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Effects of Salinity and Ultraviolet Radiation on the Bioaccumulation of Mycosporine-like Amino Acids in *Artemia* from Lake Urmia (Iran)

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ABSTRACT

We investigated the effects of salinity and artificial UV radiation on the accumulation of mycosporine-like amino acids (MAAs) in sexual and parthenogenetic *Artemia* from Lake Urmia. The nauplii hatched from the cysts were cultured until adulthood under two salinities (150 and 250 g L^{-1}) and two light treatments (PAR and PAR+UVR) in the laboratory. Finally, the *Artemia* were analyzed for their concentration of MAAs. In most of the cases, the higher salinity level applied was found to increase the MAA concentrations in both *Artemia* populations significantly. The acquisition efficiency of MAAs in both *Artemia* populations increased under exposure to UVR-supplemented photosynthetically active radiation (PAR) compared to those raised under PAR, except for Porphyra-334. It was observed that combination of UV radiation and elevated salinity significantly increased the bioaccumulation of MAAs. Thus, the presence of these compounds in these populations of *Artemia* may increase their adaptability for living in high-UV and high-salinity conditions prevailing in Lake Urmia. Higher concentrations of MAAs in the parthenogenetic population of *Artemia* could be probably attributed to its mono sex nature and higher adaptation capacities to extreme environmental conditions.

INTRODUCTION

The visible range of the solar electromagnetic spectrum (photosynthetically active radiation = PAR, 400–700 nm) provides the energy required for the photosynthetic process and thus has a key ecosystemic role. The shorter wavelengths of the spectrum referred to as ultraviolet radiation (UVR, 280–400 nm), especially ultraviolet-B (UV-B, 280–320 nm), have been reported to cause a number of deleterious effects such as genetic, physiologic and ecological damages in various organisms (1–6). Terrestrial, marine and freshwater organisms have developed strategies to diminish the direct and indirect damaging effects of environmental UVR by synthesizing, accumulating and metabolizing a variety of UV-absorbing substances called mycosporine-like amino acids (MAAs) (7–10). MAAs, cyclohexenone and cyclohexenimine chromophores, conjugated with the nitrogen substituent of an amino acid or its imino alcohol, are small water-soluble compounds with absorption maxima ranging from 310 to 360 nm (7,9). Considerable interest has been centered on MAAs because experimental evidence indicates that in marine organisms the major functions of MAAs are to act as active UV filters (10–13) and/or as antioxidants (7,10,14,15).

Several other hypotheses about the role of MAAs in biological systems have been formulated: (1) they may contribute to osmotic regulation (16–18), (2) they may act as regulatory metabolites of sporulation and germination in fungi (19), and in the reproduction in marine invertebrates (20–22), (3) they may play a role under desiccation or thermal stress in certain organisms (18,23) and finally (4) they can act as an intracellular nitrogen reservoir (24). Recently, Kicklighter *et al.* (25) showed that pyrimidines and MAAs function as alarm cues in the defensive secretions of the sea hare *Aplysia californica*.

As documented above, several studies have suggested the antistress effects of MAAs in different organisms. Hence, we used the brine shrimp *Artemia* as a model organism, occurring in the surface zooplankton of saline waters. The genus *Artemia* (brine shrimp) with various geographical species and strains is commonly considered to be a worldwide euryhaline organism that is well known for its ability to adapt to diverse biotopes (inland salt lakes, coastal lagoons and solar salt pools) with variable salinity ranging from 10 g L^{-1} (26,27) to 340 g L^{-1} (28,29). It comprises bisexual species, which are found on all continents except Antarctica, and parthenogenetic populations, which are endemic to Europe, Asia and Australia (27). In Iran, the genus *Artemia* is known to occur in at least 17 salt lakes, salty rivers and lagoons from 11 provinces (26). *Artemia urmiana* is the only bisexual population found in Lake Urmia, while the rest of Iranian *Artemia* are parthenogenetic (26,27).

Lake Urmia is a thalassohaline, sodium chloride lake with oligotrophic characteristics, located in Northwestern (37°20′N, 45°40′E) Iran (30). The water salinity range of Lake Urmia used to be between 140 and 220 g L^{-1} before 1999 but its salinity has reached levels as high as 300 g L^{-1} due to drought since 2000 (27). Lake Urmia is the natural habitat of *A. urmiana*, first reported by Günther (31). The presence of a parthenogenetic *Artemia* population in the temporary small costal lagoons of Lake Urmia was initially reported by Agh and Noori (32) and later by Agh *et al.* (27). These lagoons are scattered all around the lake, present small to large areas (up to 10 000 m^2) and their depths are below 0.7 m (33). Water salinity in these lagoons ranges from 10 to 20 g L^{-1} in early spring to saturated level in early summer.

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