halophilic bacteria and their classification has not yet been much developed [11]. Salt characterization for the optimum growth of halophilic bacteria is required prior to classification, but this step is costly, time consuming and is limited to only those cultivable and clonable isolates. A test methodology for halophilic bacteria has been recommended in which the media must be added with salt and the incubation time for subsequent growth is then assessed [12].

The taxonomy of halophilic bacteria was historically based on just a few phenotypic or morphological characters and less attention was paid to the phylogenetics or biochemistry of the organisms [12-15]. Phylogenetic analyses, largely based on the 16S rRNA gene sequence, have revealed that halophilic eubacteria and halophilic archaeobacteria are from different phylogenetic

branches. Halophilic bacteria are generally represented by archaeobacteria, which are also comprised of the slightly and moderately halophilic bacteria, but most of these bacteria are eubacteria [16].

In hypersaline environments extremely halophilic bacteria and moderately halophilic bacteria are the important groups that have received most of the attention in recent research [10]. Slightly halophilic bacteria have been reported in studies focused on habitats such as the Dead Sea, GSL, Lake Magadi, Wadi El Natrun and some other extreme hypersaline environments that yield extremophilic bacteria. Slightly halophilic bacteria form a smaller proportion of the population in these environments and typically can not be found in these harsh habitats [17]. The other drawback of characterising slightly halophilic bacteria is their characteristics that resemble the non-halophilic or normal bacteria, and these are typically of a lower interest for research. Due to the lack of sufficient information on the slightly halophilic bacteria, only a description of moderately and extremely halophilic bacteria is provided in this review.

Extremely halophilic bacteria. Extremely halophilic bacteria belong to the class *Halobacteria*, family *Halobacteriaceae* and order *Halobacteriales* [18]. Fourteen genera of *Halobacteriaceae* family are recognised, namely *Haloarcula*, *Halobacterium*, *Halobaculum*, *Halococcus*, *Haloferax*, *Halogeometricum*, *Halorubrum*, *Haloterrigena*, *Natrialba*, *Natrinema*, *Natronobacterium*, *Natronococcus*, *Natronomonas* and *Natronorubrum*. They are cocci or rod - shaped and have a number of disk –

to triangle - shaped involutions. They need salt concentration of 1.5 M (~ 8.8%) NaCl for their growth and lack muramic acid but possess peptidoglycan in the cell envelop. The colonies are highlighted by shades of red colour due to the presence of optically active C₅₀- carotenoids. Their intracellular enzymes require high levels (3-5 M) of potassium chloride whilst their cytoplasmic membranes are composed of phytanyl ether lipids. They show a degree of resistance against many antibiotics and occur in hypersaline environments such as salterns, soda lakes and salt lakes [4].

Moderately halophilic bacteria. Halophilic bacteria requiring a salt concentration of 0.5 M NaCl for their growth are included in the moderately halophilic bacteria group. Taxonomically, the moderately halophilic bacteria can be divided into the two groups: moderately halophilic eubacteria and moderately halophilic archaeobacteria [19]. Most of the bacterial halophiles are moderately halophilic eubacteria rather than extreme halophiles [7], and are phototrophic or heterotrophic, the latter Including Gram - positive and Gram - negative bacteria. Gram - positive moderately halophilic species include *Deleya halophila*, *Desulfovibrio halophilus*, *Desulfohalobium retbaense*, *Flavobacterium halmephilum*, *Haloanaerobacter chitinovorans*, *Haloanaerobium praevalens*, *Halobacteroides halobius*, *Halomonas elongate*, *Halomonas eurihalina*, *Halomonas halodenitrificans*, *Halomonas halodurans*, *Halomonas subglaciescola*, *Paracoccus halodenitrificans*, *Pseudomonas beijerinckii*, *Pseudomonas halophila*, *Spirochaeta halophila*, *Sporohalobacter lortetii*, *Sporohalobacter*

Marismortui and *Vibrio costicola*. The Gram-negative moderately halophilic species include *Halobius spp.*, *Marinococcus albus*, *Marinococcus halobius* and *Sporosarcina halophila*. Phototrophic moderately halophilic bacteria are *Ectothiorhodospira vacuolata*, *Rhodospirillum salexigens* and *Rhodospirillum salinarum* [19]. Except for the methanogens, all halophilic archaea are considered as extremely Halophilic bacteria [7]. The composition of the membrane – bounded cytoplasm of moderately halophilic archaeobacteria is similar to that of extremely halophilic bacteria in having phytanyl ether lipids. They have a unique nutritional intake capacity and use methylotrophic substrates rather than acetate, carbon dioxide and hydrogen. The mode of respiration is strictly anaerobic [20]. The intracellular NaCl concentration is higher than most other bacteria (about 0.6 M or 3.5% NaCl), but this concentration is much lower than that in the extremely halophilic archaeobacteria. Species reported for moderately halophilic archaeobacteria include members of the *Methanohalophilus* genus, e.g. *M. zhilinae*, *M. portucalensis*, *M. mahii*, *M. halophilus* and *M. portucalensis* [21].

III. MOLECULAR APPROCHES TO ASSES THE DIVERSITY OF HALOPHILIC BACTERIA

Molecular phylogeny is a very useful to analyze microbial populations. A number of molecular techniques are known for identifying and analyzing the biodiversity of bacterial strains, such as random amplified polymorphic DNA (RAPD), amplified ribosomal DNA restriction analysis (ARDRA), and 16S rRNA gene analysis. The comparaison of 16S rRNA gene sequences is a powerful tool for deducing phylogenetic and evolutionary relationships among bacteria [22].

Small- subunit of rDNA gene (16S rDNA) is widely used to establish phylogenetic relationship among bacteria because this gene is universally present, sufficiently small to be easily sequenced and large database for it is available. Furthermore, rDNA that encodes Rdna comprises of highly conserved regions, crucial for structure and function, flanked by highly variable stretch, which varies among various species [23]. Identification and phylogenetic analysis of halophilic bacteria using 16S rDNA genes amplification has been extensively implemented by many authors [24,25]. 16S Rdna primers and probes for specific identification of actinomycetes and especially for streptomycetes were designed by Stackebrandt *et al.*, 1991 [26] and Mehling *et al.*, 1995 [27]. ARDRA and 16S rRNA gene sequencing have been applied to characterize many actinobacteria [28-29]. Additionally, there are degenerate primers for genes encoding polyketide synthases (PKS-1 and PKS-2) and non ribosomal peptide synthetases (PKS-1 and PKS-2) and non ribosomal peptide synthetase (NRPS) which are used to screen the biosynthetic potential in terms of natural product drug discovery as identification of these genes provides indirect evidence of potential chemical diversity among the actinobacteria [30-31].

IV. HYPERSALINE HABITATS

Hypersaline habitats can be classified based on the extremity, adaptability and geological and geographical location of the area.

Saline Soil. Soil habitats are heterogeneous and are comprised of a diverse range of minerals and salinity present within the soil at various depths [18]. Soil salinity is much more variable than water salinity [32]. Higher plants that are halotolerant (halophytes) are well adapted to growing in different levels of salinity and play important roles in different ecological nutrient

cycles, but the interactions between plants and microbes vary with different saline habitats [33].

A number of bacterial species have been reported to inhabit saline soils, but the dominant species found in such habitats belong to the *Bacillus*, *Pseudomonas*, *Micrococcus* and *Alcaligenes* genera [7]. In the Alicante, Spain, the rhizosphere and hypersaline soil have been reported to contain 5–10% NaCl. The xerophytic plants present in the area and the salt concentration range allowed the growth of isolated organisms that are not related to the salinity of the soil [16]. Half of the plants were able to grow best in a high- salinity condition (5– 15% NaCl) while the other half grew best in a low-salinity condition (1% NaCl). With respect to the culturable microbes from this environment, agar media plates with 10% NaCl revealed mostly the presence of Gram - positive rod bacteria, while Gram - negative rod bacteria were found to be abundant at NaCl concentrations of 10– 20%. Gram - positive cocci bacteria were found in soil with $\geq 20\%$ NaCl salinity, and were mostly from the *Bacillus*, *Micrococcus*, *Staphylococcus*, *Actinomycetes*, *Corynebacterium*, *Planococcus*, *Arthrobacter* and *Nocardia* genera [7].

Saline Water. Water with salinity of 3% or above is designated as saline water [34]. Brackish water, sea and oceanic water and water from salt lakes and salterns are all considered as saline water. Some of the more famous soil and saline water habitats are discussed below. The Dead Sea is a typical example of the thalassohaline habitat. It is a lake approximately 320 m in depth with a water temperature of 21– 36°C and a salt concentration of 78% NaCl. The pH is slightly low and Na^+ , Cl^- and Mg^{2+} are the most abundant ions present [35]. A number of studies have characterized the halophilic microorganisms present in the Dead Sea and those found include the eubacteria, which were aerobes or facultative anaerobes of the

genera *Pseudomonas* [3], *Flavobacterium* [3], *Chromobacterium* [3,19], *Halobacterium* [36], *Halococcus* [37], *Clostridium* [38], *Sporohalobacter* [39] and *Halomonas* [40], plus a novel species *Halobaculum gomorrense* [41]. In addition, filamentous halophilic fungi have also been reported recently from the Dead Sea [42], and so it is clear that it does in fact support life despite the high salinity.

The Great Salt Lake, USA. The Great Salt Lake (GSL) is situated in Utah, USA, and is the largest salt lake in the Western hemisphere. This is a thalassohaline lake of moderate depth (~10 m maximum) situated in a salt desert. Unlike the Dead Sea, the GSL has a relatively high pH on the alkaline side, with a high salinity of 33% NaCl [35]. However, the salt concentration has recently changed dramatically due to the activity around the GSL since 1959 [16]. The causeway that has been constructed separates the GSL into three regions (north-east, north-west and south) and prevents the mixing of water, which has resulted in two independent water habitats, the north side and the south side, where the salt concentration of the latter (12% NaCl) is much lower than that of the former (34% NaCl) [35]. The low salinity of the south side is due to a continuous supply of fresh water from the surrounding mountains. The major ions in the lake are Na⁺ and Cl⁻, and the water temperature of the lake is seasonal, ranging from - 5 to 35°C [16, 35].

The GSL has a bacterial community which has been classified into three groups. The first is the archaeobacteria and includes members of the *Halococcus* and *Halobacterium* genera that are mostly present in the north side of the GSL due to the extreme salinity. Species like *Halorhabdus utahensis* [43] and *Methanohalophilus muhii* [44] are also found in the GSL. The second is the eubacteria, which can be aerobes or facultative anaerobes and includes *Halomonas variabilis*

[45], *Pseudomonas halophila* [45], *Chromohalobacter marismortui* [19], *Halobacillus trueperi* and *Halobacillus litoralis* [46]. Finally, the third group is the anaerobic eubacteria, with *Haloanaerobium praevalens* [47] and *Desulfocella halophila* [48] being commonly found.

The Solar Lake, Egypt. The Solar Lake, located on the Sinai coast region of the Gulf of Aqaba, is also an extremely hypersaline lake, with a shallow depth of 4-6 m. The solar intensity reaches the bottom of the lake (hence providing the name of the Solar Lake), which has a high rate of evaporation and intense and complex microbial interactions in the sediment as well as in the water [49]. In summer, the water in the lake gets completely oxygenated but in autumn it stratifies. The salinity of the lake rises to 20% NaCl in the summer due to the high rate of evaporation. A gravel bar of 60 m in width separates the lake from the Red Sea. The Lake gets contaminated from the Red Sea and also by occasional showers [16]. The halophilic archaeal community isolated from this lake is dominated by *Halobacteriaceae*, *Methanococcus*, *Methanobacterium*, *Spirochaeta halophila* and *Desulfovibrio* halophiles. The moderately halophilic bacteria found in the lake include *Beggiatoa alba* and *Achromatium volutans*, a sulphur utilizing bacteria [44]. The normal varieties of halophilic bacteria are not present much in the area and the community also changes due to the continuous variation in the saline conditions of the lake.

Lakes at Natrun Valley (Wadi El Natrun), Egypt. The Natrun Valley or Wadi El Natrun is situated below sea level in the arid region of central northern Egypt. The northern region of the valley has eight seasonal hypersaline lakes that are sometimes completely dry. Like the Solar Lake, the lakes at Natrun Valley also have a high rate of evaporation. The water feed is provided from

underground seepage of water from the Great Nile River that touches the area through the burdi swamps (grass swamps) [35]. The salinity near the sediment around the valley varies in the range of 3.1– 8.6% NaCl. The Gram - positive bacterium *Bacillus haloalkaliphilus*, a polyextremophilic bacterium that shows alkalophilic and halophilic characteristics, has been isolated from these lakes [50]. This bacterium show a maximum growth in 0.5– 3 M (~2.9– 17.5%) NaCl and can even tolerate 4 M (~ 23.4%) NaCl. Some other alkalophilic and phototrophic bacteria have also been reported from the Natrun Valley [35].

Inland saltern of La Mala, Spain. The La Mala area is situated 780 m above sea level with a 2% slope [51]. The area is thalassohaline and the salt bed is created from the saline water near the surface of the soil. The other source of water that feeds the habitat is well water. The chloride concentration fed by the well water is lower than the content of Mg^{2+} , Ca^{2+} and K^{+} ions from sea water. The total salinity found in the well water is 18% NaCl. The main halotolerant species isolated from the La Mala salterns are bacteria, with the major genera being *Alteromonas*, *Flavobacterium*, *Halomonas*, *Acinetobacter*, *Vibrio*, *Halobacterium* and *Pseudomonas* [52].

In Morocco, halophilic micro flora have been reported from natural hyper saline habitats from the coastal regions of atlantic, Larache, Oualidia and Tarfaya [53, 54]. The bacteria reported from these locations (e.g., *Alkalibacillus* sp. A1, *Virgibacillus* sp. V1 and *Actinopolyspora* sp. AH1) are halo-alkaliphilic in nature, and exhibit optimal growth in the presence of 5–20% NaCl and pH 8–10. In the coastal region of Tarfaya in the south of Morocco, there are two salt water bodies. However, these saltern water bodies have not yet been explored for the presence of halophilic microbes. Therefore, we underlook this study to isolate and characterise the halophilic

bacteria and archaeae from this region. Our results reveal the existence of strict halophilic as well as halotolerant microorganisms in the sediment and salt water stream [55].

Salted Food. Fungi, especially yeasts, are common contaminants of salted food [56], along with some halophilic bacteria including *Pediococcus halophilus* [57], *Halobacterium* sp. [58], *Halococcus* sp. [58], *Halomonas salina* [59], *Pseudomonas beijerinckii* [10], *Halomonas halodenitrificans* [10] and *Vibrio costicola* [60]. The spoiling of food when preserved in salt can occur due to the toxins produced from these microorganisms, for example the aflatoxins from members of the *Aspergillus* genus.

V. MECANISM OF ADAPTATION IN SALINE ENVIRONMENT

In order to adapt to the saline conditions, halophilic bacteria have developed various strategies to their maintain cell structure and function [60]. There are two main strategies that halophiles have evolved to deal with high salt environments (i) “salt in” strategy and (ii) “compatible- solute” strategy. Bacterial cells maintain internal concentrations that are osmottically equivalent to their external environment. They maintain internal concentrations by accumulating high concentration of KCL. For every three molecules of KCL accumulated, two ATP and hydrolyzed making this strategy more energy efficient that the “compatible solute” strategy. This mechanism is accompanied by certain physiological modifications which are required to protect all the metabolic and regulatory functions (e.g. enzymatic activity, synthesis of cellular components, and structure and function of some organelles) at high salinity [1]. The “salt in” strategy of osmoregulation is adopted by members from archaeobacterial and eubacteria. In the “compatible solute” strategy cells maintain low concentration of salt in their cytoplasm by

balancing osmotic potential with organic, compatible solutes. Compatible solutes include polyols such as glycerol, sugars and their derivatives e.g; trehalose, sucrose; amino acids and their derivatives e.g. proline, glutamate and quaternary amines such as glycine betaine. Compatible solutes could be synthesized *de novo* or, if present in the medium, can be taken up by the organisms [61]. Osmoprotectants are defined as exogenously provided organic solutes that enhance bacterial growth in media having high osmolarity. These substances may themselves be compatible solutes, or they may act as precursor molecules that can be enzymatically converted into these compounds. Compatible solutes regulate cells by accumulation of them up to molar concentrations; compatible solutes lower the cytosolic osmotic potential and hence make major contributions to the restoration and maintenance of turgor [62]. Energetically this is an expensive process. This strategy of adaptation is followed by many halophilic eubacteria. In addition to their well studied function as osmoprotectants, compatible solutes also have protein- stabilizing properties that support the correct folding of polypeptides under denaturing conditions both *in vitro* and *in vivo* [63]. Besides these strategies, bacteria have evolved some other possible mechanisms to adapt to saline environments by changing the composition of their cell envelope especially the exopolysaccharides. Sandhya et al. [64] reported that *Pseudomonas*, a halotolerant bacteria could survive under stress condition by producing exopolysaccharide, which protects them from fluctuations in water potential by increasing water retention and maintaining the diffusion of carbon sources in microbial environment. Similarly, *Halomonas variabilis* and *Planococcus rifietoensis* were reported to survive under salinity stress by exopolysaccharide production [65]. The chemical composition of cell membranes is also occasionally modified and synthesis pattern of proteins, lipids, fatty acids and

peptidoglycan are changed with a moderate increase in salinity.

VI. BIOTECHNOLOGICAL APPLICATIONS

In the recent years, studies on halophilic microorganisms have significantly increased. Halophiles or their products such as enzymes, antimicrobial compounds, exopolysaccharides, biosurfactants etc. finds vital application in diversified fields ranging from industries, pharmaceuticals, food industries, environment and agriculture.

Enzymes. Halophilic bacteria are considered as one of the most important extremophiles, they can be found in saline or hypersaline environments. Enzymes from halophilic bacteria are considered as a novel alternative for use as biocatalysts in different industries. Currently, there are few studies on halophilic enzymes [66]. Due to unique properties, halophilic microorganisms have been explored for their biotechnological potential in different fields [67]. Enzymes produced by halophilic microorganisms offer important opportunities in biotechnological applications such as food processing, environmental bioremediation, biosynthetic processes fermented food, textile, pharmaceutical and leather industries [68]. These enzymes are stable at high salt concentrations, but also can withstand and carry out reactions efficiently under extreme conditions such as high pH values, high or low temperature, low oxygen availability, pressure, and toxic metals [69,70]. Enzymes such as xylanases, dehydrogenase, amylases, proteases, α -amylases and lipases, have been produced by different genera of halophilic bacteria such as *Cyanobacteria*, *Proteobacteria*, *Firmicutes*, *Actinobacteria*, *Spirochaetes* *Salinivibrio*, *Halomonas*, *Bacillus-Salibacillus*, *Bacteroidetes*, *Pseudoalteromonas ruthenica*, *Bacillus*, *Halobacillus* and *Thalassobacillus*. These enzymes have been commercialized especially in

the production of polyunsaturated fatty acids, food, biodiesel, baking, feed, chemical and pharmaceutical, paper and pulp, detergent, leather industries, fish sauce and soy sauce preparations, saline waste water, and oil field waste treatment [71-74]. Lipases, proteases and amylases isolated from halophilic bacteria constitute an excellent alternative in the industrial processes due to their stability and versatility [75]. Hydrolases is other enzymes characterized from halophilic bacteria [76]. During the last years, the halophiles have developed of novel enzymes. These enzymes have unique structural features and catalytic power to sustain the metabolic and physiological processes under high salt conditions [77, 78]. Due to stability under high salt concentrations, the demand for enzymes produced by halophiles has increased considerably [79]. Various investigations have reported on production or purification of haloenzymes from halophilic bacteria, resistance of the enzymes toward different organic solvents has been examined [80]. Enzymes produced by halophilic bacteria show interesting properties for use in different biotechnological and industrial applications.

Exopolysaccharides (EPS). Polysaccharides are the most abundant organic material in the world. They are ubiquitous, as they can be recovered from plants, animals, algae and microorganisms in soil, water and atmosphere. The chemical structure of a polysaccharide comprises monomers called monosaccharides (**Table I**), linked to each other through glycosidic linkages. They can be constituted of one type of monosaccharide, in homopolysaccharides, or by several types, usually up to ten, in heteropolysaccharides. They can display either a regular repeating unit, or random, or block distribution of monosaccharides. Various types of inorganic and organic substituents (sulphates, phosphates, acetates, ethers, amino acids, lactates and pyruvates) can decorate the polysaccharide

backbone that in turn can be linear or branched. Arms can show different lengths and include the same monosaccharide types or different ones. Additionally, branches can be distributed in a regular or random way on the backbone. Finally, polysaccharides sizes range between 50 Da up to several thousand KDa.

Table I
Typical monosaccharide components of marine EPS

Monosaccharides	Example
Pentoses	arabinose (Ara), ribose (Rib), xylose (Xyl)
Hexoses	glucose (Glc), galactose (Gal), mannose (Man)
Deoxy-hexoses	quinovose (Qui), fucose (Fuc), rhamnose (Rha)
Uronic acids	glucuronic acid (GlcA), galacturonic acid (GalA), mannuronic acid (ManA)
Amino sugars	glucosamine (GlcN), galactosamine (GalN), mannosamine (ManN)
Uncommon sugars	3-deoxy-D-manno-2-octulosonic acid (Kdo), neuraminic acid (Neu)

Polysaccharides are used in several industrial fields, as thickeners, stabilisers and gelling agents in food products and as antitumoral, antioxidant and/or prebiotic in pharmacology [81]. They derived from a variety of sources: bacteria, fungi, algae and plants. Despite all these sources, the world market is dominated by polysaccharides from algae [82], like carrageenans, agar and alginates [83,84] and from lactic acid bacteria, due to the high number of EPSs recovered after the extraction. In the last years, EPSs produced by marine bacteria have been attracted the interest of

several researchers for their unique properties of considerable biotechnological importance and, therefore, of commercial significance (Table II). Currently, despite the vast number and biodiversity of the marine EPSs, these polymers represent only a small fraction of the current polymers market, due to the very low amount of purified polysaccharide obtained. Therefore, to achieve a larger amount to be commercialized is necessary to proceed with an enhancement of the production. Particularly, microbial polysaccharides production is greatly influenced by fermentation conditions. Indeed, the structure, the composition and the viscosity of EPSs depend on several factors, such as the composition of the culture medium, the sources of carbon and nitrogen and the precursor molecules, the mineral salts, trace elements, the type of the strain and the fermentation conditions such as pH, temperature, oxygen concentration and agitation [85]. In addition, engineering modifications of genes involved in the polysaccharide biosynthesis could also be convenient. During the last years, diverse marine microbial exopolysaccharides turned out to be promising candidates in biotechnology field. They span from the exopolysaccharides

displaying biological activity, exploitable in the pharmaceutical and medical industry [86- 90], with particular regard to the sulphated polysaccharides [91-93], to the emulsifier EPSs, that find application in the food, pharmaceutical, cosmetic and petroleum industries [94-100]. Furthermore, it is important to consider the applications of the cryoprotectant and anti-freezing EPSs in many industrial fields [101-107].

Several EPS producing halophiles have been reported from coastal areas such as *Vibrio parahaemolyticus*, *Bacillus Licheniformis*, *Salinicoccus sp.* and *Chromohalobacter sp* [108, 109]. Similarly, poly- β -hydroxyalkanoate (PHA), a polymer containing β -hydroxybutyrate and β -hydroxyvalerate units, is accumulated by many prokaryotes. It is used for the production of biodegradable plastics. Some halophilic bacteria also produce PHA e.g. *Halomonas compisalis* [110].

Table II
Examples of marine bacterial exopolysaccharides

Microorganism	Source	Functions and applications	Reference
<i>Alteromonas</i>			
<i>A. macleodii</i> sub. <i>Fijiensis</i> biovar <i>deepsane</i> HYD 657	Deep-sea hydrothermal vent polychaete annelid	Cosmetic, keratinocytes protection	[111, 112]
<i>A. strain</i> HYD-1545	Hydrothermal vent polychaete annelid	-	[113]
<i>A. macleodii</i> sub. <i>Fijiensis</i> strain ST716	Deep-sea hydrothermal vent	Gel forming	[114, 115]
<i>A. strain</i> JL2810	Sea water	Biosorption of heavy metal	[116, 117]

<i>A. infernus</i> GY785	Hydrothermal vent	Metal recover	[118,119]
<i>A. hispanica</i> F32	Hypersaline inland	-	[120]
<i>Bacillus</i>			
<i>B. strain B3-15 halophile</i>	Marine hot spring	-	[121, 122]
<i>B. strain B3-72 thermophile</i>	Hydrothermal vent	-	[123]
<i>B. strain I-450 haloalkaliphile</i>	Mudflats	Gel forming	[124, 125]
<i>Cobetia marina</i> DSMZ 4741	Coast	-	[126]
<i>Colwellia</i>			
<i>C. psychrerythraea</i> 34H	Sea sediments, sea ice	Anti-freeze	[127, 128]
<i>C. psychrerythraea</i> 34H	Sea sediments, sea ice	No anti-freeze activity	[129]
<i>Flavobacterium uliginosum</i> MP-55	Sea weed	-	[130]
<i>Geobacillus</i>			
<i>G. strain 4004 thermophile</i>	Sea water	-	[131]
<i>G. tepidamans</i> V264 thermophile	Hot spring	Immunomodulant, anti-viral	[132]
<i>G. thermodenitrificans thermophile</i>	Shallow marine vent		[133]
<i>Hahella chejuensis strain</i> 96CJ1035	Marine sediments	Emulsifier	[134, 135]
<i>Halomonas</i>			
<i>H. eurihalina</i> F2-7	Dead Sea	Emulsifier	[136, 137]
<i>H. maura halophile</i>	Solar saltern	Viscous, pseudoplastic	[138, 139]
<i>H. sp. OKOH halophile</i>	Bottom sediments	Flocculant	[140]
<i>H. sp AAD6 (JCM 15723)</i>	Soil saltern	-	[141, 142]
<i>H. alkaliantarctica strain</i> CRSS	Salt lake	-	[143]
<i>Hyphomonas</i>			
<i>H. strain MHS-3</i>	Shallow marine sediments	Adhesion	[144- 146]
<i>H. strain VP-6</i>	Vent region	Adhesion	[147]
<i>Polaribacter sp. SM1127 psychrophile</i>	Arctic brown alga Laminaria	Cryoprotectant, anti-oxidant	[148]

<i>Pseudoalteromonas</i>			
<i>P. strain HYD721</i>	Deep-sea hydrothermal vent	-	[149]
<i>P. strain TG12</i>	Sea-water	Metal binding	[150]
<i>P. ulvae TC14</i>	Marine biofilm	Anti-biofilm	[151]
<i>P. ruthenica</i>	Sea-water	Pseudoplastic	[152]
<i>P. sp. strain MD12-642</i>	Marine sediments	Viscosity	[153]
<i>P. haloplanktis TAC125 psychrophile</i>	Antarctic sea water	-	[154]
<i>P. sp. strain SM20310 psychrophile</i>	Arctic sea-ice	Cryoprotectant	[155]
<i>P. arctica KOPRI 21653 psychrophile</i>	Sea-side sediments	Cryoprotectant	[156]
<i>P. sp. CAM025 psychrophile</i>	Particles from Antarctic sea	Adhesion	[157]
<i>P. sp. CAM036 psychrophile</i>	Particles from Southern Ocean	-	[157]
<i>P. sp. SM9913 psychrophile</i>	Deep-sea sediment	Metal binding	[158]
<i>P. sp. MER144 psychrophile</i>	Terra Nova Bay, Ross Sea Antarctic	-	[159]
<i>Pseudomonas</i>			
<i>P. sp. NCMB 2021</i>	Not reported	metal binding (A) Adhesion (B)	[160]
<i>P. sp. S9 psychrophile</i>	Polar basin	Adhesion	[161]
<i>P. sp. WAK1</i>	Brown seaweed <i>Undaria pinnatifida</i>	Anti-cancer	[162]
<i>P. stutzeri 273</i>	Marine sediments	Anti-biofilm, anti-biofouling, antioxidant	[163]
<i>P. sp. ID1</i>	Marine sediments	Cryoprotectant	[164]
<i>Rhodococcus</i>			
<i>R. sp. 33</i>	Contaminate site near a chemical plant	-	[165, 166]
<i>R. erythropolis PR4</i>	Ocean	Emulsifier	[167]

<i>Salipinger mucosus</i> <i>A3Thalophile</i>	Solar saltern	Metal binding, emulsifier, pseudoplastic	[168]
<i>Shewanella</i>			
<i>S. colwelliana</i>	Associate bivalve	-	[169]
<i>Vibrio</i>			
<i>V. diabolicus</i>	Deep-Sea hydrothermal ventA. pompejana	Filler of bone defects in rat calvaria	[170, 171]
<i>V. alginolyticus</i>	Sea water	Shearing properties	[172]
<i>V. alginolyticus</i> CNCM I 4994	Sea water	-	[173]
<i>V. harveji</i> VB23	Sea water	Emulsifier	[174]
<i>V. furnissii</i> strain VB0S3	Sea water	Emulsifier	[175]
<i>V. sp. QY101</i>	Laminaria thallus	Anti-biofilm	[176]

Biosurfactants. Biosurfactants are one such extracellular amphiphilic compounds produced by Halobacteria especially when grown on hydrophobic substrates. Biosurfactants are a structurally diverse group of surface-active substances produced by microorganisms [177]. All biosurfactants are amphiphiles and consist of a polar (hydrophilic) and a non polar (hydrophobic) group. They are used as emulsifiers, foaming and dispersing agents. In comparison to the chemically synthesized biosurfactants they are considered to be environmental friendly, biodegradable and non-hazardous. They are active at extreme temperatures, pH and salinity and can be produced from industrial wastes and by-products. Because of their potential advantages they are widely used in industrial and medicinal applications. Biosurfactants can also be produced from cheap raw materials like rapeseed oil, potato process effluents, oil refinery waste, cassava flour wastewater, curd whey and distillery waste,

sunflower oil etc. [178]. In recent years, much attention has been directed towards biosurfactants due to their broad range of functional properties and diverse synthetic capabilities of microbes. The most significant advantage of a microbial surfactant over chemical surfactant is its ecological acceptance [177]. Biosurfactants can be efficiently used in handling industrial emulsions, control of oil spills, biodegradation and detoxification of industrial effluents and in bioremediation of contaminated soil. Due to their unique properties and application, identification of new biosurfactant producing microbes are in great demand. There are reports of biosurfactant production by many halophilic bacteria such as *Bacillus circulans*, *Kocuria marina*, *Halomonas sp.*, *Planococcus maritimus* [179, 180].

Fermented food. The industrial production of fermented products, like soy sauce and fish sauce that uses the degradative properties of halophiles. The fermentation of salty foods such as Chinese fermented beans, salted cod, salted anchovies,

sauerkraut, often involves halobacteria as essential ingredients. Halophiles including *Halobacteria*, *Halococci* have been isolated from various food sources including fermented foods and sauces, including Kimchi and Thai fish sauce [181]. A culture independent method of isolation of bacteria diversity from Kimchi showed the presence of many halophilic bacteria including lactic acid bacteria [182].

Probiotics. Probiotics are live microorganisms thought to be beneficial to the host organism. These are commonly consumed as part of fermented foods with specially added active live cultures. Recently halophilic lactic acid bacteria *Tetragenococcus halophilus* was isolated from soy sauce and showed to possess an immunomodulatory activity that promotes helper type 1 immunity in humans. Thus this strain can be efficiently used as probiotics for humans [183]. Similarly, the use of halophilic *Bacillus sp.* as probiotics for shrimps has been reported from India [184] and also the use of *Tetragenococcus halophilus* from miso has been reported from Japan [185].

Pharmaceutical applications. The mechanism of drug resistance among the pathogenic microorganisms lessens the efficacy of available antibiotics and this in turn strengthens the need to search new antibiotics. Marine microbes are continuously explored for production of novel antimicrobial compounds. Bioactive compounds from halophilic bacteria have typical features because of their varied environmental conditions (pH, temperature, salinity, pressure, etc). Among marine microorganisms, halophilic bacteria are recognized as most promising prokaryote for novel bioactive metabolite production. There are several reports of production of antimicrobial metabolites, antimicrobial biosurfactants and anticancer agents such as *Staphylococcus aureus*, *Bacillus sp.* [186, 187].

Environmental applications. The large numbers of contamination sites are often saline to hypersaline and halophiles are prevalent in such environments making their significant utilization in bioremediation of contaminants. The accelerated industrial activities such as mining and metal plating resulting in pollution, due to the release of the high amount of organic and heavy metals into the environments. These toxic compounds are often found in runways and accumulate near seashores. Due to the evaporitic nature of hypersaline environments, heavy metals are frequently found in concentrated brine. As a result, many halophiles have developed tolerance to heavy metals [188, 189]. The use of halophilic bacteria for bioremediation of Cd has been reported by Solanki and Kothari [190]. The textile industry produces a large quantity of polluted wastewater containing azo dyes, phenol and other toxic anions. These effluents are highly saline with typical salt concentration of 15- 20%. Recently, a halophilic bacterium *Kocuria rosea* has been reported to decolorize triphenyl methane dyes like malachite green, crystal violet and methyl violet [191]. Similarly, fluorides are prevalent in environment and have cytotoxic effect on humans. A halophilic bacteria *Bacillus flexus* has been reported to reduce fluoride concentration up to 67.45% in contaminated soil [192]. These halophilic microbes play a bioremediative role by transforming these anions and xenobiotics into less toxic forms.

Agricultural applications. Soil salinity is a naturally occurring problem in various parts of the world, but the exhaustive use of chemical fertilizers, inadequate cultivation practices, and improper irrigation schemes management have resulted in exacerbated salt concentrations in soil. Salinity is one of the important abiotic stresses that limit the plant growth and crop productivity. In addition, salinity also affects nutrient uptake by

plants. Agriculture under saline conditions already presents major challenges in many countries. Application of halotolerant plant growth promoting rhizobacteria (PGPR) is an important strategy by which cultivation in saline soils can be improved [193]. Many reports have been published stating the beneficial effects of inoculation of halotolerant bacteria on plant growth under salt stress conditions such as *Micrococcus* sp. on cowpea, *Bradyrhizobium saurashtrense* on groundnut etc [194, 195]. Halotolerant bacterial and their role in plant growth promotion under saline condition are mentioned in table III.

Table III

Role of halophilic microbes in plant growth promotion under the saline environments

Microbes	Strain	Response	Reference
<i>Aeromonas hydrophila</i>	MAS-765	Alleviate salinity, growth	[196]
<i>Bacillus insolitus</i>	MAS17	Alleviate salinity, growth	[196]
<i>Bacillus</i> sp.	MAS617	Alleviate salinity, growth	[196]
<i>Staphylococcus kloosii</i>	EY37	Alleviate the moderately salt	[197]
<i>Kocuria erythromyxa</i>	EY43	Alleviate the moderately salt	[197]
<i>Pseudomonas aurantiaca</i>	TSAU22	Growth and salinity tolerate	[198]
<i>Pseudomonas chlororaphis</i>	TSAU13	Growth and salinity tolerate	[198]
<i>Pseudomonas extremorientalis</i>	TSAU20	Growth and salinity tolerate	[198]
<i>Pseudomonas extremorientalis</i>	TSAU6	Growth and salinity tolerate	[198]

<i>Pseudomonas fluorescens</i>	153	Salinity stress, growth	[199]
<i>Pseudomonas putida</i>	108	Salinity stress, growth	[199]
<i>Pseudomonas putida</i>	TSAU1	Growth and salinity tolerate	[198]
<i>Arthrobacter</i> sp.	AS 18	Growth and salt stress	[200]
<i>Bacillus licheniformis</i>	RS656	Ameliorates salt stress, nutrient uptakes	[201]
<i>Brevibacterium iodinum</i>	RS16	Ameliorates salt stress, nutrient uptakes	[201]
<i>Nitricola lacisaponensis</i>	SL 11	Growth salt stress	[200]
<i>Zhihengliuella alba</i>	RS111	Ameliorates salt stress, nutrient uptakes	[201]
<i>Metarhizium anisopliae</i>	LHL07	Growth and salt stress	[202]
<i>Azotobacter chroococcum</i>	C5	Alleviated the saline stress	[203]

VII. CONCLUSION AND FUTURE PERSPECTIVES

Both academic and industrial research mainly focuses on marine microorganisms due to its impulsive potential. The importance of halophilic bacteria as potential applications has been recognized in various field varying from antioxidants, sunscreens, compatible solutes and hydrolytic enzymes. These biomolecules are valuable and show commercial potential for food, pharmaceutical, biomedical, industrial and environment. The availability of these halophilic biomolecules and their advantages in production can be optimized to produce sustainable yields at industrial scale. The recent availability of various complete genome sequences of halophiles together with advances in omics technologies

would further provide new opportunities for exploration, discovery and identification of unique properties and/or novel biomolecules derived from halophiles in the future.

References

- [1] Zahran, H.H. 1997 Diversity, adaptation and activity of the bacterial flora in saline environments. *Biology and Fertility of Soils*, 25, 211-223.
- [2] Spring, S., Sorokin, D.Y., Verburg, S., Rohde, M., Woyke, T., Kyrpides, N.C. 2019. Sulfate-Reducing Bacteria That Produce Exopolymers Thrive in the Calcifying Zone of a Hypersaline Cyanobacterial Mat. *Frontiers in Microbiology*, 10 (862), 1-19.
- [3] Ventosa, A., Joaquin, J.N. et Oren, A. 1998. Biology of moderately halophilic aerobic bacteria. *Microbiology and Molecular Biology Reviews*, 62, 504- 544.
- [4] Ventosa, A. 2006. Unusual microorganisms from unusual habitats: hypersaline environments. In *Prokaryotic Diversity-Mechanism and Significance*; Logan, N.A., Lppin-Scott, H.M., Oyston, P.C.F., Eds.; Cambridge University Press: Cambridge, UK, 2006; pp. 223-254.
- [5] Kushner, D.J. et Kamekura, M. 2006. Physiology of halophilic eubacteria. In *Halophilic Bacteria*, Rodriguez-Varela, F., Ed., CRC Press: Boca Raton, FL, USA, 1988; pp. 109- 138.
- [6] Madigan, M.T. et Oren, A. 1999. Thermophilic and halophilic extremophiles. *Current Opinion in Microbiology*, 2, 265-269.
- [7] Oren, A. 2002. Diversity of halophilic microorganisms: Environments, phylogeny, physiology, and applications. *Journal of Industrial Microbiology and Biotechnology*, 28, 58-63.
- [8] Nieto, J.J. et Vargas, C. 2002. Synthesis of osmoprotectants by moderately halophilic bacteria: Genetic and applied aspects. *Recent Research Developments in Microbiology*, 6, 403-418.
- [9] Hosseiniyan Khatibi, S.M., Zununi, V.F., Sharifi, S, Ardalan, M., Mohajel, S.M., Zununi, V.S. 2019. Osmolytes resist against harsh osmolarity: Something old something new. *Biochimie*, 158, 156-164.
- [10] Oren, A. 2010. Industrial and environmental applications of halophilic microorganisms. *Environmental Technology*, 31, 825-834.
- [11] Oren, A. 2013. Life at high salt concentrations, in *The Prokaryotes. A Handbook on the Biology of Bacteria: Ecophysiology and Biochemistry* (Ed. E. Rosenberg, E. F. DeLong, F. Thompson, S. Lory and E. Stackebrandt) Springer, New York, 2013, pp.429-440.
- [12] Vreeland, R.H. et Huval, J.H. 1991. Taxonomy of halophilic bacteria from underground saline waters and salt formations”, in *General and Applied Aspects of Halophilic Bacteria* (Ed. F. Rodriguez-Valera), Plenum Press, New York, 1991, pp.53-60.
- [13] Stan-Lotter, H., Pfaffenhueimer, M., Legat, A., Busse, H.J., Radax, C., Gruber C. 2002. *Halococcus dombrowskii* sp. nov., an archaeal isolate from a Permian alpine salt deposit. *International Journal of Systematic and Evolutionary Microbiology*, 52, 1807-1814.
- [14] Yoon, J.H., Kang, K.H., Park, Y.H. 2003. *Halobacillus salinus* sp. nov., isolated from a salt lake on the coast of the East Sea in Korea. *International Journal of Systematic and Evolutionary Microbiology*, 53, 687-693.
- [15] Boujida, N., Palau, M., Charfi, S., Manresa, À., Skali- Senhaji N., Abrini, J., Miñana-Galbís, D. 2019. *Marinobacter maroccanus* sp. nov., a moderately halophilic bacterium isolated from a saline soil. *International Journal of Systematic and Evolutionary Microbiology*, 69(1), 227-234.
- [16] Al-Abri, K. 2011. Use of molecular approaches to study the occurrence of extremophiles and extremodures in non-extreme environments. PhD Thesis, 2011, University of Sheffield, UK.
- [17] Rodriguez-Valera, F. 1988. Characteristics and microbial ecology of hypersaline environments, in “*Halophilic Bacteria*”, Vol. I (Ed. F. Rodriguez-Valera), CRC Press, Boca Raton, 1988, pp.3-30.
- [18] Ali, A., Akbar, M., Aslam, S., Ullah, M., Anwar, H., Punnapayak, P., Lotrakul, S., Prasongsuk, B., Yanwisetpakdee, P., Permpornsakul P., Rakshit S.K. 2016. Comparative study of physical factors and microbial diversity of four man-made extreme ecosystems. *Proceedings of the National Academy of Sciences India*, 86, 767-778.
- [19] Ventosa, A., Gutierrez, M.C., Garcia, M.T., Ruiz-Berraquero, F. 1989. Classification of *Chromohalobacter marismortui* in a new genus, *Chromohalobacter* gen. nov., as *Chromohalobacter marismortui* comb. nov., nom. rev. *International Journal of Systematic and Evolutionary Microbiology*, 39, 382-386.
- [20] Zinder, S.H. 1993. Physiological ecology of methanogens, in *Methanogenesis: Ecology, Physiology, Biochemistry and Genetics* (Ed. J. G. Ferry), Chapman and Hall, London, 1993, pp.128-206.
- [21] A. Oren, “Halophilic Microorganisms and Their Environments”, Kluwer Academic Publishers, Dordrecht, 2002.
- [22] Weisburg, W.G., Barns, S.M., Pelletier D.A., Lane, D.G. 1991. 16S ribosomal DNA amplification for phylogenetic study. *Journal of Bacteriology*, 173, 697-703.
- [23] Maidak, B.L., Larsen, N., McCanghey, M.J., Overbeek R., Olsen, G.K., Fogel, K., Blandy, J., Woese, C.R. 1994. The ribosomal database project. *Nucleic Acid Research*, 22, 3485- 3488.
- [24] Donio, M.B.S., Ronica, F.A., Vigi, V.T., Velmurugan, S., Jenifer, J.S.C.A., Michaelbadu M., Dhar, P., Citarasu T. 2013. *Halomonas* sp. *BS4*, a biosurfactant producing halophilic bacterium isolated from solar salt works in India and their biomedical importance. *SpringerPlus*, 2, 149-158.
- [25] Surve, V.V., Patil, M.U., Dharmadekari, S.M., 2012. Moderately halophilic bacteria from solar salt pans of Ribander, Goa : a comparative study. *International Journal of Advanced Biotechnology Research*, 635-643.
- [26] Stackebrandt, E., Witt, D., Kemmerliug, C., Kroppested R., Liesack W. 1991. Designation of *Streptomyces* 16S and 23S rRNA- based target regions for oligonucleotide probes. *Applied and Environmental Microbiology*, 57, 1468- 1477.
- [27] Mehling, A., Wehmeier, U.F., Piepersberg, W. 1995. Nucleotide sequences of *Streptomyces* 16S ribosomal DNA: towards a specific identification system for *Streptomyces* using PCR. *Microbiology*, 141, 2139- 2147.

- [28] Meena, B., Rajan, L.A., Vinithumar, N.V., Kirubakaran, R. 2013. Novel marine actinobacteria from emerald Andaman & Nicobar Islands: a prospective source for industrial and pharmaceutical byproducts. BMC Microbiology, 13, 145-161.
- [29] Jose P.A. et Jebakumar, S.R.D. 2012. Phylogenetic diversity of actinomycetes cultured from coastal multipond solar saltern in Tuticorin, India. Aquatics Biosystems, 8, 23-31.
- [30] Jiang, S., Li, X., Zhang, L., Sun, W., Dai, S., Xiel, L., Liu, Y et Lee, K.J. 2008. Culturable actinobacteria isolated from marine sponge *Lotrocota* sp. Marine Biology, 153, 945- 952.
- [31] Jose, P.A., Santhi, Jebakumar, S.R.D. 2011. Phylogenetic affiliation, antimicrobial potential and PKS gene sequence analysis of moderately halophilic *Streptomyces* sp. inhabiting an indian saltpan. Journal of Basic Microbiology, 5, 348- 356.
- [32] Quesada, E., Ventosa, A., Rodriguez-Valera, F., Ramos-Cormenzana, A. 1982. Types and properties of some bacteria isolated from hypersaline soils. Journal of Applied Microbiology, 53, 155-161.
- [33] Rodriguez-Valera, F. 1993. Introduction to saline environments, in The Biology of Halophilic Bacteria (Ed. R. H. Vreeland and L. I. Hochstein), CRC Press, Boca Raton, 1993, pp.1-12.
- [34] De-Dekker, P. 1983. Australian salt lakes: Their history, chemistry, and biota-a review, Hydrobiologia, 105, 231-244.
- [35] Javor, B. 1989. Hypersaline environments: Microbiology and Biogeochemistry, Springer-Verlag, Berlin, 1989.
- [36] Nissenbaum, A. 1975. The microbiology and biogeochemistry of the Dead Sea. Microbial Ecology, 2, 139-161.
- [37] Larsen, H. 1980. Chapter 3: Ecology of hypersaline environments, *Development in Sedimentology*, 28, 23-39.
- [38] Oren, A. 1983. *Clostridium lortetii* sp. nov., a halophilic obligatory anaerobic bacterium producing endospores with attached gas vacuoles. Archives Microbiology, 136, 42-48.
- [39] Oren, A., Pohla, H., Stackebrandt, E. 1987. Transfer of *Clostridium lortetii* comb. nov. and description of *Sporohalobacter marismortui* sp. nov. Systematic and Applied Microbiology, 9, 239-246.
- [40] Huval, J.H., Latta, R., Wallace, R., Kushner, D.J., Vreeland, R.H. 1995. Description of two new species of *Halomonas*: *Halomonas israelensis* sp. nov. and *Halomonas canadensis* sp. nov. Canadian Journal of Microbiology, 41, 1124-1131.
- [41] Oren, A., Gurevich, P., Gemmell, R.T., Teske, A. 1995. *Halobaculum gomorrense* gen. nov., sp. nov., a novel extremely halophilic archaeon from the Dead Sea. International Journal of Systematic Bacteriology, 45, 747-754.
- [42] Nazareth, S., Gonsalves, V., Nayak, S. 2012. A first record of obligate halophilic Aspergilli from the Dead Sea. Indian Journal of Microbiology, 52, 22-27.
- [43] Waino, M., Tindall, B.J., Ingvorsen, K. 2000. *Halorhabdus utahensis* gen. nov., sp. nov., an aerobic, extremely halophilic member of the archaea from Great Salt Lake, Utah. International Journal of Systematic and Evolutionary Microbiology, 50, 183-190.
- [44] DasSarma, S., Kennedy, S.P., Berquist, B., Ng, W.V., Baliga, N.S., Spudich, J.L., Krebs, M.P., Eisen, J.A., Johnson, C.H., Hood, L. 2001. Genomic perspective on the photobiology of *Halobacterium* species NRC-1, a phototrophic, phototactic, and UV-tolerant haloarchaeon. Photosynthesis. Research, 70, 3-17.
- [45] Fendrich, C. 1988. *Halovibrio variabilis* gen. nov. sp. nov., *Pseudomonas halophila* sp. nov. and a new halophilic aerobic coccoid eubacterium from Great Salt Lake, Utah, USA. Systematic Applied Microbiology, 11, 36-43.
- [46] Spring, S., Ludwig, W., Marquez, M.C., Ventosa, A., Schleifer, K.H. 1996. *Halobacillus* gen. nov., with descriptions of *Halobacillus litoralis* sp. nov. and *Halobacillus trueperi* sp. nov., and transfer of *Sporosarcina halophila* to *Halobacillus halophilus* comb. nov. International Journal of Systematic and Evolutionary Microbiology, 46, 492-496.
- [47] Zeikus, J.G., Hegge, P.W., Thomson, T.E., Phelps, T.J., Langworthy, T.A. 1983. Isolation and description of *Haloanaerobium praevalens* gen. nov. and sp. nov., an obligately anaerobic halophile common to Great Salt Lake sediments. Current Microbiology, 9, 225-233.
- [48] Brandt, K.K., Patel, B.K.C., Ingvorsen, K., 1999. *Desulfocella halopila* gen. nov., sp. nov., a halophilic, fatty-acid-oxidizing, sulfate-reducing bacterium isolated from sediments of the Great Salt Lake. International Systematic Bacteriology, 49, 193-200.
- [49] Cohen, Y., Krumbein, W.E., Goldberg, M., Shilo, M. 1977. Solar Lake (Sinai). 1. Physical and chemical limnology. Limnology and Oceanographie, 22, 597-608.
- [50] Weisser, J. et Trüper, H.G. 1985. Osmoregulation in a new haloalkaliphilic *Bacillus* from the Wadi Natrun (Egypt). Systematic and Applied Microbiology, 6, 7-11.
- [51] Ramos-Cormenzana, A. 1989. Ecological distribution and biotechnological potential of halophilic microorganisms, in Microbiology of Extreme Environments and its Potential for Biotechnology (Ed. M. S. DeCosta, J. C. Duarte and R. A. D. Williams), Elsevier, London, 1989, pp.289-309.
- [52] del Moral, A., Quesada, E., Ramos-Cormenzana, A. 1987. Distribution and types of bacteria isolated from an inland saltern. Annales de l'Institut Pasteur. Institut Pasteur Microbiologie, 138, 59-66.
- [53] Berrada, I., Willems, A., De Vos, P., El fahime, E., Swings, J., Bendaou, N., Melloul, M., Amar, M. 2012. Diversity of culturable moderately halophilic and halotolerant bacteria in a marsh and two salterns a protected ecosystem of Lower Loukkos (Morocco). African Journal of Microbiology Research, 6(10), 2419-2434.
- [54] Boum'handi, N., El Alaoui, M., El Filali, F., Hanoune, S., Miri, M., El Berkaoui, A. 2020. Screening et isolement de bactéries halophiles productrices d'exo-enzymes hydrolytiques d'intérêt industriel à partir des marées salants du centre ouest du Maroc. Afrique Science, AS-2193.
- [55] Boum'handi, N., El Filali, F., Boualouch, B., Hanoune, S., Miri, M., El Berkaoui, A. 2018. Biodiversity of moderate halophilic bacteria producing extracellular hydrolytic enzymes. Afrique Science, 14(2), 353 – 370.

- [56] Ali, I., Kanhayuwa, L., Rachdawong, S., Rakshit, S.K., 2013. Identification, phylogenetic analysis and characterization of obligate halophilic fungi isolated from a man-made solar saltern in Phetchaburi province, Thailand. *Annals Microbiology*, 63, 887-895.
- [57] Villar, M., de Ruiz, A.P., Holgado, Sanchez, J.J., Trucco, R.E., Oliver, G. 1985. Isolation and characterization of *Pediococcus halophilus* from salted anchovies (*Engraulis anchoita*). *Applied Environmental Microbiology*, 49, 664-666.
- [58] Thongthai, C., Suntinanalert, P. 1991. Halophiles in Thai fish sauce (Nam Pla), in *General and Applied Aspects of Halophilic Microorganisms* (Ed. F. Rodriguez-Valera), Plenum Press, New York, pp.381-388.
- [59] Vilhelmsson, O., Hafsteinsson, H., Kristjánsson, J.K. 1996. Isolation and characterization of moderately halophilic bacteria from fully cured salted cod (bachalao). *Journal of Applied Microbiology*, 81, 95-103.
- [60] Setati, M.E. 2012. Diversity and industrial potential of hydrolase producing halophilic/ Halotolerant eubacteria. *Afrique Journal of Biotechnology*, 1555- 1560.
- [61] Gontia- Mishra, I., Sharma, A. 2012. Exogenously supplied osmoprotectants confer enhanced salinity tolerance in rhizobacteria. *Journal of Ecobiotechnology*, 4, 11-13.
- [62] Kempf, B., Bremer, E. 1998. Uptake and synthesis of compatible solutes as microbial stress responses to high osmolality environments. *Archives in Microbiology*, 170, 319-333.
- [63] Paul, D., Lade, H. 2014. Plant-growth- promoting rhizobacteria to improve crop growth in saline soils : a review. *Agronomy Sustainable Development*, 34, 737-752.
- [64] Sandhya, V., Ali, S.K.Z., Grover, M., Reddy, G., Venkateswarlu, B. 2009. Alleviation of drought stress effects in sunflower seedlings by the exopolysaccharides producing *Pseudomonas putida* strain GAPP45. *Biology and Fertility of Soils*, 46, 17-26.
- [65] Quarshi, A.W., Sabri, A.N. 2012. Bacterial exopolysaccharide and biofilm formation stimulate chickpea growth and soil aggregation under salt stress. *Brazilian Journal of Microbiology*, 43, 1183-1191.
- [66] Dassarma, P., Coker, J.A., Huse V. and Dassarma, S. 2014. Halophiles, industrial applications. *Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation and Cell Technology*, edited by Michael C.Flickinger, J.W. and Sons. Inc. 2010.
- [67] Selvam, K. and riya, B. 2013. Bioremediation otic compound and heavy metals by the novel marine actinobacteria. *International Journal of Pharmacology and Chemistry Sciences*, 2, 1589-1597.
- [68] Solanki, P. and Kothari, V. 2012. Metal tolerance in halotolerant bacteria isolated from saline soil of Khambhat. *Research in Biotechnology*, 3, 01-11.
- [69] Shihora, N.A. 2013. Isolation and characterization of halotolerant bacteria and identification by FAME analysis. *Indian Journal of Applied Research*, 3, 51-53.
- [70] Pal, K.C., Mondal, N.K., Chatterjee, S., Ghosh, T.S. and Datta, J.K. 2014. Characterization of fluoride- tolerant halophilic *Bacillus flexus* NM25 (HQ875778) isolated from fluoride- affected soil in Birbhum District, West Bengal, India. *Environmental Monitoring and Assessment*, 186, 699- 709.
- [71] Jha, B., Gontia, I. and Hartmann, A. 2012. The roots of the halophyte *Salicornia brachiata* are a source of new halotolerant diazotrophic bacteria with plant growth promoting potential. *Plant Soil*, 356? 265-277.
- [72] Dastager, S.G., Deepa, C.K. and Panday, A. Isolation and characterization of novel plant growth promoting *Micrococcus* sp NII-0909 and its interaction with cowpea. *Plant Physiology and Biochemistry*, 48, 987-992.
- [73] Shukla, P.S., Agarwal, P.K. and JHA, B. 2012. Improved salinity tolerance of *Arachis hypogaea* (L.) by the interaction of halotolerant plant-growth- promoting rhizobacteria. *Journal of Plant Growth Regulation*, 31, 195- 206.
- [74] Vidyasagar, M., Prakash, S.B. and Sreeramulu, K. 2006. Optimization of culture conditions for the production of haloalkaliphilic thermostable protease from an extremely halophilic archaeon *Halogeometricum* sp. TSS101. *Letters and Applied Microbiology*, 43, 385- 391.
- [75] Vidyasagar, M., Prakash, S., Lithfield, C. and Sreeramulu, K. Purification and characterization of a thermostable, haloalkaliphilic extracellular serine protease from the extreme halophilic archaeon *Halogeometricum borinquense* strain TSS101. *Archaea*, 2, 51- 57.
- [76] Shivanand, P. and Jayaramam, G. 2009. Production of extracellular protease from halotolerant bacterium *Bacillus aquimaris* strain VITP4 isolated from Kumta coast. *Process Biochemistry*, 44, 1088- 1094.
- [77] Rameshbathy, M., Jayaramam, G., Devi, R.V., Vickman, A.S. and Sridharan, T.B. 2012. Emergence of a multidrug resistant *Halomonas hydrothermalis* strain VITP09, producing a class-a β - lactamase, isolated from Kumta coast. *International Journal of Pharmaceutical Sciences*, 4, 639- 644.
- [78] Sinha, R. and Khare, S.K. 2012. Isolation of halophilic *Virgibacillus* sp. EMB13, characterization of its protease for detergent application. *Indian Journal of Biotechnology*, 11, 416- 426.
- [79] Baindara, P., Mandal, S.M., Chawla, N., Singh, P.K., Pinnaka, A.K. and Korpole, S. 2013. Characterization of two antimicrobial peptides produced by a halotolerant *Bacillus subtilis* strain SKDU4 isolated from a rhizosphere soil sample. *AMB Express*, 3, 1-11.
- [80] Solomon, F.E. and Viswalingam, K. 2013. Isolation, characterization of halotolerant bacteria and its biotechnological potentials. *International Journal of Scientific & Engineering Research*.
- [81] Liu, C., Lu, J., Lu, L., Liu, Y., Wang, F. and Xiao, M. 2010. Isolation, structural characterization and immunological activity of an exopolysaccharide produced by *Bacillus licheniformis* 8-37-0-1. *Bioresource Technology*, 101, 5528–5533.
- [82] Leung, M.Y.K., Liu, C., Koon, J.C.M. and Fung, K.P. 2006. Polysaccharide biological response modifiers. *Immunology Letters*, 105, 101–114.
- [83] De Ruiter, G.A. and Rudolph, B. 1997. Carrageenan biotechnology. *Trends Food Science and Technology*, 8, 389–395.

- [84] Li, D., Chen, L., Yi, X., Zhang, X. and Ye, N. 2010. Pyrolytic characteristics and kinetics of two brown algae and sodium alginate. *Bioresource Technology*, 101, 7131–7136.
- [85] Nicolaus, B. and Kambourova, M. and Oner, E.T. 2010. Exopolysaccharides from extremophiles: From fundamentals to biotechnology. *Environmental Technology*, 31, 1145–1158.
- [86] Kambourova, M., Mandeva, R., Dimova, D., Poli, A., Nicolaus, B. and Tommonaro, G. Production and characterization of a microbial glucan, synthesized by *Geobacillus tepidamans* V264 isolated from Bulgarian hot spring. *Carbohydrate Polymers*, 77, 338–343.
- [87] Sun, M.L., Zhao, F., Shi, M., Zhang, X.Y., Zhou, B.C., Zhang, Y.Z. and Chen, X.L. 2015. Characterization and biotechnological potential analysis of a new exopolysaccharide from the Arctic marine bacterium *Polaribacter* sp. SM1127. *Scientific Reports*, 5, 18435.
- [88] Brian-Jaisson, F., Molmeret, M., Fahs, A., Dombrowsky, L.G., Culioli, G., Blache, Y., Cérantola, S. and Ortalo-Magné, A. 2016. Characterization and anti-biofilm activity of extracellular polymeric substances produced by the marine biofilm-forming bacterium *Pseudoalteromonas ulvae* strain TC14. *Biofouling*, 32, 547–560.
- [89] Wu, S., Liu, G., Jin, W., Xiu, P., and Sun, C. 2016. Antibiofilm and anti-infection of a marine bacterial exopolysaccharide against *Pseudomonas aeruginosa*. *Frontiers in Microbiology*, 7, 102.
- [90] Rougeaux, H., Kervarec, N., Pichon, R., and Guezennec, J. 1999. Structure of the exopolysaccharide of *Vibrio diabolus* isolated from a deep-sea hydrothermal vent. *Carbohydrate Research*, 322, 40–45.
- [91] Cambon-Bonavita, M.A., Rague'ne's, G., Jean, J., Vincent, P. and Guezennec, J. 2002. A novel polymer produced by a bacterium isolated from a deep-sea hydrothermal vent polychaete annelid. *Journal of Applied Microbiology*, 93, 310–315.
- [92] Le Costaouëc, T., Cérantola, S., Ropartz, D., Ratiskol, J., Sinquin, C., Collic-Jouault, S. and Boisset, C. 2012. data on a bacterial exopolysaccharide produced by a deep-sea *Alteromonas macleodii* strain. *Carbohydrate Polymers*, 90, 49–59.
- [93] Matsuda, M., Yamori, T., Naitoh, M. and Okutani, K. 2003. Structural revision of sulfated polysaccharide b-1 isolated from a marine *Pseudomonas* species and its cytotoxic activity against human cancer cell lines. *Marine Biotechnology*, 5, 13.
- [94] Mata, J.A., Be'jar, V., Bressollier, P., Tallon, R., Urdaci, M.C., Quesada, E. and Llamas, I. 2008. Characterization of exopolysaccharides produced by three moderately halophilic bacteria belonging to the family *Alteromonadaceae*. *Journal of Applied Microbiology*, 105, 521–528.
- [95] Lee, H.K., Chun, J., Moon, E.Y., Ko, S.H., Lee, D.S., Lee, H.S. and Bae, K.S. 2001. *Hahella chejuensis* gen. nov., sp. nov., an extracellular-polysaccharide-producing marine bacterium. *International Journal of Systematic and Evolutionary*, 51, 661–666.
- [96] Yim, J.H., Kim, S.J., Aan, S.H. and Lee, H.K. 2004. Physicochemical and rheological properties of a novel emulsifier, EPS-R, produced by the marine bacterium *Hahella chejuensis*. *Biotechnology and Bioprocess*, 9, 405.
- [97] Bejar, V., Calvo, C., Moliz, J., Diaz-Martinez, F. and Quesada, E. 1996. Effect of growth conditions on the rheological properties and chemical composition of *Volcaniella eurihalina* exopolysaccharide. *Applied Biochemistry and Biotechnology*, 59, 77.
- [98] Urai, M., Anzai, H., Ogiwara, J., Iwabuchi, N., Harayama, S., Sunairi, M. and Nakajima, M. 2007. Structural analysis of an acidic, fatty acid ester-bonded extracellular polysaccharide produced by a pristane-assimilating marine bacterium, *Rhodococcus erythropolis* PR4. *Carbohydrate Research*, 342, 933–942.
- [99] Bramhachari, P.V. and Dubey, S.K. 2006. Isolation and characterization of exopolysaccharide produced by *Vibrio harveyi* strain VB23. *Letters in Applied Microbiology*, 43, 571.
- [100] Bramhachari, P.V., Kavi Kishor, P.B., Ramadevi, R., Kumar, R., Rao, B.R. and Dubey, S.K. 2007. Isolation and characterization of mucous exopolysaccharide (EPS) produced by *Vibrio furnissii* strain VB0S3. *Microbial Biotechnology*, 17, 44.
- [101] Carillo, S., Casillo, A., Pieretti, G., Parrilli, E., Sannino, F., Bayer-Giraldo, M., Cosconati, S., Novellino, E., Ewert, M. and Deming, J.W. 2015. A unique capsular polysaccharide structure from the psychrophilic marine bacterium *Cohwellia psychrerythraea* 34H that mimics antifreeze (Glyco)proteins. *Journal of American Chemical Society*, 137, 179–189.
- [102] Kim, S.J., Kim, B.G., Parka, H.U. and Yim, J.H. 2016. Cryoprotective properties and preliminary characterization of exopolysaccharide (P-Arcpo 15) produced by the Arctic bacterium *Pseudoalteromonas ehvakovii* Arcpo 15. *Preparative Biochemistry and Biotechnology*, 46, 261–266.
- [103] Casillo, A., Parrilli, E., Sannino, F., Mitchell, D.E., Gibson, M.I., Marino, G., Lanzetta, R., Parrilli, M., Cosconati, S. and Novellino, E. 2017. Structure-activity relationship of the exopolysaccharide from a psychrophilic bacterium: A strategy for cryoprotection. *Carbohydrate Polymers*, 156, 364–371.
- [104] Sun, M.L., Zhao, F., Shi, M., Zhang, X.Y., Zhou, B.C., Zhang, Y.Z. and Chen, X.L. Characterization and biotechnological potential analysis of a new exopolysaccharide from the Arctic marine bacterium *Polaribacter* sp. SM1127. *Scientific Reports*, 5, 18435.
- [105] Liu, S.B., Chen, X.L., He, H.L., Zhang, X.Y., Xie, B.B., Yu, Y., Chen, B., Zhou, B.C. and Zhang, Y.Z. 2013. Structure and ecological roles of a novel exopolysaccharide from the Arctic Sea ice bacterium *Pseudoalteromonas* sp. strain SM20310. *Applied Environmental Microbiology*, 79, 224–230.
- [106] Kim, S.J. and Yim, H.J. 2007. Cryoprotective properties of exopolysaccharide (P-21653) produced by the Antarctic bacterium, *Pseudoalteromonas arctica* KOPRI 21653. *Journal of Microbiology*, 45, 510–514.
- [107] Carrión, O., Delgado, L. and Mercade, E. 2015. New emulsifying and cryoprotective exopolysaccharide from Antarctic *Pseudomonas* sp. ID1. *Carbohydrate Polymers*, 117, 1028–1034.
- [108] Kavita, K., Mishra, A. and Jha, B. 2011. Isolation and physico-chemical characterization of extracellular polymeric substances produced by the marine bacterium *Vibrio parahaemolyticus*. *Biofouling*, 27, 309–317.
- [109] Biswas, J. and Paul, A.K. 2014. Production of extracellular polymeric substances by halophilic bacteria of solar salterns. *Chinese Journal of Biology*, 2014, 1–12.

- [110] Joshi, A.A., Kanekar, P.P., Kelkar, A.S., Samaik, S.S., Souche, Y. and Wani, A. 2007. Moderately halophilic, alkalitolerant *Halomonas campisalis*, MCM B-365 from Lonar Lake India. *Journal of Basic Microbiology*, 47, 213-221.
- [111] Cambon-Bonavita, M.A., Raguene, G., Jean, J., Vincent, P. and Guezennec, J. 2002. A novel polymer produced by a bacterium isolated from a deep-sea hydrothermal vent polychaete annelid. *Journal of Applied Microbiology*, 93, 310-315.
- [112] Le Costaouëc, T., Cérantola, S., Ropartz, D., Ratiskol, J., Sinquin, C., Collic-Jouault, S. and Boisset, C. 2012. Structural data on a bacterial exopolysaccharide produced by a deep-sea *Alteromonas macleodii* strain. *Carbohydrate Polymers*, 90, 49-59.
- [113] Vincent, P., Pignet, P., Talmont, F., Bozzi, L., Fournet, B., Guezennec, J., Jeanthon, C. and Prieur, D. 1994. Production and characterization of an exopolysaccharide excreted by a deep-sea hydrothermal vent bacterium isolated from the polychaete annelid *Alvinella pompejana*. *Applied and Environmental Microbiology*, 60, 4134-4141.
- [114] Raguene, G., Pignet, P., Gauthier, G., Peres, A., Christen, R., Rougeaux, H., Barbier, G. and Guezennec, J. 1996. Description of a new polymer-secreting bacterium from a deep-sea hydrothermal vent, *Alteromonas macleodii* subsp. *fijiensis* and preliminary characterization of the polymer. *Applied and Environmental Microbiology*, 62, 67-73.
- [115] Rougeaux, H., Talaga, P., Carlson, R.W. and Guezennec, J. 1998. Structural studies of an exopolysaccharide produced by *Alteromonas macleodii* subsp. *fijiensis* originating from a deep-sea hydrothermal vent. *Carbohydrate Research*, 312, 53-59.
- [116] Zhang, Z., Chen, Y., Wang, R., Cai, R., Fu, Y. and Jiao, N. 2015. The Fate of marine bacterial exopolysaccharide in natural marine microbial communities. *PLoS ONE*, 10, 1-19.
- [117] Zhang, Z., Cai, R., Zhang, W., Fu, Y. and Jiao, N. 2017. A Novel Exopolysaccharide with Metal Adsorption Capacity Produced by a Marine Bacterium *Alteromonas* sp. JL2810. *Marine Drugs*, 15, 175.
- [118] Raguene, G.H.C., Peres, A., Ruimy, R., Pignet, P., Christen, R., Loaec, M., Rougeaux, H., Barbier, G. and Guezennec, J.G. 1997. *Alteromonas infernus* sp. nov., a new polysaccharide-producing bacterium isolated from a deep-sea hydrothermal vent. *Journal of Applied Microbiology*, 82, 422-430.
- [119] Roger, O., Kervarec, N., Ratiskol, J., Collic-Jouault, S. and Chevolot, L. 2004. Structural studies of the main exopolysaccharide produced by the deep-sea bacterium *Alteromonas infernus*. *Carbohydrate Research*, 339, 2371-2380.
- [120] Mata, J.A., Bejar, V., Bressollier, P., Tallon, R., Urdaci, M.C., Quesada, E. and Llamas, I. 2008. Characterization of exopolysaccharides produced by three moderately halophilic bacteria belonging to the family *Alteromonadaceae*. *Journal of Applied Microbiology*, 105, 521-528.
- [121] Maugeri, T.L., Gugliandolo, C., Caccamo, D., Panico, A., Lama, L., Gambacorta, A. and Nicolaus, B. 2002. A halophilic thermotolerant *Bacillus* isolated from a marine hot spring able to produce a new exopolysaccharide. *Biotechnology Letters*, 24, 515-519.
- [122] Arena, A., Maugeri, T., Pavone, B., Iannello, D., Gugliandolo, C. and Bisignano, G. 2006. Antiviral and immunoregulatory effect of a novel exopolysaccharide from a marine thermotolerant *Bacillus licheniformis*. *International Immunopharmacology*, 6, 8-13.
- [123] Nicolaus, B., Panico, A., Manca, A.C., Lama, L., Gambacorta, A., Maugeri, T., Guagliandolo, C. and Caccamo, D. 2000. A thermophilic *Bacillus* isolated from an Eolian shallow hydrothermal vent, able to produce exopolysaccharides. *Systematic and Applied Microbiology*, 23, 426-432.
- [124] Mao, R., Tang, J. and Swanson, B.G. 2001. Water holding capacity and microstructure of gellan gums. *Carbohydrate Polymers*, 46, 365-371.
- [125] Kumar, C.G., Joo, H.S., Choi, J.W., Koo, Y.M. and Chang, C.S. 2004. Purification and characterization of an extracellular polysaccharide from haloalkaliphilic *Bacillus* sp. I-450. *Enzyme and Microbial Technology*, 34, 673-681.
- [126] Lelchat, F., Cérantola, S., Brandily, C., Collic-Jouault, S., Baudoux, A.C., Ojima, T. and Boisset, C. 2015. The marine bacteria *Cobetia marina* DSMZ 4741 synthesizes an unexpected K-antigen-like exopolysaccharide. *Carbohydrate Polymers*, 124, 347-356.
- [127] Marx, J.G., Carpenter, S.D. and Deming, J.W. 2009. Production of cryoprotectant extracellular polysaccharide substances (EPS) by the marine psychrophilic bacterium *Colwellia psychrerythraea* strain 34H under extreme conditions. *Canadian Journal of Microbiology*, 55, 63-72.
- [128] Casillo, A., Parrilli, E., Sannino, F., Mitchell, D.E., Gibson, M.I., Marino, G., Lanzetta, R., Parrilli, M., Cosconati, S. and Novellino, E. 2017. Structure-activity relationship of the exopolysaccharide from a psychrophilic bacterium: A strategy for cryoprotection. *Carbohydrate Polymers*, 156, 364-371.
- [129] Casillo, A., Stahle, J., Parrilli, E., Sannino, F., Mitchell, D.E., Pieretti, G., Gibson, M.I., Marino, G., Lanzetta, R. and Parrilli, M. 2017. Structural characterization of an all-aminosugar-containing capsular polysaccharide from *Colwellia psychrerythraea* 34H. *Antonie Van Leeuwenhoek*, 110, 1377-1387.
- [130] Umezawa, H., Okami, Y., Kurasawa, S., Ohnuki, T., Ishizuka, M., Takeuchi, T.U., Shiio, T. and Yugari, Y. 1983. Marinactin, antitumor polysaccharide produced by marine bacteria. *Journal of Antibiotics*, 471, 471-477.
- [131] Schiano Moriello, V., Lama, L., Poli, A., Gugliandolo, C., Maugeri, T.L., Gambacorta, A. and Nicolaus, B. 2003. Production of exopolysaccharides from a thermophilic microorganism isolated from a marine hot spring in flegrean areas. *Journal of Industrial Microbiology and Biotechnology*, 30, 95-101.
- [132] Kambourova, M., Mandeva, R., Dimova, D., Poli, A., Nicolaus, B. and Tommonaro, G. 2009. Production and characterization of a microbial glucan, synthesized by *Geobacillus tepidamans* V264 isolated from Bulgarian hot spring. *Carbohydrate Polymers*, 77, 338-343.
- [133] Arena, A., Gugliandolo, C., Stassi, G., Pavone, B., Iannello, D., Bisignano, G. and Maugeri, T.L. 2009. An exopolysaccharide produced by *Geobacillus thermodenitrificans* strain B3-72: Antiviral activity on immunocompetent cells. *Immunology Letters*, 123, 132-137.
- [134] Lee, H.K., Chun, J., Moon, E.Y., Ko, S.H., Lee, D.S., Lee, H.S. and Bae, K.S. 2001. *Hahella chejuensis* gen. nov., sp. nov., an extracellular-polysaccharide-producing marine bacterium. *International Journal of Systematic and Evolutionary Microbiology*, 51, 661-666.

- [135] Yim, J.H., Kim, S.J., Aan, S.H. and Lee, H.K. 2004. Physicochemical and rheological properties of a novel emulsifier, EPS-R, produced by the marine bacterium *Hahella chejuensis*. *Biotechnology Bioprocess*, 9, 405-413.
- [136] Bejar, V., Calvo, C., Moliz, J., Diaz-Martinez, F. and Quesada, E. 1996. Effect of growth conditions on the rheological properties and chemical composition of *Volcaniella eurihalina* exopolysaccharide. *Applied Biochemistry and Biotechnology*. 59(1), 77-86.
- [137] Martínez-Checa, F., Toledo, F.L., El Mabrouki, K., Quesada, E. and Calvo, C. 2007. Characteristics of bioemulsifier V2-7 synthesized in culture media added of hydrocarbons: Chemical composition, emulsifying activity and rheological properties. *Bioresource Technology*, 98, 3130-3135.
- [138] Bouchotroch, S., Quesada, E., Del Moral, A., Llamas, I. and Bejar, V. 2001. *Halomonas maura* sp. nov., a novel moderately halophilic, exopolysaccharide-producing bacterium. *International Journal of Systematic and Evolutionary Microbiology*, 51, 1625-1632.
- [139] Arias, S., Del Moral, A., Ferrer, M.R., Tallon, R., Quesada, E. and Béjar, V. 2003. Mauran, an exopolysaccharide produced by the halophilic bacterium *Halomonas maura*, with a novel composition and interesting properties for biotechnology. *Extremophiles*, 7(4), 319-326.
- [140] Mabinya, L.V., Cosa, S., Mkwetshana, N. and Okoh, A.I. 2011. *Halomonas* sp. OKOH-A marine bacterium isolated from the bottom sediment of Algoa bay—Produces a polysaccharide bioflocculant: Partial characterization and biochemical analysis of its properties. *Molecules*, 16, 4358-4370.
- [141] Poli, A., Kazak, H., Gürleyenda, H., Tommonaro, G., Pieretti, G., ToksoyÖner, E. and Nicolaus, B. High level synthesis of levan by a novel *Halomonas* species growing on defined media. *Carbohydrate Polymers*, 78, 651-657.
- [142] Küçükaşık, F., Kazak, H., Güney, D., Finore, I., Poli, A., Yenigün, O., Nicolaus, N. and Öner, E.T. 2011. Molasses as fermentation substrate for levan production by *Halomonas* sp. *Applied Microbiology and Biotechnology*, 89, 1729-1740.
- [143] Poli, A., Schiano Moriello, V., Esposito, E., Lama, L., Gambacorta, A. and Nicolaus, B. 2004. Exopolysaccharide production by a new *Halomonas* strain CRSS isolated from saline lake Cape Russell in Antarctica growing on complex and defined media. *Biotechnology Letters*, 26, 1635-1638.
- [144] Quintero, E.J. and Weiner, R.M. 1995. Evidence for the adhesive function of the exopolysaccharide of *Hyphomonas* strain MHS-3 in its attachment to surfaces. *Applied Environmental Microbiology*, 61(5), 1897-1903.
- [145] Quintero, E.J. and Weiner, R.M. 1995. Physical and chemical characterization of the polysaccharide capsule of the marine bacterium, *Hyphomonas* strain MHS-3. *Journal of Industrial Microbiology and Biotechnology*, 15, 347-351.
- [146] Quintero, E.J., Langille, S.E. and Weiner, R.M. 2001. The polar polysaccharide capsule of *Hyphomonas adhaerens* MHS-3 has a strong affinity for gold. *Journal of Industrial Microbiology and Biotechnology*, 27, 1-4.
- [147] Langille, S.E. and Weiner, R.M. 1998. Spatial and temporal deposition of *Hyphomonas* strain vp-6 capsules involved in biofilm formation. *Applied Environmental Microbiology*, 64(8), 2906-2913.
- [148] Sun, M.L., Zhao, F., Shi, M., Zhang, X.Y., Zhou, B.C., Zhang, Y.Z. and Chen, X.L. 2015. Characterization and biotechnological potential analysis of a new exopolysaccharide from the Arctic marine bacterium *Polaribacter* sp. SM1127. *Scientific Reports*, 5, 18435.
- [149] Rougeaux, H., Guezennec, J., Carlson, R.W., Kervarec, N., Pichon, R. and Talaga, P. 1999. Structural determination of the exopolysaccharide of *Pseudoalteromonas* strain HYD 721 isolated from a deep-sea hydrothermal vent. *Carbohydrate Research*, 315, 273-285.
- [150] Gutierrez, T., Shimmield, T., Haidon, C., Black, K. and Green, D.H. 2008. Emulsifying and metal ion binding activity of a glycoprotein exopolymer produced by *Pseudoalteromonas* sp. Strain TG12. *Applied Environmental Microbiology*, 74, 4867-4876.
- [151] Brian-Jaisson, F., Molmeret, M., Fahs, A., Dombrowsky, L.G., Culioli, G., Blache, Y., Cérantola, S. and Ortalo-Magné, A. Characterization and anti-biofilm activity of extracellular polymeric substances produced by the marine biofilm-forming bacterium *Pseudoalteromonas ulvae* strain TC14. *Biofouling*, 32, 547-560.
- [152] Saravanan, P. and Jayachandran, S. 2008. Preliminary characterization of exopolysaccharides produced by a marine biofilm-forming bacterium *Pseudoalteromonas rutenica* (SBT 033). *Letters Applied Microbiology*, 46, 1-6.
- [153] Roca, C., ; Lehmann, M., Torres, C.A.V., Baptista, S., Gaudêncio, S.P., Freitas, F. and Reis, M.A.M. 2016. Exopolysaccharide production by a marine *Pseudoalteromonas* sp. strain isolated from Madeira Archipelago ocean sediments. *New Biotechnology*, 33, 460-466.
- [154] Corsaro, M.M., Lanzetta, R., Parrilli, E., Parrilli, M., Tutino, M.L. and Ummarino, S. 2004. Influence of growth temperature on lipid and phosphate contents of surface polysaccharides from the Antarctic bacterium *Pseudoalteromonas haloplanktis* TAC 125. *Journal of Bacteriology*, 186, 29-34.
- [155] Liu, S.B., Chen, X.L., He, H.L., Zhang, X.Y., Xie, B.B., Yu, Y., Chen, B., Zhou, B.C. and Zhang, Y.Z. 2013. Structure and ecological roles of a novel exopolysaccharide from the Arctic Sea ice bacterium *Pseudoalteromonas* sp. strain SM20310. *Applied Environmental Microbiology*, 79, 224-230.
- [156] Kim, S.J. and Yim, H.J. 2007. Cryoprotective properties of exopolysaccharide (P-21653) produced by the Antarctic bacterium, *Pseudoalteromonas arctica* KOPRI 21653. *Journal of Microbiology*, 45, 510-514.
- [157] MancusoNichols, C.A., Garon, S., Bowman, J.P., Raguénès, G. and Guézennec, J. 2004. Production of exopolysaccharides by Antarctic marine bacterial isolates. *Journal of Applied Microbiology*, 96, 1057-1066.
- [158] Qin, G., Zhu, L., Chen, X., Wang, P.G. and Zhang, Y. 2007. Structural characterization and ecological roles of a novel exopolysaccharide from the deep-sea psychrotolerant bacterium *Pseudoalteromonas* sp. SM9913. *Microbiology*, 153, 1566-1572.
- [159] Caruso, C., Rizzo, C., Mangano, S., Poli, A., Di Donato, P., Nicolaus, B., Di Marco, G., Michaud, L. and Lo Giudice, A. 2017. Extracellular polymeric substances with metal adsorption capacity produced by

Pseudoalteromonas sp. MER144 from Antarctic seawater. Environmental Science and Pollution Research, 25 (5), 4667- 4677.

[160] Christensen, B.E., Kjosbakken, J. and Smidsrød, O.L. 1985. Partial chemical and physical characterization of two extracellular polysaccharides produced by marine, periphytic *Pseudomonas* sp. strain NCMB 2021. Applied Environmental Microbiology, 50, 837–845.

[161] Wrangstadh, M., Conway, P.L. and Kjelleberg, S. 1986. The production and release of an extracellular polysaccharide during starvation of a marine *Pseudomonas* sp. and the effect thereof on adhesion. Archives Microbiology, 145(3), 220- 227.

[162] Matsuda, M., Yamori, T., Naitoh, M. and Okutani, K. 2003. Structural revision of sulfated polysaccharide b-1 isolated from a marine *Pseudomonas* species and its cytotoxic activity against human cancer cell lines. Marine Biotechnology, 5(1), 13- 19.

[163] Wu, S., Liu, G., Jin, W., Xiu, P. and Sun, C. 2016. Antibiofilm and anti-Infection of a marine bacterial exopolysaccharide against *Pseudomonas aeruginosa*. Frontiers in Microbiology, 7(102), 1- 115.

[164] Carrión, O., Delgado, L. and Mercade, E. 2015. New emulsifying and cryoprotective exopolysaccharide from Antarctic *Pseudomonas* sp. ID1. Carbohydrate Polymers, 117, 1028–1034.

[165] Aizawa, T., Neilan, A.B., Couperwhite, I., Urai, M., Anzai, H., Iwabuchi, N., Nakajima, M. and Sunairi, M. 2005. Relationship between extracellular polysaccharide and benzene tolerance of *Rhodococcus* sp. 33. Actinomycetologica, 19, 1–6.

[166] Urai, M., Aizawa, T., Anzai, H., Ogihara, J., Iwabuchi, N., Neilan, B., Couperwhite, I., Nakajima, M. and Sunairi, M. 2006. Structural analysis of an extracellular polysaccharide produced by a benzene tolerant bacterium *Rhodococcus* sp. 33. Carbohydrate Research, 341, 616–623.

[167] Urai, M., Anzai, H., Ogihara, J., Iwabuchi, N., Harayama, S., Sunairi, M. and Nakajima, M. 2007. Structural analysis of an acidic, fatty acid ester-bonded extracellular polysaccharide produced by a pristane-assimilating marine bacterium, *Rhodococcus erythropolis* PR4. Carbohydrate Research, 342, 933–942.

[168] Llamas, I., Mata, J.A., Tallon, R., Bressollier, P., Urdaci, M.C., Quesada, E. and Béjar, V. 2010. Characterization of the exopolysaccharide produced by *Salipiger mucosus* A3T, a halophilic species belonging to the Alphaproteobacteria, isolated on the Spanish Mediterranean seaboard. Marine Drugs, 8, 2240–2251.

[169] Sledjeski, D.D. and Weiner, R.M. 1993. Production and characterization of monoclonal antibodies specific for *Shewanella colwelliana* exopolysaccharide. Applied Environmental Microbiology, 59, 1565–1572.

[170] Rougeaux, H., Kervarec, N., Pichon, R. and Guezennec, J. 1999. Structure of the exopolysaccharide of *Vibrio diabolus* isolated from a deep-sea hydrothermal vent. Carbohydrate Research, 322, 40–45.

[171] Zanchetta, P., Lagarde, N. and Guezennec, J. 2003. New bone-healing material: A hyaluronic acid-like bacterial exopolysaccharide. Calcified Tissue International, 72, 74–79.

[172] Muralidharan, Y. and Jayachandran, S. 2003. Physicochemical analyses of the exopolysaccharides produced by a marine biofouling bacterium, *Vibrio alginolyticus*. Process Biochemistry, 38, 841–847.

[173] Drouillard, S., Jeacomine, I., Buon, L., Boisset, C., Courtois, A., Thollas, B., Morvan, P.Y., Vallée, R. and Helbert, W. 2015. Structure of an amino acid-decorated exopolysaccharide secreted by a *Vibrio alginolyticus* strain. Marine Drugs, 13, 6723–6739

[174] Bramhachari, P.V. and Dubey, S.K. 2006. Isolation and characterization of exopolysaccharide produced by *Vibrio harveyi* strain VB23. Letters in Applied Microbiology, 43(5), 571- 577.

[175] Bramhachari, P.V., Kavi Kishor, P.B., Ramadevi, R., Kumar, R., Rao, B.R. and Dubey, S.K. 2007. Isolation and characterization of mucous exopolysaccharide (EPS) produced by *Vibrio furnissii* strain VB0S3. Microbiology and Biotechnology, 17 (1), 44-51.

[176] Jiang, P., Li, J., Han, F., Duan, G., Lu, X., Gu, Y. and Yu, W. 2011. Antibiofilm activity of an exopolysaccharide from marine bacterium *Vibrio* sp. QY101. PLoS ONE, 6 (4), 1-11.

[177] Desai, J.D. and Banat, I.M. 1997. Microbial production of Surfactant and Their Commercial Potential. Microbiology and Molecular Biology Review, 61, 47-64.

[178] Muthusamy, K., Gopalakrishnan, S., Ravi, T.K. and Sivachidambaram, P. 2008. Biosurfactants: Properties, commercial production and application. Current science, 736-746.

[179] Sarafin, Y., Donio, M.B.S., Velmurugan, S., Michaelbabu, M. and Citarasu, T. 2014. *Kocuria marina* BS-15 a biosurfactant producing halophilic bacteria isolated from solar salt works in India. Saudi Journal of Biological Science, 21, 511- 519.

[180] Samadhan, W., Mangesh, S., Laxmikant, D., Shraddha, K., Vikas, G., Parijat, D., Arun, B., and Surekha, K. S. 2019. Genomic Insights of Halophilic *Planococcus maritimus* SAMP MCC 3013 and Detail Investigation of Its Biosurfactant Production. Frontiers in Microbiology, 235 (10), 1-14.

[181] Namwong, S., Tanasupawat, S., Visessanguan, W. Kudo, T. and Itoh, T. 2007. *Halococcus thailandensis* sp. nov., from fish sauce in Thailand. International Journal of Systematic and Evolutionary Microbiology, 51, 2199- 2203.

[182] Chang, H.W., Kim, K.H., Nam, Y.D., Roh, S.W., Kim, M.S., Jeon, C.O., Oh, H.M. and Bae, J.W. 2008. 126, 159- 166.

[183] Nishimura, I., Igarashi, T., Dake, Y., Okuno, Y. and Obata, A. 2009. Clinical efficacy of halophilic lactic acid bacterium *Tetragenococcus halophilus* Th221 from soy sauce moromi for perennial allergic rhinitis. Allergy International, 58, 179-185.

[184] Ashokkumar, S. and Mayavu, P. 2014. Screening identification and antagonistic activity of halo stable *Bacillus* sp. Mk22 used as probiotic in *Penaeus monodon* Fabricius. African Journal of Food Science, 8, 48- 53.

[185] Toshihiko, K., Atsuhisa, N., Noriyuki, A., Takahiro, A. and Adachi, T. 2018. Isolation of immune-regulatory *Tetragenococcus halophilus* from miso. PLoS ONE, 26, 1-19.

[186] Mayavu, P., Sugesh, S., Suriya, M. and Sundaram, E. 2014. Enumeration of halophilic forms in Paragipetta saltpan and its antagonistic activities against *Vibrio* sp. Journal Applied Biology and Biotechnology, 2, 19-21.

- [187] Deepesh, K.N., Akhil, A., Anuj, K.T., Shreetama, B., Ankit, S., Medicharla, V.J., Chandi, C.M. and Pawan K.D. 2019. A *Piscibacillus* sp. Isolated from A Soda Lake Exhibits Anticancer Activity Against Breast Cancer MDA-MB-231 Cells. *Microorganisms*, 7 (34), 1-16.
- [188] Dassarma, P. Coker, J.A., Huse, V. and Dassarma, S. 2010. Halophiles, industril applications. *Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation and Cell Technology*, edited by Michael, C.F., John W. and Sons. Inc.
- [189] Voica, D.M., Bartha, L., Banciu, H.L. and Oren, A. 2016. Heavy metal resistance in halophilic Bacteria and Archaea. *FEMS Microbiology Letters*, 363(14).
- [190] Solanki, P. and Kothari, V. 2012. Metal tolerance in halotolerant bacteria isolated from saline soil of Khambhat. *Research Biotechnology*, 3, 1-11.
- [191] Shihora, N.A. 2013. Isolation and characterization of halotolerant bacteria and identification by FAME analysis. *Indian Journal of Applied Research*, 3, 51- 53.
- [192] Pal, K.C., Mondal, N.K., Chatterjee, S., Ghosh, T.S. and Datta, J.K. 2014. Characterization of fluoride- tolerant halophilic *Bacillus flexus* NM25 (HQ875778) isolated from fluoride – affected soil in Birbhum District, West Bengal, India. *Environmental Monitoring and Assesment*, 186, 699- 709.
- [193] Jha, B., Gontia, I. and Hartmann, A. 2012. The roots of the halophyte *Salicornia brachiata* are a source of new halotolerant diazotrophic bacteria with plant growth promoting potential. *Plant Soil*, 356, 265- 277.
- [194] Dasstager, S.G., Deepa, C.K. and Pandey, A. 2010. Isolation and characterization of novel plant growth promoting *Micrococcus* sp NII-0909 and its interaction with cowpea. *Plant Physiology and Biochemistry*, 48, 987- 992.
- [195] Shukla, P.S., Agarwal, P.K. and Jha, B. 2012. Improved salinity tolerance of *Archis hypogaena* (L.) by the interaction of halotolerant plant-growth- promoting rhizobacteria. *Journal of Plant Growth Regulation*, 31, 195- 206.
- [196] Ashraf, M., Hasnain, S., Berge, O. and Mahmood, T. 2004. Inoculating wheat seedlings with exopolysaccharide-producing bacteria restricts sodium uptake and stimulates plant growth under salt stress. *Biology and Fertility of Soils*, 40, 157-162.
- [197] Yildirim, E., Turan, M. and Donmez, M.F. 2008. Mitigation of salt stress in radish (*Raphanus sativus* L.) by plant growth promoting rhizobacteria. *Roum Biotechnology Letters*, 13, 3933-3943.
- [198] Egamberdieva, D. and Kucharova, Z. 2009. Selection for root colonising bacteria stimulating wheat growth in saline soils. *Biology and Fertility Soils*, 45, 563-751.
- [199] Abbaspoor, A., Zabihi, H.R., Movafegh, S., Asl and M.A. 2009. The efficiency of plant growth promoting rhizobacteria (PGPR) on yield and yield components of two varieties of wheat in salinity condition. *American-Euasian Journal of Sustainable Agriculture*, 3, 824-828.
- [200] Tiwari, S., Singh, P., Tiwari, R., Meena, K.K., Yandigeri, M. and Singh, D.P. 2011. Salt-tolerant rhizobacteria-mediated induced tolerance in wheat (*Triticum aestivum*) and chemical diversity in rhizosphere enhance plant growth. *Biology and Fertility Soils*, 47(8), 907- 916.
- [201] Siddikee, M.A., Glick, B.R., Chauhan, P.S., Yim, W.J. and Sa, T. 2011. Enhancement of growth and salt tolerance of red pepper seedlings (*Capsicum annuum* L.) by regulating stress ethylene synthesis with halotolerant bacteria containing 1-aminocyclopropane-1-carboxylic acid deaminase activity. *Plant Physiology and Biochemistry*, 49, 427-34.
- [202] Khan, A.L., Hamayun, M., Khan, S.A., Kang, S.M., Shinwari, Z.K. and Kamran, M. 2012. Pure culture of *Metarhizium anisopliae* LHL07 reprograms soybean to higher growth and mitigates salt stress. *World Journal of Microbiology and Biotechnology*, 28, 1483-94.
- [203] Rojas-Tapias, D., Moreno-Galván, A., Pardo-Díaz, S., Obando, M., Rivera, D. and Bonilla, R. 2012. Effect of inoculation with plant growth promoting bacteria (PGPB) on amelioration of saline stress in maize (*Zea mays*). *Applied Soil Ecology*, 61: 264- 272.

