Black Radiotrophic fungi: Adaptation and exploitation of ionizing radiation and potential applications [a]

Daniel Antonio VÁZQUEZ SÁNCHEZ [b]

[a] *Final Degree Work - Treball de Fi de Grau*

[b] *Microbiology Bachelor's Degree, Universitat Autònoma de Barcelona, Bellaterra, Spain*

E-mail: danielantonio.vazquez@e-campus.uab.cat

Fungi and Radiation

Fungi in general and specially melanized ones are highly **radioresistant**[1]. There are evidence that fungi survived radioactive periods on the early Earth[6]. They are capable of inhabiting environments with high radiation levels. Such as: high altitude, space stations[Fig.1], Antarctic and Arctic mountains [Fig.2] and even nuclear reactors [Fig.3].

Radiotrophic Fungi Discovery

In 1991, Zhdanova *et al.* reported that some fungi were colonizing the walls of the highly radioactive damaged reactor and growing in the area around the site of 1986 Chernobyl's nuclear accident [Fig.3]. The melanized fungal species were *Cladosporium sphaerospermum, Wangiella dermatitidis*, and *Cryptococcus neoformans* [Fig.4].

They termed this attraction of fungi to radiation as "**radiotropism**". These discoveries and the laboratory observations of the resistance of melanized fungi to ionizing radiation suggested a role for this pigment in radioprotection [3].

Radiobiological Importance of melanin

Melanin is a high molecular weight dark brown pigment with a variety of biological functions [2] ubiquitous in all biological domains.

Apart of being a virulence factor; melanin protects fungi against ionizing radiation and its **radioprotective** properties are a function of its chemical composition, free radical quenching and spherical spatial arrangement [11].

These pigments have the ability to absorb all types of electromagnetic radiation[1] which provides them with the capacity for both energy transduction and shielding. The findings of melanized fungi in high radiation environments with phenomenon of **radiotropism** raises the possibility that melanins have functions analogous to other energy harvesting pigments as chlorophylls.

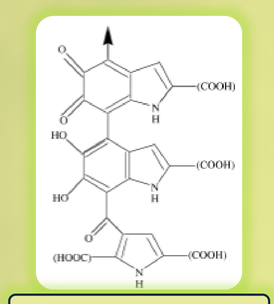

Fig 5. Structure of eumelanin oligomer. [3]

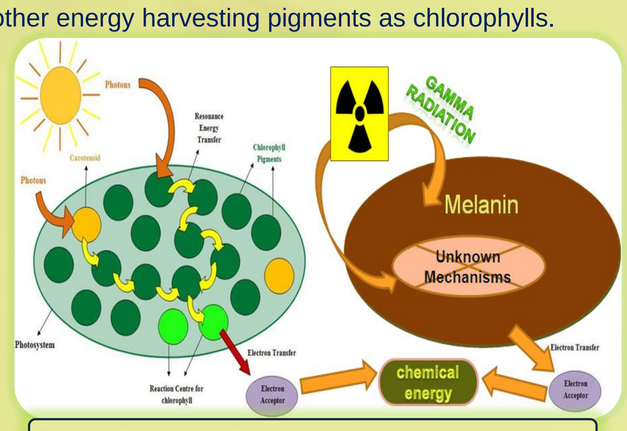

Fig 6. Simplified comparison of energy harvesting mechanisms of chlorophylls and the hypothesis about that melanin is able to harness ionizing radiation for metabolic energy.

Fig1. International Space Station.

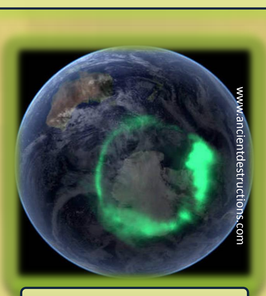

Fig2. Antarctic Ozone Hole.

Fig 3. Chernobyl's Nuclear Plant.

Confirming Radiotrophic Discovery

In contrast to general view, that radiation is with no doubt harmful to life, this abilities of fungal cell to survive or maybe even benefit from exposure to ionizing radiation are of considerable interest [1]. Supporting this notion, Dadachova *et al.* demonstrated that ionizing radiation could enhance the growth of melanized fungi and change the electronic properties of melanin such that the pigment could function in energy transduction and utilization [4].

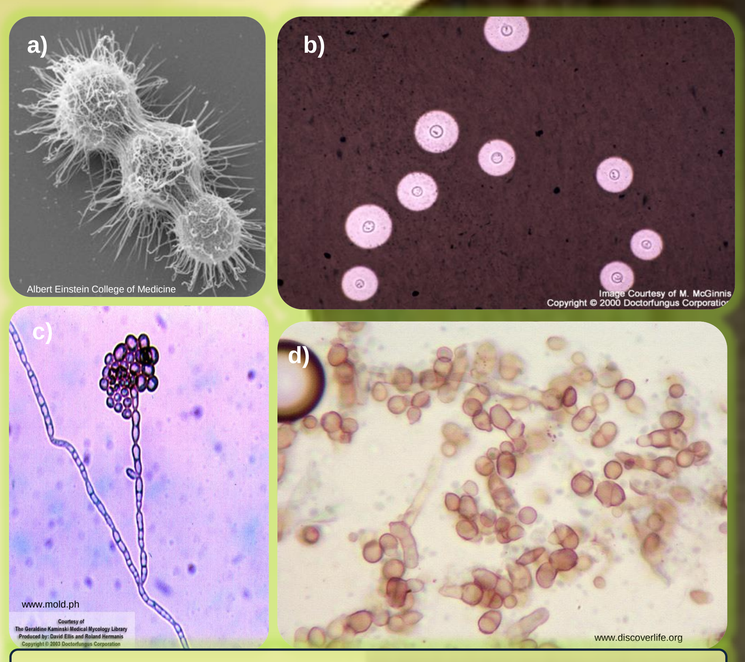

Fig 4. A) *Cryptococcus neoformans* electronic microscopy image and B) India ink preparation. C) *Wangiella dermatitidis* D) *Cladosporium sphaerospermum*

Radiotropism of Chernobyl-associated Fungi

For confirm the radiotropism effect, fungal samples extracted from the remains of the Chernobyl's reactor and isolates from control uncontaminated soil were inoculated near radioactively decaying ^{109}Cd or ^{32}P radionuclides. The authors measured the return angle[Fig.7] between the point of impact of radioactivity in the culture vessel and the direction of growth of the emergent hyphum from each spore. Zhdanova *et al.* concluded that both β- and γ-radiation promoted directional growth of fungi from contaminated and clean areas towards the sources of ionizing radiation[4]. In total, 66,7% responses of interactions between fungal isolates and radiation source showed positive stimulation[Fig. 8]

They observed as well that radiation promoted spore germination in species from contaminated regions and they called this effect: "**radiostimulation**" [5].

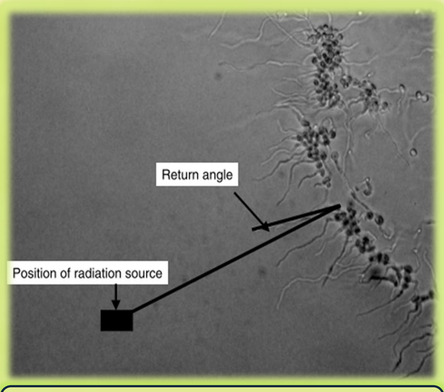

Fig 7. Digital photomicrograph of germinating fungal spores indicating the way in which image analysis was performed to calculate the 'angle return' [4].

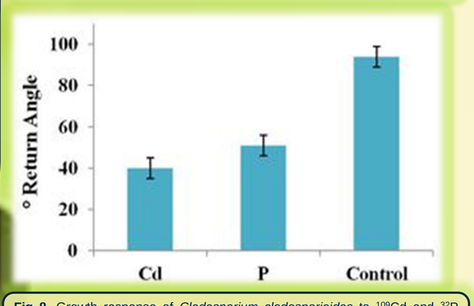

Fig 8. Growth response of *Cladosporium cladosporioides* to ^{109}Cd and ^{32}P radionuclides, compared to a non-irradiated control environment [4]. A return angle fewer than 90º is indicative of hyphal growth towards the source of radioactivity.

Gamma radiation interaction with melanin

Dadachova *et* al. exposed [4] the three species of fungi isolates from Chernobyl[Fig4] to levels of ionizing gamma radiation 500 times higher than background levels in normal environments showed a growth rate significantly faster than irradiated non-melanized cells or irradiated albino mutants[Fig9]. They confirmed as well that gamma radiation increases the ability of melanin to oxidize NADH.

The ability of melanin to capture electromagnetic radiation combined with its oxidation-reduction properties may confer upon melanized organisms the ability to convert radiation in metabolic energy.

The effect of melanin on energy conversion, however, is so subtle that further detailed investigations are required to prove this hypothesis such as the quantification of cellular protein and metabolic energy in single cells[9].

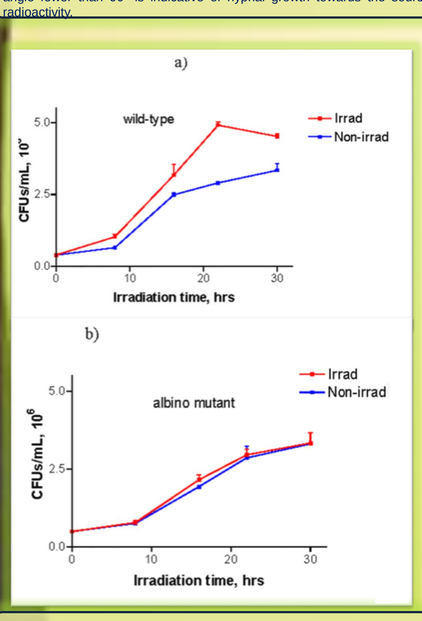

Fig 9. Growth of *W. dematitidis* a) wild type; b) albino mutant *wdpks1Δ-1.* Cells were grown under conditions of limited nutrients in radiation field of 0,05 mGy/hr or at background radiation level[4].

Melanized Fungi and Radiation in Perspective

- Future studies targeting fungal growth and stress response to ionizing radiation are the key to a better understanding of the use and maintenance of melanin as a radioprotective material[1].
- The ability of melanin to capture electromagnetic radiation combined with its oxidation-reduction properties may confer upon melanized organisms the ability to convert radiation in metabolic energy.
- The enhanced growth and radiostimulation of melanized fungi in conditions of radiation fluxes suggests the need for additional investigations to determine the mechanism for this effect[4] .
- Radiotrophy could probably be the evolutionary reason because fungi survived radioactive periods on the early Earth and can survive extreme radioactive environments.

Potential Applications

- ✓ Astronauts might be able to use these fungi as an inexhaustible food source on long missions or for colonizing other planets[7]. Radiotrophy would allow this black fungi to be grown gaining energy from the high levels of ionizing radiation
- ✓ The radioresistance of melanized fungi should be taken into consideration when gamma radiation is used for sterilization of food or medical supplies.
- ✓ Maybe melanin has potential usefulness for the design of new radio-protective biomimetic materials [8] for a wide range of applications like protection of bone marrow during cancer radiotherapy [9], to nuclear energy protection, treatment and technology and in space exploration(30).
- ✓ This fungi may have the radioresistance to absorb and break down radioactive compounds in the environment, which may be the result of contamination by industrial effluent or nuclear accidents.

Bibliography

[1].Dadachova, E., & Casadevall, A. (2008). Ionizing radiation: how fungi cope, adapt, and exploit with the help of melanin. Current Opinion in Microbiology, 11(6), 525–531; [2] Dadachova, E., Casadevall, A. (2008). The radioprotective properties of fungal melanin are a function of its chemical composition, stable radical presence and spatial arrangement. Pigment Cell and Melanoma Research, 21, 192–199.; [3] Dadachova, E., Casadevall, A. (2007). Ionizing radiation changes the electronic properties of melanin and enhances the growth of melanized fungi. PLoS ONE, 2(5), e457.; [4] Zhdanova, N. (2004). Ionizing radiation attracts soil fungi. Mycological Research, 108, 1089–1096. ; [5] Zhdanova, N. N., Zheltonozhsky, V., Sadovnikov, L., & Dighton, J. (2006). The influence of ionizing radiation on spore germination and emergent hyphal growth response reactions of microfungi. Mycologia, 98(4), 521–7.; [6] Raup, D. M., & Sepkoski, J. J. (1984). Periodicity of extinctions in the geologic past. Proceedings of the National Academy of Sciences of the United States of America, 81(3), 801–5.; [7] . Gostinčar, C., Muggia, L., & Grube, M. (2012). Polyextremotolerant black fungi: oligotrophism, adaptive potential, and a link to lichen symbioses. Frontiers in Microbiology, 3(November), 390.; [8] Bryan, R., Jiang, Z., Friedman, M., & Dadachova, E. (2011). The effects of gamma radiation, UV and visible light on ATP levels in yeast cells depend on cellular melanization. Fungal Biology, 115(10), 945–9.; [8] Turick, C. E., Ekechukwu, A. A., Milliken, C. E., Casadevall, A., & Dadachova, E. (2011). Gamma radiation interacts with melanin to alter its oxidation-reduction potential and results in electric current production. Bioelectrochemistry, 82, 69–73.; [9] Robertson, K. L., Mostaghim, A., Cuomo, C. a, Soto, C. M., Lebedev, N., Bailey, R. F., & Wang, Z. (2012). Adaptation of the black yeast *Wangiella dermatitidis* to ionizing radiation: molecular and cellular mechanisms. PloS One, 7(11), e48674.; [10] Khajo, A., Bryan, R. a., Friedman, M., Burger, R. M., Levitsky, Y., Casadevall, A., Dadachova, E. (2011). Protection of melanized *Cryptococcus neoformans* from lethal dose gamma irradiation involves changes in melanin's chemical structure and Paramagnetism. PLoS ONE, 6(9), e25092; [11] Dadachova, E., Bryan, R. A., Howell, R. C., Schweitzer, A. D., Aisen, P., Nosanchuk, J. D., & Casadevall, A. (2008). The radioprotective properties of fungal melanin are a function of its chemical composition, stable radical presence and spatial arrangement. Pigment Cell and Melanoma Research, 21, 192–199.