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Fungi in hot and cold deserts with particular reference to microcolonial fungi

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ABSTRACT

The occurrence of fungi in soils of the hot deserts and the dry areas of the Antarctic and Arctic are described. A number of filamentous fungi and yeasts have been documented from both – the hot and cold habitat – however, investigations on the abundance and activity of the filamentous hyphomycetes isolated are still missing. There is striking evidence that many ubiquitous species just survive in hot desert soil by their spores, however, without any physiological activity. There is also reasonable suspicion that man-made contamination of the Antarctic deserts might be the reason for finding a broad distribution of *Penicillium* and other ubiquitous fungi in soil and air. Basidiomycetous yeasts are reported to be endemic in the dry valley of Antarctica. Unrivaled conquerors of the desert environment are black, microcolonial fungi that are part of the epi- and endolithic community in hot and cold arid and semi-arid habitats. These fungi are one of the most stress-tolerant eukaryotic life forms on Earth.

Introduction

For a long time desert regions including the hot deserts of North America (Great Basin Desert), Africa (Sahara desert, Kalahari desert), Asia (Gobi desert), the Middle East (Syrian desert), Australia (Great Victoria desert) as well as the permafrost environments up to the cold, dry valleys of Antarctica, Arctic and Patagonia were believed to be too hostile for any forms of life (Cary *et al.* 2010). Today, we know that deserts are full of life with representatives of all domains and throughout all kingdoms of life (Cockell *et al.* 2001). Doubtlessly, deserts together with the deep biosphere provide the most extreme conditions for life on Earth and triggered manifold adaptation mechanisms in plants, animals and micro-organisms (Navarro-Gonzales *et al.* 2003; Direito *et al.* 2011).

The main and most important stress factors in desert regions are: (1) the constant or temporal matric stress due to the extremely limited availability of water; (2) the extreme temperatures and temperature changes; (3) the limited availability of organic carbon; (4) high ultraviolet and infrared irradiation; and (5) osmotic stress whenever raised amounts of salt are present in the soil or on rock surfaces. Characteristic parameters of some typical deserts are listed in Table 1.

Concerning stress tolerance, bacteria and archaea are regarded as the most extremophilic and extremotolerant organisms on Earth. The so called "Strain 121", growing at temperatures up to 121 °C (Kashefi & Lovley 2003) is regarded a marker for the upper limits of temperature for life; species of the genus "*Deinococcus*" are highly tolerant of radioactivity (Makarova & Daly 2011) and many chemolithotrophic bacteria tolerate pH values down to pH1 or up to pH13 (Huang *et al.* 2011; Sanchez *et al.* 2011). These findings led to the general view that prokaryotes – and especially those that are phylogenetically ancient – are much more extremotolerant than any eukaryotic

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Table 1 – Characteristic climate parameters of selected deserts[a]

Desert name	Location/ description	Precipitation [mm/year]	Temperature [°C]	Soil pH	Relative humidity
McMurdo	Antarctica, dry valley cold desert	Snow 3–50 mm (water equivalent)	Av winter −40 °C Av summer ±0 °C Min −49 °C Max 9 °C	Acidic to alkaline pH 4.1–8.4	58–68 %
Arctic desert	Arctic, cold desert	Snow and rain 150–250 mm	Av winter −34 °C Av summer 3–12 °C	Non acidic to acidic <pH 5.5 to >pH 6.5	50–60 %
Atacama	South America, Chile	0.6–2.1 mm some regions without rainfall for years	Av 22 °C (day) and 4 °C (night) not much variation between summer and winter	Acidic > pH 2.0	1.9–3.1 % during the day up to 27 % during the night
Negev	Middle East, Israel	31–200 mm	Av winter 14.2 °C Av summer 25.7 °C max 45 °C min −5 °C	7.6–8.0	<35–40 %
Mojave desert	North America	120 mm	Av winter 12 °C Av summer 30 °C Max 49–54 °C Min 8 °C	Alkaline > pH 8.0	<40 %, occasionally higher after rain events

a Sources: Fountain et al. 2009; Piacentini et al. 2003; Danmarks Meteorologiske Institut, Center for Ocean and Ice; Fricke et al. 2011; Dose et al. 2001; Wilhelm et al. 2011; Walker et al. 1998; Desert Studies Center, California State University.

life form known today. However, all these extremophilic bacteria and archaea live in the aqueous environments or in biofilms formed at the interface between a solid substratum and the aqueous phase, for example, thermal springs, deep sea sediments or alkaline lakes. Nearly all taxa of bacteria and archaea – with the exception of some cyanobacteria (Danin 1983; Buedel et al. 2009a, b) – need a relatively constant level of water potential beyond −14.5 MPa. The real challenge to survive in the desert environment is desiccation and neither bacteria nor archaea are specialists of survival under conditions of matric water stress. Some regions in one of the driest and Mars-like environments on Earth – the area around the Yungay station of the hyperarid Atacama desert (Chile) – are nearly free of any cultivable bacteria. In contrast several hyphomycetes survive in this region in a re-cultivable state by the formation thick-walled spores (Conley et al. 2006). Some fungi, thus, are really specialized to survive states of complete desiccation, by thick-walled spores, and also to thrive – albeit growing slowly – at extremely low levels of water availability.

Fungi existing in desert areas can be clustered in four main ecological groups: (1) terricolous, epi- and endolithic lichens with ascomycetous and – less frequent – basidiomycetous mycobionts in hot and cold deserts have been extensively studied and reported (Nienow & Friedmann 1993; Wirth 2010; Dojani et al. 2011); (2) fungi associated with plants as phylloplane fungi or in mycorrhizal associations – even truffles are able to grow in the Australian outback and the African Kalahari (Trappe et al. 2008, 2010); (3) free living hyphomycetes and yeasts living in the soil; and (4) microcolonial fungi (MCF) living as endo- and epilithic fungi. Lichenized and mycorrhizal fungi differ widely from free living hyphomycetes and MCF, both ecologically and in their phylogenetic position and will not be discussed here. The focus of the review is on fungi in groups (3) and (4), i.e. non-symbiotic fungi able to cope with desert conditions without the support of plant, algal or cyanobacterial partners.

Biodiversity of fungi in desert soil

The number of mycological studies on desert soil is rather limited. Several authors assume the diversity of microbes including fungi is low compared to soil in moderate or tropical regions. For this reason they suggest these extreme ecosystems as suitable *in-situ* models to study the relationship between phylogenetic biodiversity and function (Adams et al. 2006). Other taxonomic studies demonstrate that the fungal diversity in the soil is remarkably high (Mulder & El-Hendawy 1999; Ciccarone & Rambelli 2000). 185 species were found in the hot desert soil of Makhtesh Ramon desert (Israel) (Grishkan & Nevo 2010). The desert soil myco-biota was dominated by imperfect ascomycetes in all studies, with a clear dominance of the genus *Aspergillus* in many of them. In desert soils from Saudi Arabia and Libya *Aspergillus amstelodami*, *A. chevalieri*, *A. ruber*, *A. ochraceous*, *A. fumigatus*, *A. flavus*, *A. sydowii*, *A. terreus* and *A. ustus* were the most common species (Abdel-Hafez 1982, 1994). The teleomorph genera *Emericella* (*E. nidulans*) and *Eurotium* – with *E. amstelodami* and *E. chevalieri* – and *Chaetomium* are common in desert soils. Many so called "dematiaceous fungi" with darkly-pigmented and rigid-walled spores like *Cladosporium*, *Stachybotrys* and *Pleospora* are frequently found, although to a lesser extent than *Aspergillus* and *Eurotium* (El-Said & Saleem 2008). Species with large spores, like *Alternaria*, *Ulocladium* and *Drechslera* are also frequently found. Some, but not all of the fungi found in hot deserts, are thermophilic comprising ascomycetes and zygomycetous genera, including *Mucor* and *Rhizomucor* (e.g. *Mucor miehei*, *M. thermohyalospora*, *M. thermoaerospora*, *Rhizomucor tauricus* and *R. pusillus*) as well as perfect Ascomycota (*Talaromyces thermophilus*) and imperfect Ascomycota as *Remersonia thermophila* and *Stilbella thermophila* (Mouchacca 1997, 2007). Conley et al. (2006) reported the following 12 genera of fungi isolated from the driest locations on Earth – the Atacama