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Lichens and Fungi on Sandstone Tombs at the Historical Jewish Cemetery in Wrocław (Poland)

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ABSTRACT
Microflora inhabiting rock surfaces, including bacteria, fungi, algae, and lichens, form a specific kind of an ecosystem. Unique and not well known forms of this environment are old cemetery tombs. To better understand such environments, lichenological and mycological studies were conducted in the old Jewish cemetery in Wrocław, Poland. The research covered 13 tombstones made of several varieties of sandstone. This research shows that some gravestones made of sandstone from Wartowice were strongly populated by fungi. Physical and chemical properties of the stone as well as the quality of the starting raw material were favourable for this deterioration process to occur. The most frequently recorded lichens were: *Psilolechia lucida*, *Verrucaria nigricans,* and *Lepraria* sp. The species of fungi most frequently found on the monuments were: *Cladosporium herbarium*, *Aspergillus niger,* and *Alternaria alternata*. The aim of the study was to detect the mycobiota living on tombstones in the historical Jewish cemetery in Wrocław, which contains stones originating from Lower Silesian quarries that now exhibit traces of biodegeneration.

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Introduction

The old Jewish cemetery in Wrocław, now the Museum of Cemetery Art, is a branch of the Municipal Museum of Wrocław. The site dates back to 1856 and includes graves of Jews from various parts of Poland, as well as from distant places such as Bonn, Hamburg, and Boston. There are currently around 12,000 gravestones in an area of 4.6 hectares. The cemetery clearly differs from others in Eastern Europe. It is a place of various forms of grave art, rich symbolism, unusual ornamentation of matzevot, and other structures. Some ornaments are modelled in the Moorish or Egyptian style. The necropolis is a particularly important place for historians, as a place of burial of many famous people not only from Wrocław, but from all over Europe.

Many of the tombstones in the cemetery were made of several varieties of sandstone, differing in mineral composition, porosity, and water absorption, which over time have undergone a process of deterioration. Deterioration of the stone includes a number of changes taking place in its structure, including its weakening, deterioration, and destruction (Jarmontowicz, Krzywobłocka-Lurów, and Lehmann 1994; Lorenc and Mazurek 2007). Destruction and decomposition of the stone can be caused by many factors: physical, chemical, and biological (Pavia and Bolton 2000; Lorenc 2003, 2009; Lorenc and Lorenc 2018; Chlebicki et al. 2021).

Microorganisms play one of the most important roles in the biodeterioration process (Steiger, Wolf, and Dannecker 1993; Wittenburg 1994; Mukerji et al. 1999; Warscheid and Braams 2000). Most of the organisms that first inhabit the surface of the stone (fungi, lichens, and some bacteria) produce a number of organic acids that, when chemically reacted with the substrate, cause its acidolytic or oxidative corrosion (Ortega-Calvo et al. 1994). That opens the gate for microorganisms – called endoliths – to enter the new unsettled niches such as cracks, depressions, and sometimes even pores between mineral components (Hirsch, Eckhardt, and Palmer 1995). Most of the endoliths are autotrophs, which obtain the organic substances that build their body and are necessary for their life through processing of inorganic substances. Among the endoliths there are three groups: hasmoendoliths that colonise cracks and fissures in the rock, euendoliths which actively penetrate into the interior of the rocks and produce cracks adapted to their size and body shape, and cryptoendoliths that colonise structural defects in porous rocks, including defects created and abandoned by the euendoliths (Golubic, Friedmann, and Schneider 1981). Depending on the studied group of organisms there are different

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approaches and collection methods that enable the scientist to discover individual groups of endoliths (Pandey et al. 2011; Gupta, Sharma, and Circl 2012). Due to the fact that these organisms live in an environment where there is very little availability of water and elements necessary for life, they have rather slow metabolism and growth rates.

Lichens are another group of organisms widely found on rock surfaces. They play a key role in the biodegradation process, mainly thanks to produced metabolites that destroy rocks and stones. Their secondary metabolites, particularly oxalic acid, are efficient chelates that form silicate salts on the surface of the stone. In addition, lichen with significantly different structures (powdery, crusty, bushy) create a specific microclimate on the surface of the stone, strongly affecting water retention (Seaward and Giacobini 1988). This particular feature is largely related to the rate of progressive biodeterioration that makes lichens so important in this process (Pinna 2014).

The aim of the study was to detect the mycobiota living on tombstones in the historical Jewish cemetery in Wrocław, which contains stones originating from Lower Silesian quarries that now exhibit traces of biodegeneration.

Materials and methods

Kinds of stone and collection from tombstones

Lichenobiotic and mycobacterial surveys of cemetery gravestones were carried out in 2017 at the old Jewish cemetery, now the Museum of Cemetery Art in Wrocław located at Ślężna St. (Figure 1). They included 13 sandstone tombstones showing changes in the form of swelling, pitting, peeling, and falling of sand from the stone. The sandstones came from the Wardowice region (eight tombstones), Żerkowice (two), Rakowice Małe (one), Radków (one), and Słupiec (one). The identification of the type of sandstone used to make the examined tombstones was supplemented with numerical data from the study of Dziedzic et al. (1979) and Walendowski (2009) and obtained from the Sandstone Mine S.A. in Bolesławiec and the Red Sandstone Quarries – Building Masonry in Nowa Ruda. The changes visible on the tombstones were located, the degree of biodeterioration was assessed (percentage of the damaged surface in relation to the whole monument), and the percentage of the area covered with lichen was measured. Then, samples for laboratory tests were taken from the places with visible symptoms of ongoing biodegradation process like discolouration (mostly blackening) and/or surface structure changes. All samples were processed within five hours of collection.

Isolation and identification of fungi

Stone samples from tombstones designated for mycological research were collected using two methods: inoculation of stone material on solidified medium and with cotton swabs (swabbing surfaces with sterile cotton swabs) (Figure 1). A dilution plate method was used for isolation of fungi. One gram of fresh ground/stone samples were placed in 10 mL of sterile distilled water and shaken by vortexing the mixture for 30 min at room temperature. Then 100 µL portions of the suspensions were inoculated onto plates containing 3% potato dextrose agar (Difco), distilled in sterile water ('hungry agar'). Chloramphenicol was added to the molten medium after autoclaving. The plates were incubated at 28 ± 2°C for seven days and examined regularly. As soon as the colonies appeared, they were counted and transferred to potato dextrose agar slants. Isolated fungal strains were identified on the basis of morphological studies (Raper and Thom 1949; Raper and Fennell 1965; Rifai 1969; Zycha and Siepmann 1969; Lodder 1970; Ellis 1971). The identified strains were maintained on PDA slants at low temperature (4 ± 1° C). Samples were taken for mycological analyses using another method – by swabbing surfaces with sterile cotton swabs (plastic test tubes with sterile water). Further steps were carried out in the same manner as with the first method. On Petri dishes, irrespective of the applied inoculation method, the occurrence of particular species of fungi was determined using the division: + weak intensity (1–4 colonies), ++ medium (5–10 colonies), and +++ strong (> 10 colonies per Petri dish).

Identification of lichens and assessment of their occurrence

On selected tombstones, the severity of individual lichen species contamination was determined, using the division: + – weak intensity (single colonies), ++ – medium (covering the monument's surface up to 10%), and +++ – strong (covering the monument's surface by more than 10%). Due to difficult conditions for lichen collection, limited by interference in the structure of the monument, some specimens were marked in the field on the basis of morphological features. A study of the physiochemistry of lichens by staining (using standard chemical reagents – spot tests) was also performed (Fałtynowicz 2016). Fragments of the thallium (required for later microscopic observations and analyses) were placed on pieces of adhesive tape, together with a fragment of the substrate, and then identified using stereoscopic and optical microscopes. Due to the characteristics of the research, rock lichens were documented only with the help of photographs. Naming of lichens was carried out according to Wirth, Hauck, and Schultz (2013) and Smith et al. (2013).

Results

The stone analysis

The research allowed the identification among the sandstone objects of the most overgrown by fungi

Figure 1. Gravestones at the historical Jewish cemetery in Wrocław (Poland) with traces of biodeterioration. Red arrows mark sampling locations.

and lichens; several varieties of these rocks originate from the Lower Silesian quarries. The origin and characteristics of sandstones and the condition of tombstones are presented in Table 1.

The area around Bolesławiec is represented by varieties of Upper Cretaceous sandstones from Wartowice, Żerkowice, and Rakowice Małe. The first one is a fine-grained and well sorted variety, composed of quartz grains (about 87%), with clay binder (about 5%). Similarly, a variety from Żerkowice has fine and well sorted grains. In this case, the quartz grains (about 77%) are joined by clay-silica binder (about 18%). Sandstone from Rakowice Małe has slightly finer and well sorted grains. Although the quantitative

Table 1. Characteristics of sandstones and the state of their preservation.

Tomb No.	Stone origin	Type, colour, and age	Kind of stone	Porosity and absorption	Tomb condition: Surface destroyed by fungi	Tomb condition: Surface covered by lichens
1–8	Wartowice (8 km to SE from Bolesławiec)	Type: Fine grained quartz sandstone with clay binder Colour: yellow with single brown dots 3 mm in diameter Age: Upper Cretaceous	Hard, medium weather resistant, over time covered by a light grey patina	Porosity [1] 9.39% Absorption [1] 4.47%	1–15% 2–20% 3–25% 4–10% 5–40% 6–30% 7–20% 8–20%	1–10% 2–15% 3–0% 4–3% 5–5% 6–0% 7–7% 8–35%
9–10	Żerkowice (14 km to S from Bolesławiec)	Type: Fine grained sandstone with clay-siliceous binder Colour: yellow Age: Upper Cretaceous	Hard, medium weather resistant, over time covered by a light grey to grey-yellow patina	Porosity [1] 15.13% Absorption [1] 7.55%	5% and 20%	1% and 27%
11	Rakowice Małe (14 km to SSE from Bolesławiec)	Type: Fine grained quartz sandstone with clay-siliceous binder Colour: white Age: Upper Cretaceous	Hard, weather resistant, over time covered by a light grey patina	Porosity [1] 9.82% Absorption [1] 4.77%	10%	12%
12	Radków (25 km to WNW from Kłodzko)	Type: Fine grained sandstone with siliceous- clay binder Colour: grey Age: Upper Cretaceous	Hard, weather resistant, over time covered by a light grey to dark yellow patina	Porosity [2] 14.8% Absorption [2] 4.0%	5%	2%
13	Słupiec (16 km to NW from Kłodzko)	Type: Fine grained quartz sandstone with siliceous binder, with small amounts of clay minerals and iron oxides Colour: red Age: Lower Permian	Hard, weather resistant	Porosity [3] 10.21% Absorption [3] 5.79%	5%	15%

Note: [1]Sandstone Mines S.A. in Bolesławiec; [2]Walendowski (2009); [3]Red Sandstone Quarry, Building Masonry in Nowa Ruda.

proportions of quartz grains (about 86%) to the binder (about 5%) are similar to those of the Wartowice variety, the siliceous binder of this rock is much stronger. Due to the mineral composition and structure, the third variety is more resistant to destruction than the first two.

The degree of deterioration of the varieties of stone from the vicinity of Kłodzko presented itself differently (the Upper Cretaceous, grey sandstone from Radków and the dark red coloured, Lower Permian sandstone from Słupiec). The first one is a fine-grained rock with a well-sorted clastic material which has a mineral and granulometric composition that is quite varied. Its grain skeleton consists of quartz grains and silica rocks (about 72%) as well as feldspar, mica, and other rocks (altogether about 19%), whereas the binder has a silica-clay nature (about 9%). The sandstone from Słupiec is structurally similar to the previous one, but the quantity of grain skeleton made up of quartz grains, potassium feldspar, and crumbs of various rocks (about 80%) is different. The silica binder (about 14%) with a small admixture of clay minerals and iron oxides is also different. The latter are responsible for the characteristic colour of the rock. Both varieties of stone are more resistant to adverse weather conditions than the first two from the vicinity of Bolesławiec. Sandstones from Żerkowice and Radków were characterised by the highest porosity and the sandstones from Żerkowice and Słupiec were characterised by the highest absorbability.

The degree of biodeterioration of the examined tombstones varied. Changes in their structure occurred in various parts of the monument: on the pedestal (No. 1, 2, 6, 9, 13), in the middle or bottom part of the mainboard (No. 3, 5, 7, 10, 11), and on the columns (No. 4, 8, 12). The degree of damage to sandstones from Wartowice ranged from 10% to 40%. The most damaged by the microorganisms were monuments No. 5 (40%), 6 and 8 (30%), while the least were No. 4 (10%) and 1 (15%). A monument made of sandstone from Rakowice Małe was also damaged at the level of 15%. Tombstones made of stone brought from Żerkowice were destroyed at levels of 5% and 20%. The weakest biotic destruction of the stone was found on tombstones made from sandstones from the Kłodzko region (Radków and Słupiec) – 5% of the surface was noted to be damaged.

The percent coverage of the tombstone surface by lichen was significantly different between different studied objects. The largest area of tombstones was occupied by lichen on locations No. 8 (35%) and 10 (27%), made of stone from Wartowice. Some of the objects studied were devoid of lichens (No. 3 and 6 – sandstones from the Wartowice area) or there were individual isolates (tombstones No. 9 and 12 made of sandstones from the Żerkowice and Radków regions).

Fungi and lichen on stone surfaces

Fourteen species of lichens were found on the examined tombstones, forming crust-like and leafy patches (Table 2). Leaf thalluses were formed by *Pheophyscia orbiscularis*, *Physcia tenella*, *Protopermaliopsis muralis*, and *Xanthoria parietina*; crusty thalusses were formed by *Candelariella* spp. *Lecanor dispersa*, *Lecidea stigmatea*, *Lepraria* sp., *Psilolechia lucida*, *Trapelia obtegens,* and *Verrucaria* spp. The most common lichen species on sandstone tombstones were: *P. lucida* and *Verrucaria nigricans* colonising eight of the tombstones and *Lepraria* sp. colonising five tombstones. The first two taxa also occupied the largest area of tombstones, however *V. nigricans* was noted more often than *P. lucida*. The largest number of species of lichens were recorded on monuments No. 13 (eight species), No. 10 (seven), and No. 4 (seven) made of sandstones from Słupiec, Żerkowice, and Wartowice; and the least on tombstones No. 5, 9, and 12 (one to two species). On tombstones No. 3 and 6 (sandstones from Wartowice) lichens were not found at all.

In total, 19 species of fungi were isolated from the monuments, 14 by inoculation and 12 by swabbing (Table 3). The method by which a larger number of fungal colonies was isolated was the inoculation of the stone material on solidified medium. With the swab method, the fungi were obtained by half when compared to the previous method. When using both methods on the same tombstone, different fungal species were often isolated, only five taxa (*Aspergillus niger*, *Cladosporium herbarium*, *Penicillium decumbens*, *Rhodotorula glutinis*, and *Trichoderma koningii*) were isolated in both cases. The predominant group among the isolated fungi were representatives of the *Ascomycota* type. Sporadically found were *Zygomycota* (*Mucor hiemalis*) and *Basidiomycota* (*R. glutinis*). The species isolated most often were *A. niger*, whose presence was noted on more than half of the examined monuments (seven tombstones), as well as *C. herbarum* and *R. glutinis*, which were found on the surface of five monuments. The greatest species diversity was observed within the *Penicillium* genus, in which five species were isolated. Among them, *P. chrysogenum* (syn. *P. notatum*) was most frequently recorded.

Settlement by microorganisms differed on stones originating from different sites. Sandstones from Wartowice were colonised by various species of fungi and lichens (Tables 2 and 3); *Cladosporium* genus predominated, especially *C. herbarum* and *A. niger*. Lichens were mostly represented by *P. lucida* and *V. nigricans*. Large numbers of *C. herbarium* isolates were obtained from tombstone No. 13 (sandstone from Słupiec), regardless of the applied method. The remaining species were less numerous: *A. niger, E. nigrum, Alternaria alternata, P. chrysogenum,* and *R. glutinis*. The monument was also colonised by numerous lichens, mainly *Candelariella reflexa* and *L. dispersa*. Few colonies of *A. alternata, E. nigrum, C. herbarum,* and *T. koningii* were isolated from Żerkowice sandstones (tombstones 9 and 10). Eight species were found among the lichens, mainly *V. nigricans* and *P. lucida*. The stone originating from Rakowice Małe was populated by numerous *P. lucida* and two species of fungi – *A. niger* and *Chloridium chlamydosporis*. The first of them was, however, more numerous. The gravestone from Radków was covered only with the thalluses of the most common lichens in the cemetery: *V. nigricans* and *P. lucida*. Sandstone tombstones from the area of Wartowice (No. 2) and Słupiec (No. 13) turned out to be the most diverse in terms of the number of species. A total of 14 species of lichens and fungi were obtained from them. The smallest number of microorganisms was found on monuments No. 6 (Wartowice) and No. 9 (Żerkowice) – only one to three species. On the remaining gravestones the number of lichens and fungi species isolated ranged from five to ten (Tables 2 and 3).

Discussion

According to Owczarek-Kościelniak et al. (2020) fungal and lichen communities are rather weakly related to stone deterioration symptoms, especially in the early stage of the process. In this study, we came to a similar conclusion, finding that the populations of microorganisms that settle on the surfaces of stones with visible versus barely noticeable signs of degradation are not very different. In our opinion, in early stages of the fungal settlement process in the Jewish Cemetery in Wrocław, more important factors that affect the mycobiota are mineral (chemical) composition, and the porosity and absorbability of sandstones used in tombstone production. The lack of stone maintenance also allowed the development of unique microbial niches, often settled by rare and slow growing organisms (Owczarek-Kościelniak and Sterflinger 2018; Owczarek-Kościelniak 2020).

Depending on the type and variety, the stones and tombstones made from them may deteriorate over time due to atmospheric conditions and/or biochemical activity of microorganisms, as was the case in the monuments researched in this study. The basic features of the stone, on which resistance to destruction depends, are their mineral (chemical) composition and porosity and absorbability. The most resistant to destruction are crystalline rocks, made of minerals resistant to chemically aggressive solutions. These include some varieties of igneous rocks (granites, basalts) and metamorphic rocks (gneisses, quartzites, marbles). The course of the deterioration largely depends on the physical properties of the substrate, primarily on the size of the quartz grains in the material (Pinna 2014). In the group of sedimentary rocks, compact types (limestones, sandstones) are more resistant than porous ones. In the case of porous varieties of clastic rocks, the type and chemical nature of the binder joining the grain skeleton play a decisive role in the resistance. The silica binder of stone contributes to the increase in its resistance to adverse effects

Table 2. The occurrence of lichen on various types of sandstone.

	Tombstone Number													
Species of lichen	1	2	3	4	5	6	7	8	9	10	11	12	13	Σ
Candelariella aurella		+									+		+	3
Candelariella reflexa										+			++	2
Candelariella vitallina				+				+		+				3
Lecanora dispersa				+			+			+			++	4
Lecidea stigmatea				+										1
Lepraria sp.	++						+	+	+				+	5
Pheophyscia orbiscularis										+				1
Physcia tenella	+			+										2
Protopermaliopsis muralis		+		+						+			+	4
Psilolechia lucida	+	++			+		+	+++		+++	+++	+	+++	8
Trapelia obtegens				+				+++					++	3
Verrucaria muralis													+	1
Verrucaria nigricans	++	+++			++		++	++		+++	++	++		8
Xanthoria parietina													+	1
Number of species	**4**	**4**	**0**	**6**	**2**	**0**	**4**	**5**	**1**	**7**	**3**	**2**	**8**	**46**

Note: + weak intensity (single colonies), ++ medium (covering the monument's surface up to 10%), +++ strong (covering the monument's surface by lichen >10%)

of both weather conditions and microorganisms. This is particularly evident for monuments No. 11, 12, and 13, which were among the least damaged tombstones, although some microorganisms were isolated from them, such as numerous colonies of *C. herbarum* and heavy coverage by *P. lucida*. Paradoxically, although neither the porosity nor the mineral composition is conducive to microbial settlement, tomb No. 13 was one of the most colonised monuments across all of the ones studied. The reason for high presence of lichens (eight species) and fungi (six species, isolated both from the surface and inner part of the stone) might be found in the presence of iron oxide particles in the stone. Many microorganisms growing under aerobic conditions need iron for a variety of metabolic functions and some of them developed special compounds called siderophores, which allow them an iron-chelating process (Varma and Chincholkar 2007). All of the fungal species detected on tomb No. 13 evolutionarily developed this ability (Frederick et al. 1981; Varma and Chincholkar 2007; Pourhassan et al. 2014; Cudowski and Pietryczuk 2019; Bello, Adebola, and Asemoloye 2022), which helps them conquer new territories, such as stone surfaces or soil after fire, etc. In addition, the taxonomical position of most of the mycobionts in lichenicolous fungi suggests that they also should be able to produce siderophores (Varma and Chincholkar 2007) which can explain such an abundant presence of lichen species on this particular monument, No. 13.

Not only the type of stone base, but also the percentage content and mutual quantitative proportions of silica and clay minerals in the binder play a decisive role. The ability to absorb water through the stone, resulting from its porosity, is also important. The presence of moisture, atmospheric water, and capillary infiltration causes the slow chemical degradation of the stone, and are also the basic factors enabling the development of microorganisms not only on the surface, but also in the deeper parts of the stone. The significant clay content and distance from the ground (related to capillary infiltration) might be the reason for fungal presence, both as biofilm or as a hyphae penetrating into a deeper part of the monument, on sandstone from Wartowice No. 1–5, on which fungal colonies were mostly isolated by inoculation method. Fungi, identified through the means of production of various pigments (*Cladosporium* spp. and *Alternaria* spp.) and organic acids (some species of the genus *Aspergillus*, *Alternaria*, and *Penicillium*) can cause dissolution of mineral components and the rock binder, leading to the exfoliation of the stone material, that was observed in other studies (Silverman and Munoz 1970). Following Owczarek-Kościelniak (2017), species of fungi isolated during these studies, even though not typical lithobionts, very often settle on the stones and tombstone surfaces, affecting deterioration processes. Although, to prove negative impact of fungi and lichens on tomb structures in the Jewish Cemetery in Wrocław, more studies should be performed.

As the studies have shown, the deterioration observed is not always are associated with the microorganisms occurring on the stone surfaces. The destructive effects of atmospheric conditions were observed on monuments No. 6 and 7. They exhibited serious damage, manifesting in the dissolution and elimination of the binder of the structurally weaker part of the stone and the scattering of sand on approximately 20–30% of the surface. However, there was no significant fungal colonisation of these monuments; only *A. niger, A. versicolor,* and a single colony of *C.cladosporioides* were isolated from the stone (by swabbing method) which might suggest its random occurrence on the surface from air or as a biofilm pioneer.

In the case of lichens, which cover a total of 15% of the area of the aforementioned monument, it is difficult to clearly determine their role in stone degradation. Their appearance also is mostly dictated by the

Table 3. The occurrence of fungi on various types of sandstone (Method of isolation: I – inoculation, S – swab).

	Tombstone Number																										
	1		2		3		4		5		6		7		8		9		10		11		12		13		
Species of fungi	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	Σ
	ZYGOMYCOTA																										
Mucor hiemalis			+																								1
	ASCOMYCOTA																										
Alternaria alternata			+		+												+								+		4
Aspergillis versicolor														+													1
Aspergillus fumigatus					+																						1
Aspergillus niger		+	+									+		++		+					+	++				+	7
Botrytis cinerea			+																								1
Chloridium chlamydosporis																						+					1
Cladosporium cladosporioides				+						++				+									+				4
Cladosporium herbarum			+	+	+++		+													+			+		+++	+++	5
Epicoccum nigrum			+														+								+	+	3
Penicillium chrysogenum			+			+			+																	++	4
Penicillium decumbens									+						+												2
Penicillium nigricans	+																										1
Penicillium urticae															+												1
Penicillium velutinum			+++																								1
Trichoderma harzianum									+																		1
Trichoderma koningii																+			+								2
	BASIDIOMYCOTA																										
Rhodotorula glutinis				+	+				+							+							+		+		6
	OTHERS																										
White non-sporulating colony																				+							1
Number of species	1	1	8	3	4	1	1	0	4	1	0	1	0	3	2	3	2	0	1	2	1	2	2	0	4	4	-
Total of species	**2**		**10**		**5**		**1**		**5**		**1**		**3**		**5**		**2**		**3**		**2**		**2**		**6**		**47**

Note: + weak intensity (1–4 colonies), ++ medium (5–10 colonies), and +++ strong (> 10 colonies per Petri dish).

mineral availability and acidity of stones (Adamo and Violante 2000; Bungartz, Garvie, and Nash 2004). Hoppert et al. (2004) even hypothesised that lichens might serve as a kind of binder that, with a dense network of cells and extracellular polymers, stabilises and partially immobilises stone-building mineral particles. As demonstrated by Chiari and Cossio (2002) on the example of Wyoming petroglyphs, the presence of lichens on historic rock surfaces can protect them from the negative effects of rain and sunlight, without affecting the porosity of the stone. Lichens can also limit the rate of natural stone degradation, by limiting the intensity of water exchange between the substrate and the atmosphere, as well as protect against airborne pollutants and salts and other abiotic factors (Ariño et al. 1995; Wendler and Prasartet 1999; Carballal et al. 2001; Garcia-Vallès, Topal, and Vendrell-Saz 2003; Bungartz, Garvie, and Nash 2004; Warscheid and Leisen 2011). On the examined tombstones, lichens such as *Verrucaria nigricans, Psilolechia lucida,* and *Lepraria* sp. were found most frequently. All described lichens are commonly found throughout the country. Some of the species, such as *Candelariella* spp., *P. tenella,* and *X. parietina* might settle on monuments as a secondary surface, originating as spores spread by air from tree bark, which is their main growth place. All of the detected species owe their wide spread to high resistance to air pollution, which allows them occur in city centres. The small diversity of lichens found can be explained by the close proximity of the Jewish cemetery to the city centre and busy streets, which indirectly translates into their biota. Publications dealing with lichens and fungi isolated from the tombstones of Polish Jewish cemeteries are rare (Matwiejuk 2016) and this is one of the few records tracking this unique environment.

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