Soil micromycete diversity in the hypersaline Dead Sea coastal area, Israel

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In the present study, a soil microfungal community was examined over a one-year period (1999-2000) at the western shore of the Dead Sea. A total of 78 species from 40 genera were isolated. The most prominent features of mycobiota of the territory studied were: (i) the prevailing number of melanin-containing micromycetes (46 species, 65.5 % of the total isolate number); (ii) a large share of teleomorphic Ascomyceta (26 species, 18.5 % of isolates); (iii) combination of true soil and plant surface inhabiting species; (iv) spatial and temporal variation of the mycobiota composition; (v) very low fungal density (nearly 500-fold lower than in the Judean Desert soil). These features are formed under the extremely stressful xeric and oligotrophic conditions in which the Dead Sea coastal micromycete community exists. Nine species (*Alternaria alternata, A. raphani, Aspergillus niger, Aureobasidium pullulans, Chaetomium globosum, Ch. murorum, Cladosporium cladosporioides*, *Penicillium aurantiogriseum,* and *Stachybotrys chartarum*) were considered a characteristic micromycete complex for the Dead Sea coastal habitat based on the spatial and temporal occurrence of these species. Many of the micromycetes isolated, including almost all the species listed above, are known to be distributed worldwide occurring in different soil types. This confirms the conclusion of many mycologists working in areas with saline and arid soils that there is no halo- and thermophilous mycobiota characteristic for those soils.

Biodiversity in extreme habitats attracts great attention among researchers because the study of these systems can increase our understanding of the relationship between organisms and their environment, and the unraveling of mechanisms of their adaptation to extreme conditions (HORIKOSHI & GRANT 1998, OREN 1999). The Dead Sea (DS) area is a unique and one of the most stressful habitats in the world (with respect to hypersalinity), so all kinds of biological studies here are of supreme interest and importance.

The Dead Sea is located in the Syrian-African Rift Valley, between Israel and Jordan, in the lowest place in the world (400 m below sea level). Its water is hypersaline, 340 g/l total dissolved salts (STILLER & NISSENBAUM 1999), and has a very low water activity of < 0.669 (KRUMGALZ & MILLERO 1982). The Dead Sea is surrounded by the Judean and eastern Moav deserts, and the climate of this region is arid, with a mean annual rainfall near 60 mm and a mean temperature of the hottest and coldest months at 32–35 ºC and 14–16 ºC, respectively (ATLAS OF ISRAEL 1985). The DS coastal sand is high in salinity (up to 50% of the DS water in the near-water localities), with a pH near neutral or slightly alkaline (DAN et al. 1976). In such an environment, a combination of long-term high temperature and continuous hypersaline and oligotrophic conditions is extremely stressful and must greatly influence the mycobiota.

Mycological studies of the DS coastal sand started recently, with 47 micromycete species identified (GUIRAUD et al. 1995, STEIMAN et al. 1995, 1997, VOLZ & WASSER 1995). A survey of the DS water mycobiota also found 56 species in this hostile environment (BUCHALO et al. 1998, 1999, 2000a, b, KIS-PAPO et al. 2001). The purpose of our present investigation is to examine the soil microfungal community of the DS coastal area. It is the first study devoted not only to the survey of fungal species composition, but to the investigation of adaptive mycobiota features formed under extremely stressful and selective conditions of the area studied.

Material and methods

Sampling. The samples were collected at seven different sites along the western shore of the Dead Sea (Fig. 1) at four times during 1999–2000: in February, June, September 1999 and February 2000. The sampling scheme was the same as for the Dead Sea water mycological study (KIS-PAPO et al. 2001).

The sample series consisted of (i) sand 3–15 m inland from the DS water (2 samples at each station); (ii) mineral mud

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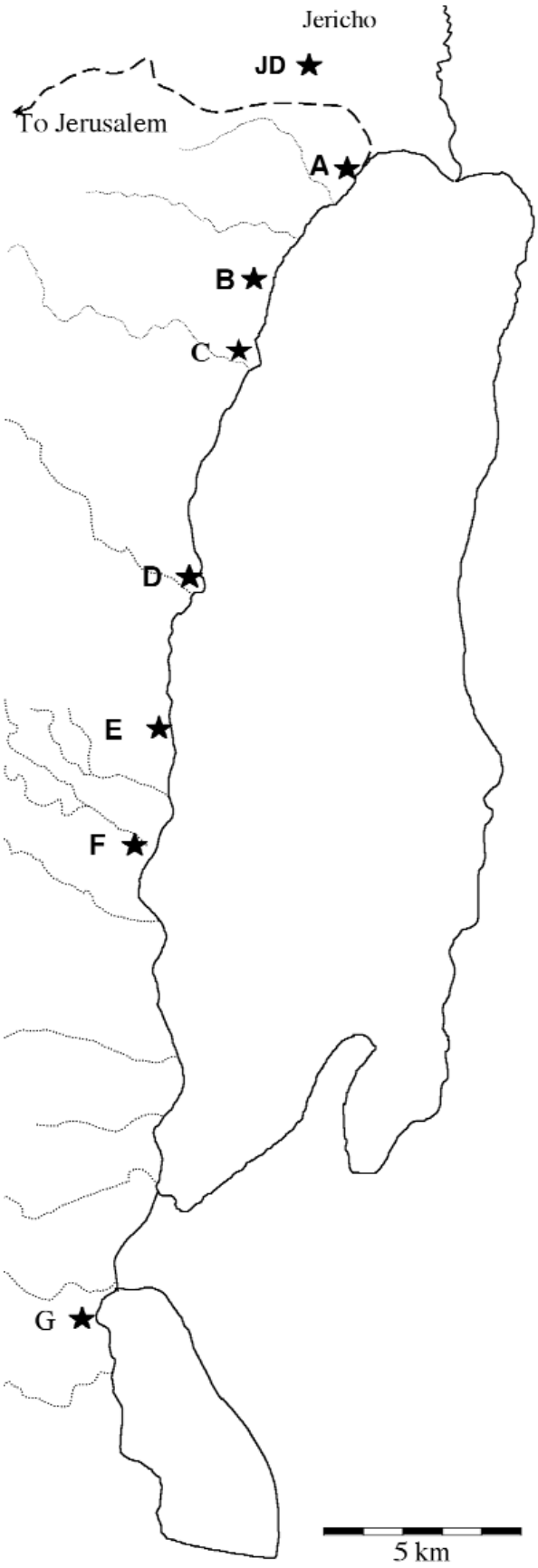

Fig. 1. Map of the Dead Sea area showing sampled locality in the Judean Desert (JD) and seven sampled coastal localities: A – Kalya Beach; B – Enot Zuqim; C – Nahal Mazen; D – Layered Beach; E – Kedem Ravine; F – En Gedi; G – The southern end.

3–5 m inland from the DS water (stations A, B, where this substrate is located; 1 sample at each station). The first sample series (February 1999) also consisted of (i) soil under bushes (mainly *Anabasis articulata*) in the adjacent area of the Judean Desert (3 km from the northern part of DS): 4 samples; (ii) soil under vegetation (*Alhagi maurorum, Desmostachya bipinnata, Phoenix dactilifera*) near a fresh water spring at the Enot-Zuqim Oasis (about 200 m inland from the DS water): 2 samples.

Samples were collected from the upper layer of substrates (1–3 cm deep). At each microlocality, 5 subsamples from the plot of 25 cm^2 were combined into a single pooled sample (20–30 g).

Altogether, 70 samples were taken from the studied area. The samples were stored before processing (1–5 days) in a dry place.

Fungal isolation and identification. Micromycetes were isolated by means of soil dilution plate method (Davet & Rouxel 2000) (1:5 or 1:10 by weight for sand and mud samples, 1:1000 for soil samples from the Judean Desert and the locality near the fresh water spring; 10 g of each sample were suspended in sterile water). Two culture media were used (both of SIGMA production): malt extract agar (MEA) prepared in distilled water, and Czapek's agar (CzA) prepared in a mixture of 20 % DS water and 80 % distilled water. CzA with DS water in this range was used as suitable medium for isolation and growth of halotolerant and halophilic species. Streptomycin (100 mg/mL) was added to each medium to suppress bacterial growth. One mL of sample suspension was mixed with the agar medium of the temperature near 40 ºC in Petri dishes of 90-mm diameter. The plates were incubated at 25 ºC and 37 ºC in darkness for 2–4 weeks (3 plates for each medium and temperature). After incubation, the emerging fungal colonies were transferred for purification on MEA (non-halophilic strains) and CzA with 20 % DS water (halophilic strains). Pure cultures of the strains on these media were used for further taxonomic identification.

Taxonomic identification by morphology of fungal isolates was mainly based on the following sources: Arx, Guarro & Figueras (1986), Domsch, Gams & Anderson (1993), Ellis (1971, 1976), Ellis & Ellis (1997, 1998), Gams (1971), Hanlin (1990), Kiffer & Morelet (2000), Morton & Smith (1963), Pitt (1979, 1994), Raper & Fennell (1965), Samson (1979, 1994), Sutton (1980). All names of the *Penicillium* and *Aspergillus* species were cited according to Pitt, Samson & Frisvad (2000).

Data analyses. For all species from the DS coastal area in each sampling period, frequency of occurrence was calculated as percent of samples (from 16 samples collected in each of the designated months) in which a particular species was registered. Analysis of micromycete diversity was based on species richness (number of isolated species), on the Shannon-Weaver index (H) and evenness (J), which were defined as:

$H = -\sum p_i \ln p_i$, where p_i is the probability of finding each species *i* in a sampling plot; $J = H/H_{max}$, where H_{max} is the maximum value of diversity for the number of species present (*S*); ($H_{max} = \ln S$) (PIELOU 1975).

Density of fungal isolates was expressed in "colony forming units" (CFU) per g dry substrate. This characteristic usually includes a number of colonies arising from spores and from hyphal fragments, and so can hardly be interpreted. But we could safely assume that in such a hostile environment as the DS shore the great majority of micromycetes (if not all) exist in dormant spore state, because only a few xerophilic species can germinate and produce mycelium when water activity is less than 0.80 (HOCKING 1993). Thus, the number of CFU may reflect the actual situation with micromycete density in the studied area.

Statistical analysis was conducted using STATISTICA (StatSoft, Inc., Tulsa, USA, 1996). We used the non-parametric Wilcoxon matched pair test to compare data on densities of fungal isolates, and biodiversity characteristics. The correlation of species richness and density data with the DS water salinity was estimated by the Pearson correlation test.

Results

Species composition. The mycobiota of the DS shore studied here contained a total of 78 species (607 isolates) belonging to 40 genera: Zygomycota (1 species), Ascomycota (63 species from 29 genera; 26 species from 13 genera are teleomorphic), and mitosporic fungi (16 species from 10 genera) (Tab. 1). The prevailing genera were *Aspergillus* (11 species, 20.5 % of the total isolate number), *Chaetomium* (11, 8.3 %), *Penicillium* (8, 10.3 %), *Alternaria* (4, 8.6 %). The most abundant species were: *Cladosporium cladosporioides* (102 isolates), *Aspergillus niger* (52), *A. fumigatus* (40), *Aureobasidium pullulans* (33), *Alternaria alternata* (27), *Penicillium aurantiogriseum* (27), *Chaetomium globosum* (26). Fifty-three sterile isolates were also recovered. We isolated 26 and 15 species from the Judean Desert soil and the soil near the fresh water spring, respectively (Tab. 2).

The majority of micromycetes in our study were isolated on MEA at 25 ºC, even *Aspergillus egyptiacus* that was described as osmophilic and thermophilic species (SAMSON & MOUCHACCA 1974). But eight species (*Aspergillus flavipes, A. fumigatus, A. proliferans, Chaetomium nigricolor, Helicodendron tubulosum, Microascus trigonosporus, Pseudeurotium zonatum, Thielavia terricola*) were recovered only at 37 ºC, and three, *Aspergillus niger, A. terreus*, *Chaetomium seminudum*, mainly at 37 ºC (60–82 % of isolates of these species). We isolated only six micromycetes, which grew much more successfully on CzA with 20 % DS water – speed of their colony growth on MEA was 1.8–2.5 fold lower, with spore structures not developed or aborted. These are *Eurotium amstelodami, E. herbariorum, Aspergillus proliferans,* and 3 sterile strains – 2 white and 1 dark-colored; the first three species are known as microfungi of an osmophilic nature (RAPER & FENNELL 1965).

Species richness, biodiversity indices and characteristic group of species. The biodiversity characteristics of the DS coastal mycobiota were low, with an increase in rainfall and milder winter temperatures, when comparing the total meanings over the shore (Tab. 3). This increase however wasn't statistically significant ($p > 0.05$), when comparing the data from each sampling point. Spatially, the highest species richness was registered at the Layered Beach (28 species), the lowest – at the southern end of DS (20) (Fig. 1, localities E and G, respectively). The DS water salinity, which was measured at each locality in our previous study (KIS-PAPO et al. 2001), had a weak influence on the spatial patterning of species richness (Pearson correlation coefficient not significant, $r = -0.038$, $n = 28$).

As Table 1 shows, most of the species had low frequency of spatial and temporal occurrence – more than half of them were isolated only from one locality and only once during the period of investigation (40 and 45 species, respectively). Five species were recovered during the entire investigation period, from two or more sampling plots, namely *Alternaria alternata, Aspergillus niger, Chaetomium globosum, Cladosporium cladosporioides*, *Penicillium aurantiogriseum* (they also belong to the most abundant species). These species were isolated by French mycologists from sand on the DS shore (GUIRAUD et al. 1995, STEIMAN et al. 1995, 1997), plus *Alternaria raphani, Aureobasidium pullulans, Chaetomium murorum,* and *Stachybotrys chartarum,* which were also registered in our study in three sampling periods. Accordingly, these nine species (eight of them melanin-containing) may be considered a characteristic group forming a stable core of the DS coastal micromycete community (the species are in bold in Tab. 1).

Density of fungal isolates. The number of micromycete isolates in the DS coastal area had low spatial and temporal variations. The highest CFU number per g dry substrate was obtained from the sand of En Gedi (41.4 ± 5.1), the lowest – from the sand of the southern end of DS (31.5 ± 4.9) (Fig. 1, localities D and G, respectively). Temporally, February and June 1999 were characterized by highest and lowest CFU numbers (41.2 ±7.3 and 32.7 ±6.2, respectively). Like the species richness, the spatial distribution of isolate densities correlated non-significantly with the DS water salinity (Pearson correlation coefficient –0.127, $n = 28$).

The number of colonies isolated on MEA was 1.3-4.5 fold higher then on CzA with the DS water (Wilcoxon test, $p < 0.001$) (our previous studies showed that MEA and ordinary CzA at the same temperature did not display any significant difference on fungal densities). A similar result was obtained when we compared the data on incubations at 25ºC and 37 ºC (2.5–9.3-fold difference, $p < 0.0005$). On the whole, the micromycete density in the DS sand and mud was very low in comparison with the Judean Desert soil (18,500 ±3,100) and the soil near the fresh water spring (10,200 ±2,300).

Tab. 1. Micromycetes from the Dead Sea coastal sand and mud with frequency of occurrence (%) and localities of isolation (in brackets, letters as on the map). Melanin-containing species are underlined, species included in the characteristic group (see text) are boldfaced.

Species	Feb-99	Jun-99	Sept-99	Feb-00	Average
Zygomycota					
Rhizopus oryzae Went et Prins. Geerl.	–	–	–	6 (F)	1.5
Ascomycota (teleomorphic)					
Arthroderma quadrifidum C.O.Dawson et Gentles	12 (D,E)	–	–	–	3
Amphisphaeria millepunctata (Fuckel) Petr.	6 (E)	–	–	–	1.5
Chaetomium aureum Chivers *	–	6 (B)	–	–	1.5
Ch. bostrychoides Zopf	6 (B)	–	–	–	1.5
Ch. cochlioides Pall.	–	6 (C)	–	6 (B)	3
Ch. elatum Kunze ex Steud.	–	–	–	6 (A)	1.5
Ch. globosum Kunze ex Fr.*	**37 (A,B,C,E,G)**	**25 (C, E, F)**	**12 (B,C)**	**25 (B,D,F)**	**25**
Ch. gracile Udagawa	–	–	–	6 (D)	1.5
Ch. murorum Corda	**12 (E,F)**	**–**	**12 (A,F)**	**12 (C,D)**	**9**
Ch. nigricolor L.M. Ames *	–	6 (G)	6 (D)	–	3
Ch. olivaceum Cooke et Ellis	–	–	–	6 (C)	1.5
Ch. seminudum L.M. Ames	–	–	18 (F,G)	–	4.5
Ch. succineum L.M. Ames	–	–	12 (F,H)	–	3
Coniochaeta pulveracea (Ehrh.) Munk	–	–	–	6 (G)	1.5
Emericella acristata (Fennel et Raper)Y. Horie	–	–	6 (E)	–	1.5
Eupenicillium egyptiacum (T.H. Beyma) Stolk et D.B. Scott	6 (G)	–	–	6 (A)	3
Eurotium amstelodami L. Mangin *	6 (D)	–	–	–	1.5
E. herbariorum (Wigg.) Link ex Gray *	–	–	–	12 (A,B)	3
Gymnoascus reesii Baran.	–	–	–	6 (B)	1.5
Microascus trigonosporus C.W. Emmons et B.O. Dodge	–	–	6 (F)	–	1.5
Pleospora herbarum (Pers.: Fr.) Rabenh. (with *Stemphylium* anamorph)	12 (C,D)	–	–	–	3
P. pellita (Fr.) Rabenh.	6 (C)	–	–	–	1.5
Pseudeurotium zonatum T.H. Beyma	–	–	–	6 (B)	1.5
Sordaria fimicola (Roberge) Ces. et De Not.	–	12 (C)	–	12 (B,C)	6
Sporormiella australis (Speg.) S.I. Ahmed et Cain	–	–	6 (C)	–	1.5
Thielavia terricola (J.C. Gilman et E.V. Abbott) C.W. Emmons *	–	6 (E)	–	31 (B,C,E,F)	9
Ascomycota (anamorphic)**					
Alternaria alternata (Fr.) Keissl. *	**12 (C,E)**	**25 (A,B,E)**	**12 (B,E)**	**37 (A,B,D,E,G)**	**21.5**
A. chlamydospora Mouch.	12 (D,G)	–	–	–	3
A. dianthi F. Stevens et C.J.J. Hall	–	6 (A)	–	–	1.5
A. raphani J.W. Groves et Skolko	**18 (C,D,G)**	**–**	**6 (E)**	**25 (A,B,F,G)**	**12**
Arthrinium phaeospermum (Corda) M.B. Ellis	–	6 (D)	–	–	1.5
Aspergillus awamori Nakaz.	–	–	12 (F)	–	3
A.candidus Link	–	6 (G)	–	–	1.5
A. egyptiacus Moubasher et Mustafa	–	–	12 (C,E)	–	3
A. flavipes (Bainier et Sartory) Thom et Church	6 (F)	6 (A)	–	–	3
A. flavus Link	–	6 (A)	–	–	1.5
A. fumigatus Fresen. *	12 (E,F)	–	–	12 (A)	6
A. niger Tiegh. *	**31 (B,C,D,F)**	**37 (A,C,F,G)**	**50 (A,B,D,E,G)**	**18 (B,F,G)**	**34**
A. proliferans G. Sm.	6 (D)	–	–	–	1.5
A. terreus Thom *	6 (A)	–	6 (F)	12 (G)	6
A. versicolor (Vuill.) Tirab. *	–	6 (E)	6 (C)	–	3
A. wentii Wehmer	6 (D)	–	6 (F)	12 (A,B)	6

Tab. 1. Continued

Species	Feb-99	Jun-99	Sept-99	Feb-00	Average
Botrytis cinerea Pers. ex Nocca et Balb.	6 (C)	–	–	–	1.5
Cladosporium cladosporioides (Fresen.) G.A. de Vries *	**25 (A,B,D,E)**	**37 (A,B,E, F,G)**	**31 (B,D,E, F,G)**	**44 (A,B,C, D,E,F)**	**34**
Coniothyrium fuckelii Sacc.	6 (D)	–	6 (E)	–	3
Curvularia clavata B.L. Jain	6 (F)	–	–	–	1.5
Dematophora necatrix R. Hartig	–	–	–	6 (C)	1.5
Drechslera hawaiiensis (Bugnic.) Subram., B.L. Jain et M.B. Ellis	–	–	6 (A)	6 (F)	1.5
D. rostrata (Drechsler) M.J. Richardson et E.M. Fraser	–	–	6 (C)	–	1.5
Fusarium oxysporum Schltdl.	–	12 (C,D)	–	18 (A,D)	7.5
Nigrospora oryzae (Berk. et Broome) Petch	–	–	6 (D)	12 (C)	4.5
Paecilomyces farinosus (Holm ex Gray) A.H.S. Brown et G. Sm. *	–	–	–	6 (D)	1.5
Penicillium adametzii K.M. Zalessky	–	–	–	6 (A)	1.5
P. aurantiogriseum Dierckx	**12 (D,F)**	**12 (A)**	**6 (F)**	**25 (A,B,F)**	**14**
P. brevicompactum Dierckx *	–	–	–	12 (A)	3
P. chrysogenum Thom *	6 (G)	–	–	–	1.5
P. fellutanum Biourge *	–	6 (D)	–	–	1.5
P. glabrum (Wehmer) Westling	–	12 (D,F)	–	–	3
P. herquei Bainier et Sartory	–	6 (A)	–	6 (F)	3
P. lanosum Westling	–	6 (A)	–	12 (A)	4.5
Phoma cava Schulzer.	12 (F,G)	–	–	–	3
Trichoderma harzianum Rifai	–	–	–	6 (A)	1.5
Mitosporic fungi					
Acremonium persicinum (Nicot) W. Gams *	6 (A)	–	–	–	1.5
A. strictum W.Gams	–	–	6 (G)	–	1.5
A. terricola (Miller et al.) W. Gams *	12 (D,F)	12 (D)	–	–	6
Aureobasidium pullulans (de Bary) G.Arnaud*	**18 (B,G)**	**12 (B,D)**	**12 (C,E)**	–	**10.5**
Cheiromycella microscopica (Karst.) Hughes	–	–	6 (D)	–	1.5
Helicodendron tubulosum (Riess) Linder	–	6 (C)	–	–	1.5
Phialophora sp.	–	–	6 (D)	–	1.5
Rhinocladiella sp.	6 (E)	–	–	–	1.5
Scytalidium lignicola Pezante	6 (G)	–	6 (F)		3
Stachybotrys chartarum (Ehrenb. et Link) S.Hughes *	**12 (E,G)**	**12 (B,E)**	–	**6 (B)**	**7.5**
Torula herbarum Pers. ex Gray	–	6 (F)	–	–	1.5
Ulocladium atrum Preuss *	6 (G)	12 (B,E)	–	–	4.5
U. botrytis Preuss	–	–	–	6 (B)	1.5
U. chlamydosporum (Preuss) Simmons *	6 (C)	–	–	–	1.5
U. consortiale (Thum.) Simmons	–	–	6 (A)	6 (A)	3
Mycelia sterilia, dark-colored	31 (A,B, D,E,G)	18 (C,E,F)	37 (A,B, D,E,F,G)	44 (C,D, E,F,G)	31
Mycelia sterilia, light-colored	25 (B,C,F)	25 (C,E,D,	18 (A,F,G)	31 (C,D,E,G)	25

* species found in the DS water (Buchalo et al. 1999, 2000 a,b, Kis-Papo et al. 2001);

** according to the system in Kirk et al. (2001)

Tab. 2. Soil micromycetes from the samples taken in February, 1999

Species	Coastal sand and mud	Judean Desert soil	Soil near fresh water spring
Zygomycota			
Rhizopus oryzae	–	+	–
Ascomycota (teleomorphic)			
Arthroderma quadrifidum	+ (D,E)	–	–
Amphisphaeria millepunctata	+ (E)	–	–
Chaetomium bostrychoides	+ (B)	–	–
Ch. globosum	+ (A,B,C,E,G)	–	–
Ch. murorum	+ (E,F)	–	–
Eupenicillium egyptiacum	+ (G)	–	–
Eurotium amstelodami	+ (D)	–	–
Pleospora herbarum (with *Stemphylium* anamorph)	+ (CD)	*Stemphylium* anamorph only	–
P. pellita	+ (C)	–	–
Ascomycota (anamorphic)			
Alternaria alternata	+ (C,E)	–	–
A. chlamydospora	+ (D,G)	+	–
A. raphani	+ (C,D,G)	–	–
Aspergillus egyptiacus	–	+	–
A. granulosus Raper et Thom	–	+	–
A. flavipes	+ (F)	–	–
A. fumigatus	+ (E,F)	+	–
A. niger	+ (B,C,D,F)	–	–
A. proliferans	+ (D)	–	–
A. terreus	+ (A)	–	–
A. versicolor	–	+	+
A. wentii	+ (D)	–	+
Beauveria alba (Limber) Saccas.	–	+	–
Botryotrichum piluliferum Sacc. et Marchal	–	+	+
Botrytis cinerea	+ (C)	+	–
Chrysosporium luteum (Costantin) Carmich.	–	+	+
Cladosporium cladosporioides	+ (A,B,D,E)	+	+
Colletotrichum coccodes (Wallr.) S. Hughes	–	+	+
Coniothyrium fuckelii	+ (D)	–	–
Curvularia clavata	+ (F)	–	–
Fusarium oxysporum	–	+	–
F. solani (Mart.) Sacc.	–	–	+
Penicillium aurantiogriseum	+ (D,F)	+	+
P. chrysogenum	+ (G)	+	+
P. janthinellum Biourge	–	+	–
P. lanosum	–	+	–
P. fellutanum	–	+	+
Phoma cava	+ (F,G)	–	–
P. exigua Desm.	–	+	–
Scopulariopsis candida (Gueg.) Vuill.	–	+	–
Mitosporic fungi			
Acremonium charticola (Lindau) W. Gams	–	+	–
A. persicinum	+ (A)	–	+
A. terricola	+ (D,F)	–	–
Aureobasidium pullulans	+ (B,G)	–	+
Camarosporium sp.	–	–	–
Monocillium tenue W. Gams	–	–	+
Papulaspora sepedonioides Preuss	–	+	–
Rhinocladiella sp.	+ (E)		
Scytalidium lignicola	+ (G)	–	–
Stachybotrys chartarum	+ (E,G)	+	+
Ulocladium atrum	+ (G)	+	+
U. botrytis	–	+	–
U. chlamydosporum	+ (C)	+	–

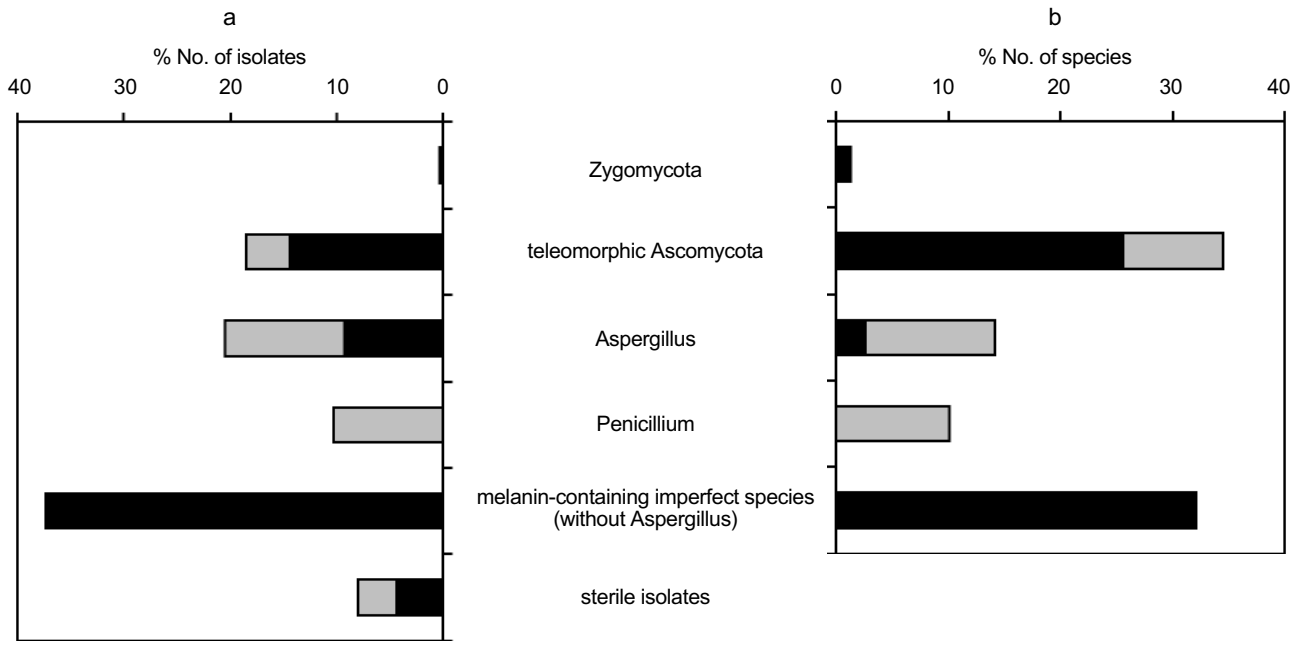

Fig. 2. Main groups of microfungi (a. % of total isolate number, b. % of general species number) in the Dead Sea coastal mycobiota. Black bars indicate the proportion of melanin-containing isolates (a) and species (b)

Tab. 3. Biodiversity data of the Dead Sea coastal micromycete communities

Locality	Number of species				Shannon index				Evenness			
	F-99	J-99	S-99	F-00	F-99	J-99	S-99	F-00	F-99	J-99	S-99	F-00
Kalya Beach	6	9	6	14	1.308	1.615	1.427	1.964	0.730	0.735	0.796	0.744
Enot Zuqim	7	6	6	14	1.254	1.167	1.386	1.812	0.644	0.651	0.773	0.687
Nahal Mazen	9	8	6	9	1.543	1.417	1.402	1.513	0.702	0.686	0.782	0.687
Layered Beach	13	7	8	8	1.918	1.211	1.203	1.316	0.748	0.622	0.579	0.633
Kedem Ravine	9	10	8	6	1.609	1.586	1.478	1.308	0.732	0.689	0.711	0.730
En Gedi	9	7	12	9	1.543	1.375	1.873	1.596	0.702	0.707	0.754	0.726
The southern end	11	6	6	7	1.753	1.218	1.106	1.158	0.731	0.680	0.617	0.595
All shore	34	27	28	35	2.174	1.712	1.635	1.994	0.606	0.507	0.485	0.551

Discussion

As seen in Fig. 2, the characteristic features of the mycobiota of the DS shore constitute the prevailing number of melanin-containing micromycetes (65.5 % of isolates from 26 imperfect species and 20 teleomorphic ascomycetes – they are underlined in Tab. 1), and the large share of teleomorphic ascomycetes (18.5 % of isolates from 26 species, only six of them have teleomorphic and anamorphic stage). In the characteristic micromycete group, eight of the ten species are melanin containing, and two - teleomorphic.

Similar trends in the mycobiota structure can be observed when analyzing the lists of species isolated from the DS area (GUIRAUD et al. 1995, STEIMAN et al. 1995, 1997) and from the salt marshes of Kuwait (MOUSTAFA 1975). In the desert, dematiaceous microfungi appear to be a characteristic group of soil mycobiota (CHRISTENSEN 1981), and such species as *Alternaria alternata, Stachybotrys chartarum, Cladosporium cladosporioides, Aspergillus niger, Ulocladium* spp, *Dreshlera* spp. are among the most frequent and abundant micromycetes (e.g. BORUT 1960, EL-SAID 1994, HASHEM 1991, MOUBASHER et al. 1990).

It is well known that the dilution plate method widely used in soil mycological investigations favors isolation of heavily sporulating fungi (*ruderal*-selected, according to the definitions of the theory of fungal life-history strategies – see ANDREWS 1992; DIX & WEBSTER 1995), and in forest soils, representatives of the genera *Penicillium, Trichoderma, Mu-*

cor usually overdominate micromycete communities. But in highly stressful habitats, such as the DS coastal area, expansive *ruderal*-selected fungi lose their dominant position, and the contribution of slower-reproducing but *stress*-selected micromycetes (such as most of melanin-containing species) in the community structure becomes much more significant.

In their general features, sexual species also fit the definition of *stress*-selected fungi. They mainly have non-rapid reproduction rate and frequently possess special enzyme activities (keratinolytic, cellulolytic, coprolytic, etc). In favorable nutrient, temperature, and moisture (water availability) soil conditions they need special isolation methods (soil heating, various bait techniques, etc). For example, in our present study, all 32 species isolated from the winter soil samples taken in the Judean Desert and near the fresh water spring were imperfect (Tab. 2). But from the DS sand and mud, the keratinophilic *Arthroderma quadrifidum*, the coprophilous *Sordaria fimicola, Sporormiella australis*, and 11 species of the cellulolytic genus *Chaetomium* were easily isolated by means of the dilution plate method; *Chaetomium* was also significantly represented in soil of the Dead Sea area (13 species, STEIMAN et al. 1995), in the salt marshes of Kuwait (8 species, MOUSTAFA 1975), in surface organic horizons of coastal sands and salt marshes in Britain (12 species, APINIS & CHESTERS 1964). Two species of *Pleospora, Amphisphaeria millepunctata,* and *Coniochaeta pulveracea,* well known on dead parts of various plants (ELLIS & ELLIS 1997), but not in soil, were also recovered; we found only two references on rare isolation of *Pleospora* species from soil – *P. tarda* in soil of Bahreen (EL-SAID 1994) and *P. richtophensis* in biological soil crusts of Utah (STATES & CHRISTENSEN 2001). According to DOMSCH, GAMS & ANDERSON (1993), the perithecia of *Pleospora herbarum* mature *in vitro* in 2–12 months at low temperatures, but we obtained them in pure culture on MEA in 3-4 weeks at 25 ºC.

In our study concerning the relationship between ecological stress and sex evolution in soil microfungi (GRISHKAN et al. 2003), we showed a highly significant trend of increasing proportion of sexuals in mycobiota composition with increasing aridity/salinity stress southwards in Israel. Among the surveyed sites, this proportion climaxed in the most stressful DS coastal area. The above data are in accordance with the concept that perfect fungi have high adaptive plasticity in a highly stressful environment, which is associated with sexual reproduction. This is important for the long-term adaptive success of species because it may provide an efficient mechanism for producing novel variants able to colonize new niches (e.g., ANDERSON, KOHN & LESLIE 1992, TAYLOR, JACOBSON & FISHER 1999). Another advantage of teleomorphic ascomycetes (at least in comparison with hyphomycetes) is morphological, because they produce fruit bodies, which protect ascospores from harmful influence of external factors (most of ascomycetes isolated in the present study have thick-walled dark brown or black perithecia). In such conditions, ascospores carry out both dispersal and resting functions, i.e., have a combination of memnospore and xenospore characteristics (DIX & WEBSTER 1995), likewise with the melanin-containing multicelled conidia of asexual micromycetes: almost 30 % of the isolated imperfect species have such conidia.

The studied mycobiota of the DS shore includes a relatively small number of true soil micromycetes from the genera *Acremonium, Fusarium, Penicillium*, *Trichoderma*, and zygomycetous species. Only the genus *Aspergillus* was abundantly represented (11 species, 20.5% of isolates), and it is considered one of the most characteristic taxa of arid mycobiotas (e.g., DOMSCH, GAMS & ANDERSON 1993, KLICH 2002) and mycobiotas of saline soils (e.g., ABDEL-HAFEZ 1981, ABDEL-HAFEZ et al. 1977, MOUBASHER et al. 1990, MOUSTAFA 1975). More than a third of the mycobiota is composed of melanin-containing microfungi, which occur on various plants (mainly hyphomycetes). Some of these species were known only as phylloplane inhabiting fungi (ELLIS 1971, 1976, SUTTON 1980). A similar feature of mycobiota composition was noted in the mycological study of mudflats in Kuwait (EL-WAHID, MOUSTAFA & KHORAWI 1982). Some parallelism is thus apparent in the development of micromycete communities on different substrates, namely plant surface (at least at the first stages of its colonization) and hypersaline sand, because both these highly stressful environments are inhabited by stress-selected species, which are tolerant to harsh climate (high temperature and radiation, low water potential) and limited nutrient supply.

On the whole, the mycobiota obtained in this study consisted mostly of halo- and thermotolerant rather than halo- and thermophilic species. This statement is based on the above data that (i) only 8 species out of 78 were isolated at 37 ºC; (ii) only 3 species and 3 sterile strains required medium with 20 % of DS water for their successful growth; (iii) the density of fungal colonies isolated on non-saline medium and at 25 ºC were much higher than on medium with DS water and at 37 ºC. These results agree with the conclusion of mycologists working in areas with saline and arid soils that there is no mycobiota specific for these soils (EL-MORSY 1999, EL-WAHID, MOUSTAFA & KHORAWI 1982, MOUSTAFA 1975, STEIMAN et al. 1995). A similar absence of specific acido- and psychrophilous mycobiota were found in very acidic (pH 3.4-3.6) cold permafrost peat soils in the Upper Kolyma River Basin (northeastern Russia) (GRISHKAN & BERMAN 1992). Micromycete species from saline soils can display the ability to grow under high salt concentration (e.g., TRESNER & HAYES 1971) or under relatively low oxygen tensions if we are referring to mud micromycetes (EL-WAHID, MOUSTAFA & KHORAWI 1982). Some of these species have been found in the DS water (BUCHALO et al. 1999, 2000a, b, KIS-PAPO et al. 2001). But many microfungi isolated in the present investigation are known to be distributed worldwide (DOMSCH, GAMS & ANDERSON 1993) and occur in different soil types. This fact likewise is in agreement with the experimentally proven finding that some micromycetes (mainly melanin-containing) are able

to change their behavior and grow as *R*-strategists or *S*-strategists, depending on the environmental conditions (ZHDANOVA, BORISYUK & ARTZATBANOV 1990).

In summary, the present investigation showed that the mycobiota of the Dead Sea coastal area is characterized by spatial and temporal variation and has evolved under extremely stress-ful conditions. The adaptive features of the DS shore mycobiota are predominance of melanin-containing micromycetes, a large number of teleomorphic ascomycete species, and the combination of true soil and phylloplane inhabiting microfungi. However the mycobiota cannot be characterized as specifically halo- and thermophilous because many of the species (among them almost all species included in the characteristic micromycete complex) are cosmopolitan and occur in different soil types. Our results and those of previous investigations suggest that many species in mycobiotas of extremely hostile environments, such as the DS coastal area, are organisms adapted to long- or short-term survival in stressful conditions, but are not extremophilic organisms. It mithz be desirable in future studies to access their genetic distances and levels of novel speciation.

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