It's a stressful life: biodiversity and molecular evolution of dormancy strategies in tardigrades

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Tardigrades are microscopic animals that inhabit nearly every ecosystem on Earth, from marine and freshwater environments to terrestrial mosses and soils, representing a striking example of hidden biodiversity. Their success across such diverse habitats is closely linked to their ability to enter dormant states, including cryptobiosis and diapause, which allow survival under extreme environmental stress. However, our understanding of how these strategies vary across the phylogenetic diversity of tardigrades remains limited, as most studies have focused on a few model species.

The present study explores the diversity and evolutionary distribution of dormancy molecular adaptations (anhydrobiosis and encystment) across tardigrade lineages with an omics-based approach, with a focus on underrepresented taxa. Particular attention is given to *Bertolanius volubilis*, a rare boreo-alpine species found in Italy from the poorly characterized superfamily Eohypsibioidea. *B. volubilis* is notable for its ability to undergo both desiccation-driven cryptobiosis and encystment. Encystment was further investigated in *Dactylobiotus parthenogeneticus* (Macrobiotoidea superfamily), and in a newly identified *Hypsibius* species (Hypsibioidea superfamily), spanning distinct evolutionary branches.

Transcriptomic analyses revealed that *B. volubilis* maintains a constitutive expression of tardigrade-specific intrinsically disordered proteins (TDPs), suggesting a lineage-specific strategy adapted to frequent environmental fluctuations. Comparative analyses across eutardigrade species identified conserved TDP families, representing key evolutionary determinants of anhydrobiosis. Despite their phylogenetic distance, all investigated species exhibited profound transcriptional reorganization during encystment, including a shared involvement of TDPs and other conserved molecular components. These findings have strong valorization potential: tardigrade stress-related molecules represent promising tools for biotechnological applications, including biobanking, preservation of biological materials, and the development of stress-resistant biomolecules and cells, providing a framework for translating biodiversity-driven discoveries into innovative solutions.

Overall, integrating molecular and phylogenetic perspectives reveals how evolutionary history shapes survival strategies, unlocking new opportunities for both biodiversity research and technological innovation.