



Structure of soil fungi complexes associated with rhizosphere of woody plants of the Zailisky Alatau (Kazakhstan)

Rakhimova YV, Assylbek AM, Yermekova BD, Kyzmetova LA, Jetigenova UK

Institute of Botany and Phytointroduction, Almaty, Kazakhstan

Rakhimova YV, Assylbek AM, Yermekova BD, Kyzmetova LA, Jetigenova UK 2020 – Structure of soil fungi complexes associated with rhizosphere of woody plants of the Zailisky Alatau (Kazakhstan). *Current Research in Environmental & Applied Mycology (Journal of Fungal Biology)* 10(1), 206–223, Doi 10.5943/cream/10/1/21

Abstract

In the rhizosphere of woody plants of the Zailisky Alatau 78 species of soil fungi were found. The largest number of fungal species in the rhizosphere was recorded in the Big Almaty gorge and Turgen. Dominant classes were *Eurotiomycetes*, *Sordariomycetes* and *Zygomycota*. Their percent in Ajusai gorge was 100%, in the Small Almaty gorge – 92.8%, in Turgen – 92.1%, in the Big Almaty gorge – 90.7%, in Prokhodnoe gorge – 72%. The greatest similarity of the species composition of soil fungi was found between the gorges Big Almaty and Turgen, Small Almaty and Prokhodnoe, Small Almaty and Ajusay. A low degree of similarity in species composition was found between the gorges Big Almaty and Ajusay, Big Almaty and Prokhodnoe, Ajusay and Turgen. The most common species in the complexes of soil fungi were *Absidia spinosa*, *Mucor mucedo*, and *Purpureocillium lilacinum*. The largest number of species of soil fungi was found in the rhizosphere of *Picea schrenkiana* (36 species, 22%), slightly less – in the rhizosphere of *Malus sieversii* (18 species, 11%), *Crataegus* spp. (18, 11%) and *Sorbus tianschanica* (19, species, 11%), the smallest – in the rhizosphere of *Quercus robur* (6 species, 4%) and *Pinus sylvestris* (5 species, 3%).

Key words – *Armeniaca vulgaris* – *Betula pendula* – *Crataegus* spp. – *Juniperus* spp. – *Malus sieversii* – *Picea schrenkiana* – *Pinus sylvestris* – *Populus* spp. – *Populus tremula* – *Quercus robur* – *Salix* spp. – similarity – *Sorbus tianschanica* – species composition

Introduction

Zailisky Alatau, the most northern range of the Tien Shan, is located in the southeast of Kazakhstan. Range is almost 380 km long, 30-40 km wide, up to 5017 m above sea level heights. In the east, the ridge breaks up into the mountains of Sugaty, Turaigyr, and Boguty, in the west the continuation of the Zailisky Alatau are the Chu-Ili mountains. The climate is differentiated by high-altitude climatic zones.

Vegetation is characterized with specific spectrum of altitudinal belts: Dzungar-Northern Tien Shan group of zonation types, including subnival vegetation (3300-3600 m a.s.l.), cryophytic (alpinotypic) meadows and cobresniks (2800-3300 m a.s.l.), subalpinotype meadows and dwarf forests (2300-2800 m a.s.l.), dark coniferous forests and meadows (1700-2300 m a.s.l.), small-leaved forests (1400-1700 m a.s.l.), steppes (800-1400 m a.s.l.), and foothill deserts (700-800 m a.s.l.) (Akzhigitova et al. 2003). There is no continuous belt of coniferous forests and alpine tundra

belt in the range. A distinctive feature of Zailisky Alatau ridge is the wide spread of all subtypes of mountain steppes.

The soil mycobiota of the Zailisky Alatau has been poorly studied. Prior to our research the list of soil fungi species in the mixed forests of Zailisky Alatau consisted of only 4 species of micromycetes, 20 species were found in coniferous forests (Schwarzman 1962). In the studies of soil fungi associated with rhizosphere of various woody plants 32 species were identified: in mixed forests in the rhizosphere of *Quercus robur*, *Betula pendula*, *Malus sieversii*, 9 species have been found, in spruce forests in the rhizosphere of *Picea schrenkiana*, *Juniperus* spp., *Sorbus tianschanica* and *Populus tremula* – 24 species (Rakhimova et al. 2018). In addition, 9 species of Zygomycetes belonging to six different genera, were identified; 8 species from mixed forest trees, three species from spruce forests (Rakhimova et al. 2019).

The purpose of this study was to identify the species composition of soil fungi complexes associated with rhizosphere of different woody plants of the Zailisky Alatau.

Materials & Methods

Soil sampling

Soil samples of the coniferous, deciduous and mixed forests of the Zailisky Alatau were collected during the growing seasons of 2018–2019 (April, May, July, and August). Samples were collected randomly in the soil horizon of 5–20 cm, after removal of the top litter layer, in the rhizosphere of various woody plants (*Armeniaca vulgaris* Lam., *Betula pendula* Roth, *B. tianschanica* Rupr., *Crataegus* spp., *Juniperus* spp., *Malus sieversii* (Ledeb.) M. Roem., *Picea schrenkiana* Fisch. et C. A. Mey., *Pinus sylvestris* L., *Populus tremula* L., *Populus* spp., *Quercus robur* L., *Salix* spp., *Sorbus tianschanica* Rupr.). The geographic location of each sample collection site was recorded using digital GPS (Germin). In total, 134 samples were collected (Table 1).

Table 1 Data on soil samples of the forests of the Zailisky Alatau

Samples	Altitude above sea level, m	Latitude, N	Longitude, E	Rhizosphere of
256	1924	43°06'24.1"	76°57'12.8"	<i>Picea schrenkiana</i>
257	1927	43°06'23.8"	76°56'46.4"	<i>Populus</i> spp.
258	1930	43°06'28.7"	76°56'21.2"	<i>Populus</i> spp.
262	1926	43°06'27.1"	76°56'15.9"	<i>Armeniaca vulgaris</i>
263	1937	43°06'22.0"	76°57'11.0"	<i>Picea schrenkiana</i>
264	1923	43°05'50.1"	76°57'30.0"	<i>Betula pendula</i>
265	1923	43°05'53.0"	76°57'23.1"	<i>Malus sieversii</i>
266 a, b	1411	43°08'20.3"	76°54'22.0"	<i>Malus sieversii</i> , <i>Crataegus</i> spp.
286	2407	43°04'00.6"	76°59'14.7"	<i>Picea schrenkiana</i>
288	2477	43°03'47.0"	76°56'18.5"	<i>Picea schrenkiana</i>
289	2509	43°03'44.6"	76°59'19.3"	<i>Picea schrenkiana</i>
290	2553	43°03'39.9"	76°59'24.4"	<i>Sorbus tianschanica</i>
291	2563	43°03'39.4"	76°59'25.3"	<i>Salix</i> spp.
292	2446	43°03'40.7"	76°59'07.7"	<i>Juniperus</i> spp.
293	2480	43°03'50.6"	76°59'05.1"	<i>Picea schrenkiana</i>
295	2499	43°03'37.7"	76°59'15.0"	<i>Picea schrenkiana</i>
296	2537	43°03'32.7"	76°59'17.1"	<i>Sorbus tianschanica</i>
297	2563	43°03'32.7"	76°59'17.1"	<i>Juniperus</i> spp.
298	2326	43°04'18.1"	76°59'14.6"	<i>Betula pendula</i>
299 a, b	2312	43°04'19.8"	76°59'11.1"	<i>Salix</i> spp., <i>Populus tremula</i>
300	2365	43°04'10.1"	76°59'25.3"	<i>Juniperus</i> spp.
301	2377	43°04'08.5"	76°59'27.2"	<i>Picea schrenkiana</i>
302	2395	43°04'06.4"	76°59'26.9"	<i>Sorbus tianschanica</i>

Table 1 Continued.

Samples	Altitude above sea level, m	Latitude, N	Longitude, E	Rhizosphere of
304	1831	43°05'43.4"	76°56'44.9"	<i>Picea schrenkiana</i>
305	1864	43°05'35.0"	76°56'52.9"	<i>Picea schrenkiana</i>
306 a, b	1874	43°05'31.4"	76°56'53.2"	<i>Populus tremula, Sorbus tianschanica</i>
307	1877	43°05'26.0"	76°56'51.9"	<i>Crataegus</i> spp.
308	1888	43°05'18.4"	76°56'46.2"	<i>Sorbus tianschanica</i>
309 a, b, c	1477	43°06'37.0"	76°54'53.1"	<i>Crataegus</i> spp., <i>Sorbus tianschanica</i> , <i>Malus sieversii</i>
310 a, b	1504	43°06'36.2"	76°54'49.1"	<i>Quercus robur, Armeniaca vulgaris</i>
311	1556	43°06'31.4"	76°54'43.8"	<i>Betula pendula</i>
312	1582	43°06'29.5"	76°54'43.8"	<i>Picea schrenkiana</i>
313	1628	43°06'26.0"	76°54'46.6"	<i>Malus sieversii</i>
314	1667	43°06'21.9"	76°54'47.9"	<i>Pinus sylvestris</i>
315 a, b, c	1703	43°06'18.3"	76°54'49.6"	<i>Sorbus tianschanica, Malus sieversii</i> , <i>Pinus sylvestris</i>
321 a, b	1040	43°19'00.7"	77°38'22.9"	<i>Armeniaca vulgaris, Crataegus</i> spp.
322 a, b	1281	43°17'21.4"	77°39'41.1"	<i>Malus sieversii, Crataegus</i> spp.
323 a, c	1287	43°16'17.1"	77°44'18.9"	<i>Populus</i> spp., <i>Sorbus tianschanica</i>
324 a, b, c	1687	43°15'12.2"	77°45'26.6"	<i>Picea schrenkiana, Sorbus tianschanica</i> , <i>Salix</i> spp.
325 a, c	1446	43°16'29.4"	77°43'03.5"	<i>Malus sieversii, Populus tremula</i>
326 a, b	1757	43°14'10.0"	77°46'27.3"	<i>Sorbus tianschanica, Picea schrenkiana</i>
327 a, b, c	1436	43°16'33.1"	77°42'41.2"	<i>Armeniaca vulgaris, Populus</i> spp., <i>Salix</i> spp.
328 a	1507	43°06'15.7"	76°55'22.8"	<i>Betula pendula</i>
329 a, b, c	1571	43°05'59.2"	76°55'51.1"	<i>Picea schrenkiana, Populus tremula</i> , <i>Malus sieversii</i>
331 a, b	1576	43°06'01.0"	76°56'45.6"	<i>Picea schrenkiana, Crataegus</i> spp.
332	1646	43°14'02.9"	77°46'24.4"	<i>Picea schrenkiana</i>
333 a, b	1901	43°13'55.2"	77°46'58.0"	<i>Picea schrenkiana, Sorbus tianschanica</i>
334 a, b, c	1910	43°13'46.8"	77°47'25.3"	<i>Picea schrenkiana, Salix</i> spp., <i>Sorbus</i> <i>tianschanica</i>
335	1942	43°16'37.5"	77°42'55.3"	<i>Salix</i> spp.
336 a, b	1737	43°13'55.8"	77°45'27.2"	<i>Picea schrenkiana, Populus tremula</i>
337 a, b, c	1814	43°13'23.6"	77°45'34.5"	<i>Picea schrenkiana, Betula pendula, Salix</i> spp.
338 a, b, c	1862	43°12'48.6"	77°45'01.5"	<i>Picea schrenkiana, Sorbus tianschanica</i> , <i>Salix</i> spp.
339 a, b	1861	43°11'55.0"	77°43'54.0"	<i>Picea schrenkiana, Sorbus tianschanica</i>
340 a	1886	43°04'56.1"	76°54'27.4"	<i>Picea schrenkiana</i>
341a, b, c, d	1871	43°04'47.4"	76°54'28.5"	<i>Sorbus tianschanica, Picea schrenkiana</i> , <i>Salix</i> spp., <i>Betula pendula</i>
342 a, b	1936	43°04'45.2"	76°54'25.6"	<i>Pinus sylvestris, Betula pendula</i>
343 a, b	1994	43°04'37.0"	76°54'28.6"	<i>Pinus sylvestris, Salix</i> spp.
344 a, b	2069	43°04'18.9"	76°54'28.6"	<i>Picea schrenkiana, Sorbus tianschanica</i>
345 a, b	2085	43°03'59.7"	76°54'27.7"	<i>Picea schrenkiana, Sorbus tianschanica</i>
346 a, b	2240	43°03'51.2"	76°54'28.6"	<i>Picea schrenkiana, Sorbus tianschanica</i>
348 a, c	2143	43°13'46.0"	77°49'07.1"	<i>Salix</i> spp., <i>Picea schrenkiana</i>
349 a, b	2169	43°13'18.5"	77°50'25.2"	<i>Picea schrenkiana, Juniperus</i> spp.
350 a, b	1516	43°16'11.1"	77°44'26.4"	<i>Populus</i> spp., <i>Betula tianschanica</i>
351	1644	43°15'11.2"	77°45'38.4"	<i>Picea schrenkiana</i>
352 a, b, c	1711	43°15'07.8"	77°45'34.6"	<i>Populus tremula, Picea schrenkiana</i> , <i>Sorbus tianschanica</i>

Table 1 Continued.

Samples	Altitude above sea level, m	Latitude, N	Longitude, E	Rhizosphere of
353 a	1579	43°16'15.7"	77°44'22.9"	<i>Populus tremula</i>
354 a, b, c	1173	43°19'47.3"	77°37'02.0"	<i>Malus sieversii</i> , <i>Crataegus</i> spp., <i>Armeniaca vulgaris</i>
355	1647	43°09'34.9"	77°01'57.0"	<i>Betula pendula</i>
356 a	1790	43°09'35.3"	77°01'43.0"	<i>Populus tremula</i>
357 a, b	1969	43°09'23.0"	77°01'31.0"	<i>Populus tremula</i> , <i>Malus sieversii</i>
358	2063	43°09'14.5"	77°01'07.8"	<i>Pinus sylvestris</i>
359 a, b, c	2070	43°09'01.9"	77°00'49.3"	<i>Pinus sylvestris</i> , <i>Betula pendula</i> , <i>Crataegus</i> spp.
360 a, b, c	2190	43°08'41.9"	77°00'25.8"	<i>Picea schrenkiana</i> , <i>Juniperus</i> spp., <i>Salix</i> spp.
361	2172	43°08'25.3"	76°59'48.5"	<i>Picea schrenkiana</i>
362 a, b	1949	43°07'51.5"	76°58'42.1"	<i>Pinus sylvestris</i> , <i>Picea schrenkiana</i>
363 b, c	1874	43°07'38.6"	76°58'17.7"	<i>Salix</i> spp., <i>Picea schrenkiana</i>
364 a, b, c	1772	43°07'42.9"	76°57'29.5"	<i>Betula pendula</i> , <i>Populus tremula</i> , <i>Picea schrenkiana</i>
365a, b, c, d	1523	43°07'40.7"	76°56'06.1"	<i>Malus sieversii</i> , <i>Crataegus</i> spp., <i>Populus tremula</i> , <i>Picea schrenkiana</i>

Isolation of fungi and preparation of medium

Soil fungi were isolated by the serial dilution method (Polyksenova et al. 2004). Suspensions with standard level of dilution (1:10,000) were inoculated on agar. After the appearance of sporulation or signs of development of the mycelium, the isolates were transferred to a nutrient medium (potato sucrose agar). Petri dishes were labeled, sealed with paraffilm in order to avoid contamination, and incubated at 25°C.

Potato sucrose agar was made from 1800 g of potatoes per 4500 ml of water, 40 g of sucrose, 40 g of agar. The medium was autoclaved at 120°C for 30 minutes. A pinch of ampicillin (30 mg/ml) was added to the autoclaved medium to avoid the bacterial growth (Polyksenova et al. 2004).

Macroscopic and microscopic characterization of colonies and identification

Fungal cultures were examined when they were 5–10 days old. Appearance on medium, color, texture, and growth rate of fungal colonies were analyzed. Radial growth of fungal colonies on solid media was measured and calculated based on the average of perpendicular diameter measurements. Fungal growth and other characteristics were registered by a digital camera Canon 600E.

For light microscopy, small pieces of fungal colonies growing up to 10 days were cut, placed in a drop of distilled water on a microscope slide without any staining, examined and photographed using a photomicroscope Polyvar with Nomarski interference contrast optics. The dimensions of conidiophores, conidia, phialides, vesicles and other fungal structures were recorded. Mean sizes were calculated and the differences between the isolates were tested. The obtained data were compared with the available literature.

Specimens were identified based on the taxonomic keys for various groups of soil fungi (Raper & Fennel 1965, Raper & Thom 1968, Pidoplichko & Mil'ko 1971, Pitt 1979, Sutton 1980, Watanabe 2002, Domsch et al. 2007, Seifert et al. 2011). The systematics of the taxa were in accordance with Kirk et al. (2008) and they were listed in alphabetical order. Names of fungi are given according to Index Fungorum database.

The similarity level of the species composition of soil fungi in different gorges was determined by the Sørensen-Chekanovsky similarity coefficient (Ksc).

Results

In the course of research, 78 species of soil fungi were found.

Fungi

Ascomycota Caval.-Sm.

Insertae sedis

Oidiodendron griseum Robak

Prokhodnoye gorge, border of pine and birch forests, 342 b, 07.14.2019, EV Rakhimova.

Dothideomycetes O.E. Erikss. & Winka

Dothideomycetidae P.M. Kirk, P.F. Cannon, J.C. David & Stalpers, Spatafora, Crous & Shoemaker
Capnodiales Woron.

Davidiellaceae C.L. Schoch, Spatafora, Crous & Shoemaker

Cladosporium herbarum (Pers.) Link

Small Almaty gorge, October 1954, NM Leonova; Big Almaty gorge, north-western exposure slope, spruce forest, p. 290, 02.08.2018, LA Kyzmetova; in the same gorge, mixed forest, 265, 27.04.2018; in the same gorge, trail from the Kok-Dzhailau pass, mixed forest, 364 c, 20.08. 2019, EV Rakhimova; Prokhodnoye gorge, spruce forest, 346 a, 16.07.2019, EV Rakhimova; Turgen gorge, border of the spruce forest, 352 c, 18.08.2019, EV Rakhimova.

Pleosporomycetidae C.L. Schoch, Spatafora, Crous & Shoemaker

Pleosporales Luttr. ex M.E. Barr

Pleosporaceae Nitschke

Alternaria alternata (Fr.) Keissl.

Big Almaty gorge, north-western slope, spruce forest, 289, 01.09.2018, EV Rakhimova; Turgen gorge, north-east slope, deciduous forest, 324 c, 20.05.2019, LA Kyzmetova.

Alternaria tenuissima (Kunze) Wiltshire

Big Almaty gorge, slope of the Big Almaty peak, spruce forest, 312, 29.08.2018, AM Assylbek; Turgen gorge, north-east slope, deciduous forest, 321 b, 20.05.2019, LA Kyzmetova; Prokhodnoe gorge, spruce forest, 345 a, 15.07.2019, AM Assylbek; in the same gorge, the border of pine and birch forests, 342 b, 14.07.2019, EV Rakhimova.

Curvularia inaequalis (Shear) Boedijn

Big Almaty gorge, slope of the Big Almaty peak, spruce forest, 312, 29.08.2018, LA Kyzmetova.

Eurotiomycetes O.E. Erikss. & Winka

Eurotiales G.W. Martin ex Benny & Kimbr.

Trichocomaceae E. Fisch.

Aspergillus candidus Link

Big Almaty gorge, north-western slope, spruce forest, 289, 01.09.2018, EV Rakhimova.

Aspergillus clavatus Desm.

Zailisky Alatau, spruce forest, 1952, NM Leonova.

Aspergillus fischeri Wehmer

Zailisky Alatau, spruce forest, October 1952, NM Leonova.

Aspergillus flavipes (Bainier & R. Sartory) Thom & Church

Zailisky Alatau, deciduous forest, July 1952, AN Ustimenko.

Aspergillus flavus Link

Big Almaty gorge, mixed forest, 265, 27.04.2018; in the same gorge, spruce forest, April 1952, NM Leonova.

Aspergillus fumigatus Fresen.

Zailisky Alatau, spruce forest, 02.05.1952, NM Leonova.

Aspergillus nidulans (Eidam) G. Winter

Zailisky Alatau, spruce forest, April 1952, NM Leonova.

Aspergillus niger Tiegh.

Zailisky Alatau, spruce forest, April 1952, NM Leonova; Big Almaty gorge, western slope, spruce forest, 297, 05.09.2018, AM Assylbek; in the same gorge, 04.09.2018, LA Kyzmetova; in the same gorge, spruce forest border, 331 b, 23.05.2019, EV Rakhimova; in the same gorge, south west slope, spruce forest, 293, 03.09.2018, EV Rakhimova; in the same gorge, 292, 03.09.2018, AM Assylbek; in the same gorge, 295, 04.09.2018, UK Jetigenova; in the same gorge, north-western slope, spruce forest, 290, 02.09.2018, LA Kyzmetova; in the same gorge, slope of the Big Almaty peak, mixed forest, 310 b, 29.08.2018, AM Assylbek; in the same gorge, along the river Tersbutak, mixed forest, 365 a, d, 20.08.2019, EV Rakhimova; in the same gorge, spruce forest, 362 b, 20.08.2019, G Sypabekkyzy; Small Almaty gorge, trail to the Kok-Dzhailau pass, deciduous forest, 357 b, 19.08.2019, AM Assylbek; Turgen gorge, above the village Batan, north slope, spruce forest, 326 b, 22.05.2019, LA Kyzmetova; in the same gorge, north-west slope, spruce forest, 333 a, 11.07.2019, AM Assylbek; in the same gorge, path to Kairak waterfall, north slope, spruce forest, 337 a, 12.07.2019, AM Assylbek; in the same gorge, floodplain forest of the Turgen river, 336 b, 12.07.2019, UK Jetigenova; Prokhodnoe gorge, spruce forest, 346 b, 16.07.2019, EV Rakhimova.

Aspergillus ochraceus G. Wilh.

Zailisky Alatau, deciduous forest, July 1952, NM Leonova.

Aspergillus ustus (Bainier) Thom & Church

Big Almaty gorge, mixed forest, 266 b, 27.04.2018, UK Jetigenova.

Penicillium aurantiogriseum Dierckx

Zailisky Alatau, spruce forest, April-May, 1952, NM Leonova.

Penicillium brevicompactum Dierckx

Big Almaty gorge, north-west slope, spruce forest, 290, 02.09.2018, LA Kyzmetova.

Penicillium canescens Sopp

Big Almaty gorge, spruce forest, 256, 27.04.2018, UK Jetigenova; in the same gorge, mixed forest, 266 a, 27.04.2018, UK Jetigenova; Ajusai gorge, spruce forest, 308, 29.08.2018, AM Assylbek; Turgen gorge, north-east slope, deciduous forest, 321 a, 20.05.2019, LA Kyzmetova.

Penicillium chrysogenum Thom

Zailisky Alatau, spruce forest, 1952, NM Leonova; in the same gorge, May, 1952, NM Leonova; Big Almaty gorge, mixed forest, 258, 27.04.2018, LA Kyzmetova; in the same gorge, west slope, spruce forest, 296, 04.09.2018, LA Kyzmetova; Turgen gorge, above the village Batan, north slope, spruce forest, 324 c, 20.05.2019, AM Assylbek; in the same gorge, at the beginning of Assy plateau, spruce forest, 349 a, 16.08.2019, AM Assylbek.

Penicillium citrinum Thom

Prokhodnoe gorge, spruce forest, 346 a, 16.07.2019, EV Rakhimova.

Penicillium concavorugulosum S. Abe

Turgen gorge, west slope, floodplain forest of the river Karagaily, 325 a, 21.05.2019, EV Rakhimova.

Penicillium cyaneofulvum Biourge

Zailisky Alatau, spruce forest, 02.05.1952, NM Leonova.

Penicillium expansum Link

Big Almaty gorge, spruce forest, 256, 27.04.2018; in the same gorge, west slope, spruce forest, 296, 04.09.2018, LA Kyzmetova; in the same gorge, north-west slope, mixed forest, 298, 06.08.2018, UK Jetigenova; in the same gorge, trail from the Kok-Dzhailau pass, mixed forest, 364 c, 20.08.2019, EV Rakhimova; in the same gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova; Ajusai gorge, spruce forest, 308, 29.08.2018, AM Assylbek; Turgen gorge, north slope, spruce forest, 324 a, 20.05.2019, AM Assylbek; in the same gorge, above the village Batan, north slope, spruce forest, spruce

forest, 326 a, 22.05.2019, LA Kyzmetova; in the same gorge, west slope, floodplain forest of the river Karagaily, 325 a, 21.05.2019, EV Rakhimova; in the same gorge, floodplain forest, 353 a, 18.08.2019, AM Assylbek; in the same gorge, not far from the Altyn Adam complex, north-west slope, deciduous forest, 354 c, 18.08.2019, G Sypabekkyzy.

Penicillium glabrum (Wehmer) Westling

Big Almaty gorge, south-west slope, spruce forest, 293, 03.09.2018, EV Rakhimova; in the same gorge, trail from the Kok-Dzhailau pass, mixed forest, 365 c, d, 20.08.2019, EV Rakhimova; in the same gorge, floodplain mixed forest, 363 c, 20.08.2019, UK Jetigenova; Ajusai gorge, spruce forest, 308, 29.08.2018, AM Assylbek; Small Almaty gorge, path to the Kok-Dzhailau pass, birch forest, 355, 19.08.2019, UK Jetigenova; Turgen gorge, above the village Batan, north slope, spruce forest, 326 b, 22.05.2019, LA Kyzmetova; in the same gorge, path to Kairak waterfall, floodplain forest, 336 b, 12.07.2019, UK Jetigenova; in the same gorge, not far from the Altyn Adam complex, north-west slope, deciduous forest, 354 b, 18.08.2019, G Sypabekkyzy.

Penicillium granulatum Bainier

Turgen gorge, path to the Bear falls, floodplain forest, 327 b, 22.05.2019, AM Assylbek; Big Almaty gorge, north slope, spruce forest, 329 a, 23.05.2019, LA Kyzmetova.

Penicillium herquei Bainier & Sartory

Zailisky Alatau, mixed forest, 1952, AN Ustimenko.

Penicillium hirsutum Dierckx

Small Almaty gorge, spruce forest, 1952, NM Leonova.

Penicillium jensenii K.W. Zaleski

Big Almaty gorge, path from the Kok-Dzhailau pass, mixed forest, 365 d, 20.08.2019, EV Rakhimova; Turgen gorge, not far from the Altyn Adam complex, north-west slope, deciduous forest, 354 b, 18.08.2019, G Sypabekkyzy.

Penicillium lanosum Westling

Zailisky Alatau, spruce forest, 1952, NM Leonova; Big Almaty gorge, north-west slope, north slope, spruce forest, 329 b, 23.05.2019, LA Kyzmetova.

Penicillium lapidosum Raper & Fennell

Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova.

Penicillium lineatum Pitt (Fig. 1)

Big Almaty gorge, mixed forest, 266 b, 27.04.2018, UK Jetigenova; in the same gorge, path from the Kok-Dzhailau pass, mixed forest, 365 c, 20.08.2019, EV Rakhimova; in the same gorge, 362 a, 20.08.2019, G Sypabekkyzy; Small Almaty gorge, path to the Kok-Dzhailau pass, aspen forest, 356 a, 19.08.2019, EV Rakhimova.

Penicillium miczynskii K.W. Zaleski

Zailisky Alatau, spruce forest, 1952, NM Leonova.

Penicillium purpurascens (Sopp) Biourge

Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova; in the same gorge, birch forest, 264, 27.04.2018, UK Jetigenova.

Penicillium roqueforti Thom

Big Almaty gorge, mixed forest, 258, 27.04.2018, LA Kyzmetova; in the same gorge, 266 a, 27.04.2018, UK Jetigenova.

Penicillium simplicissimum (Oud.) Thom

Big Almaty gorge, path from the Kok-Dzhailau pass, mixed forest, 365 d, 20.08.2019, EV Rakhimova.

Penicillium solitum Westling

Zailisky Alatau, spruce forest 1952, NM Leonova.

Penicillium thomii Maire

Zailisky Alatau, spruce forest, 1952, NM Leonova.

- Penicillium velutinum*** J.F.H. Beyma
Small Almaty gorge, path to the Kok-Dzhailau pass, aspen forest, 356 a, 19.08.2019, EV Rakhimova.
- Penicillium* sp.–1**
Big Almaty gorge, birch mixed forest, 309 c, 29.08.2018, EV Rakhimova.
- Penicillium* sp.–2**
Big Almaty gorge, mixed forest, 266 a, 27.04.2018, UK Jetigenova; in the same gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova; Turgen gorge, floodplain forest, 336 a, 12.07.2019, UK Jetigenova; Small Almaty gorge, path to the Kok-Dzhailau pass, planting birch and pine, 359, 19.08.2019, UK Jetigenova.
- Penicillium* sp.–3**
Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova.
- Penicillium* sp.–4**
Turgen gorge, above the village Batan, northern slope, border of spruce forest, 324 c, 20.05.2019, AM Assylbek.
- Penicillium* sp.–5**
Big Almaty gorge, north-west slope, spruce forest, 289, 01.09.2018, EV Rakhimova.
- Penicillium* sp.–6**
Turgen gorge, north-east slope, deciduous forest, 321 b, 20.05.2019, LA Kyzmetova; in the same gorge, path to the Bear Falls, floodplain forest, 327 a, 22.05.2019, AM Assylbek.
- Talaromyces diversus*** (Raper & Fennell) Samson, N. Yilmaz & Frisvad (Fig. 2)
Turgen gorge, floodplain forest, 353 a, 18.08.2019, AM Assylbek.
- Talaromyces luteus*** C.R. Benj.
Zailisky Alatau, spruce forest, 1952, NM Leonova.
- Talaromyces ruber*** (Stoll) N. Yilmaz, Houbraken, Frisvad & Samson
Zailisky Alatau, deciduous forest, 1952, AN Ustimenko.
- Talaromyces rugulosus*** (Thom) Samson, N. Yilmaz, Frisvad & Seifert
Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 c, 29.08.2018, EV Rakhimova.
- Talaromyces variabilis*** (Sopp) Samson, N. Yilmaz, Frisvad & Seifert
Turgen gorge, above the village Batan, floodplain mixed forest, 334 b, 11.07.2019, EV Rakhimova.
- Sordariomycetes*** O.E. Erikss. & Winka
Sordariomycetidae O.E. Erikss. & Winka
Sordariales Chadeff. ex D. Hawksw. & O.E. Erikss.
Chaetomiaceae G. Winter
Humicola nigrescens Omvik
Turgen gorge, above the village Batan, mixed forest, 334 c, 11.07.2019, EV Rakhimova.
- Sordariaceae*** G. Winter
***Monilia* sp.**
Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 310 b, 29.08.2018, AM Assylbek.
- Neurospora sitophila*** Shear & B.O. Dodge
Turgen gorge, floodplain forest, 353 a, 18.08.2019, AM Assylbek.
- Hypocreomycetidae*** O.E. Erikss. & Winka
Hypocreales Lindau
Insertae sedis
Gliomastix guttuliformis J.C. Br. & W.B. Kendr.

Turgen gorge, path to Kairak waterfall, northern slope, spruce forest, 337 b, 12.07.2019, AM Assylbek.

Hyalopus curtipes (Sacc.) M.A.J. Barbosa

Small Almaty gorge, spruce forest, 1951, NM Leonova.

Clavicipitaceae O.E. Erikss.

Metarhizium carneum (Duché & R. Heim) Kepler, S.A. Rehner & Humber (Fig. 3)

Turgen gorge, north-east slope, deciduous forest, 321 b, 20.05.2019, LA Kyzmetova; in the same gorge, northern slope, border of spruce forest, 324 a, 20.05.2019, AM Assylbek; in the same gorge, path to the Bear Falls, floodplain forest, 327 b, 22.05.2019, AM Assylbek; in the same gorge, floodplain forest, 336 a, 12.07.2019, Y UK Jetigenova.

Cordycipitaceae Kreisel ex G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora

Cordyceps farinosa (Holmsk.) Kepler, B. Shrestha & Spatafora

Big Almaty gorge, west slope, spruce forest, 297, 05.09.2018, AM Assylbek.

Lecanicillium fungicola (Preuss) Zare & W. Gams

Turgen gorge, north-east slope, deciduous forest, 321 b, 20.05.2019, LA Kyzmetova.

Hypocreaceae De Not.

Acrostalagmus niveus Delacr.

Small Almaty gorge, spruce forest, 1951, NM Leonova.

Trichoderma atroviride P. Karst.

Turgen gorge, path to the Bear Falls, floodplain forest, 335, 12.07.2019, LA Kyzmetova.

Trichoderma hamatum (Bonord.) Bainier

Big Almaty gorge, northern slope, spruce forest, 329 c, 23.05.2019, LA Kyzmetova.

Trichoderma harzianum Rifai

Turgen gorge, floodplain forest, 338 b, 13.07.2019, EV Rakhimova; in the same gorge, above the village Batan, at the beginning of the plate of Assy, spruce forest, 349 b, 16.08.2019, AM Assylbek.



Figs 1–3 – Species of the genera *Penicillium*, *Talaromyces* and *Metarhizium*. 1 Asci with ascospores of *Penicillium lineatum*. Scale bar = 18 μ m. 2 Conidiophores with conidial chains of *Talaromyces diversus*. Scale bar = 10 μ m. 3 Conidiophore with conidia of *Metarhizium carneum*. Scale bar = 5 μ m.

Trichoderma koningii Oudem.

Big Almaty gorge, north-west slope, spruce forest, 290, 02.09.2018, LA Kyzmetova; Turgen gorge, above the village Batan, northern slope, spruce forest, 324 c, 20.05.2019, AM Assylbek; in the same gorge, spruce forest, 326 b, 22.05.2019, LA Kyzmetova.

Trichoderma koningiopsis Samuels, Carm. Suárez & H.C. Evans

Turgen gorge, above the village Batan, northern slope, spruce forest, 326 b, 22.05.2019, LA Kyzmetova.

Trichoderma polysporum (Link) Rifai

Big Almaty gorge, north-west slope, spruce forest, 290, 02.09.2018, LA Kyzmetova; in the same gorge, path from the Kok-Dzhailau pass, spruce forest, 361, 20.08.2019, AM Assylbek; in the same gorge, slope of the Big Almaty peak, mixed forest, 310, 29.08.2018, UK Jetigenova.

Trichoderma viride Pers.

Big Almaty gorge, west slope, spruce forest, 296, 04.09.2018, LA Kyzmetova; in the same gorge, 297, 05.09.2018, AM Assylbek; in the same gorge, northern slope, spruce forest, 302, 10.09.2018, EV Rakhimova; in the same gorge, west slope, spruce forest, 331 b, 23.05.2019, EV Rakhimova; Turgen gorge, above the village Batan, northern slope, spruce forest, 326 a, 22.05.2019, LA Kyzmetova; in the same gorge, path to the Bear Falls, floodplain forest, 327 a, 22.05.2019, AM Assylbek; Prokhodnoe gorge, spruce forest, 346 b, 16.07.2019, EV Rakhimova.

***Trichoderma* sp.**

Turgen gorge, floodplain forest, 338 b, 13.07.2019, EV Rakhimova.

Nectriaceae Tul. & C. Tul.

Fusarium acuminatum Ellis & Everh.

Turgen gorge, above the village Batan, mixed forest, 334 a, 11.07.2019, EV Rakhimova; in the same gorge, north-east slope, deciduous forest, 321 b, 20.05.2019, LA Kyzmetova; Prokhodnoe gorge, spruce forest, 345 a, 15.07.2019, AM Assylbek.

Fusarium oxysporum Schltdl.

Big Almaty gorge, mixed forest, 257, 27.04.2018, LA Kyzmetova; in the same gorge, 265, 27.04.2018; in the same gorge, west slope, spruce forest, 297, 05.09.2018, AM Assylbek; in the same gorge, northern slope, spruce forest, 329 b, 23.05.2019, LA Kyzmetova; Turgen gorge, above the village Batan, northern slope, spruce forest, 324 c, 20.05.2019, AM Assylbek.

***Fusarium* sp.-1**

Big Almaty gorge, birch forest, 264, 27.04.2018, UK Jetigenova; Ajusai gorge, spruce forest, 308, 29.08.2018, AM Assylbek.

***Fusarium* sp.-2**

Turgen gorge, east slope, deciduous forest, 322 b, 20.05.2019, UK Jetigenova; in the same gorge, above the village Batan, northern slope, spruce forest, 326 a, 22.05.2019, LA Kyzmetova.

***Fusarium* sp.-3**

Big Almaty gorge, spruce forest, 256, 27.04.2018.

Mariannaea elegans (Corda) Samson

Small Almaty gorge, spruce forest, 1951, NM Leonova.

Ophiocordycipitaceae G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora

Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson (Fig. 4)

Big Almaty gorge, west slope, spruce forest, 295, 04.09.2018, UK Jetigenova; in the same gorge, northern slope, spruce forest, 329 b, 23.05.2019, LA Kyzmetova; in the same gorge, west slope, birch forest, 328 a, 23.05.2019, UK Jetigenova; in the same gorge, path from the Kok-Dzhailau pass, mixed forest, 363 c, 20.08.2019, UK Jetigenova; in the same gorge,

mixed forest, 365 a, b, 20.08.2019, EV Rakhimova; Small Almaty gorge, path to the Kok-Dzhailau pass, birch forest, 355, 19.08.2019, UK Jetigenova; in the same gorge, planting birch and pine, 359 b, 19.08.2019, UK Jetigenova; Prokhodnoe gorge, spruce forest, 346 a, 16.07.2019, EV Rakhimova; in the same gorge, pine forest border, 342 a, 14.07.2019, EV Rakhimova; in the same gorge, spruce forest, 341 b, 14.07.2019, AM Assylbek; in the same gorge, pine forest border, 343 a, 15.07.2019, LA Kyzmetova; in the same gorge, spruce forest, 345 b, 15.07.2019, AM Assylbek; in the same gorge, 344 a, 15.07.2019, UK Jetigenova; Turgen gorge, at the beginning of the plate of Assy, spruce forest, 349 a, 16.08.2019, AM Assylbek; in the same gorge, floodplain forest, 353 a, 18.08.2019, AM Assylbek; in the same gorge, mixed forest, 348 c, 16.08.2019, EV Rakhimova; in the same gorge, floodplain forest, 350 a, b, 16.08.2019, G Sypabekkyzy; in the same gorge, spruce forest, 351, 18.08.2019, UK Jetigenova; in the same gorge, 352 a, b, 18.08.2019, EV Rakhimova; in the same gorge, not far from the Altyn Adam complex, north-west slope, deciduous forest, 354 b, c, 18.08.2019, G Sypabekkyzy.

***Heterokontophyta* Moestrup**

***Oomycota* Arx**

***Peronosporales* A. Fisch.**

***Pythiaceae* J. Schröt.**

***Pythium* sp.**

Big Almaty gorge, mixed forest, 262, 27.04.2018, EV Rakhimova.

***Zygomycota* Moreau**

***Mucoromycotina* Benny**

***Mucorales* Dumort.**

***Cunninghamellaceae* Naumov ex R.K. Benj.**

***Cunninghamella echinulata* (Thaxt.) Thaxt. ex Blakeslee (Fig. 5)**

Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 a, 29.08.2018, EV Rakhimova; in the same gorge, path from the Kok-Dzhailau pass, mixed forest, 365 b, 20.08.2019, EV Rakhimova; Turgen gorge, above the village Batan, mixed forest, 334 c, 11.07.2019, EV Rakhimova.



Figs 4–5 – Species of the genera *Purpureocillium* and *Cunninghamella*. 1 Conidiophore with conidia of *Purpureocillium lilacinum*. Scale bar Bar = 10 μ m. 2 Vesicles on branches of *Cunninghamella echinulata*. Scale bar = 20 μ m.

Mucoraceae Dumort.

Absidia spinosa Lendn. (Figs 6, 7)

Big Almaty gorge, mixed forest, 315 c, 30.08.2018, EV Rakhimova; in the same gorge, north-west slope, mixed forest, 299 a, 06.08.2018, UK Jetigenova; in the same gorge, 262, 27.04.2018; EV Rakhimova; in the same gorge, 258, 27.04.2018, LA Kyzmetova; in the same gorge, northern slope, spruce forest, 301, 09.09.2018, AM Assylbek; in the same gorge, 329 b, 23.05.2019, LA Kyzmetova; in the same gorge slope of the Big Almaty peak, mixed forest, 309 a, 29.08.2018, AM Assylbek; in the same gorge, 310 b, 29.08.2018, AM Assylbek; in the same gorge, spruce forest, 313, 29.08.2018, EV Rakhimova; in the same gorge, pine forest border, 314, 30.08.2018, EV Rakhimova; in the same gorge, path from the Kok-Dzhailau pass, spruce forest, 361, 20.08.2019, AM Assylbek; in the same gorge, 362 a, b, 20.08.2019, G Sypabekkyzy; in the same gorge, mixed forest, 363 c, 20.08.2019, UK Jetigenova; in the same gorge, 364 a, 20.08.2019, EV Rakhimova; in the same gorge, mixed forest, 365 b, 20.08.2019, EV Rakhimova; Big Almaty gorge, path to the Kok-Dzhailau pass, deciduous forest, 357 a, b, 19.08.2019, AM Assylbek; in the same gorge, spruce forest, 360 a, b, 19.08.2019, EV Rakhimova; in the same gorge, birch forest, 355, 19.08.2019, UK Jetigenova; Prokhodnoe gorge, spruce forest, 341 a, b, 14.07.2019, AM Assylbek; in the same gorge, 344 b, 15.07.2019, UK Jetigenova; Ajusai gorge, south-west slope, spruce forest, 304, 27.08.2018, LA Kyzmetova; Turgen gorge, path to the Bear Falls, floodplain forest, 327 b, c, 22.05.2019, AM Assylbek; in the same gorge, above the village Batan, northern slope, spruce forest border, 324 c, 20.05.2019, AM Assylbek; in the same gorge, mixed forest, 334 a, 11.07.2019, EV Rakhimova; in the same gorge, path to the Bear Falls, floodplain forest, 335, 12.07.2019, LA Kyzmetova; in the same gorge, floodplain forest, 353 a, 18.08.2019, AM Assylbek; in the same gorge, not far from the Altyn Adam complex, north-west slope, deciduous forest, 354 c, 18.08.2019, G Sypabekkyzy.

Actinomucor elegans (Eidam) C.R. Benj. & Hesselt.

Big Almaty gorge, slope of the Big Almaty peak, mixed forest, 309 a, 29.08.2018, AM Assylbek.

Mucor mucedo Fresen.

Big Almaty gorge, north-west slope, spruce forest, 288, 01.08.2018, LA Kyzmetova; in the same gorge, 291, 02.08.2018, LA Kyzmetova; in the same gorge, mixed forest, 298, 06.08.2018, UK Jetigenova; in the same gorge, northern slope, spruce forest, 329 a, 23.05.2019, LA Kyzmetova; in the same gorge, north-west slope, mixed forest, 299 a, b, 06.09.2018, UK Jetigenova; in the same gorge, 262, 27.04.2018; EV Rakhimova; in the same gorge, mixed forest, 258, 27.04.2018, AM Assylbek; in the same gorge, south-west slope, spruce forest, 293, 03.09.2018, EV Rakhimova; in the same gorge, 289, 01.09.2018, EV Rakhimova; in the same gorge, slope of the Big Almaty peak, pine forest border, 314, 30.08.2018, EV Rakhimova; in the same gorge, mixed forest, 309 a, b, 29.08.2018, EV Rakhimova; in the same gorge, spruce forest border, 331 b, 23.05.2019, EV Rakhimova; in the same gorge, pine forest border, 314, 30.08.2018, EV Rakhimova; in the same gorge, mixed forest, 310 a, b, 29.08.2018, UK Jetigenova; in the same gorge, birch forest, 311, 29.08.2018, EV Rakhimova; in the same gorge, spruce forest, 312, 29.08.2018, AM Assylbek; in the same gorge, mixed forest, 315 b, 30.08.2018, EV Rakhimova; path to the Kok-Dzhailau pass., mixed forest, 365 b, 20.08.2019, EV Rakhimova; Ajusai gorge, south-east slope, spruce forest, 305, 27.08.2018, LA Kyzmetova; Turgen gorge, east slope, deciduous forest, 322 b, 20.05.2019, UK Jetigenova; in the same gorge, west slope, floodplain forest, 323 c, 20.05.2019, EV Rakhimova; in the same gorge, northern slope, spruce forest border, 324 b, 20.05.2019, AM Assylbek; in the same gorge, path to the Bear Falls, floodplain forest, 335, 12.07.2019, LA Kyzmetova; in the same gorge, path to the Kairak Falls, northern slope, spruce forest, 337 a, 12.07.2019, AM Assylbek; in the same gorge, floodplain forest, 338, 13.07.2019, EV Rakhimova; Prokhodnoe gorge, spruce forest, 341 a, b, d, 14.07.2019, AM Assylbek; in the same gorge, 346 a, 16.07.2019, EV Rakhimova;

in the same gorge, pine forest border, 343 b, 15.07.2019, LA Kyzmetova; Small Almaty gorge, path to the Kok-Dzhailau pass, planting birch and pine, 359 c, 19.08.2019, UK Jetigenova.

Mucor racemosus Fresen.

Turgen gorge, path to the Kairak Falls, northern slope, spruce forest, 337 b, 12.07.2019, AM Assylbek.

Mucor silvaticus Hagem

Big Almaty gorge, mixed forest, 265, 27.04.2018. EV Rakhimova.

Mucor strictus Hagem

Big Almaty gorge, birch forest, 264, 27.04.2018; Turgen gorge, path to the Kairak Falls, northern slope, spruce forest, 337 c, 12.07.2019, AM Assylbek.

***Mucor* sp.-1**

Ajusai gorge, mixed forest, 306 a, 29.08.2018, UK Jetigenova.

***Mucor* sp.-2**

Big Almaty gorge, slope of the Big Almaty peak, pine forest border, 314, 30.08.2018, EV Rakhimova.

***Mucor* sp.-3**

Big Almaty gorge, slope of the Big Almaty peak, birch forest, 311, 29.08.2018, EV Rakhimova.

***Mucor* sp.-4**

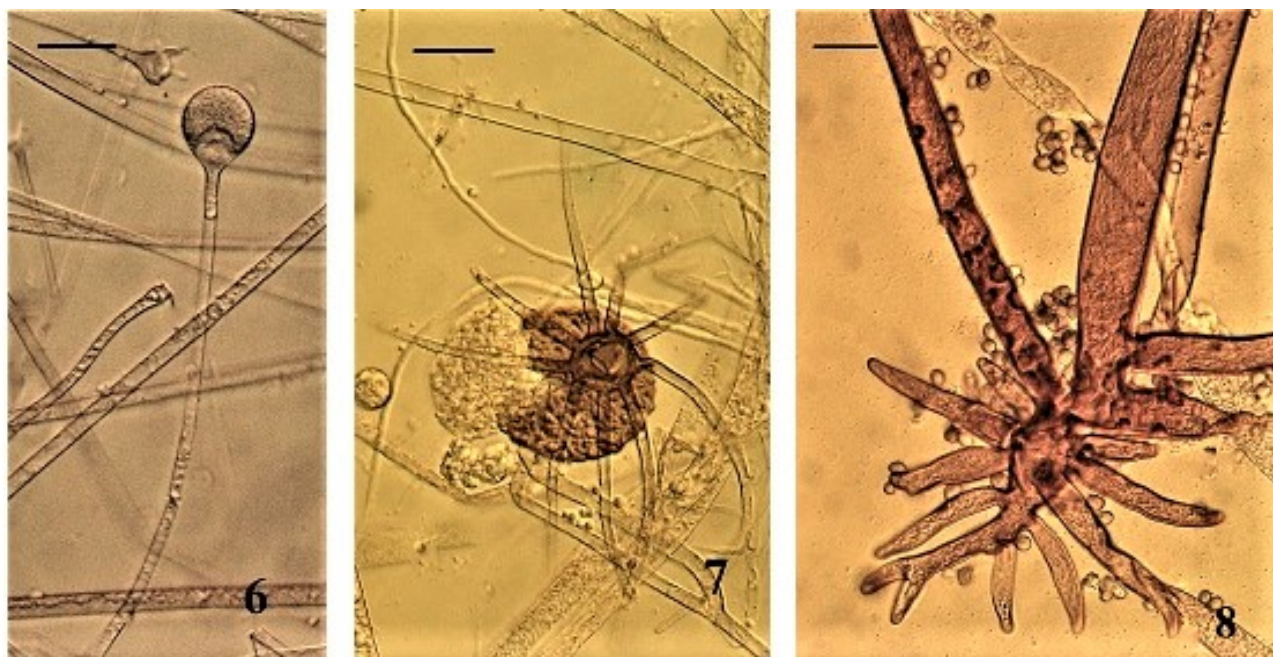
Ajusai gorge, mixed forest, 306 b, 29.08.2018, UK Jetigenova.

***Mucor* sp.-5**

Big Almaty gorge, northern slope, spruce forest, 329 a, 23.05.2019, LA Kyzmetova.

Rhizopus stolonifer (Ehrenb.) Vuill. (Fig. 8)

Big Almaty gorge, spruce forest, 263, 27.04.2018; Turgen gorge, above the village Batan, northern slope, spruce forest, 326 a, 22.05.2019, LA Kyzmetova; in the same gorge, 332, 11.07.2019, LA Kyzmetova; in the same gorge, spruce forest border, 324 b, 20.05.2019, AM Assylbek; in the same gorge, path to the Kairak Falls, northern slope, spruce forest, 339 b, 13.07.2019, LA Kyzmetova.



Figs 6–8 – Species of the genera *Absidia* and *Rhizopus*. 6 Sporangioophore and sporangium of *Absidia spinosa*. Scale bar = 25 μ m. 7 Zygosporangium of *Absidia spinosa*. Scale bar = 30 μ m. 8 Rhizoids of *Rhizopus stolonifer*. Scale bar = 25 μ m.

Umbelopsidaceae W. Gams & W. Mey.

Umbelopsis ramanniana (Möller) W. Gams

Big Almaty gorge, western exposure slope, birch forest, 328 a, 23.05.2019, UK Jetigenova.

Zoopagomycotina Benny

Zoopagales Bessey ex R.K. Benj.

Piptocephalidaceae J. Schröt.

Piptocephalis arrhiza Tiegh. & G. Le Monn.

Big Almaty gorge, northern slope, spruce forest, 329 b, 05.23.2019, LA Kyzmetova; in the same gorge, slope of the Big Almaty peak, mixed forest, 310 b, 29.08.2018, AM Assylbek; Small Almaty gorge, trail to the Kok-Dzhailau pass, spruce forest, 360 a, b, 08.19.2019, E.V. Rakhimova

The largest number of fungal species in the rhizosphere of woody plants is recorded in the Big Almaty gorge and in Turgen (Fig. 9). It should be noted that members of the *Eurotiomycetes* class dominate in the Big and Small Almaty gorge and in Turgen. The percent of *Sordariomycetes* species is 36.8% in Turgen, 36.3% – in Prokhodnoe gorge, 28.5% – in the Small Almaty gorge, 18.5% – in the Big Almaty gorge. *Zygomycota* representatives dominate in the rhizosphere of woody plants of Ajusai gorge; while the percent of zygomycetous fungi in the Big Almaty gorge is 24%, in Turgen – 18.4%. Generally, the percent of *Eurotiomycetes*, *Sordariomycetes* и *Zygomycota* in Ajusai gorge is 100%, in the Small Almaty gorge – 92.8%, in Turgen – 92.1%, in the Big Almaty gorge – 90.7%, in Prokhodnoe gorge – 72%.

The greatest similarity of the species composition of soil fungi is found between the gorges Big Almaty and Turgen ($K_{sc} = 0.7$), Small Almaty and Prokhodnoe ($K_{sc} = 0.7$), Small Almaty and Ajusay ($K_{sc} = 0.6$). A low degree of similarity in species composition is found between the gorges Big Almaty and Ajusay ($K_{sc} = 0.2$), Big Almaty and Prokhodnoe ($K_{sc} = 0.3$), Ajusay and Turgen ($K_{sc} = 0.3$).

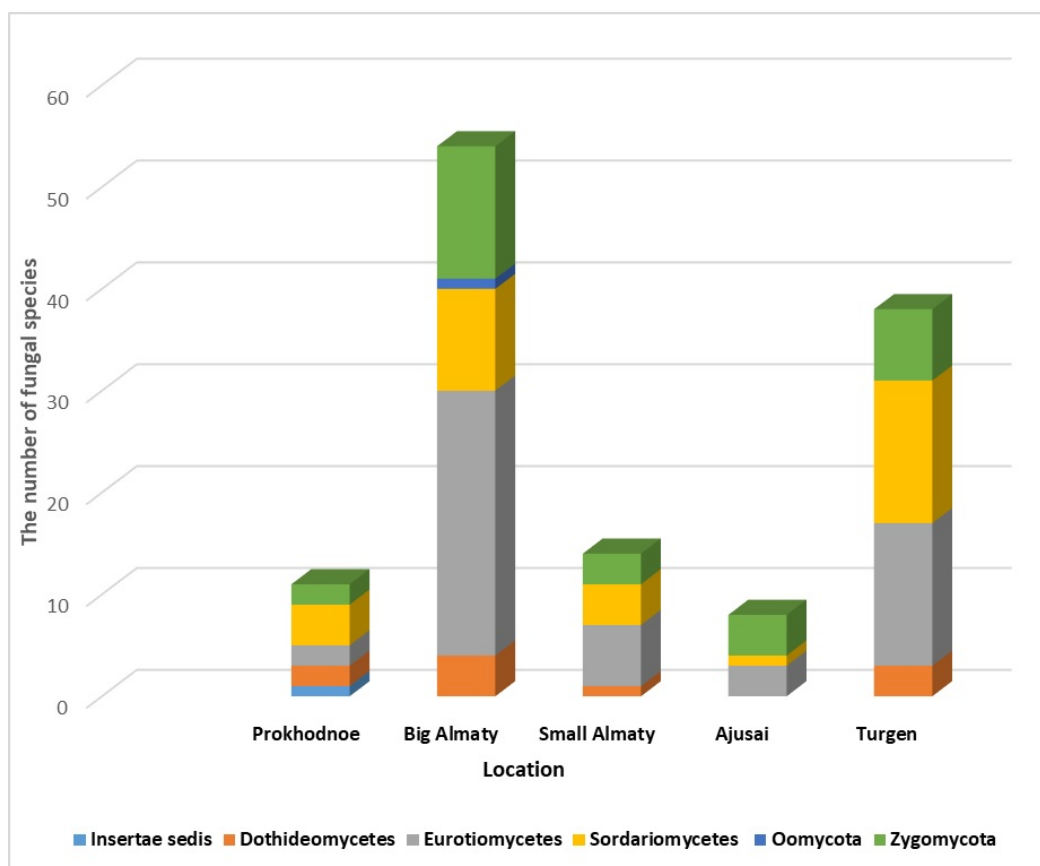


Fig. 9 – The number of species and the species composition of soil fungi in different gorges of the Zailisky Alatau

Soil fungi associated with rhizosphere of *Malus sieversii* are registered in three gorges: Big Almaty (17 species), Small Almaty (2) and Turgen (2 species) (Fig. 10). Both species *Absidia spinosa* and *Aspergillus niger*, noted in the Big Almaty gorge, are also found in the Small Almaty gorge, while *Penicillium concavorugulosum* is characteristic only of the Turgen gorge.

The complexes of soil fungi in *Armeniaca vulgaris* rhizosphere in the Big Almaty and Turgen gorges (Fig. 10) are characterized by the same number of species (6 species each), however, only the *Absidia spinosa* species is common for these complexes. *Aspergillus niger*, *Monilia* sp., *Mucor mucedo*, *Piptocephalis arrhiza*, *Pythium* sp. are found in the Big Almaty gorge, while *Penicillium canescens*, *P. expansum*, *Penicillium* sp.–6, *Trichoderma viride*, *Purpureocillium lilacinum* – in the Turgen gorge.

Soil fungi associated with rhizosphere of *Populus tremula* are observed in the Big Almaty (8 species), Small Almaty (3), Turgen (7) and Ajusai (1 species) (Fig. 10). Only *Absidia spinosa* are found in the first three gorges, while *Mucor* sp.–1 is characteristic only of the Ajusai gorge. *Penicillium lineatum* is noted in the Big Almaty gorge and Small Almaty gorge, and *Purpureocillium lilacinum* – in Big Almaty gorge and Turgen.

The complexes of fungi in the birch rhizosphere (*Betula pendula*, *B. tianschanica*) consist of 9 species in the Big Almaty gorge, of 3 species in the Small Almaty gorge, of 3 species in Prokhdnoe gorge, of 3 species in Turgen. *Purpureocillium lilacinum* is found in three of these gorges, *Absidia spinosa* – in two gorges.

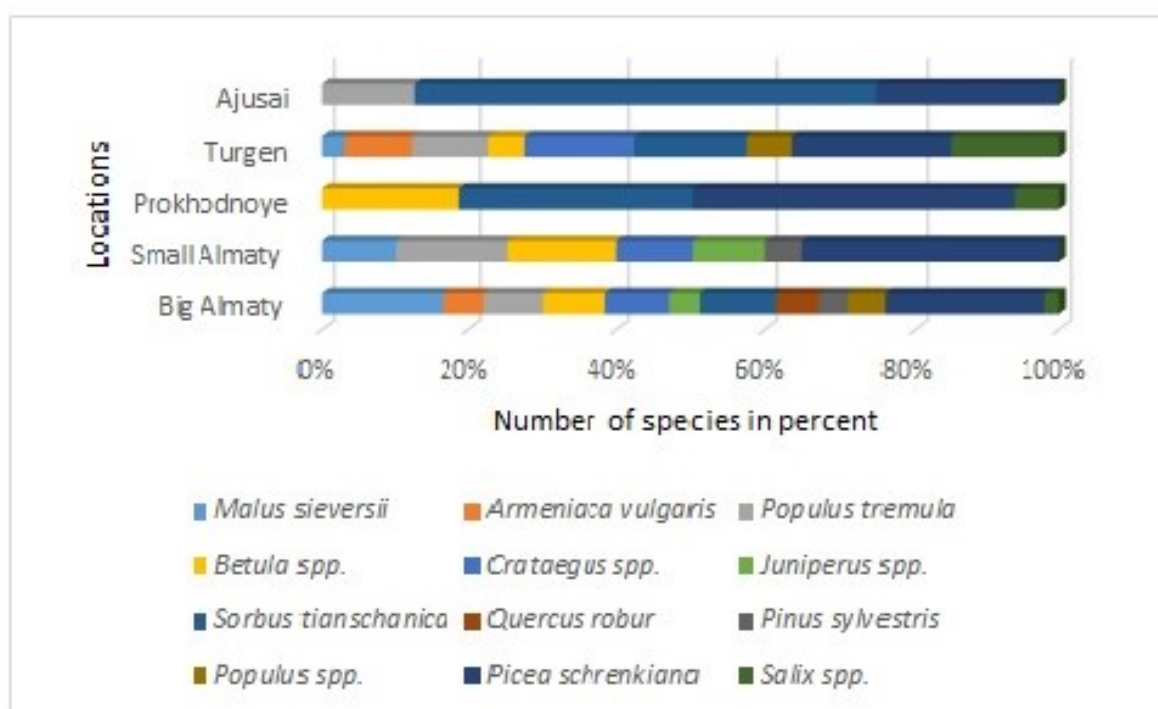


Fig. 10 – The number of soil fungi species associated with rhizosphere of some woody plants in different gorges of the Zailisky Alatau

Soil fungi in the rhizosphere of *Crataegus* spp. (*Crataegus almaatensis* Pojark., *C. korolkowii* L. Henry et al.) are found in three gorges. The largest number of species of soil fungi is characteristic of Turgen gorge (10 species) and the Big Almaty gorge (9 species). Only *Mucor mucedo* is noted in all these gorges.

The complexes of fungi associated with *Juniperus* spp. (*Juniperus sabina* L., *J. pseudosabina* Fisch. & C.A. Mey. et al.) consist of 4 species in the Big Almaty gorge, of 2 species in Small Almaty gorge, moreover, species characteristic of the Big Almaty gorge are not found in the Small Almaty gorge.

Soil fungi in the rhizosphere of *Sorbus tianschanica* are found in Big Almaty (11 species), Prokhdnoe gorge (5), Turgen (10) and Ajusai (5 species) (Fig. 10). The most common are *Mucor mucedo* and *Trichoderma viride*, found in three gorges. It should be noted, that in the rhizosphere of *Sorbus tianschanica* there are several species of the genus *Trichoderma*: *T. harzianum*, *T. koningii*, *T. viride*, *Trichoderma* sp.

The complex of fungi associated with *Quercus robur* consists of 6 species in oak plantings of the Big Almaty gorge, and the complex of fungi in the rhizosphere of *Pinus sylvestris* plantings consists of 4 species in the Big Almaty gorge, of 1 species in the Small Almaty gorge.

Soil fungi in the rhizosphere of *Populus* spp. are found in two gorges: in Big Almaty (5 species) and Turgen (4) (Fig. 10). *Absidia spinosa* is marked in both gorges.

The complexes of fungi in the *Picea schrenkiana* rhizosphere consist of 23 species in the Big Almaty gorge, of 7 species in Small Almaty gorge, of 7 species in Prokhdnoe gorge, of 14 species in Turgen and of 2 species in Ajusai. The most common species are *Absidia spinosa*, *Mucor mucedo*, *Cladosporium herbarum* and *Purpureocillium lilacinum*, found in five-three gorges.

Soil fungi in the rhizosphere of *Salix* spp. are found in Big Almaty (2 species), Prokhdnoe (1) and Turgen (10) (Fig. 10). *Absidia spinosa* and *Mucor mucedo* are the most common species.

Generally, the largest number of species of soil fungi is found in the rhizosphere of *Picea schrenkiana* (36 species, 22%) (Fig. 11), slightly less – in the rhizosphere of *Malus sieversii* (18 species, 11%), *Crataegus* spp. (18, 11%) and *Sorbus tianschanica* (19, species, 11), the smallest – in the rhizosphere of *Quercus robur* (6 species, 4%) and *Pinus sylvestris* (5 species, 3%).

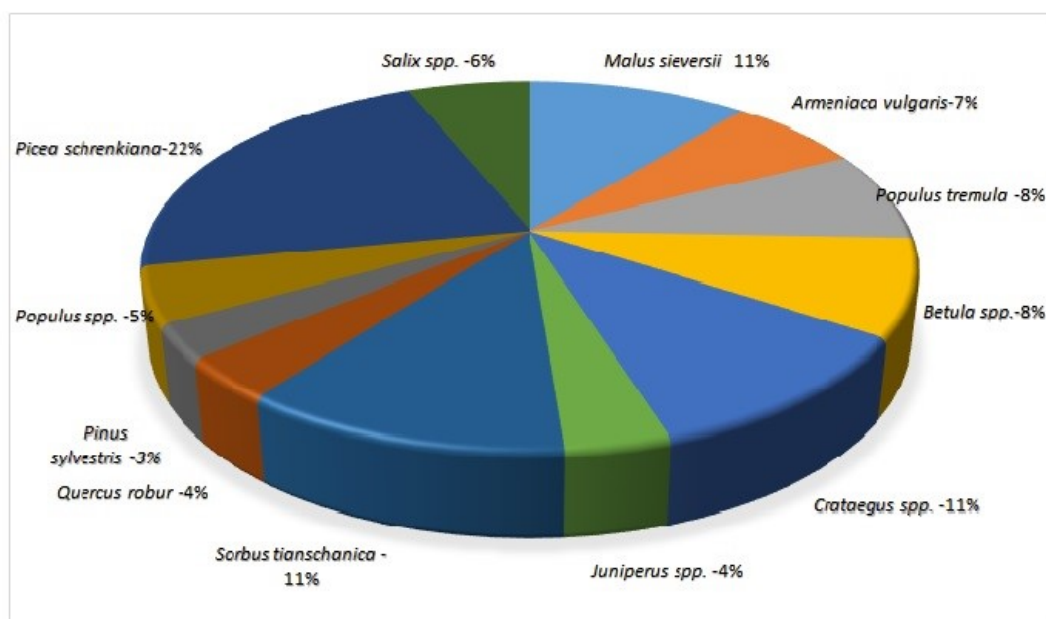


Fig. 11 – The number of soil fungi species the rhizosphere of woody plants of the Zailisky Alatau

Discussion

Trees are thought to have a stimulating effect on rhizospheric microorganisms and thus support a greater diversity of fungi (Christensen 1969). Therefore, higher fungal diversity is recorded in forest soil compared to agricultural fields and degraded lands (Sharma et al. 2015). This may be due to the fact that the difficult conditions of the humus-litter layer in forest soil are optimal for different species of fungi, because this layer consists of a mixture of decaying leaves and is exposed to propagules carried by air and water (Novak & Whittingham 1968).

In fairly rich forest soils of Zailisky Alatau, as well as in soils of small-leaved, mixed and coniferous forests of the Far East of Russia (Egorova & Kovaleva 2012, Egorova et al. 2013, Shumilova 2013) and the European part of Russia (Kurakov & Semenova 2016), *Penicillium* is the dominant genus. On the other hand, the maximum number of isolates associated with the

rhizospheres of plants from different polluted soils of Pakistan belongs to the genus *Aspergillus* (Samina et al. 2017), since representatives of this genus have the maximum ability to survive in a nutrient-poor environment.

The prevalence of zygomycetous fungi in forest soils of both India (Devi et al. 2012, Sharma et al. 2015) and Kazakhstan is associated with a high content of poorly decomposed organic substances in the latter (Dyakov 2006, Berseneva et al. 2008).

Our research supports the findings of other scientists (Pandey et al. 2006, Xu et al. 2013) that coniferous trees in subtropical and temperate regions support a relatively higher population of microorganisms compared to deciduous species.

Acknowledgements

This work was financed by the Project with title “Evaluation of the effect of micromycetes soil reserve on the restoration potential of the Zailisky (Trans-Ili) Alatau forests after fires”, IRN AP05131258.

References

- Akzhygitova NI, Breckle SW, Winkler G, Volkova EA et al. 2003 – Botanical geography of Kazakhstan and Middle Asia (desert region)., St. Peterburg. [in Russian]
- Berseneva OA, Salovarova VP, Pristavka AA. 2008 – Soil micromycetes of main natural areas. News of Irkutsk state University. Series “Biology. Ecology”. 1(1), 3–9. [in Russian]
- Christensen M. 1969 – Soil microfungi of dry to mesic conifer-hardwood forests in northern Wisconsin. Ecology 50, 9–27.
- Devi LS, Khaund P, Nongkhaw MW, Joshi SR. 2012 – Diversity of culturable soil micro-fungi along altitudinal gradients of Eastern Himalayas. Mycobiology 40, 151–158.
- Domsch KH, Gams W, Anderson TH. 2007 – Compendium of soil fungi. IHW-Verlag.
- Dyakov YuT. 2006 – Fungi and plants. Moscow. [in Russian]
- Egorova LN, Kovaleva GV. 2012. – Soil micromycetes of the nature reserve “Botchinsky” (Khabarovsk territory). Mycology & Phytopathology 46(2), 131–145. [in Russian]
- Egorova LN, Kovaleva GV, Aleshina OA. 2013 – Soil micromycetes of the nature reserve “Bolonsky” (Khabarovsk territory). Mycology & Phytopathology 47(4), 497–503. [in Russian]
- Index Fungorum. 2018 – Available from: <http://www.indexfungorum.org> (cited 2020 February 4)
- Kirk PM, Cannon PF, David JC, Stalpers JA. 2008 – Ainsworth and Bisby’s Dictionary of Fungi. CAB International.
- Kurakov AV, Semenova TA. 2016 – Species diversity of microfungi in the forest ecosystems of southern taiga in the European part of Russia. Mycology & Phytopathology 50(6), 367–378. [in Russian]
- Novak RO, Whittingham WF. 1968 – Soil and litter microfungi of a maple-elm-ash flood plain community. Mycology 60, 776–787.
- Pandey A, Trivedi P, Chaurasia B, Palini LMS. 2006 – Soil microbial diversity from the Himalaya, Need for documentation and conservation. NBA Science Bulletin 5, 28–60.
- Pidoplichko NM, Mil’ko AA. 1971 – Atlas of Mucorales fungi. Kiev. [in Russian]
- Pitt JI. 1979 – The genus *Penicillium* and its teleomorphic states *Eupenicillium* and *Talaromyces*. London.
- Polyksenova VD, Khramtsov AK, Piskun SG. 2004 – Methods of experimental study of microscopic fungi (Methodical instructions). Minsk. [in Russian]
- Rakhimova YV, Assylbek AM, Jetigenova UK, Kyzmetova LA, Yermekova BD. 2018 – Study of soil fungi of the rizosphere of main forest-forming trees of the Big Almaty Gorge of Transily Alatau (Kazakhstan). Problems of modern science and education 11 (131), 9–13. [in Russian]

- Rakhimova YV, Kyzmetova LA, Assylbek AM, Yermekova BD. 2019 – Diversity of Zygomycetes associated with the rhizosphere of woody plants from Ile-Alatau national park (Kazakhstan). *Current Research in Environmental & Applied Mycology* 9 (1), 53–65.
Doi: 10.5943/cream/9/1/6
- Raper KB, Fennel DI. 1965 – The genus *Aspergillus*. Baltimore.
- Raper KB, Thom Ch. 1968 – A manual of the *Penicillia*. New York.
- Samina S, Tahreem M, Shabnum S, Farah K et al. 2017 – Micromycete diversity associated with the rhizospheres of plants from different polluted soils of Lahore, Pakistan. *Current Research in Environmental & Applied Mycology* 7(3), 193–202.
- Schwarzman SR. 1962 – Materials to history of mycoflora in Kazakhstan. Alma-Ata. [in Russian]
- Seifert K, Morgam-Jones G, Gams W, Kendrick B. 2011 – The genera of Hyphomycetes. Utrecht.
- Sharma D, Gosai K, Dutta J, Arunachalam A et al. 2015 – Fungal diversity of twelve major vegetational zones of Arunachal Himalaya, India. *Current Research in Environmental & Applied Mycology* 5(2), 101–119.
- Shumilova LP. 2013 – Microscopic fungi of mountain brown-taiga soils of Dzhagdy ridge. *Problems of ecology of the Upper Amur region* 15, 83–90. [in Russian]
- Sutton BC. 1980 – The coelomycetes. Kew.
- Watanabe T. 2002 – Pictorial atlas of soil and seed fungi: Morphologies of cultured fungi and key to species. CRC Press.
- Xu X, Han L, Wang Y, Inubushi K. 2013 – Influence of vegetation types and soil properties on microbial biomass carbon and metabolic quotients in temperate volcanic and tropical forest soil. *Soil Science and Plant Nutrition* 53, 430–440.