Version of Record: https://www.sciencedirect.com/science/article/pii/S157106452100035X
Manuscript_2334f42a06dee61ef11ad1c94cd44260

Melanin – protecting and enhancing the earliest life on Earth

Comment on "Insoluble organic matter in chondrites: Archetypal melanin-like PAH-based multifunctionality at the origin of life?" by Marco d'Ischia et al.

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The review by d'Ischia et al. [1] puts forward a fascinating hypothesis of the close similarity of compounds composing the Insoluble Organic Matter (IOM) which is found in carbonaceous chondrites and melanins, the versatile dark pigments which are present in all life forms on Earth. By making such connection, the authors propose that melanin-like compounds played an essential role in the origins of life. The review presents a convincing proof of this hypothesis by critically analyzing the data from astrobiological, chemical and microbiological literature.

From physical point of view melanin is distinguished other polycyclic aromatic hydrocarbons (PAH) by being a stable free radical which has paramagnetic properties as a result of possessing an unpaired electron. In addition, its π-electrons cloud contributes to its unusual interaction with electromagnetic radiation [1]. Chemically, melanin can by synthesized from a broad range of structurally diverse precursors [1]. It can play a role of a reducing or an oxidizing agent in chemical reactions [2] and is capable of self-repair after being oxidized by "pirating" the electrons from the environment [3]. In biological systems, such as fungal or bacterial cells, melanin can provide protection from multiple environmental insults as well as possibly play a role of a energy transducer under nutrient and energy-deficient conditions [4]. Taken together, these unique properties of melanin provide the justification of it being placed by d'Ischia et al. into the center of their origin of life hypothesis.

The protective properties of melanin against high doses of UV and ionizing radiation have been well documented. In this regard, studies devoted to the investigation of the origins and survival of life on other planets such as Mars provide additional evidence for the hypothesis of melanin role in life origin on Earth. Studies in which cold- and desiccation-tolerant organisms were exposed to simulated Mars-surface conditions while being embedded in regolith-like rock have been carried out and revealed high levels of survival of melanized organisms, including melanized fungus *Wangiela dermatitis*. Melanized fungus survived much better than compared its albino mutant [5]. Melanin can absorb/dissipate electromagnetic radiation such as UV and ionizing radiation. Consistent with this, there is a high incidence of melanized fungi in such extreme environments as the rocky deserts of Antarctica and the damaged nuclear reactor in Chernobyl, Ukraine [reviewed in 6]. It has also been demonstrated that melanized fungi can survive cosmic radiation while exposed on the surface of the International Space Station [7]. Thus, presence of melanin could have protected biological molecules and vulnerable earliest life forms on Earth from high fluxes of electromagnetic radiation.

And even more intriguing aspect of possible melanin involvement into the life origin is its energy transduction ability. e.g. converting the energy of ionizing radiation into the chemical

energy which early melanized organisms could have used in their lifecycle [4, 8]. The latest research has shown that melanin allows melanized organisms to "sense" the presence of ionizing radiation in the environment via its interaction with ionized species [9]. Energy transduction process which takes place during this interaction results in enhanced growth of melanized organisms in comparison with non-melanized controls [10]. One can hypothesize, that melanin was playing a role of an energy transducer in early life forms before more specialized energy transducing pigments such as chlorophyll have emerged.

It will be exciting to follow in the years to come the interdisciplinary experimental efforts to further investigate melanin role in the origins of life on Earth.

Acknowledgements:

This work was supported by the Canadian Space Agency (grant # 18FASASB13).

References:

[1] d'Ischia M., Manini P., Martins Z., Remusat L., Alexander C. O. D., Puzzarini C., Barone V., Saladino R. Insoluble organic matter in chondrites: Archetypal melanin-like PAHbased multifunctionality at the origin of life? Physics of Life Reviews 2021, 37: 65-93.

[2] Turick CE, Ekechukwu AA, Milliken CE, Casadevall A, Dadachova E. Gamma radiation interacts with melanin to alter its oxidation-reduction potential and results in electric current production. Bioelectrochemistry. 82(1):69-73 (2011).

[3] Khajo A., R.A. Bryan, Y. Levitsky, M. Friedman, R. Burger, A. Casadevall, R. Magliozzo and E. Dadachova Protection of melanized Cryptococcus neoformans from lethal dose gamma irradiation involves changes in melanin's chemical structure and paramagnetism. PLOS ONE 6(9): e25092 (2011).

[4] Dadachova E, Bryan RA, Huang X, Moadel T, Schweitzer AD, Aisen P, Nosanchuk JD, and Casadevall A. Ionizing radiation changes the electronic properties of melanin and enhances the growth of melanized fungi. PLoS One 5:e457 (2007).

[5] Johnson A.P., L. M. Pratt, T. A. Vishnivetskaya, S. Pfiffner, R. A Bryan, E. Dadachova, L. Whyte, K. Radke, E. Chan, S. Tronick, G. Borgonie, R. L. Mancinelli, L. J. Rothschild, D. A. Rogoff, D. D. Horikawa, T. C. Onstott Extended Survival of Several Organisms and Amino Acids under Simulated Martian Surface Conditions. Icarus 211(2):1162-1178 (2011).

[6] Malo ME, Dadachova E. Melanin as an Energy Transducer and a Radioprotector in Black Fungi, p. 175-182. In: TIQUIA-ARASHIRO, S. M. & GRUBE, M. (eds.) Fungi in Extreme Environments: Ecological Role and Biotechnological Significance. Cham: Springer International Publishing, 2019.

[7] de Vera JP, et al. Limits of Life and the Habitability of Mars: The ESA Space Experiment BIOMEX on the ISS. Astrobiology. 19(2):145-157 (2019).

[8] Bryan R.A., Z. Jiang, M. Friedman, and E. Dadachova The effects of gamma radiation, UV and visible light on ATP levels in yeast cells depend on cellular melanization. Fungal Biol. 115(10): 945-949 (2011).

[9] Malo M.E., Frank C., Dadachova E. Radioadapted Wangiella dermatitidis senses radiation in its environment in a melanin-dependent fashion. Fungal Biol. 124(5):368-375 (2020).

[10] Malo M.E., Z. Schultzhaus, C. Frank, J. Romsdahl, Z. Wang, E. Dadachova Transcriptomic and Genomic Changes Associated with Radioadaptation in Exophiala dermatitidis. Comput. Structur. Biotech. J., 2020 Dec 19;19:196-205.