

Mini-review

## Halophilic and halotolerant microorganisms: bio-factories of amazing compounds with an outstanding biotechnological potential

Fatima Nas<sup>\*1</sup>, Nihel Klouche Khelil<sup>1,2</sup>

<sup>1</sup>Laboratory of Applied Microbiology in Food, Biomedical and Environment (LAMAABE), Department of Biology, Faculty of Nature and Life, Earth and Universe Sciences, Abou bekr Belkaïd University - Tlemcen, 13000 Tlemcen, Algeria. [fatima.nas@univ-tlemcen.dz](mailto:fatima.nas@univ-tlemcen.dz), [fatimanas18@gmail.com](mailto:fatimanas18@gmail.com)

<sup>2</sup>Laboratory of Experimental Surgery, Medical Faculty, Dental Surgery Department, Aboubekr Belkaïd University of Tlemcen, Tlemcen, Algeria. [nklouche2000@gmail.com](mailto:nklouche2000@gmail.com)

### Abstract

**Introduction:** Halophilic and halotolerant microorganisms are a group of extremophiles that are adapted to survive in high salt conditions. The successful occupancy of life form in such unfavorable environment has attracted and focused the attention of the scientific community for potential applications of their bioactive molecules. This mini-review summarizes some potential applications of those microorganisms in biotechnology that have been highlighted in specialty journals with a significant impact factor.

**Methods:** To carry out this exploratory review involve the online survey including and coordinating information from convincing publications on *in vitro* works by means of electronic database and scientific tools such as Google Scholar, PubMed, Springer link and Science Direct.

**Results:** This systematic review was structured based on the years of the publication of the journals, the categories and the used keywords. The results showed the potential of production of highly stable biomolecules by halophilic and halotolerant such as extreme-enzymes, antimicrobial compounds, antioxidant, biomolecules with anticancer and anti-diabetic activities, compatible solutes, carotenoid pigments, exo-polysaccharides, and biosurfactants products which can be used in medicine, agriculture, bioenergy and other industries and that can resolve current challenges.

**Conclusion:** Halophiles and halotolerant microorganisms have the potential to offer significant opportunities for biotechnology. Their high metabolic diversity and highly stable biomolecules suggests that they will prove even more valuable in the future.

**Keywords:** Halophilic microorganisms - halotolerant microorganisms - bioactive compounds - biotechnological applications.

### Introduction

Saline and hypersaline habitats are a typical example of extreme environments, they host unique microbial communities conditioned by several parameters such as high salt concentration, alkalinity, low oxygen concentrations, nutrient availability, temperature, sunlight, heavy metals, pressure and other toxic compounds like pesticides and chemicals (Martínez et al. 2022).

Microorganisms that thrive in saline and hypersaline habitats are divided into two communities: halophiles and halotolerant, they can be found in all three domains of life including *Archaea*, *Bacteria*, and *Eukarya*. The halophilic microorganisms depend strictly on the presence of salt (NaCl) for their optimal growth; they may be classified according to the amount of their salt (NaCl) requirement: slight, moderate, and extreme halophiles that grow optimally at 0.2–0.85 M (1–5%), 0.85–3.4 M (5–20%), and 3.4–5.1 M (20–30%) of NaCl, respectively. The halotolerant microorganisms have no absolute requirement of salt, are able to grow in the presence or absence of high salt concentration. Extreme halotolerant microorganisms are considered to grow above 2.5 M salt (Dutta and Bandopadhyay 2022).

Halophilic and halotolerant microorganisms apply two main osmoadaptation strategies to survive in hostile conditions. The first is the “salt-in” strategy where osmotic balance is achieved by accumulation of high concentrations of inorganic salts in the medium. As Na<sup>+</sup> ions are excluded as much as possible from cells in all

---

\* Corresponding Author: Fatima Nas; email. [fatima.nas@univ-tlemcen.dz](mailto:fatima.nas@univ-tlemcen.dz); [fatimanas18@gmail.com](mailto:fatimanas18@gmail.com)

three domains of life, the “saltin” strategy is based on KCl rather than on NaCl as the main intracellular salt. The second strategy is the accumulation or biosynthesis of compatible solutes such as polyols, sugars, amino acids, betaines, ectoine and *N*-derivatized carboxamides of glutamine (Gunde-Cimerman et al. 2018).

In recent years, there has been a significant increase in the search for halophilic and halotolerant microorganisms. This growing interest in these extremophile microorganisms and the biotechnological potential they contain is largely due to the fact that they constitute a new frontier to explore. They are a source of highly stable secondary metabolites under extreme conditions with a wide range of biotechnological applications, ranging from the production of biomolecules such as compatible solutes, exopolysaccharides, biosurfactants, carotenoids, antimicrobial, anticancer and anti-diabetic molecules, extremoenzymes, to bioremediation processes of the environment as well as biological control against phytopathogens (Corral et al. 2020 ; Ruginescu et al. 2020; Giani et al. 2019; Quadri et al. 2016).

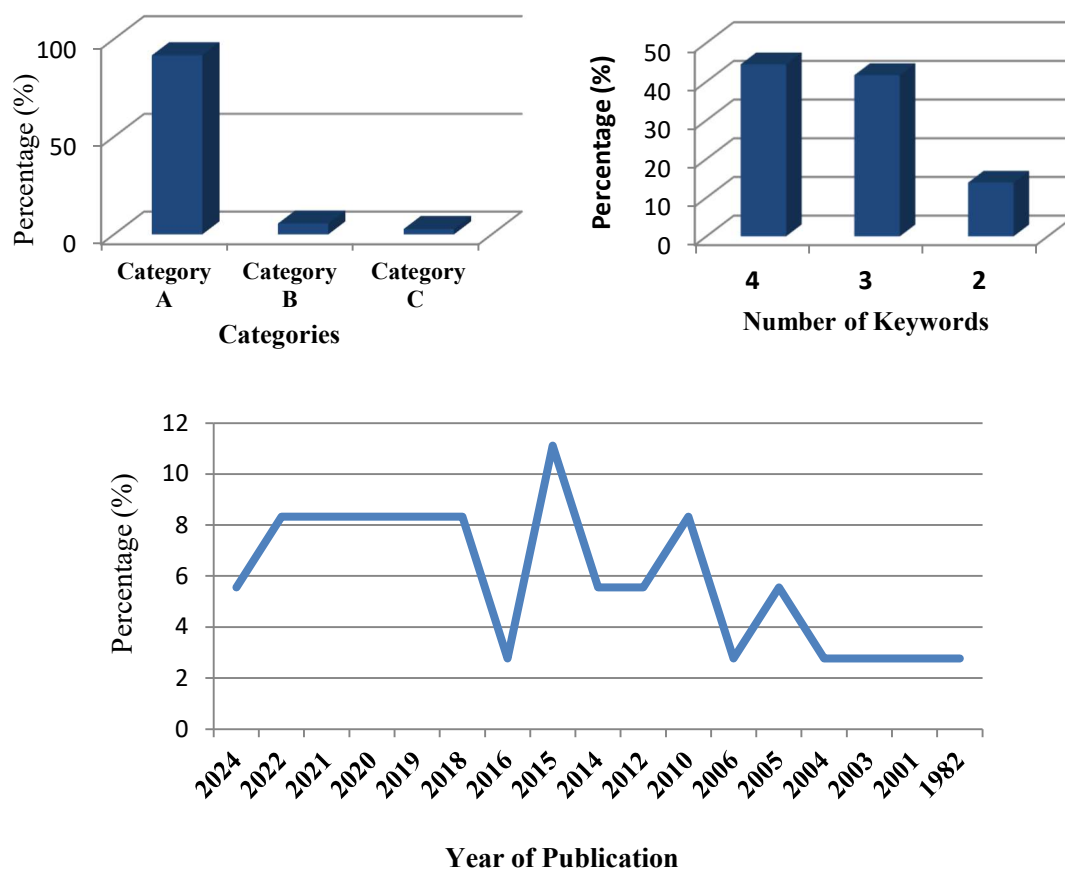
This overview summarizes the most important applications of halophilic and halotolerant microorganisms in biotechnology that have been featured in special journals with significant impact factors.

### Methods

To direct this work, we focused our research primarily on collecting information from journals of category A, based mainly on keywords (halophilic microorganisms, halotolerant microorganisms, bioactive compounds and biotechnological applications) and the date of publication. Progressively, we spread our research towards journals of other categories using divers electronic tools.

### Results

The results of the investigation enclosed the use of journals of 91.66% category A, 5.55% category B and 2.77% category C. Globally 44.44% of journals are focalized on the totality of the keywords we searched for. About 41.66% of the journals concerned the use of three (3) keywords purpose of our study (Fig. 1).



**Figure 1.** Classification of journals by category, keywords and the year of publication

Finally, 13.88% of the journals cited two (2) keywords utilized in our work. The main study has cited references ranking from 1982 to 2024 (Fig. 1).

### ***Production of extremo-enzymes***

Halophilic and halotolerant enzymes are more efficient alternatives to mesophilic counterparts for catalyzing various industrial reactions carried out under high salinity conditions that can prevent enzymatic transformations (Liu et al. 2019).

They are not only stable and active at high salt concentrations, but are also tolerant to cold and high temperatures, stable at alkaline pH and in the presence of organic solvents (Mokashe et al. 2018).

Several purified halophilic and halotolerant enzymes such as protease, lipase, amylase, cellulase and xylanase have shown promising potential for bioremediation of hypersaline environments contaminated with organic pollutants (Fathepure 2014), food processing (Cai et al. 2018), decomposition of different types of non-food biomasses and the production of biofuels (Amoozegar et al. 2019) and in the biocleaning of mural paintings (Ruginescu et al. 2020). These salt-adapted enzymes are characterized by an excess of acidic amino acids at the protein surface and by a general decrease in hydrophobic amino acid frequency. As an example of salt-adapted enzyme, an amylase isolated from *Haloarcula* sp. which functions optimally at 4.3 M salt at 50°C, and is stable in solvents benzene, toluene and chloroform (Fukushima et al. 2005).

### ***Production of compatible solutes***

Some halophilic and halotolerant microorganisms adopt the strategy of biosynthesis of organic molecules of low molecular weight to ensure their osmotic equilibrium; these are the compatible solutes can stabilize the cytoplasmic and the whole cells' structural components against extreme conditions by enhanced osmotic activity (Vargas et al. 2006). The types of organic molecules used for osmotic balance include polyols and derivatives, sugars and derivatives, amino acids and derivatives, betaines and ectoines.

Among the common compatible solutes in bacteria, ectoin, it was first discovered in the photosynthetic haloalkaloid bacterium *Ectothiorhodospira halochloris* (Oren 2010). This molecule is applied in several biotechnological fields and is used for the in vitro preservation of enzymes and commercial nucleic acids (Uratani et al. 2014). It protects the skin from premature aging and alterations caused by ultraviolet radiation, hence its incorporation into the preparations of certain moisturizing creams (Van den Burg 2003), it is also known to increase the immune defenses of Langerhans cells (Buenger and Driller 2004) and it prevents aggregation and neurotoxicity of Alzheimer's  $\beta$ -amyloid (Kanapathipillai et al. 2005).

### ***Production of pigment***

Three types of microorganisms are among the best known by their power to produce pigments, the extreme halophilic archaea which contain bacterioruberine and bacteriorhodopsin, the green algae *Dunaliella salina* which produces the  $\beta$ -carotene and the halophilic bacterium *Salinibacter rubber* which produces C40-carotenoid acyl glycoside (Aljohny 2015).

Bacterioruberine is a membrane photo-pigment, it is responsible for the red color of brines and allows the production of ATP when the oxygen content in the external environment is too low. This compound is formed of bacteriorhodopsin (25-kDa) associated with a photo-pigment similar to a carotenoid. Bacteriorhodopsin is a very unusual protein within *Halobacterium* proteins. It is stable in the absence of salts and retains its photochemical properties, it also resists to digestion by most proteases. It is commercially manufactured as a flat purple membrane prepared from *Halobacterium salinarum*. It has the most recognizable applications in photoelectric devices, artificial retinas, holograms. The  $\beta$ -carotene is used in the food industry as a dye or in cosmetics as a precursor of vitamin A, so its antioxidant activities makes it popular for use in sanitary foods (Oren 2010).

The haloarchaea, *Natrialba* sp. produce the C50 carotenoid bacterioruberin, which showed robust activity against hepatitis C virus (HCV) and hepatitis B virus (HBV) (Hegazy et al. 2020). This unique property could be used to formulate drugs for cancer and viral hepatitis.

### ***Production of antimicrobial compounds***

Halophilic and halotolerant microorganisms constitutes a valuable source of antimicrobial compounds. Among microorganisms that are known to be factories for the production of antimicrobial compounds, bacterial species of the genera *Streptomyces*, *Halomonas*, *Bacillus* and *Nocardiopsis* (Corral et al. 2020). Similarly, halophilic archaea are also used in various industries such as the textile industry which uses significant amounts of salts for tanning through to their power to produce halocins that are antimicrobial substances of a protein nature. These

molecules were first described by Rodriguez-valera et al. (1982), they inhibit phylogenetically bound haloarchaea. Some halocines also have medical potential such as halocin H6 produced by *Haloferax gibbonsii* which has been indicated as a treatment to reduce ischemia during organ transplantation in dogs (Charlesworth and Burns 2015).

#### ***Production of biosurfactant***

Biosurfactants are biologically synthesized surfactants (SURFace ACTive AgeNTS). They are synthesized by microorganisms to improve the assimilation of insoluble compounds in water, such as hydrocarbons, to metabolize them. Indeed, biosurfactants facilitate the attachment of cells to hydrocarbons by increasing their solubility in water (emulsification) and their diffusion inside the microbial cell (Chafale and Kapley 2022). Their ability to modify inter-facial properties and induce emulsion formation, phase separation, solubilization, wetting, detergency and viscosity reduction, allows the biosurfactant to be applied in a wide variety of industrial and biotechnological processes. They are employed in agriculture as antagonists, in bioremediation of contaminated sites with hydrocarbons, organic pollutants and heavy metals, in petroleum industry, particularly in oil tank cleaning operations, in food industry as food additives, and in the cosmetics and pharmaceutical industries as therapeutic agents with antimicrobial, anti-cancer and antioxidant activities (Huang et al. 2010).

#### ***Production of exopolysaccharides***

Halophilic and halotolerant microorganisms are recognized as a valuable source of exopolysaccharides (Margesin and Schinner 2001). For example, we cite the halophilic strain *Halomonas marina* HMA103 that produces a heteropolymer of glucose and mannose at a saline concentration of 10% NaCl (p/v). They are polymers consisting of a sequence of oses synthesized by certain microorganisms, using intracellular mechanisms requiring the presence of a substrate in the cell. After intracellular synthesis, they are either excreted in the external environment, or remain attached to the cell by forming a capsule (Llamas et al. 2012). In terms of biotechnological exploitation, exopolysaccharides have some advantages, which they can be used to modify the rheological properties of aqueous systems by improving the viscosity of solutions, even at low concentrations. These polymers are used as stabilizers, thickeners, gelling agents and emulsifiers in the pharmaceutical, petroleum, food, paper, and textile and cosmetics industries. They are also used as metal solvents and bio-absorbent in oil recovery, mining and petroleum industries (Amjres et al. 2015).

#### ***Biodegradation of effluents***

Many industrial sectors such as agro-food sectors (salting, vegetable conservation, olive oil, fish industry), pharmaceutical, petrochemical, paper industries, leather and pesticides generate effluents that contain not only toxic compounds but also significant salt concentrations.

The biological treatment of such effluents could reduce the cost of physical-chemical purification, and can only be carried out with microorganisms that are tolerant or require high salt concentrations. Indeed, several halophilic and halotolerant microorganisms have been isolated from habitats contaminated by hydrocarbons or uncontaminated and many studies have revealed the high potential of these microorganisms in bioremediation processes and their ability to degrade organic compounds in contaminated salt environments (Lu et al. 2015 ; Martins and Peixoto 2012 ; Zhuang et al. 2010).

#### ***Plant Growth Promoting (PGP)***

Salts can be present in the soil through various addition processes (irrigation or fertilizer) or already present in the soil. Plants absorb dissolved salt with the nutrients they need; thus, salts are accumulated in plants. Soil salinity affects plant physiology (photosynthesis), morphology (reduction of leaf area), and biochemical processes, including water and nutrient absorption and seed germination (Liu et al. 2021).

To cope with salinity, many technological and biotic strategies have been adopted. The technological approach consists of modifying the salt soil by leaching, application of chemicals, drainage systems, application of organic compound (sewage sludge, composts and manures). However, these methods are expensive and are not always a suitable solution to the problem of soil salinity. On the other hand, the environmental friendly strategy (biotic approach) using salt-tolerant microorganisms is promising and considerable to mitigate the problem of soil salinity, improve soil fertility and enhance plant productivity and many studies have proven that the hypersaline microflora is rich in genes responsible for plant growth promotion; hence, they can act as a significant bio-stimulating agent and can be used as bio-fertilizing agents for agricultural practices in salinized areas by alleviating prevalent stresses (Dindhorja et al. 2024; Orhan 2021).

### ***Food biotechnology***

Halotolerant and halophilic microorganisms play an essential role in food biotechnology for the production of fermented food and food supplements. As an example of these microorganisms the species of the genera *Halobacterium*, *Halococcus* and *Bacillus*, they produce various compounds that give the organoleptic characteristics of the resulting products. These microorganisms have been used to produce a wide variety of foods including pickles, Asian fish and meat sauces, rice and flour noodles and Indonesian soy sauce (Aljohny 2015).

### **Discussion**

Microbial diversity is the key to human survival and economic well-being and is considered a large reservoir of resources that can be utilized for the benefit of human-kind. The systematic exploration, evaluation, and exploitation of microbial resources are thus essential for scientific and industrial development that serves the needs of society. Due to their unique properties, halophilic and halotolerant microorganisms constitute a considerable reservoir and an inexhaustible natural source of bioactive molecules with interesting biological activities. These biomolecules are valuable and have commercial potential for the food, pharmaceutical, biomedical, industrial and environmental sectors. These benefits increasingly encourage the exploitation of extreme ecosystems, the optimization of production conditions, as well as the use of omics technologies, This offers new possibilities for the discovery and identification of unique properties and/or new biomolecules derived from halophiles in the future and production with sustainable yields on an industrial scale.

### **Conclusion**

Halophiles and halotolerant microorganisms are special species that have a pertinent power in biotechnologies. Their potential of adaptation makes them an inexhaustible resource of bioactive compounds especially in green, white, red and yellow biotechnologies (production of carotenoids, antimicrobials and anticancer and bioremediation processes of the environment).

### **Acknowledgment**

The authors are grateful to the Laboratory of Applied Microbiology, to the Agri-food, Biomedical and Environment (LAMAABE), Department of Biology, Faculty of Nature and Life, Earth and Universe Sciences, Abou bekr Belkaïd University-Tlemcen (Algeria), for providing infrastructural facilities and assistance.

### **Conflict of interest:**

The author states that he has no conflicts of interest.

### **References**

- Aljohny BO (2015). Halophilic Bacterium - A Review of New Studies. *Biosci Biotechnol Res Asia* 12(3):2061-2069. <http://dx.doi.org/10.13005/bbra/1874>
- Amjres H, Béjar V, Quesada E, Carranza D, Abrini J et al. (2015). Characterization of haloglycan, an exopolysaccharide produced by *Halomonas stenophila* HK30. *Int J Biol Macromol* 72:117-124. <https://doi.org/10.1016/j.ijbiomac.2014.07.052>
- Amoozegar MA, Safarpour A, Noghabi KA, Bakhtiary T, Ventosa A (2019). Halophiles and Their Vast Potential in Biofuel Production. *Front Microbiol* 10: 1895. <https://doi.org/10.3389/fmicb.2019.01895>
- Buenger J, Driller H (2004). Ectoin: an effective natural substance to prevent UVA-induced premature photoaging. *Skin Pharmacol Physiol* 17(5): 232-237. <https://doi.org/10.1159/000080216>
- Cai ZW, Ge HH, Yi ZW, Zeng RY, Zhang GY (2018). Characterization of a Novel Psychrophilic and Halophilic  $\beta$ -1,3-Xylanase from Deep-Sea Bacterium, *Flammeovirga pacifica* Strain WPAGA1. *Int J Biol Macromol* 118: 2176-2184. <https://doi.org/10.1016/j.ijbiomac.2018.07.090>
- Chafale A, Kapley A (2022) Biosurfactants as microbial bioactive compounds in microbial enhanced oil recovery. *J Biotechnol* 352:1-15. <https://doi.org/10.1016/j.jbiotec.2022.05.003>
- Charlesworth JC, Burns BP (2015). Untapped Resources: Biotechnological Potential of Peptides and Secondary Metabolites in Archaea. *Archaea*. <https://doi.org/10.1155/2015/282035>
- Corral P, Amoozegar MA, Ventosa A (2020). Halophiles and Their Biomolecules : Recent Advances and Future Applications in Biomedicine. *Mar Drugs* 18 (1): 33. <https://doi.org/10.3390/md18010033>
- Dindhorja K, Kumar R, Bhargava B, Kumar R (2024). Metagenomic assembled genomes indicated the

- potential application of hypersaline microbiome for plant growth promotion and stress alleviation in salinized soils. *mSystems* 9 (3). <https://doi.org/10.1128/msystems.01050-23>
- Dutta B, Bandopadhyay R (2022). Biotechnological potentials of halophilic microorganisms and their impact on mankind. *Beni Suef Univ J Basic Appl Sci* 11(1):75. <https://doi.org/10.1186/s43088-022-00252-w>
  - Fathepure BZ (2014). Recent Studies in Microbial Degradation of Petroleum Hydrocarbons in Hypersaline Environments. *Front Microbiol* 5 : 173. <https://doi.org/10.3389/fmicb.2014.00173>
  - Fukushima T, Mizuki T, Echigo A, Inoue A, Usami R (2005) Organic solvent tolerance of halophilic alpha-amylase from a Haloarchaeon, *Haloarcula* sp. strain S-1. *Extremophiles* 9: 85-89. <https://doi.org/10.1007/s00792-004-0423-2>
  - Giani M, Garbayo I, Vilchez C, Martínez-Espinosa RM (2019). *Haloarchaeal* Carotenoids: Healthy Novel Compounds from Extreme Environments. *Mar Drugs* 17 :524. <https://doi.org/10.3390/md17090524>
  - Guevara-Luna J, Arroyo-Herrera I, Tapia-García EY, Estrada-de Los Santos P, Ortega-Nava AJ, Vásquez-Murrieta MS (2024). Diversity and Biotechnological Potential of Cultivable Halophilic and Halotolerant Bacteria from the "Los Negritos" Geothermal Area. *Microorganisms* 12(3):482. <https://doi.org/10.3390/microorganisms12030482>
  - Gunde-Cimerman N, Plemenitaš A, Oren A (2018) Strategies of adaptation of microorganisms of the three domains of life to high salt concentrations. *FEMS Microbiol Rev* 42:353–375. <https://doi.org/10.1093/femsre/fuy009>
  - Hegazy GE, Abu-Serie MM, Abo-Elela GM, Ghozlan H, Sabry SA, Soliman NA, Abdel-fattah YR (2020). In vitro dual (anticancer and antiviral) activity of the carotenoids produced by haloalkaliphilic archaeon *Natrialba* sp. M6. *Sci Rep* 10: 5986. <https://doi.org/10.1038/s41598-020-62663-y>
  - Huang XF, Guan W, Liu J, Lu LJ, Xu JC, Zhou Q (2010). Characterization and phylogenetic analysis of bio emulsifier producing bacteria. *Bioresour Technol* 101(1):317–323. <https://doi.org/10.1016/j.biortech.2009.07.086>
  - Kanapathipillai M, Lentzen G, Sierks M, Park CB (2005). Ectoïne and hydroxyectoïne inhibit aggregation and neurotoxicity of Alzheimer's beta-amyloid. *FEBS Lett* 579 (21):4775–4780. <https://doi.org/10.1016/j.febslet.2005.07.057>
  - Liu C, Baffoe DK, Zhan Y, Zhang, M, Li Y, Zhang G (2019). Halophile, an Essential Platform for Bioproduction. *J Microbiol Methods* 166 :105704. <https://doi.org/10.1016/j.mimet.2019.105704>
  - Liu Y, Zhang S, De Boeck HJ, Hou F (2021). Effects of Temperature and Salinity on Seed Germination of Three Common Grass Species. *Front Plant Sci* 12:731433. <https://doi.org/10.3389/fpls.2021.731433>
  - Llamas I, Amjres H, Mata JA, Quesada E, Béjar V (2012). The potential biotechnological applications of the exopolysaccharide produced by the halophilic bacterium *Halomonas almeriensis*. *Molecules* 17(6):7103–7120. <https://doi.org/10.3390/molecules17067103>
  - Lu ZY, Guo XJ, Li H, Huang ZZ, Lin K F, Liu YD (2015). High-throughput screening for a moderately Halophilic phenol-degrading strain and its salt tolerance response. *Int J Mol Sci* 16(6):11834-11848. <https://doi.org/10.3390/ijms160611834>
  - Margesin R, Schinner F (2001). Potential of halotolerant and halophilic microorganisms for biotechnology. *Extremophiles: life under extreme conditions* 5(2): 73-83. <https://doi.org/10.1007/s007920100184>
  - Martínez GM, Pire C, Martínez-Espinosa RM (2022). Hypersaline environments as natural sources of microbes with potential applications in biotechnology: The case of solar evaporation systems to produce salt in Alicante County (Spain). *Curr Res Microb Sci* 3:100136. <https://doi.org/10.1016/j.crmicr.2022.100136>
  - Martins L F, Peixoto RS (2012). Biodegradation of petroleum hydrocarbons in hypersaline environments. *Braz J Microbiol* 43(3):865-872. <https://doi.org/10.1590/S1517-83822012000300003>
  - Mokashe N, Chaudhari B, Patil U (2018). Operative utility of salt-stable proteases of halophilic and halotolerant bacteria in the biotechnology sector. *Int J Biol Macromol* 117:493-522. <https://doi.org/10.1016/j.ijbiomac.2018.05.217>
  - Oren A (2010). Industrial and environmental applications of halophilic microorganisms. *Environ Technol* 31(8-9):825–834. <https://doi.org/10.1080/09593330903370026>
  - Orhan F (2021). Potential of Halophilic/Halotolerant Bacteria in Enhancing Plant Growth Under Salt Stress. *Curr Microbiol* 78 : 3708-3719. <https://doi.org/10.1007/s00284-021-02637-z>
  - Quadri I, Hassani II, l'Haridon S, Chalopin M, Hacène H, Jebbar M (2016). Characterization and Antimicrobial Potential of Extremely Halophilic Archaea Isolated from Hypersaline Environments of the Algerian Sahara. *Microbiol Res* 186–187 :119–131. <https://doi.org/10.1016/j.micres.2016.04.003>
  - Rodriguez-Valera F, Ventosa A, Quesada E, Ruiz-Berruero F (1982). Some physiological features of

- a *Halococcus* sp. at low salt concentrations, FEMS Microbiol Lett 15 (4):249-252, <https://doi.org/10.1111/j.1574-6968.1982.tb00227.x>
- Romero Soto L, Thabet H, Maghembe R, Gameiro D, Van-Thuoc D et al. (2021). Metabolic potential of the moderate halophile *Yangia* sp. ND199 for co-production of polyhydroxyalkanoates and exopolysaccharides. *MicrobiologyOpen* 10(1). <https://doi.org/10.1002/mbo3.1160>
  - Ruginescu R, Gomoiu I, Popescu O, Cojoc R, Neagu S, Lucaci I, Batrinescu-Moteau C, Enache M (2020). Bioprospecting for Novel Halophilic and Halotolerant Sources of Hydrolytic Enzymes in Brackish, Saline and Hypersaline Lakes of Romania. *Microorganisms* 8(12):1903. <https://doi.org/10.3390/microorganisms8121903>
  - Uratani JM, Kumaraswamy R, Rodríguez J (2014). A systematic strain selection approach for halotolerant and halophilic bioprocess development: a review. *Extremophiles: life under extreme conditions* 18 (4):629–639. <https://doi.org/10.1007/s00792-014-0659-4>
  - Van den Burg B (2003). Extremophiles as a source for novel enzymes. *Curr Opin Microbiol* 6(3):213-218. [https://doi.org/10.1016/s1369-5274\(03\)00060-2](https://doi.org/10.1016/s1369-5274(03)00060-2)
  - Vargas C, Jebbar M, Carrasco R, Blanco C, Calderón MI, Iglesias-Guerra F, Nieto JJ (2006). Ectoines as compatible solutes and carbon and energy sources for the halophilic bacterium *Chromohalobacter salexigens*. *J Appl Microbiol* 100 :98–107. <https://doi.org/10.1111/j.1365-2672.2005.02757.x>
  - Zhuang X, Han Z, Bai Z, Zhuang G, Shim H (2010). Progress in decontamination by halophilic microorganisms in saline wastewater and soil. *Environ Pollut* 158 (5):1119-1126. <https://doi.org/10.1016/j.envpol.2010.01.007>