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Review

Fungi utilizing keratinous substrates

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ABSTRACT

One of the basic tasks in the field of biodeterioration is to recognise the microbial species responsible for the destruction of particular substrates, and to identify factors impacting the level of damage caused by microorganisms. Even in 1839, it was known that there existed some fungi capable of attacking keratinized tissues, although, at that time, only dermatophytes were recognised. The relevant literature pertaining to microbiological deterioration of keratinous substrates includes 299 fungi belonging to 100 genera. Representatives of the genera *Aspergillus*, *Penicillium*, *Chrysosporium*, *Fusarium*, *Microsporum*, *Trichophyton*, and *Acremonium* appear to be the most common. Of the 299 species collected, 107 belonging primarily to the Onygenales and Eurotiales are pathogenic to humans. The research focusing on microbial ability to colonize and destroy keratinous materials has been carried out mainly on sheep fleece, hairs, and feathers, but only a few authors have dealt with woollen fabric biodeterioration, which is of particular significance for the preservation of antique textiles.

Contents

1. Introduction

Keratins form a group of highly specialized proteins produced in epithelial cells of vertebrates. Proteins, the principal constituents of a horny epidermis layer and of its products—such as hairs, spines, horns, nails, hooves, claws, or feathers—belong to a group of hard keratins characterized by a high (3–12%) concentration of cystine. A large number of disulfide bonds originating from the cystine produce a solid polymer structure of high molecular weight and play an important role in forming the resistance of keratin to enzymatic decay (Asquith, 1977; Timar-Balazsy and Eastop, 1998). The susceptibility of individual keratinous materials to fungal attack is attributed to the various proportions of basic structural components, namely: cuticle, cortex, and medulla, as well as to different microfibril packings and the quantity and composition of the matrix.

When growing on keratinous materials, microorganisms initially use non-keratinous substrate components such as membrane material, nucleic remnants, cytoplasm residues, endocuticle, or a cell membrane complex, as well as lipids present in the material (Baxter and Mann, 1969–1970; Al Musallam and Radwan, 1990). They begin to decompose keratin only after they have utilized all these components. Although the non-keratinous elements of horny epidermal products can be utilized by a wide variety of fungi, the total decomposition of keratinous material is caused only by specialized microorganisms capable of generating a specific sequence of events (Dix and Webster, 1995; Jennings, 1995). The keratinolysis process does not involve only keratinase activity; the keratinous substrate is altered prior to this activity, as a result of the breaking of the disulfide bridges. This process, called

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sulfitolysis, is considered to be the key reaction of keratinolysis, as proteases alone cannot break the disulfide bonds and generate the complete hydrolysis of the keratin. Thus, biodegradation of keratin is the result of three reactions, namely: deamination, sulfitolysis, and proteolysis (Kunert, 1972, 1992, 2000; Ruffin et al., 1976).

While investigating the process of keratin decomposition caused by microorganisms, it is important to supplement the results of biochemical analyses with morphological observations of the hyphal penetration into the keratinous substrates. Two main modes of invading keratinous materials, namely surface erosion and radial penetration, are specified. The first mode is a progressive destruction developing from the outside toward the centre of the fibre and manifests itself as cuticle decay and the wavy appearance of the cortex surface. The second mode is an accidental invasion of the substrate by more or less specialized hyphae penetrating the fibres perpendicularly to the surface; its most advanced form causes perforating organs to develop. Detection of either of these invasion modes in the fungi means that the digestion of keratin molecules is in progress and these organisms are classified as keratinolytic (Filipello Marchisio et al., 1994; Filipello Marchisio, 2000). The detailed descriptions of individual phases of fungal keratin filament decomposition are contained in a research project dealing with hair samples (English, 1963, 1965). The layered construction and the physically resistant structure of these materials induce a frond-like mycelium, and cause borers to form. All fungi able to grow on keratinous substrates produce frond-like mycelia, and it seems that the formation of such mycelia is a necessary condition for fungi to grow on materials of such complicated structure. The main function of the frond-like mycelium is to absorb nutrients. Only some fungi contacting hard keratins form borers. It seems that these borers penetrate the substrate by generating pressure, but are unable to digest it, suggesting that they have only a mechanical role that consists of the penetration of resistant and poorly digestible materials. In the case of keratinophilic fungi, keratinous substrates are invaded by the fronded mycelia, by boring hyphae, or by non-specialized mycelia. The fronded mycelium and the boring hyphae are the eroding fronds and perforating organs in the keratinolytic fungi. These specialized structures formed by the two groups are very similar to each other, and the only difference is that the eroding fronds and perforating organs have some keratinolytic properties contrary to the fronded mycelium and boring hyphae of keratinophilic fungi (Vanbreuseghem, 1952; English, 1965; Hawks and Rowe, 1988).

Microbial activity in materials causes several types of deterioration. They are: surface changes such as changes in the saturation of colour; obliteration of the original appearance of material; characteristic mould odour (the foregoing three are the first signs of microbial growth on the substrate); unsightly stains of various kinds, usually very difficult to remove; and structural decomposition of the material as a result of the continuous growth and metabolic activity of microorganisms leading to chemical changes in the substrates and, in consequence, reduction in strength and loss of the material as the final result. Many factors impact the degree of material biodeterioration, including microbial metabolic products, i.e., enzymes, acids, and pigments; chemical composition of the material and whether or not additional substances, such as dyes, are contained in the materials; moisture content and its accessibility to microorganisms; history of the material and its age; and local microclimate: availability of oxygen and light, temperature, and relative humidity.

The basic objective of this paper was to catalogue fungi, which might be expected to be active in the cases of microbial deterioration of keratinous materials, and to identify the most destructive. Fungi pathogenic to man are also shown.

2. Taxonomic classification of fungi

Microorganisms as listed in Tables 1–3 and described in the text belong to two kingdoms: Chromista and Fungi, although the former is represented by only one species of phylum Oomycota, i.e., *Pythium oligandrum* Drechsler (isolated from feathers, Kornillowicz, 1991–1992). Three phyla are present in the Fungi. The phylum Chytridiomycota is represented by two species, *Catenophlyctis variabilis* (Karling) Karling, and *Rhizophydium keratinophilum* Karling, which were found in soil growing on all common forms of keratin-containing tissues, including wool, but not on other materials (White et al., 1950; Batko, 1975). The phylum Zygomycota is represented by 24 species (Table 1), and the Ascomycota by 54 species (Table 2). A separate group, which is the most numerous, is formed by anamorphic fungi represented by 218 species (Table 3), covering 73% of all the fungi presented in this paper. The majority of species belong to two orders: Onygenales and Eurotiales. It is not surprising that the species belonging to the Onygenales occur very often on keratinous materials. This is because the fungi of the following genera—*Arthroderma*, *Aphanoascus*, *Onygena*, *Epidermophyton*, *Microsporum*, *Trichophyton*, *Chrysosporium*, etc.—are highly specialized organisms, biologically capable of metabolizing horny products of epidermis containing keratin. Some of these keratinolytic fungi use keratin saprophytically, while others develop biochemical activity and change into pathogens capable of invading and using keratin contained in living organisms (Mercantini et al., 1989; Benny et al., 2001; Geiser and LoBuglio, 2001; Kirk et al., 2001). The Eurotiales includes species of the *Aspergillus* and *Penicillium* anamorphs, which are very important and the most common fungi found in nature.

Analysis of the genera shows that the following representatives predominate: *Aspergillus* and *Penicillium* (29 species each), *Chrysosporium* (21 species), *Fusarium* (13 species), *Trichophyton*, *Microsporum*, and *Acremonium* (11 species each), *Mucor* (10 species), *Arthroderma* (8 species), *Malbranchea* (7 species), *Chaetomium*, *Ulocladium*, and *Verticillium* (6 species each), and *Paecilomyces* and *Scopulariopsis* (5 species each). All other genera contain 4 or fewer species, with the majority represented by one species only.

3. Keratinolytic potential

The majority of keratinolytic fungi do not entirely depend on keratin as their only source of carbon and nitrogen. However, there are highly specialized, substrate-specific organisms that grow only on keratinous materials and feed on the nutrients contained therein. Such species include the soil-populating representatives of Chytridiomycota, i.e., *C. variabilis* and *R. keratinophilum*.

Table 4, which catalogues fungi based on the type of substrate from which they were isolated or which they degraded, highlights those species that are most active in the degradation of keratinous materials. Three species, *Aspergillus terreus*, *Gliocladium catenulatum*, and *Scopulariopsis brevicaulis*, showed high activity toward keratin in cultures grown on hooves as the single source of carbon and nitrogen. Six species of fungi, *Auxarthron conjugatum*, *S. brevicaulis*, *Chrysosporium indicum*, *Chrysosporium pannicola*, *Microsporum gypseum*, and *Trichophyton ajelloi*, utilized human hair as a sole source of carbon and nitrogen (see also Tables 2 and 3). It should be added that many other species from the *Chrysosporium*, *Microsporum*, and *Trichophyton* genera manifested high hair-degrading activity (Table 3). One of the types of keratinous materials that is rarely studied, the textiles, suffers the severest degradation if exposed to *Gymnoascus arxii* (Table 2). Three fungal strains, *Chrysosporium queenslandicum*, *Engyodontium album*, and *Graphium penicillioides*, digested insoluble keratin used as the sole source of carbon, nitrogen, and sulphur (Table 3). Two species,

Table 1
Fungi utilizing keratinous substrates. Zygomycota.

No.	Species name	Strain source, comments	References
Mucorales			
1.	***Absidia corymbifera* (Cohn) Saccardo & Trotter**[a]	■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus	English (1965)
2.	*Absidia cylindrospora* Hagem	■ degradation of keratinous substrates such as human scalp hair (most favoured), sheep's wool, dog claws, cow horns, hooves, snake skin and hen feathers; ■ keratinase secretion which has stronger hydrolytic action on keratin of human origin than that of animal origin	Rajak et al. (1992)
3.	*Absidia glauca* Hagem	■ isolated from feathers	Kornillowicz (1991–1992)
4.	*Absidia spinosa* Lendner	■ isolated from human hair	Ramesh and Hilda (1999)
5.	*Cunninghamella echinulata* (Thaxter) Thaxter ex Blakeslee	■ isolated from human hair	Ramesh and Hilda (1999)
6.	*Cunninghamella elegans* Lendner	■ isolated from feathers, human and cow hair; ■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus	Griffin (1960), English (1965), Kornillowicz (1991–1992), Moubahser et al. (1992)
7.	***Mucor circinelloides* van Tieghem**	■ isolated from sheep's wool; ■ isolated from donkey hair; ■ frequent infections of sheep fleece	Michalska (1957), Ali-Shtayeh et al. (1988b), Abdel-Gawad (1997)
8.	*Mucor genevensis* Lendner	■ isolated from donkey hair	Ali-Shtayeh et al. (1988b)
9.	***Mucor hiemalis* Wehmer**	■ isolated from feathers, donkey and rabbit hair	Ali-Shtayeh et al. (1988b), Kornillowicz (1991–1992)
10.	*Mucor mucedo* Fresenius	■ isolated from rabbit hair	Ali-Shtayeh et al. (1988b)
11.	*Mucor piriformis* Fischer	■ isolated from goat and rabbit hair	Ali-Shtayeh et al. (1988a,b)
12.	*Mucor plumbeus* Bonorden	■ frequent infections of sheep fleece	Michalska (1957)
13.	*Mucor racemosus* Fresenius	■ isolated from sheep's wool; ■ isolated from buffalo, rabbit and cow hair; ■ frequent infections of sheep fleece	Michalska (1957), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Abdel-Gawad (1997)
14.	***Mucor ramosissimus* Samoutsevitch**	■ isolated from feathers	Kornillowicz (1991–1992)
15.	*Mucor saturninus* Hagem	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
16.	*Mucor strictus* Hagem	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
17.	*Rhizomucor pusillus* (Lindt) Schipper	■ isolated from feathers; ■ degradation of keratinous substrates such as human scalp hair (most favoured), sheep's wool, dog nails, cow horns, hooves, snake skin and hen feathers; ■ keratinase secretion which has stronger hydrolytic action on keratin of human origin than that of animal origin	Kornillowicz (1991–1992), Rajak et al. (1992)
18.	***Rhizopus oryzae* Went & Prinsen Geerligs**	■ isolated from human and cow hair	Moubahser et al. (1992)
19.	***Rhizopus stolonifer* (Ehrenberg) Lind**	■ isolated from sheep's wool; ■ isolated from human, cow, rabbit, goat and camel hair; ■ frequent infections of sheep fleece; ■ human hair degradation by means of surface erosion and radial penetration; production of invasive structures; ■ strongly keratinolytic	Michalska (1957), Ali-Shtayeh et al. (1988a,b), Bagy and Abdel-Mallek (1991), Abdel-Gawad (1997), Ramesh and Hilda (1999), Ali-Shtayeh and Jamous (2000)
20.	***Syncephalastrum racemosum* Cohn ex Schroeter**	■ isolated from human, goat and rabbit hair; ■ keratinophilic	Ali-Shtayeh et al. (1988a,b), Ulfig (2003)
21.	*Thamnidium elegans* Link	■ frequent infections of sheep fleece	Michalska (1957)
22.	*Zygorhynchus moelleri* Vuillemin	■ isolated from feathers	Kornillowicz (1991–1992)
Mortierellales			
1.	*Mortierella alpina* Peyronel	■ isolated from cow hair	Ali-Shtayeh et al. (1988b)
2.	*Mortierella mutabilis* Linnemann	■ isolated from human hair	Griffin (1960)

Notes: All the fungal names presented in the table have been checked with respect to taxonomy. Currently valid taxonomic names are given based on: Shipper (1976), Domsch et al. (1993), CBS List of cultures (1994), Hawksworth et al. (1995), Kirk et al. (2001), Samson et al. (2002), CBS Filamentous fungi database (2008), The Index Fungorum (2008) and MycoBank (2008). Pathogenicity of the fungal strains presented in the table has been given on the basis of: Summerbell et al. (1989), Tan et al. (1994), De Hoog (1996), De Hoog and Guarro (1995, 2000), Midgley et al. (1997), Baran (1998), Flannigan et al. (2001), Straus (2004), ATCC The global bioresource center (2008) and CBS Filamentous fungi database (2008).

[a] Bold indicates fungus pathogenic for man.

M. gypseum and *T. ajelloi*, seem to possess the highest potential to digest keratinous materials regardless of the type of substrate.

Table 3 shows that the literature may be contradictory (see *Aspergillus fumigatus* No. 25, *A. terreus* No. 41, *Chrysosporium carmichaeli* No. 53, *Chrysosporium merdarium* No. 60, *C. queenslandicum* No. 62, and *Chrysosporium sulfureum* No. 63). This may result from the fact that strains belonging to the same species differ in their keratinolytic activity, as this type of activity, like many other physiological features, is not a fixed attribute of a given species, but rather a characteristic of a given strain influenced by and depending on numerous factors. Under the same environmental conditions, the same species may contain both active and inactive strains. In addition, there are different modes and different intensities of substrate attack, as well as various types of specialized structures developed for this purpose. Another contradiction comes in the terminology used; some authors describe a given species as keratinolytic, others as keratinophilic (Table 3 contains all the information available and analysed). This is due to the fact that, for many years, several definitions of keratinolytic and keratinophilic fungi have been in use, and the terms have even been used as synonyms. The term "keratinolytic" is now applied to a group of microorganisms producing specialized enzymes (keratinases) capable of attacking and decomposing α-keratin, potentially pathogenic to humans, while keratinophilic species are those capable of utilizing only easily degradable substances (products of partial decomposition of keratin, materials related to keratin, etc.).

Table 2
Fungi utilizing keratinous substrates. Ascomycota.

No.	Species name	Strain source, comments	References
Onygenales			
1.	Amauroascus mutatus (Quelet) Rammeloo	■ degradation of human hair; ■ keratinolytic	Ulfig (2003)
2.	*Aphanoascus cinnabarinus* Zukal	■ isolated from hair; ■ formation of perforating organs and eroding fronds which occur on and in the hair; ■ highly keratinolytic	De Vries (1964)
3.	***Aphanoascus fulvescens* (Cooke) Apinis**[a]	■ isolated from cow and donkey hair; ■ utilization of native feather keratin; ■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration; ■ keratinolytic	Ali-Shtayeh et al. (1988b), Filipello Marchisio et al. (1994), Kornillowicz-Kowalska (1997)
4.	*Aphanoascus* sp. (strain GPCK 534)	■ cuticle lifting in human hair by development of needle, tunnel, fissure and torpedo types of perforators	Katiyar and Kushwaha (2002)
5.	*Arthroderma cuniculi* Dawson	■ isolated from goat and rabbit hair and feathers	Ali-Shtayeh et al. (1988a), ATCC The global bioresource center (2008), CBS Filamentous fungi database (2008)
6.	*Arthroderma curreyi* Berkeley	■ isolated from wool; ■ frequently isolated from bird feathers; ■ isolated from goat hair; ■ complete solubilization of native feather keratin; ■ keratinase production	Pugh and Mathison (1962), Pugh and Evans (1970a), Parbery (1977), Ali-Shtayeh et al. (1988a), Kornillowicz-Kowalska (1997, 1999), ATCC The global bioresource center (2008)
7.	***Arthroderma incurvatum* (Stockdale) Weitzman et al.**	■ isolated from horse hair	Chmel et al. (1972)
8.	*Arthroderma gertleri* Böhme	■ isolated from horse hair	Chmel et al. (1972)
9.	***Arthroderma gypseum* (Nannizzi) Weitzman et al.**	■ isolated from wool and hair; ■ degradation of wool after 40 days	Griffin (1960), McQuade (1964), Parbery (1974, 1977)
10.	Arthroderma quadrifidum Dawson & Gentles	■ isolated from bird feathers; ■ isolated from horse hair; ■ complete solubilization of native feather keratin; ■ keratinase production	Pugh and Evans (1970a), Chmel et al. (1972), Kornillowicz-Kowalska (1997, 1999)
11.	***Arthroderma tuberculatum* Kuehn**	■ isolated from hair; ■ isolated from feathers; ■ degradation of feather keratin; ■ very rapid wool degradation under moist and warm conditions; ■ keratinase production	Parbery (1974, 1977), Kornillowicz-Kowalska (1997)
12.	*Arthroderma uncinatum* Dawson & Gentles	■ isolated from horse hair and bird feathers	Pugh and Evans (1970a,b), Chmel et al. (1972)
13.	*Auxarthron conjugatum* (Kuehn) Orr & Kuehn	■ isolated from feathers; ■ utilization of human hair as a sole source of carbon and nitrogen, degradation of the substrate	Deshmukh and Agrawal (1982), CBS Filamentous fungi database (2008)
14.	*Auxarthron umbrinum* (Boudier) Orr & Plunkett	■ degradation of human hair by means of surface erosion; ■ keratinolytic	Filipello Marchisio et al. (1994)
15.	***Auxarthron zuffianum* (Morini) Orr & Kuehn**	■ isolated from sheep's wool and buffalo hair	Moubahser et al. (1992)
16.	*Ctenomyces mentagrophytes* (Robin) Langeron & Milochevitch	■ degradation of wool after 40 days	McQuade (1964)
17.	*Ctenomyces persicolor* (Sabouraud) Nannizzi	■ very active in hair degradation; production of perforating organs; ■ keratinolytic	Vanbreuseghem (1952)
18.	*Ctenomyces serratus* Eidam	■ isolated from wool, horse hair and feathers; ■ frequently found on feathers; ■ degradation of feather keratin; ■ keratinase production	Pugh and Mathison (1962), Pugh and Evans (1970a,b), Chmel et al. (1972), Parbery (1977), Kornillowicz (1994), Kornillowicz-Kowalska (1997), Gugnani (2000)
19.	*Ctenomyces* sp.	■ isolated from woollen fabric (strain CBS 228.51); ■ degradation of wool after 40 days (strain 381 TDEL)	McQuade (1964), Denizel et al. (1974)
20.	***Emmonsia parva* (Emmons & Ashburn) Ciferri & Montemartini**	■ growth on wool	Al Musallam and Radwan (1990)
21.	*Gymnascella citrina* (Massee & Salmon) Orr et al.	■ isolated from human, buffalo and cow hair as well as sheep's wool	Moubahser et al. (1992)
22.	*Gymnascella marginispora* (Kuehn & Orr) Currah	■ isolated from human hair; ■ keratinophilic	Ulfig (2003)
23.	*Gymnoascoideus petalosporus* Orr et al.	■ decomposition of human hair; ■ keratinase production	Rajak et al. (1991)

Table 2 (*continued*)

No.	Species name	Strain source, comments	References
24.	*Gymnoascus arxii* Cano & Guarro	■ isolated from contemporary woollen textiles; ■ abundant growth on woollen textiles, overgrowth of the other fungi; ■ very rapid and severe degradation of undyed and dyed woollen textiles; ■ strongly keratinolytic, conversion of woollen textiles into powder	Błyskal (2005)
25.	***Onygena corvina* Albertini & Schweinitz**	■ isolated from wool; ■ isolated from wool remnants	Denizel et al. (1974), CBS Filamentous fungi database (2008)
26.	*Onygena piligena* Fries	■ isolated from a woollen slipper	Denizel et al. (1974)
Eurotiales			
1.	***Emericella nidulans* (Eidam) Vuillemin**	■ isolated from sheep's wool; ■ isolated from human, buffalo, rabbit, goat, donkey and cow hair	Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992), Abdel-Gawad (1997)
2.	*Emericella quadrilineata* (Thom & Raper) Benjamin	■ isolated from sheep's wool; ■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991), Abdel-Gawad (1997)
3.	*Emericella rugulosa* (Thom & Raper) Benjamin	■ isolated from sheep's wool	Abdel-Gawad (1997)
4.	***Eurotium chevalieri* Mangin**	■ isolated from sheep's wool and antique woollen textiles; ■ slight structural but strong aesthetic (mainly cinnamon discolouration) deterioration of undyed and dyed woollen textiles	Moubahser et al. (1992), Błyskal (2005)
5.	***Fennellia nivea* (Wiley & Simmons) Samson**	■ isolated from cow, goat and rabbit hair	Ali-Shtayeh et al. (1988a,b)
6.	***Neosartorya fischeri* (Wehmer) Malloch & Cain**	■ isolated from human and rabbit hair; ■ isolated from ancient woollen textiles; ■ keratinophilic	Bagy and Abdel-Mallek (1991), Abdel-Kareem (2000), Ulfig (2003)
7.	*Talaromyces luteus* (Zukal) Benjamin	■ isolated from human, buffalo and cow hair	Moubahser et al. (1992)
8.	*Talaromyces trachyspermus* (Shear) Stolk & Samson	■ isolated from buffalo hair; ■ decomposition of human hair; ■ keratinase production	Rajak et al. (1991), Moubahser et al. (1992)
9.	*Thermoascus aurantiacus* Miehe	■ isolated from rabbit, camel, horse and sheep hair	Bagy and Abdel-Mallek (1991)
Sordariales			
1.	*Chaetomidium fimeti* (Fuckel) Saccardo	■ isolated from goat and donkey hair	Ali-Shtayeh et al. (1988a,b)
2.	*Chaetomium cochlioides* Palliser	■ isolated from human hair	Griffin (1960)
3.	***Chaetomium globosum* Kunze: Fries**	■ isolated from sheep's wool, destruction of the wool; ■ isolated from human, camel and buffalo hair; ■ isolated from contemporary woollen textiles; ■ structural and aesthetic (greenish, brownish and reddish discolourations) deterioration of undyed and dyed woollen textiles; ■ utilization of non-keratinous protein components of sheep's wool (intercellular material); denaturation of hard keratin, i.e. cleavage of S–S bonds does not occur; ■ growth on wool in the presence of distilled water only; ■ disintegration of the cortex of hedgehog spines, cattle and human hair by means of boring hyphae and fronded mycelium, also disintegration the medullae of the spines, human toe-nails, human plantar callus and cattle hair; ■ low keratinolytic activity	White et al. (1950), Kowalik and Czerwinska (1956), Michalska (1957), English (1965), Stefaniak (1969), Safranek and Goos (1982), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Mahmoud (1995), Abdel-Gawad (1997), Błyskal (2005)
4.	*Chaetomium indicum* Corda	■ disintegration of the cortex of hedgehog spines, cattle and human hair by means of boring hyphae and fronded mycelium, also disintegration of the medullae of the spines, human toe-nails, human plantar callus and cattle hair	English (1965)

(*continued on next page*)

Table 2 (*continued*)

No.	Species name	Strain source, comments	References
5.	*Chaetomium nozdrenkoae* Sergejeva	■ isolated from feathers	Kornillowicz (1991–1992)
6.	*Chaetomium seminudum* Ames	■ isolated from sheep's wool	Abdel-Gawad (1997)
7.	*Chaetomium spirale* Zopf	■ isolated from sheep's wool	Abdel-Gawad (1997)
8.	Corynascus sepedonium (Emmons) von Arx	■ isolated from human hair; ■ keratinolytic	Griffin (1960)
9.	*Sordaria fimicola* (Roberge) Cesati & de Notaris	■ strong destruction of sheep's wool	Michalska (1957)
Pleosporales			
1.	***Cochliobolus hawaiiensis* Alcorn**	■ isolated from sheep's wool	Abdel-Gawad (1997)
2.	***Cochliobolus spicifer* Nelson**		
3.	*Pleospora herbarum* (Fries) Rabenhorst		
4.	*Setosphaeria rostrata* Leonard		
Hypocreales			
1.	*Nectria haematococca* Berkeley & Broome	■ isolated from sheep's wool; ■ isolated from cow hair	Ali-Shtayeh et al. (1988b), Abdel-Gawad (1997)
2.	*Nectria ventricosa* Booth	■ isolated from human hair	Ali-Shtayeh et al. (2002)
Incertae sedis			
1.	*Apiospora montagnei* Saccardo	■ isolated from contemporary woollen textiles; ■ blackish discolouration on undyed woollen textiles	Błyskal (2005)
2.	***Pseudallescheria boydii* (Shear) McGinnis et al.**	■ isolated from human hair and sheep's wool; ■ keratinophilic	Moubahser et al. (1992), Ulfig (2003)
Microascales			
1.	***Microascus cirrosus* Curzi**	■ isolated from antique woollen textiles; structural and aesthetic (black, brown and grey discolourations) deterioration of undyed and dyed textiles	Błyskal (2005)
Xylariales			
1.	*Monographella cucumerina* (Lindfors) Arx	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)

Notes: All the fungal names presented in the table have been checked with respect to taxonomy. Currently valid taxonomic names are given based on: Ajello (1968), Shipper (1976), Salata and Rudnicka-Jezierska (1979), Domsch et al. (1993), CBS List of cultures (1994), Hawksworth et al. (1995), Simpanya (2000), Vidal et al. (2000), Kirk et al. (2001), Samson et al. (2002), CBS Filamentous fungi database (2008), The Index Fungorum (2008) and MycoBank (2008). Pathogenicity of the fungal strains presented in the table has been given on the basis of: Summerbell et al. (1989), Tan et al. (1994), De Hoog (1996), De Hoog and Guarro (1995, 2000), Midgley et al. (1997), Baran (1998), Simpanya (2000), Flannigan et al. (2001), Geiser and LoBuglio (2001), Straus (2004), ATCC The global bioresource center (2008) and CBS Filamentous fungi database (2008).
[a] Bold indicates fungus pathogenic for man.

Filipello Marchisio (2000), however, referred to the etymological derivation of the word "keratinophilic" and suggested that the term be assigned to all organisms colonizing keratinous materials.

4. Keratinous substrates

Table 4 shows that hairs and sheep's wool were the most common substrates used to study fungal ability to utilize keratinous materials as a source of nutrients (225 fungi were reported in hairs, 108 fungi in sheep's wool). Only sporadically have woollen textiles been used in such studies, yet this is of particular significance in the conservation of valuable collections stored in museums. The majority of data on fungal species isolated from woollen textiles degraded by these microorganisms were provided by Błyskal (2005) and Błyskal's unpublished results. From among the fungal species isolated by the author, 15 were isolated from woollen textiles for the first time. These were *Alternaria alternata*, *Aspergillus ustus*, *Aspergillus versicolor*, *Cladosporium cladosporioides*, *Eurotium chevalieri*, *Penicillium chrysogenum*, *Penicillium glabrum*, *Penicillium simplicissimum*, *Penicillium spinulosum*, *Scopulariopsis brumptii*, *Stachybotrys chartarum*, *Acremonium camptosporum*, *Apiospora montagnei*, *G. arxii*, and *Microascus cirrosus*. Except for *A. alternata*, *A. ustus*, *P. simplicissimum*, and *S. chartarum*, all the fungal species mentioned above were reported for the first time to be capable of destroying woollen textiles. In addition, *A. camptosporum*, *A. montagnei*, *G. arxii*, and *M. cirrosus* were reported for the first time as capable of destroying a group of keratinous materials. Further information on fungi isolated from woollen textiles is available in the papers by Kowalik and Czerwinska (1956), Stefaniak (1969), Denizel et al. (1974), and Abdel-Kareem (2000). The fungi isolated from woollen textiles constitute, in total, 14% of all species isolated from keratinous materials.

From the point of view of the number of substrates colonized by a given fungus, the microorganisms can be grouped as follows: *Absidia cylindrospora*, *A. fumigatus*, *M. gypseum*, *P. chrysogenum*, and *Rhizomucor pusillus* (7 substrates each); *A. terreus*, *Chaetomium globosum*, *C. cladosporioides*, and *S. brevicaulis* (6 substrates each); *Botryotrichum piluliferum*, *Chrysosporium tropicum*, *Cunninghamella elegans*, *Fusarium solani*, *Penicillium citrinum*, *S. chartarum*, *T. ajelloi*, and *Trichophyton terrestre* (5 substrates each); and *Absidia corymbifera*, *Aspergillus flavus*, *Aspergillus niger*, *Chaetomium indicum*, *Curvularia lunata*, *Fusarium oxysporum*, *Humicola grisea*, *Madurella grisea*, *Trichoderma viride*, *Trichophyton mentagrophytes*, and *Trichophyton rubrum* (4 substrates each). Among the remaining species, 19 fungi were found to colonize three different substrates, 63 fungi two substrates, and 188 only one keratinous substrate (Table 4).

5. Pathogenicity

Among 299 fungal species listed, 107 are pathogenic to humans, i.e., 36% of the total number. The majority, 31 species, belong to the

Table 3
Fungi utilizing keratinous substrates. Anamorphic fungi.

No.	Species name	Strain source, comments	References
1.	*Acremonium butyri* (van Beyma) Gams	■ isolated from donkey hair	Ali-Shtayeh et al. (1988b)
2.	*Acremonium camptosporum* Gams	■ isolated from antique woollen textiles; ■ strong entanglement of wool fibres, creation of a tight layer of mycelium on the fabric; ■ structural and aesthetic deterioration of dyed and undyed woollen textiles	Błyskal (2005)
3.	***Acremonium falciforme* (Carrión) Gams**[a]	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
4.	*Acremonium furcatum* (Moreau & Moreau) ex Gams	■ isolated from rabbit and goat hair	Ali-Shtayeh et al. (1988a,b)
5.	*Acremonium fusidioides* (Nicot) Gams	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
6.	*Acremonium glaucum* Gams	■ isolated from a woollen overcoat	Denizel et al. (1974), CBS Filamentous fungi database (2008)
7.	***Acremonium kiliense* Grütz**	■ isolated from human, goat and cow hair as well as sheep's wool	Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992), Abdel-Gawad (1997)
8.	*Acremonium murorum* (Corda) Gams	■ degradation of wool	McQuade (1964)
9.	*Acremonium roseum* Petch	■ isolated from hair; ■ utilization of non-keratinous protein components of sheep's wool (intercellular material); denaturation of hard keratin, i.e. cleavage of S–S bonds does not occur	Safranek and Goos (1982)
10.	***Acremonium strictum* Gams**	■ isolated from sheep's wool, human, rabbit, cat and cow hair; ■ low keratinolytic activity; ■ keratinophilic	Ali-Shtayeh et al. (1988b, 2002), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Abdel-Gawad (1997), Ulfig (2003)
11.	*Acremonium* sp.	■ degradation of wool (strain 89c QMCC); ■ colonization of wool after 5 days, structural damage of wool (strain AC-R); ■ colonization of human hair after 22 days, cuticle lifting and its disruption (strain GPCK 531)	McQuade (1964), Ghawana and Shrivastava (1995), Katiyar and Kushwaha (2002)
12.	***Alternaria alternata* (Fries) Keissler**	■ isolated from sheep's wool; ■ frequently isolated from wool; ■ isolated from human, rabbit, goat, cow, donkey, cat, dog, camel and horse hair; ■ isolated from contemporary woollen textiles; severe structural and aesthetic (black discolouration) deterioration of undyed and dyed woollen textiles; ■ heavy destruction of sheep's wool; ■ low keratinolytic activity	White et al. (1950), Michalska (1957), Ali-Shtayeh et al. (1988a, 2002), McCarthy and Greaves (1988), Bagy and Abdel-Mallek (1991), Mahmoud (1995), Abdel-Gawad (1997), Ramesh and Hilda (1999), Błyskal (2005)
13.	***Alternaria chlamydospora* Mouchacca**	■ isolated from sheep's wool	Abdel-Gawad (1997)
14.	***Alternaria tenuissima* (Kunze: Fries) Wiltshire**	■ isolated from sheep's wool	Abdel-Gawad (1997)
15.	***Arthrographis kalrae* (Tewari & Macpherson) Sigler & Carmichael**	■ degradation of human hair; ■ keratinolytic	Ulfig (2003)
16.	*Aspergillus alutaceus* Berkeley & Curtis	■ isolated from human and goat hair; ■ keratinophillic	Ali-Shtayeh et al. (1988a), Ulfig (2003)
17.	***Aspergillus candidus* Link**	■ isolated from cow, donkey, rabbit, goat and dog hair	Ali-Shtayeh et al. (1988a,b)
18.	*Aspergillus carneus* (van Tiegem) Blochwitz	■ isolated from sheep's wool	Abdel-Gawad (1997)
19.	*Aspergillus cervinus* Massee	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
20.	***Aspergillus clavatus* Desmazieres**	■ isolated from sheep's wool as well as cow, donkey and rabbit hair	Ali-Shtayeh et al. (1988b), Abdel-Gawad (1997)
21.	*Aspergillus erythrocephalus* Berkeley & Curtis	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
22.	***Aspergillus flavipes* (Bainier & Sartory) Thom & Church**	■ isolated from rabbit, goat and cat hair	Ali-Shtayeh et al. (1988a,b)
23.	***Aspergillus flavus* Link**	■ isolated from sheep's wool; ■ isolated from museum exhibits (feathers), deterioration of the feathers; ■ isolated from ancient woollen textiles; ■ isolated from human, buffalo, goat, cow, donkey, cat, dog, rabbit, camel and horse hair; ■ keratinolytic	Ali-Shtayeh et al. (1988a,b, 2002), Al Musallam and Radwan (1990), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Nigam et al. (1994), Abdel-Gawad (1997), Ramesh and Hilda (1999), Abdel-Kareem (2000)
24.	*Aspergillus foetidus* Thom & Raper	■ isolated from museum exhibits (feathers), deterioration of the feathers	Nigam et al. (1994)
25.	***Aspergillus fumigatus* Fresenius**	■ isolated from feathers, human, buffalo, goat and cow hair, sheep's wool and ancient woollen textiles; ■ frequent infections of sheep fleece; ■ disintegration of the cortex of cattle and human hair and hedgehog spines by means of fronded mycelium, also disintegration of the medullae of the spines, human toe-nails, human plantar callus and cattle hair; lifting of the scales of the cuticle; very slow attack; ■ high keratinolytic activity; ■ not keratinolytic; ■ keratinophilic	Michalska (1957), English (1963, 1965), Parbery, (1977), Ali-Shtayeh et al. (1988a), Al Musallam and Radwan (1990), Moubahser et al. (1992), Mahmoud (1995), Abdel-Gawad (1997), Abdel-Kareem (2000), Ulfig (2003)

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Table 3 (*continued*)

No.	Species name	Strain source, comments	References
26.	***Aspergillus glaucus* Link**	■ frequent infections of sheep fleece	Michalska (1957)
27.	***Aspergillus japonicus* Saito**	■ isolated from sheep's wool	Abdel-Gawad (1997)
28.	***Aspergillus nidulans* (Eidam) Winter**	■ isolated from ancient woollen textiles; ■ frequent infections of sheep fleece	Michalska (1957), Abdel-Kareem (2000)
29.	***Aspergillus niger* van Tieghem**	■ isolated from museum exhibits (feathers), deterioration of the feathers; ■ isolated from sheep's wool; ■ isolated from human, cat, buffalo, goat, cow, rabbit, horse and camel hair; ■ isolated from ancient woollen textiles; ■ frequent infections of sheep fleece; ■ growth on wool fibres	Michalska (1957), Ali-Shtayeh et al. (1988a,b), McCarthy and Greaves (1988), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Nigam et al. (1994), Abdel-Gawad, 1997; Abdel-Kareem (2000)
30.	***Aspergillus ochraceus* Wilhelm**	■ isolated from buffalo, cat, cow and rabbit hair as well as sheep's wool	Ali-Shtayeh et al. (1988b), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992)
31.	***Aspergillus parasiticus* Speare**	■ isolated from rabbit, goat and horse hair	Ali-Shtayeh et al. (1988a), Bagy and Abdel-Mallek (1991)
32.	***Aspergillus penicillioides* Spegazzini**	■ isolated from cat hair	Ali-Shtayeh et al. (1988b)
33.	*Aspergillus raperi* Stolk & Meyer	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
34.	*Aspergillus repens* (Corda) Saccardo	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
35.	***Aspergillus restrictus* Smith**	■ isolated from rabbit and goat hair	Ali-Shtayeh et al. (1988a,b)
36.	*Aspergillus sparsus* Raper & Thom	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
37.	*Aspergillus spinulosus* Warcup	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
38.	*Aspergillus sulphureus* (Fresenius) Thom & Church	■ isolated from museum exhibits (feathers), human hair and sheep's wool; ■ deterioration of the feathers	Moubahser et al. (1992), Nigam et al. (1994)
39.	***Aspergillus sydowii* (Bainier & Sartory) Thom & Church**	■ isolated from sheep's wool; ■ isolated from buffalo, donkey, cow and rabbit hair	Ali-Shtayeh et al. (1988b), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Abdel-Gawad (1997)
40.	***Aspergillus tamarii* Kita**	■ isolated from sheep's wool; ■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991), Abdel-Gawad (1997)
41.	***Aspergillus terreus* Thom**	■ isolated from sheep's wool as well as human, buffalo, rabbit, cat and cow hair; ■ frequent infections of sheep fleece; ■ disintegration of the cortex of cattle and human hair and hedgehog spines by means of fronded mycelium, also disintegration of the medullae of the spines, human toe-nails, human plantar callus and cattle hair; very slow attack; ■ high activity on keratin in cultures grown on hooves as single source of carbon and nitrogen; ■ keratinolytic; ■ keratinophilic	Michalska (1957), Pugh and Mathison (1962), Mathison (1964), English (1965), Ali-Shtayeh et al. (1988b), Moubahser et al. (1992), Abdel-Gawad (1997), Ramesh and Hilda (1999), Ulfig (2003)
42.	***Aspergillus ustus* (Bainier) Thom & Church**	■ isolated from camel, goat and cow hair; ■ isolated from antique woollen textiles	Ali-Shtayeh et al. (1988a,b), Bagy and Abdel-Mallek (1991), Błyskal (2005)
43.	***Aspergillus versicolor* (Vuillemin) Tiraboschi**	■ isolated from cow, goat and rabbit hair as well as sheep's wool; ■ isolated from antique and conterporary woollen textiles	Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992), Błyskal (2005)
44.	*Aspergillus wentii* Wehmer	■ isolated from ancient woollen textiles; ■ isolated from buffalo, rabbit, goat and donkey hair; ■ frequent infections of sheep fleece	Michalska (1957), Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992), Abdel-Kareem (2000)
45.	***Aureobasidium pullulans* (de Bary) Arnaud**	■ isolated from woollen cloth	Denizel et al. (1974)
46.	*Basipetospora rubra* Cole & Kendrick	■ isolated from cow hair	Ali-Shtayeh et al. (1988b)
47.	***Beauveria bassiana* (Balsamo) Vuillemin**	■ isolated from human hair; ■ degradation of human hair by the action of boring hyphae; ■ keratinolytic	Filipello Marchisio et al. (1994), Ali-Shtayeh et al. (2002)
48.	*Botryotrichum atrogriseum* van Beyma	■ isolated from contemporary woollen textiles; ■ isolated from rabbit and camel hair	Kowalik and Czerwinska (1956), Stefaniak (1969), Bagy and Abdel-Mallek (1991)
49.	*Botryotrichum piluliferum* Saccardo & Marchal	■ isolated from feathers, human, horse and buffalo hair; ■ frequent infections of sheep fleece; ■ disintegration of the cortex of cattle and human hair by means of boring hyphae and fronded mycelium, also disintegration of the medullae of human toe-nails, human plantar callus and cattle hair; ■ keratinophilic	Michalska (1957), English (1965), Kornillowicz (1991–1992), Moubahser et al. (1992), Ulfig (2003)
50.	*Candida saitoana* Nakase & Suzuki	■ frequently isolated from wool	McCarthy and Greaves (1988)
51.	*Cephalosporium curtipes* Saccardo	■ isolated from human hair	Ramesh and Hilda (1999)
52.	***Chrysonilia sitophila* (Montagne) Arx**	■ isolated from donkey and goat hair	Ali-Shtayeh et al. (1988a,b)

Table 3 (*continued*)

No.	Species name	Strain source, comments	References
53.	***Chrysosporium carmichaeli*** **Van Oorschot**	▪ 60% weight loss of wool after 4 weeks when cultivated on a mineral medium; ▪ keratinase production; ▪ slightly keratinolytic; ▪ not keratinolytic; ▪ not keratinophilic	Nigam and Kushwaha (1992a), Kushwaha (2000)
54.	*Chrysosporium europae* Sigler et al.	▪ utilization of native feather keratin	Kornillowicz-Kowalska (1997)
55.	*Chrysosporium georgii* (Varsavsky & Ajello) Oorschot	▪ degradation of human hair by means of surface erosion and radial penetration; production of boring hyphae; ▪ keratinolytic	Van Oorschot (1980), Mitola et al. (2002)
56.	*Chrysosporium indicum* (Randhawa & Sandhu) Garg	▪ isolated from sheep's wool; ▪ isolated from museum exhibits (feathers), deterioration of the feathers; ▪ isolated from human, goat, buffalo and cow hair; ▪ utilization of human hair as a sole source of carbon and nitrogen; ▪ visual appearance of colonization of human hair first observed after 6 days, complete degradation occurs after 24 days; development of medullary, needle and tunnel types of perforators; ▪ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion; ▪ keratinase production	Deshmukh and Agrawal (1982), Ali-Shtayeh et al. (1988a), Rajak et al. (1991), Moubahser et al. (1992), Filipello Marchisio et al. (1994), Nigam et al. (1994), Abdel-Gawad (1997), Katiyar and Kushwaha (2002), Ulfig (2003)
57.	***Chrysosporium keratinophilum*** **(Frey) Carmichael**	▪ isolated from bird feathers; ▪ isolated from museum exhibits (feathers), deterioration of the feathers; ▪ isolated from human, buffalo, rabbit, camel, horse, donkey, cat, goat, dog and cow hair as well as sheep's wool; ▪ rapid attack and utilization of keratinous substrates; ▪ softening and subsequent degradation of wool fibres after 14 days; ▪ degradation of sheep's wool, peacock and chicken feathers in soil; ▪ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration and by the action of borers; ▪ rapid perforation and degradation of buffalo, cow, dog, goat, horse and human hair; infected hair showed undulation, lifting and disruption of cuticle, narrow and broad perforating organs, projection of medulla and decolouration; ▪ thermostable keratinolytic enzyme production when grown in medium containing keratin as an exogenous inducer; maximum activity of the enzyme at pH 9.0; ▪ keratinase production	Pugh and Evans (1970a), Ali-Shtayeh et al. (1988a,b, 2002), Al Musallam and Radwan (1990), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Nigam and Kushwaha (1992a,b), Nigam et al. (1994), Dozie et al. (1994), Filipello Marchisio et al. (1994), Mahmoud, 1995, Abdel-Gawad (1997), Kornillowicz-Kowalska (1997), Ramesh and Hilda (1999), Ali-Shtayeh and Jamous (2000), Kushwaha (2000), Ulfig (2003)
58.	*Chrysosporium kreiselii* Dominik	▪ degradation of feather keratin; ▪ keratinase production	Kornillowicz-Kowalska (1997)
59.	*Chrysosporium lucknowense* Garg	▪ isolated from feathers; ▪ degradation of human hair by means of surface erosion and radial penetration, production of boring hyphae; ▪ keratinolytic	Van Oorschot (1980), Mitola et al. (2002), CBS Filamentous fungi database (2008)
60.	*Chrysosporium merdarium* (Link) Carmichael	▪ degradation of chicken feathers; ▪ keratinolytic; ▪ not keratinolytic	Van Oorschot (1980), Nigam and Kushwaha (1992a), Kushwaha (2000)
61.	*Chrysosporium pannicola* (Corda) Van Oorschot & Stalpers	▪ isolated from feathers, buffalo, goat and donkey hair as well as sheep's wool; ▪ isolated from museum exhibits (feathers), deterioration of the feathers; ▪ utilization of human hair as a sole source of carbon and nitrogen; ▪ decomposition of c. 80% of human hair after only 3–5 days; ▪ degradation of feather keratin and human hair; ▪ keratinolytic	Deshmukh and Agrawal (1982), Ali-Shtayeh et al. (1988a,b), Bahuguna and Kushwaha (1989), Kornillowicz (1991–1992), Moubahser et al. (1992), Filipello Marchisio et al. (1994), Nigam et al. (1994), Kornillowicz-Kowalska (1997), Kushwaha (2000), Ulfig (2003)
62.	***Chrysosporium queenslandicum*** **Apinis & Rees**	▪ isolated from wool, feathers and hair; ▪ cuticle lifting of human hair; development of medullary, fissure and torpedo types of perforators; ▪ utilization of insoluble keratin as a sole source of carbon, nitrogen and sulphur; ▪ degradation of human hair by means of surface erosion and radial penetration, production of perforating organs; ▪ keratinase production; ▪ not keratinolytic	Van Oorschot (1980), Malviya et al. (1992b), Nigam and Kushwaha (1992a), Filipello Marchisio et al. (1994), Katiyar and Kushwaha (2002)

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Table 3 (*continued*)

No.	Species name	Strain source, comments	References
63.	*Chrysosporium sulfureum* (Fiedler) Van Oorschot & Samson	■ isolated from sheep's wool; ■ keratinolytic; ■ not keratinolytic; ■ not keratinophilic	Van Oorschot (1980), Abdel-Gawad (1997)
64.	***Chrysosporium tropicum* Carmichael**	■ isolated from a woollen overcoat; ■ isolated from sheep's wool; ■ isolated from human, buffalo, rabbit, camel, goat, horse, donkey, dog and cow hair; ■ isolated from museum exhibits (feathers), deterioration of the feathers; ■ visual appearance of colonization of human hair first observed after 7 days, complete degradation occurs after 24 days; cuticle lifting; development of medullary, tunnel and torpedo types of perforators; ■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion; ■ degradation of human hair by means of radial penetration, production of boring hyphae; ■ decomposition of chicken feathers; ■ degradation of buffalo horn, woman hair and wool; ■ keratinolytic	Denizel et al. (1974), Van Oorschot (1980), Deshmukh and Agrawal (1985), Ali-Shtayeh et al. (1988a,b, 2002), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Filipello Marchisio et al. (1994), Kornillowicz (1994), Nigam et al. (1994), Mahmoud (1995), Abdel-Gawad (1997), Ramesh and Hilda (1999), Katiyar and Kushwaha (2002), Mitola et al. (2002), ATCC The global bioresource center (2008)
65.	*Chrysosporium xerophilum* Pitt	■ isolated from sheep's wool; ■ slightly keratinolytic	Van Oorschot (1980), Abdel-Gawad (1997), Kushwaha (2000)
66.	*Chrysosporium zonatum* Al-Musallam & Tan	■ degradation of human hair; ■ strongly keratinolytic	Vidal et al. (2000), Ulfig (2003)
67.	*Chrysosporium* anamorph of *Aphanoascus clathratus* Cano & Guarro	■ degradation of human hair; ■ keratinolytic	Ulfig (2003)
68.	*Chrysosporium* anamorph of *Aphanoascus reticulisporus* (Rutien) Hubàlek	■ degradation of human hair; ■ keratinolytic	Ulfig (2003)
69.	*Chrysosporium* anamorph of *Arthroderma cuniculi* Dawson	■ isolated from feathers and rabbit fur; ■ isolated from human hair; ■ degradation of chicken feathers; ■ degradation of human hair by means of surface erosion and radial penetration also by the action of boring hyphae and 'palm of the hand' structures; ■ keratinolytic	Filipello Marchisio et al. (1994), Ramesh and Hilda (1999), Kushwaha (2000)
70.	*Chrysosporium* anamorph of *Arthroderma curreyi* Berkeley	■ degradation of human hair; ■ keratinolytic	Kushwaha (2000), Ulfig (2003)
71.	***Chrysosporium* anamorph of *Pectinotrichum llanense* Varsavsky & Orr**	■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration; ■ degradation of chicken feathers; ■ keratinolytic	Filipello Marchisio et al. (1994), Kushwaha (2000)
72.	*Chrysosporium* anamorph of *Renispora flavissima* Sigler et al.	■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration and by the action of 'palm of the hand' fungal structures; ■ keratinolytic	Filipello Marchisio et al. (1994)
73.	*Chrysosporium anamorph of Nannizziopsis vriesii* (Apinis) Currah	■ degradation of human hair by means of surface erosion and radial penetration, production of boring hyphae; ■ keratinolytic	Van Oorschot (1980), Mitola et al. (2002)
74.	***Cladophialophora bantiana* (Saccardo) de Hoog et al.**	■ isolated from cow, goat and rabbit hair	Ali-Shtayeh et al. (1988a,b)
75.	***Cladophialophora carrionii* (Trejos) de Hoog et al.**	■ isolated from donkey hair	Ali-Shtayeh et al. (1988b)
76.	***Cladosporium cladosporioides* (Fresenius) de Vries**	■ frequently isolated from wool; ■ isolated from human and goat hair; ■ isolated from antique woollen textiles; discolouration and degradation of undyed and dyed woollen textiles; ■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus; ■ no keratinolytic activity	English (1965), Ali-Shtayeh et al. (1988a), McCarthy and Greaves (1988), Mahmoud (1995), Ramesh and Hilda (1999), Szostak-Kot et al. (2004a), Błyskal (2005)
77.	*Cladosporium graminum* Corda	■ frequent infections of sheep fleece	Michalska (1957)
78.	***Cladosporium herbarum* (Persoon) Link ex Grey**	■ frequent infections of sheep fleece; ■ isolated from human, cow, donkey, goat, rabbit and dog hair; ■ keratinolytic activity	Michalska (1957), Ali-Shtayeh et al. (1988a,b), Ramesh and Hilda (1999), Ali-Shtayeh and Jamous (2000)
79.	*Clonostachys rosea* (Link: Fries) Schroers et al.	■ isolated from feathers, rabbit and goat hair; ■ degradation of wool after 40 days	McQuade (1964), Ali-Shtayeh et al. (1988a), Bagy and Abdel-Mallek (1991), Kornillowicz (1991–1992)

Table 3 (*continued*)

No.	Species name	Strain source, comments	References
80.	***Curvularia lunata* (Wakker) Boedijn**	■ disintegration of the cortex of hedgehog spines, cattle and human hair by means of boring hyphae and fronded mycelium, also disintegration of the medullae of the spines, cattle hair, human toe-nails and human plantar callus	English (1965)
81.	*Curvularia ramosa* (Bainier) Boedijn	■ disintegration of human hair cortex by means of boring hyphae and fronded mycelium, also disintegration of the medullae of human toe-nails and human plantar callus	English (1965)
82.	*Cylindrocarpon magnusianum* Wollenweber	■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991)
83.	*Drechslera biseptata* (Saccardo & Roumeguère) Richardson & Fraser	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
84.	***Engyodontium album* (Limber) de Hoog**	■ isolated from sheep's wool; ■ utilization of native keratin as a sole source of carbon and nitrogen	McCarthy and Greaves (1988), Abdel-Gawad (1997)
85.	*Epicoccum nigrum* Link	■ isolated from sheep's wool, human, buffalo and cow hair	Moubahser et al. (1992)
86.	***Epidermophyton floccosum* (Harz) Langeron & Milochevitch**	■ very active in hair degradation; production of eroding fronds; ■ keratinolytic	Vanbreuseghem (1952), De Vries (1962), English (1963)
87.	*Fusarium chlamydosporum* var. *chlamydosporum* Wollenweber et Reinking	■ isolated from cat and goat hair	Ali-Shtayeh et al. (1988a,b)
88.	*Fusarium culmorum* (Smith) Saccardo	■ isolated from feathers; ■ frequently isolated from wool	McCarthy and Greaves (1988), Kornillowicz (1991–1992)
89.	*Fusarium equiseti* (Corda) Saccardo	■ isolated from feathers	Kornillowicz (1991–1992
90.	*Fusarium heterosporum* Nees	■ isolated from human and goat hair	Ali-Shtayeh et al. (1988a, 2002)
91.	*Fusarium javanicum* Koorders	■ degradation of woollen fabrics	White et al. (1950)
92.	*Fusarium lateritium* Nees	■ isolated from human hair	Ali-Shtayeh et al. (2002)
93.	***Fusarium moniliforme* Sheldon**	■ isolated from human, cow, goat, donkey, rabbit, dog and cat hair; ■ degradation of woollen fabrics	White et al. (1950), Ali-Shtayeh et al., (1988a,b, 2002), Ramesh and Hilda (1999)
94.	***Fusarium oxysporum* Schlechtendahl**	■ isolated from feathers, human, cow, goat, donkey, cat, camel and cow hair; ■ disintegration of the cortex of human hair and hedgehog spines by means of boring hyphae and fronded mycelium, also disintegration of the medullae of the spines and human plantar callus; ■ keratinophilic	Griffin (1960), English (1965), Ali-Shtayeh et al., (1988a,b, 2002), Kornillowicz (1991–1992), Moubahser et al. (1992), Ramesh and Hilda (1999), Ulfig (2003)
95.	*Fusarium poae* (Peck) Wollenweber	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
96.	*Fusarium roseum* Link	■ isolated from human hair	Griffin (1960)
97.	***Fusarium solani* (Martius) Saccardo**	■ isolated from feathers, human, buffalo, donkey, rabbit, camel, horse, goat and cow hair as well as sheep's wool; ■ wool degradation; ■ disintegration of the cortex of human hair by means of boring hyphae and fronded mycelium, also disintegration of the medullae of human toe-nails and human plantar callus; ■ efficient degradation of nail keratin	McQuade (1964), English (1965), Ali-Shtayeh et al. (1988a,b), Kornillowicz (1991–1992), Moubahser et al. (1992), Ramesh and Hilda (1999)
98.	*Fusarium tricinctum* (Corda) Saccardo	■ isolated from human hair	Ali-Shtayeh et al. (2002)
99.	*Fusarium xylarioides* Steyaert	■ isolated from cow hair	Ali-Shtayeh et al. (1988b)
100.	***Geomyces pannorum var. pannorum* (Link) Sigler & Carmichael**	■ isolated from human, horse, goat, donkey and cat hair; ■ isolated from bird feathers; ■ penetration of the cortex of cattle and human hair and hedgehog spines by means of boring hyphae; ■ keratinolytic	English (1965), Pugh and Evans (1970a), Van Oorschot (1980), Ali-Shtayeh et al. (1988b), Filipello Marchisio et al. (1994), Ramesh and Hilda (1999)
101.	***Geotrichum candidum* Link**	■ isolated from sheep's wool, human, donkey and cow hair; ■ decomposition of human hair; ■ keratinase production	Ali-Shtayeh et al. (1988b, 2002), Rajak et al. (1991), Moubahser et al. (1992)
102.	*Gliocladium catenulatum* Gilman & Abbott	■ isolated from human hair; ■ high activity on keratin in cultures grown on hooves as single source of carbon and nitrogen	Mathison (1964), Ramesh and Hilda (1999), Ali-Shtayeh et al. (2002)
103.	*Gliocladium nigrovirens* Beyma	■ isolated from human hair	Ali-Shtayeh et al. (2002)
104.	*Gliocladium solani* (Harting) Petch	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
105.	*Gliocladium viride* Matruchot	■ isolated from cow, goat and rabbit hair	Ali-Shtayeh et al. (1988a,b)
106.	*Graphium penicillioides* Corda	■ utilization of insoluble keratin as a sole source of carbon, nitrogen and sulphur; ■ keratinase production	Malviya et al. (1992b)
107.	*Humicola fuscoatra* Traaen	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
108.	*Humicola grisea* Traaen	■ isolated from feathers, human, goat and cow hair; ■ disintegration of the cortex of cattle and human hair by means of boring hyphae and fronded mycelium, also disintegration of the medullae of cattle hair, human toe-nails and human plantar callus	Griffin (1960), English (1965), Ali-Shtayeh et al. (1988a,b), Kornillowicz (1991–1992)
109.	*Lecanicillium psalliotae* (Treschow) Zare & Gams	■ isolated from human and goat hair; ■ keratinophilic	Ali-Shtayeh et al. (1988a), Ulfig (2003)

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Table 3 (*continued*)

No.	Species name	Strain source, comments	References
110.	***Madurella grisea* McKinnon et al.**	■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus	English (1965)
111.	***Madurella mycetomi* (Laveran) Brumpt**	■ disintegration of the medullae of hedgehog spines, human toe-nails and human plantar callus	English (1965)
112.	*Malbranchea arcuata* Sigler & Carmichael	■ destruction of human hair by the action of boring hyphae; ■ keratinolytic	Filipello Marchisio et al. (1994)
113.	*Malbranchea aurantiaca* Sigler & Carmichael	■ degradation of human hair	Deshmukh and Agrawal (1985)
114.	*Malbranchea chrysosporioidea* Sigler & Carmichael	■ isolated from sheep's wool, human and cow hair	Moubahser et al. (1992)
115.	*Malbranchea cinnamomea* (Libert) Van Oorschot & De Hoog	■ destruction of human hair by an action of boring hyphae; ■ keratinolytic	Filipello Marchisio et al. (1994)
116.	*Malbranchea fulva* Sigler & Carmichael	■ destruction of human hair by an action of boring hyphae; ■ keratinolytic	Filipello Marchisio et al. (1994), Ulfig (2003)
117.	*Malbranchea anamorph* of Uncinocarpus reesii Sigler & Orr	■ isolated from wool; ■ softening and subsequent degradation of wool fibres after 14 days; ■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration; ■ keratinolytic	Al Musallam and Radwan (1990), Filipello Marchisio et al. (1994)
118.	*Malbranchea* sp. (strain GPCK 535)	■ cuticle lifting of human hair; production of needle-shaped perforators	Katiyar and Kushwaha (2002)
119.	*Memnoniella echinata* (Rivolta) Galloway	■ isolated from cow, donkey, rabbit, goat and cat hair; ■ penetration of the cortex of hedgehog spines, cattle and human hair through boring hyphae	English (1965), Ali-Shtayeh et al. (1988a,b)
120.	*Metarhizium brunneum* Petch	■ degradation of wool after 40 days	McQuade (1964)
121.	***Microsporum audouinii* Gruby**	■ isolated from rabbit and goat hair; ■ hair degradation; ■ keratinolytic	Vanbreuseghem (1952), Ali-Shtayeh et al. (1988a,b)
122.	***Microsporum boullardii* Dominik & Majchrowicz**	■ isolated from rabbit and horse hair	Bagy and Abdel-Mallek (1991)
123.	***Microsporum canis* Bodin**	■ isolated from cat hair; ■ one of the most active species in hair degradation; ■ disintegration of hair derived from various animal species such as sheep, fox, guinea pig, dog, cat and human (most resistant) by the action of keratinolytic enzymes; ■ decomposition of hair; production of a wide and solid mass of eroding fronds penetrating right through the hair shaft; ■ keratinolytic	Vanbreuseghem (1952), English (1963), Ali-Shtayeh et al. (1988b), Wawrzkiewicz et al. (1997)
124.	***Microsporum cookei* Ajello**	■ isolated from wool; ■ highly active keratin-degrading fungus; ■ sulfitolysis of human hair, i.e. denaturation of keratin by the reduction of disulfide bonds which renders keratin vulnerable to proteolytic attack; ■ degradation of feather keratin; ■ keratinase production	De Vries (1964), Safranek and Goos (1982), Simpanya and Baxter (1996), Kornillowicz-Kowalska (1997)
125.	*Microsporum fulvum* Uriburu	■ isolated from museum exhibits, commonly occurs on works of art made of feathers, hair and on woollen textiles	Agrawal (1995)
126.	***Microsporum gallinae* (Megnin ex Guéguen) Grigoraki**	■ utilization of chicken feathers as the only source of carbon and nitrogen	Wawrzkiewicz et al. (1991)
127.	***Microsporum gypseum* (Bodin) Guiart & Grigorakis**	■ isolated from a strip of wool buried in soil; ■ isolated from sheep's wool, human, buffalo, cow, cat and horse hair; ■ isolated from dyed woollen textiles; rapid degradation of the textiles; ■ ready growth on clean (devoid of contaminants and lipids) wool; ■ utilization of human hair as a sole source of carbon and nitrogen; ■ highly active keratin-degrading fungus; ■ decomposition of keratin from human hair, wool, woollen fabrics, fingernails and horns; ■ digestion of fibrillar proteins in feathers, hooves, horns, horse hair, wool, mohair (percentage-based in descending order); ■ keratin denaturation by sulfitolysis, i.e. cleavage of the substrate disulfide bridges; ■ visual appearance of colonization of human hair first observed after 6 days, complete degradation occurs after 24 days; development of medullary, needle and tunnel types of perforators; ■ human hair degradation by means of surface erosion and radial penetration; production of invasive structures; ■ highly keratinolytic	Mandels et al. (1948), Page (1950), Stahl et al. (1950), White et al. (1950), Vanbreuseghem (1952), Crewther (1955), De Vries (1964), Chmel et al. (1972), Denizel et al. (1974), Deshmukh and Agrawal (1982), Ali-Shtayeh et al. (1988b), Kunert (1989), Moubahser et al. (1992), Nigam and Kushwaha (1992a), Mahmoud (1995), Simpanya and Baxter (1996), Ramesh and Hilda (1999), Ali-Shtayeh and Jamous (2000), Katiyar and Kushwaha (2002), Ulfig (2003), Błyskal's unpublished results
128.	***Microsporum nanum* Fuentes et al.**	■ isolated from human, cow, rabbit, goat and cat hair; ■ utilization of modified keratin from chicken feathers	Ali-Shtayeh et al. (1988a,b), Wawrzkiewicz et al. (1991), Ramesh and Hilda (1999)

Table 3 (*continued*)

No.	Species name	Strain source, comments	References
129.	***Microsporum persicolor* (Sabouraud) Guiart & Grigorakis**	■ degradation of horse hair; ■ keratinolytic	Mahmoud (1995)
130.	***Microsporum racemosum* Borelli**	■ isolated from rabbit and rat hair	Bagy and Abdel-Mallek (1991)
131.	*Microsporum ripariae* Hubálek & Rush-Munro	■ destruction of chicken feathers and human hair; ■ production of perforating organs in contact with human hair	Hubalek and Rush-Munro (1973)
132.	*Monodictys castaneae* (Wallroth) Hughes	■ isolated from sheep's wool	Abdel-Gawad (1997)
133.	*Myceliophthora vellerea* (Saccardo & Spegazzini) Van Oorschot	■ isolated from horse, goat and dog hair; ■ degradation of feather keratin; ■ degradation of human hair by means of surface erosion; ■ keratinase production	Chmel et al. (1972), Van Oorschot (1980), Ali-Shtayeh et al. (1988a,b), Filipello Marchisio et al. (1994), Kornillowicz-Kowalska (1997), Ulfig (2003)
134.	*Myceliophthora* sp.(strain BBT 41, CBS 116055)	■ isolated from antique woollen textiles; ■ strong entanglement of wool fibres, creation of tight mat of mycelium on the fabric; ■ structural and aesthetic deterioration of dyed and undyed woollen textiles	Szostak-Kot et al. (2004b), Błyskal (2005)
135.	*Myrothecium verrucaria* (Albertini & Schweinitz) Ditmar	■ isolated from sheep's wool; ■ isolated from human and cow hair; ■ ready growth on clean (devoid of contaminants and lipids) wool; ■ degradation of wool after 10 days	White et al. (1950), Crewther (1955), McQuade (1964), Moubahser et al. (1992), Abdel-Gawad (1997)
136.	*Oidiodendron griseum* Robak	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
137.	*Paecilomyces carneus* (Duché & Heim) Brown & Smith	■ isolated from goat and donkey hair	Ali-Shtayeh et al. (1988a,b)
138.	*Paecilomyces farinosus* (Holmskjold) Brown & Smith	■ isolated from human, goat and donkey hair	Ali-Shtayeh et al. (1988a,b, 2002)
139.	***Paecilomyces lilacinus* (Thom) Samson**	■ isolated from feathers, human, goat, donkey, rabbit, cat, dog and cow hair as well as sheep's wool; ■ keratinophilic	Griffin (1960), Ali-Shtayeh et al. (1988a,b, 2002), Kornillowicz (1991–1992), Moubahser et al. (1992), Ulfig (2003)
140.	*Paecilomyces marquandii* (Massee) Hughes	■ isolated from human, cow, donkey, goat and dog hair; ■ keratinophilic	Ali-Shtayeh et al. (1988a,b, 2002), Ulfig (2003)
141.	***Paecilomyces variotii* Bainier**	■ isolated from antique and contemporary woollen textiles; brownish discolouration of undyed woollen textiles; ■ isolated from human, cow and goat hair	Kowalik and Czerwinska (1956), Stefaniak (1969), Ali-Shtayeh et al. (1988a,b, 2002), Błyskal (2005)
142.	*Papulaspora sepedonioides* Preuss	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
143.	*Penicillium aurantiogriseum* Dierckx	■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991)
144.	*Penicillium brevicompactum* Dierckx	■ isolated from human, rabbit, cow, donkey, goat and camel hair	Ali-Shtayeh et al. (1988a,b, 2002), Bagy and Abdel-Mallek (1991)
145.	*Penicillium canescens* Sopp	■ isolated from ancient woollen textiles; ■ isolated from cow, donkey, rabbit and goat hair	Ali-Shtayeh et al. (1988a,b), Abdel-Kareem (2000)
146.	***Penicillium chrysogenum* Thom**	■ isolated from sheep's wool; ■ isolated from museum exhibits (feathers), deterioration of the feathers; ■ isolated from human, buffalo, rabbit, cow, goat and camel hair; ■ isolated from antique and contemporary woollen textiles; structural and aesthetic deterioration of undyed and dyed woollen textiles; ■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus; ■ keratinolytic	English (1965), Ali-Shtayeh et al. (1988a,b, 2002), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Nigam et al. (1994), Abdel-Gawad (1997), Błyskal (2005)
147.	***Penicillium citrinum* Thom**	■ isolated from museum exhibits (feathers), deterioration of the feathers; ■ isolated from rabbit and goat hair; ■ disintegration of the medullae of cattle hair, hedgehog spines, human toe-nails and human plantar callus	English (1965), Ali-Shtayeh et al. (1988a,b), Nigam et al. (1994)
148.	*Penicillium cyclopium* Westling	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
149.	*Penicillium daleae* Zaleski	■ isolated from cow, goat and rabbit hair	Ali-Shtayeh et al. (1988a,b)
150.	***Penicillium expansum* Link**	■ isolated from goat hair; ■ strong destruction of sheep's wool	Michalska (1957), Ali-Shtayeh et al. (1988a)
151.	*Penicillium funiculosum* Thom	■ isolated from sheep's wool, human, buffalo, rabbit, goat and cow hair	Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992), Abdel-Gawad (1997), Ramesh and Hilda (1999)
152.	*Penicillium glabrum* (Wehmer) Westling	■ isolated from antique woollen textiles; ■ isolated from human and goat hair; ■ human hair degradation by means of surface erosion and radial penetration; production of invasive structures; ■ strongly keratinolytic	Ali-Shtayeh et al. (1988a,b, 2002), Ali-Shtayeh and Jamous (2000), Błyskal (2005)
153.	*Penicillium glandicola* (Oudemans) Seifert & Samson	■ isolated from ancient woollen textiles; ■ isolated from rabbit hair	Ali-Shtayeh et al. (1988b), Abdel-Kareem (2000)
154.	*Penicillium griseofulvum* Dierckx	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)

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Table 3 (*continued*)

No.	Species name	Strain source, comments	References
155.	*Penicillium herquei* Bainier & Sartory	■ isolated from cow and goat hair	Ali-Shtayeh et al. (1988a,b)
156.	*Penicillium islandicum* Sopp	■ isolated from human, rabbit, goat and cow hair	Ali-Shtayeh et al. (1988a,b), Moubahser et al. (1992)
157.	*Penicillium italicum* Wehmer	■ isolated from cow hair	Ali-Shtayeh et al. (1988b)
158.	*Penicillium janczewskii* Zaleski	■ isolated from human hair; ■ keratinophilic	Ulfig (2003)
159.	*Penicillium janthinellum* Biourge	■ isolated from human, goat and donkey hair; ■ keratinophilic	Ali-Shtayeh et al. (1988a,b), Ulfig (2003)
160.	*Penicillium oxalicum* Currie & Thom	■ isolated from sheep's wool; ■ isolated from human, cow, goat and donkey hair	Ali-Shtayeh et al. (1988a,b, 2002), Abdel-Gawad (1997)
161.	*Penicillium paxilli* Bainier	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
162.	***Penicillium purpurogenum* Stoll**	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
163.	*Penicillium rubrum* Stoll	■ isolated from goat and cow hair	Ali-Shtayeh et al. (1988a,b)
164.	***Penicillium rugulosum* Thom**	■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991)
165.	*Penicillium simplicissimum* (Oudemans) Thom	■ isolated from antique woollen textiles; greenish discolouration of undyed woollen textiles; ■ isolated from rabbit and goat hair	Ali-Shtayeh et al. (1988a,b), Błyskal (2005)
166.	*Penicillium soppi* Zaleski	■ isolated from ancient woollen textiles	Abdel-Kareem (2000)
167.	***Penicillium spinulosum* Thom**	■ isolated from antique woollen textiles	Błyskal (2005)
168.	*Penicillium thomii* Maire	■ isolated from human hair	Ramesh and Hilda (1999)
169.	*Penicillium variabile* Sopp	■ isolated from cow, donkey, goat and cat hair	Ali-Shtayeh et al. (1988a,b)
170.	*Penicillium verruculosum* Peyronel	■ isolated from sheep's wool	Abdel-Gawad (1997)
171.	*Penicillium vulpinum* (Cooke & Massee) Seifert & Samson	■ isolated from rabbit hair	Ali-Shtayeh et al. (1988b)
172.	*Pestalotia bicolor* Ellis & Everhart	■ degradation of wool	Denizel et al. (1974)
173.	*Phialophora cyclaminis* Beyma	■ isolated from cow and goat hair	Ali-Shtayeh et al. (1988a,b)
174.	***Phoma glomerata* (Corda) Wollenweber & Hochapfel**	■ isolated from wool; ■ isolated from camel hair; ■ development of black, hard to remove, discolouration on fleece wool, in the regions of discolouration fibres show a very low tensile strength characteristic of extreme weathering; severe mechanical disruption of cortical cells within the fibres	Mulcock (1959, 1965), Denizel et al. (1974), Bagy and Abdel-Mallek (1991)
175.	*Phoma humicola* Gilman & Abbott	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
176.	*Pithomyces sacchari* (Spegazzini) Ellis	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
177.	*Rutola graminis* (Desmazières) Crane & Schoknecht	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
178.	***Scopulariopsis acremonium* (Delacroix) Vuillemin**	■ isolated from rabbit and goat hair	Ali-Shtayeh et al. (1988a,b)
179.	***Scopulariopsis brevicaulis* (Saccardo) Bainier**	■ isolated from sheep's wool, woollen textiles, human, buffalo, rabbit, donkey, camel, goat and cow hair; ■ degradation of feathers and human hair; ■ penetration of the cortex of hedgehog spines, cattle and human hair by the action of boring hyphae (scanty borers); ■ utilization of insoluble keratin of human hair as a sole source of carbon, nitrogen and sulphur; ■ high activity on keratin in cultures grown on hooves as single source of carbon and nitrogen; ■ keratinase production	Kowalik and Czerwinska (1956), Mathison (1964), English (1965), Stefaniak (1969), Ali-Shtayeh et al. (1988a,b), McCarthy and Greaves (1988), Bagy and Abdel-Mallek (1991), Rajak et al. (1991), Malviya et al. (1992a,b), Moubahser et al. (1992), Mahmoud (1995), Abdel-Gawad (1997), Filipello Marchisio et al. (2000), Ulfig (2003)
180.	***Scopulariopsis brumptii* Salvanet-Duval**	■ isolated from antique woollen textiles; creation of a tight layer of mycelium on the fabric; ■ isolated from rabbit, goat and cow hair	Ali-Shtayeh et al. (1988a,b), Bagy and Abdel-Mallek (1991), Błyskal (2005)
181.	***Scopulariopsis candida* (Guéguen) Vuillemin**	■ growth on wool; ■ isolated from rabbit, cow, goat and donkey hair	Ali-Shtayeh et al. (1988a,b), Al Musallam and Radwan (1990), Bagy and Abdel-Mallek (1991)
182.	***Scopulariopsis koningii* (Oudemans) Vuillemin**	■ isolated from rabbit hair	Bagy and Abdel-Mallek (1991)
183.	*Sepedonium chrysospermum* (Bulliard) Fries	■ isolated from human and buffalo hair	Moubahser et al. (1992)
184.	***Sporothrix schenckii* Hektoen & Perkins**	■ isolated from goat and donkey hair	Ali-Shtayeh et al. (1988a,b)
185.	***Sporotrichum pruinosum* Gilman & Abbott**	■ isolated from feathers; ■ complete solubilization of native feather keratin; ■ keratinase production	Kornillowicz (1991–1992), Kornillowicz-Kowalska (1997, 1999)
186.	***Stachybotrys chartarum* (Ehrenberg) Hughes**	■ isolated from sheep's wool; ■ isolated from contemporary woollen textiles; blackish discolouration of undyed woollen textiles; ■ isolated from buffalo and rabbit hair; ■ decomposition of wool; ■ disintegration of the cortex of cattle and human hair by the action of boring hyphae and fronded mycelium, also disintegration of the medullae of cattle hair, human toe-nails and human plantar callus	English (1965), Bagy and Abdel-Mallek (1991), Moubahser et al. (1992), Domsch et al. (1993), Abdel-Gawad (1997), Błyskal (2005)
187.	*Staphylotrichum coccosporum* Meyer & Nicot	■ isolated from cow, goat and donkey hair	Ali-Shtayeh et al. (1988a,b)
188.	*Stemphylium macrosporoideum* (Berkeley & Broome) Saccardo	■ isolated from contemporary woollen textiles	Kowalik and Czerwinska (1956), Stefaniak (1969)

Table 3 (*continued*)

No.	Species name	Strain source, comments	References
189.	*Stilbella fimetaria* (Persoon) Lindau	▪ disintegration of the medullae of hedgehog spines, human toe-nails and human plantar callus	English (1965)
190.	*Stilbella* sp. (strain QM 833)	▪ isolated from wool	Denizel et al. (1974)
191.	*Torula herbarum* (Persoon) Link	▪ isolated from sheep and camel hair	Bagy and Abdel-Mallek (1991)
192.	*Trichoderma virens* (Miller et al.) von Arx	▪ isolated from feathers	Kornillowicz (1991–1992)
193.	***Trichoderma viride* Persoon: Fries**	▪ isolated from feathers and human hair; ▪ penetration of the cortex of hedgehog spines, cattle and human hair by an action of boring hyphae; ▪ extensive destruction of sheep's wool	Michalska (1957), Griffin (1960), English (1965), Kornillowicz (1991–1992), Ramesh and Hilda (1999), Ali-Shtayeh et al. (2002)
194.	***Trichophyton ajelloi* (Vanbreuseghem) Ajello**	▪ isolated from wool, feathers, horse and cat hair; ▪ degradation of wool, human, guinea pig hair and feather keratin; ▪ highly active keratin-degrading fungus; ▪ utilization of human hair as a sole source of carbon and nitrogen; ▪ decomposition of hair, production of a wide and solid mass of eroding fronds penetrating right through the hair shaft; growth between the laminations of the human toe-nails occurs in the same manner as in the cortex of hair or hedgehog spines, i.e. by developing eroding fronds and perforating organs; ▪ solubilization of 67% of wool in 11 days when grown on wool which acts as a sole source of carbon and nitrogen; ▪ keratinase production	Chesters and Mathison (1963), English (1963), De Vries (1964), Mathison (1964), Baxter and Mann (1969–1970), Chmel et al. (1972), Deshmukh and Agrawal (1982), Ali-Shtayeh et al. (1988b), Wawrzkiewicz et al. (1991), Kornillowicz (1991–1992), Simpanya and Baxter (1996), Kornillowicz-Kowalska (1997), Ali-Shtayeh and Jamous (2000), Simpanya (2000), Ulfig (2003)
195.	*Trichophyton equinum* (Matruchot & Dassonville) Gedoelst	▪ isolated from horse and rabbit hair; ▪ highly keratinolytic	Ali-Shtayeh et al. (1988b), Mahmoud (1995)
196.	***Trichophyton mentagrophytes* var. *interdigitale* (Priestley) Georg**	▪ degradation of hair; ▪ destruction of woollen blanket	White et al. (1950), De Vries (1962), Oyeka (2000)
197.	***T. mentagrophytes* (Robin) Blanchard**	▪ isolated from human, cow, cat, goat, dog and rabbit hair; ▪ degradation of keratin of guinea pig hair; ▪ sulfitolysis of human hair, i.e. denaturation of keratin by the reduction of disulfide bonds which renders keratin vulnerable to proteolitic attack; ▪ decomposition of hair; production of a wide and solid mass of eroding fronds penetrating right through the hair shaft; growth between the laminations of the human toe-nails occurs in the same manner as in the cortex of hair or hedgehog spines, i.e. by development of eroding fronds and perforating organs; ▪ digestion of intercellular membranes of both the fibrous α-keratin and the amorphous matrix protein (γ-keratin) of hair; ▪ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion; ▪ complete degradation of healthy human nail plate in the absence of extraneous nutrients; ▪ discolouration and slight deterioration of wool; ▪ highly keratinolytic	Cruickshank and Trotter (1956), De Vries (1962), English (1963), Mathison (1964), Agarwal and Puvathingal (1969), Baxter and Mann (1969–1970), Kamalam and Thambiah (1980), Safranek and Goos (1982), Ali-Shtayeh et al. (1988a,b), Bagy and Abdel-Mallek (1991), Wawrzkiewicz et al. (1991), Filipello Marchisio et al. (1994), Mahmoud (1995), Ramesh and Hilda (1999), Oyeka (2000)
198.	***Trichophyton rubrum* (Castellani) Sabouraud**	▪ isolated from sheep's wool; ▪ very active in hair degradation; ▪ sulfitolysis of human hair, i.e. denaturation of keratin by the reduction of disulfide bonds which renders keratin vulnerable to proteolytic attack; ▪ hair decomposition by the action of perforating organs; growth between the laminations of the human toe-nails occurs in the same manner as in the cortex of hair or hedgehog spines, i.e. by production of eroding fronds; ▪ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration; ▪ highly keratinolytic	Vanbreuseghem (1952), De Vries (1962), English (1963), Baxter and Mann (1969–1970), Kamalam and Thambiah (1980), Safranek and Goos (1982), Deshmukh and Agrawal (1985), Filipello Marchisio et al. (1994), Abdel-Gawad (1997)
199.	***Trichophyton schoenleinii* (Lebert) Langeron & Milochevitch**	▪ very active in hair degradation; ▪ keratinolytic	Vanbreuseghem (1952)

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Table 3 (*continued*)

No.	Species name	Strain source, comments	References
200.	***Trichophyton terrestre* Durie & Frey**	■ isolated from sheep's wool, feathers, human, horse, buffalo and cow hair; ■ highly active keratin-degrading fungus; ■ degradation of feather keratin; ■ sulfitolysis of human hair, i.e. denaturation of keratin by the reduction of disulfide bonds which renders keratin vulnerable to proteolytic attack; ■ growth between the laminations of the human toe-nails occurs in the same manner as in the cortex of hair or hedgehog spines, i.e. by development of eroding fronds and perforating organs; ■ decomposition of c. 80% of human hair after only 3–5 days by means of surface erosion and radial penetration; ■ keratinase production	Griffin (1960), English (1963), De Vries (1964), Chmel et al. (1972), Hsu and Volz (1975), Safranek and Goos (1982), Deshmukh and Agrawal (1985), Kornillowicz (1991–1992), Moubahser et al. (1992), Filipello Marchisio et al. (1994), Simpanya and Baxter (1996), Abdel-Gawad (1997), Kornillowicz-Kowalska (1997), Ramesh and Hilda (1999), Ulfig (2003)
201.	***Trichophyton tonsurans* Malmsten**	■ sulfitolysis of human hair, i.e. denaturation of keratin by the reduction of disulfide bonds which renders keratin vulnerable to proteolytic attack	Kamalam and Thambiah (1980), Safranek and Goos (1982)
202.	*Trichophyton vanbreuseghemii* Rioux et al.	■ isolated from horse hair; ■ degradation of hair	Chmel et al. (1972), Bahuguna and Kushwaha (1989)
203.	***Trichophyton verrucosum* Bodin**	■ isolated from cow, donkey, goat and rabbit hair; ■ hair decomposition; ■ degradation of keratin of guinea pig hair; ■ keratinolytic	English (1963), Ali-Shtayeh et al. (1988a,b), Wawrzkiewicz et al. (1991), Mahmoud (1995)
204.	***Trichophyton violaceum* Sabouraud**	■ hair degradation; ■ keratinolytic	Vanbreuseghem (1952)
205.	*Trichosporiella cerebriformis* (de Vries & Kleine-Natrop) Gams	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
206.	*Trichothecium roseum* (Persoon : Fries) Link	■ isolated from sheep's wool and goat hair; ■ frequent infections of sheep fleece	Michalska (1957), Ali-Shtayeh et al. (1988a), Moubahser et al. (1992)
207.	*Ulocladium alternariae* (Cooke) Simmons	■ isolated from sheep's wool	Abdel-Gawad (1997)
208.	*Ulocladium atrum* Preuss	■ isolated from sheep's wool	Abdel-Gawad (1997)
209.	*Ulocladium botrytis* Preuss	■ isolated from rabbit and camel hair	Bagy and Abdel-Mallek (1991)
210.	***Ulocladium chartarum* (Preuss) Simmons**	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
211.	*Ulocladium consortiale* (Thümen) Simmons	■ isolated from camel hair	Bagy and Abdel-Mallek (1991)
212.	*Ulocladium tuberculatum* Simmons	■ isolated from sheep's wool	Abdel-Gawad (1997)
213.	*Verticillium albo-atrum* Reinke & Berthold	■ isolated from human, donkey and goat hair; ■ penetration of the cortex of hedgehog spines, cattle and human hair by the action of boring hyphae	English (1965), Ali-Shtayeh et al. (1988a,b, 2002)
214.	*Verticillium chlamydosporium* Goddard	■ isolated from feathers and human hair	Kornillowicz (1991–1992), Ali-Shtayeh et al. (2002)
215.	*Verticillium lecani* (Zimmermann) Viégas	■ isolated from human, cow, goat and donkey hair; ■ keratinophilic	Ali-Shtayeh et al. (1988a,b, 2002), Ulfig (2003)
216.	*Verticillium luteoalbum* (Link) Subramanian	■ isolated from human hair; ■ frequent infections of sheep fleece; ■ degradation of wool after 40 days	Michalska (1957), McQuade (1964), Ramesh and Hilda (1999)
217.	*Verticillium nigrescens* Pethybridge	■ isolated from goat hair	Ali-Shtayeh et al. (1988a)
218.	*Verticillium nubilum* Pethybridge	■ isolated from human hair	Ali-Shtayeh et al. (2002)

Notes: All the fungal names presented in the table have been checked with respect to taxonomy. Currently valid taxonomic names are given based on: Ajello (1968), Samson (1974), Domsch et al. (1993), CBS List of cultures (1994), Hawksworth et al. (1995), Samson and Pitt (2000), Simpanya (2000), Vidal et al. (2000), Kirk et al. (2001), Seifert and Gams (2001), Zare and Gams (2001), Klich (2002), Samson et al. (2002), CBS Filamentous fungi database (2008), The Index Fungorum (2008) and MycoBank (2008). Pathogenicity of the fungal strains presented in the table has been given on the basis of: Summerbell et al. (1989), Tan et al. (1994), De Hoog (1996), De Hoog and Guarro (1995, 2000), Midgley et al. (1997), Baran (1998), Gugnani (2000), Simpanya (2000), Flannigan et al. (2001), Kantarcioglu et al. (2002), Straus (2004), ATCC The global bioresource center (2008) and CBS Filamentous fungi database (2008).

[a] Bold indicates fungus pathogenic for man.

Table 4
Grouping of fungi based on the type of substrate from which they were isolated and/or which they degraded.

Species name	Keratinous substrate[a] from which fungus was isolated and/or which it degraded								
	wool	textile	hair	feather	nail	hoof	horn	hedgehog spine	human plantar callus
1	2	3	4	5	6	7	8	9	10
Absidia corymbifera (Cohn) Saccardo & Trotter			+		+			+	+
Absidia cylindrospora Hagem	+		+	+		+	+		
Absidia glauca Hagem				+					
Absidia spinosa Lendner			+						
Acremonium butyri (van Beyma) Gams			+						
***Acremonium camptosporum* Gams**[b]		+							
Acremonium falciforme (Carrión) Gams			+						
Acremonium furcatum (Moreau & Moreau) ex Gams			+						
Acremonium fusidioides (Nicot) Gams			+						
Acremonium glaucum Gams		+							
Acremonium kiliense Grütz	+		+						
Acremonium murorum (Corda) Gams	+								
Acremonium roseum Petch	+		+						
Acremonium strictum Gams	+		+						
Acremonium sp.									
strain 89c QMCC;	+								
strain AC-R;	+								
strain GPCK 531			+						
***Alternaria alternata* (Fries) Keissler**	+	+	+						
Alternaria chlamydospora Mouchacca	+								
Alternaria tenuissima (Kunze: Fries) Wiltshire	+								
Amauroascus mutatus (Quelet) Rammeloo			+						
Aphanoascus cinnabarinus Zukal			+						
***Aphanoascus fulvescens* (Cooke) Apinis**			+	+					
Aphanoascus sp. (strain GPCK 534)			+						
Apiospora montagnei Saccardo		+							
Arthroderma cuniculi Dawson			+	+					
***Arthroderma curreyi* Berkeley**	+		+	+					
Arthroderma incurvatum (Stockdale) Weitzman et al.			+						
Arthroderma gertleri Böhme			+						
Arthroderma gypseum (Nannizzi) Weitzman et al.	+		+						
***Arthroderma quadrifidum* Dawson & Gentles**			+	+					
***Arthroderma tuberculatum* Kuehn**	+		+	+					
Arthroderma uncinatum Dawson & Gentles			+	+					
Arthrographis kalrae (Tewari & Macpherson) Sigler & Carmichael			+						
Aspergillus alutaceus Berkeley & Curtis			+						
Aspergillus candidus Link			+						
Aspergillus carneus (van Tiegem) Blochwitz	+								
Aspergillus cervinus Massee		+							
Aspergillus clavatus Desmazieres	+		+						
Aspergillus erythrocephalus Berkeley & Curtis			+						
Aspergillus flavipes (Bainier & Sartory) Thom & Church			+						
Aspergillus flavus Link	+	+	+	+					
Aspergillus foetidus Thom & Raper				+					
Aspergillus fumigatus Fresenius	+	+	+	+	+			+	+
Aspergillus glaucus Link	+								
Aspergillus japonicus Saito	+								
Aspergillus nidulans (Eidam) Winter	+	+							
Aspergillus niger van Tieghem	+	+	+	+					
Aspergillus ochraceus Wilhelm	+		+						
Aspergillus parasiticus Speare			+						
Aspergillus penicillioides Spegazzini			+						
Aspergillus raperi Stolk & Meyer		+							
Aspergillus repens (Corda) Saccardo			+						
Aspergillus restrictus Smith			+						
Aspergillus sparsus Raper & Thom		+							
Aspergillus spinulosus Warcup		+							
Aspergillus sulphureus (Fresenius) Thom & Church	+		+	+					
Aspergillus sydowii (Bainier & Sartory) Thom & Church	+		+						
Aspergillus tamarii Kita	+		+						
***Aspergillus terreus* Thom**	+		+		+	+		+	+
Aspergillus ustus (Bainier) Thom & Church		+	+						
Aspergillus versicolor (Vuillemin) Tiraboschi	+	+	+						
Aspergillus wentii Wehmer	+	+	+						
Aureobasidium pullulans (de Bary) Arnaud		+							
***Auxarthron conjugatum* (Kuehn) Orr & Kuehn**			+	+					
Auxarthron umbrinum (Boudier) Orr & Plunkett			+						
Auxarthron zuffianum (Morini) Orr & Kuehn	+		+						
Basipetospora rubra Cole & Kendrick			+						
Beauveria bassiana (Balsamo) Vuillemin			+						
Botryotrichum atrogriseum van Beyma		+	+						

(*continued on next page*)

Table 4 (*continued*)

Species name	Keratinous substrate[a] from which fungus was isolated and/or which it degraded								
	wool	textile	hair	feather	nail	hoof	horn	hedgehog spine	human plantar callus
Botryotrichum piluliferum Saccardo & Marchal	+		+	+	+				+
Candida saitoana Nakase & Suzuki	+								
Cephalosporium curtipes Saccardo			+						
Chaetomidium fimeti (Fuckel) Saccardo			+						
Chaetomium cochlioides Palliser			+						
Chaetomium globosum Kunze : Fries	+	+	+		+			+	+
Chaetomium indicum Corda			+		+			+	+
Chaetomium nozdrenkoae Sergejeva				+					
Chaetomium seminudum Ames	+								
Chaetomium spirale Zopf	+								
Chrysonilia sitophila (Montagne) Arx			+						
Chrysosporium carmichaeli Van Oorschot	+								
Chrysosporium europae Sigler et al.				+					
Chrysosporium georgii (Varsavsky & Ajello) Oorschot			+						
***Chrysosporium indicum* (Randhawa & Sandhu) Garg**	+		**+**	+					
***Chrysosporium keratinophilum* (Frey) Carmichael**	**+**		**+**	+					
Chrysosporium kreiselii Dominik				+					
Chrysosporium lucknowense Garg			+	+					
Chrysosporium merdarium (Link) Carmichael				+					
***Chrysosporium pannicola* (Corda) Van Oorschot & Stalpers**	+		**+**	+					
***Chrysosporium queenslandicum* Apinis & Rees**	+		**+**	+					
Chrysosporium sulfureum (Fiedler) Van Oorschot & Samson	+								
***Chrysosporium tropicum* Carmichael**	+	+	**+**	+			+		
Chrysosporium xerophilum Pitt	+								
Chrysosporium zonatum Al-Musallam & Tan			+						
Chrysosporium anamorph of *Aphanoascus clathratus* Cano & Guarro			+						
Chrysosporium anamorph of *Aphanoascus reticulisporus* (Rutien) Hubàlek			+						
Chrysosporium anamorph of *A. cuniculi* Dawson			+	+					
Chrysosporium anamorph of *A. curreyi* Berkeley			+						
***Chrysosporium* anamorph of *Pectinotrichum llanense* Varsavsky & Orr**			**+**	+					
***Chrysosporium* anamorph of *Renispora flavissima* Sigler et al.**			**+**						
Chrysosporium anamorph of Nannizziopsis vriesii (Apinis) Currah			+						
Cladophialophora bantiana (Saccardo) de Hoog et al.			+						
Cladophialophora carrionii (Trejos) de Hoog et al.			+						
Cladosporium cladosporioides (Fresenius) de Vries	+	+	+		+			+	+
Cladosporium graminum Corda	+								
Cladosporium herbarum (Persoon) Link ex Grey	+		+						
Clonostachys rosea (Link: Fries) Schroers et al.	+		+	+					
Cochliobolus hawaiiensis Alcorn	+								
Cochliobolus spicifer Nelson	+								
Corynascus sepedonium (Emmons) von Arx			+						
Ctenomyces mentagrophytes (Robin) Langeron & Milochevitch	+								
***Ctenomyces persicolor* (Sabouraud) Nannizzi**			**+**						
Ctenomyces serratus Eidam	+		+	+					
Ctenomyces sp.	+	+							
strain CBS 228.51									
strain 381 TDEL									
Cunninghamella echinulata (Thaxter) Thaxter ex Blakeslee			+						
Cunninghamella elegans Lendner			+	+	+			+	+
Curvularia lunata (Wakker) Boedijn			+		+			+	+
Curvularia ramosa (Bainier) Boedijn			+		+				+
Cylindrocarpon magnusianum Wollenweber			+						
Drechslera biseptata (Saccardo & Roumeguère) Richardson & Fraser			+						
Emericella nidulans (Eidam) Vuillemin	+		+						
Emericella quadrilineata (Thom & Raper) Benjamin	+		+						
Emericella rugulosa (Thom & Raper) Benjamin	+								
Emmonsia parva (Emmons & Ashburn) Ciferri & Montemartini	+								
Engyodontium album (Limber) de Hoog	+								
Epicoccum nigrum Link	+		+						
***Epidermophyton floccosum* (Harz) Langeron & Milochevitch**			**+**						
Eurotium chevalieri Mangin	+	+							
Fennellia nivea (Wiley & Simmons) Samson			+						
Fusarium chlamydosporum var. *chlamydosporum* Wollenweber et Reinking			+						
Fusarium culmorum (Smith) Saccardo	+			+					
Fusarium equiseti (Corda) Saccardo				+					
Fusarium heterosporum Nees			+						
Fusarium javanicum Koorders		+							
Fusarium lateritium Nees			+						
Fusarium moniliforme Sheldon		+	+						
Fusarium oxysporum Schlechtendahl			+	+				+	+
Fusarium poae (Peck) Wollenweber			+						
Fusarium roseum Link			+						
***Fusarium solani* (Martius) Saccardo**	+		+	+	**+**				+
Fusarium tricinctum (Corda) Saccardo			+						

Table 4 (*continued*)

Species name	Keratinous substrate[a] from which fungus was isolated and/or which it degraded								
	wool	textile	hair	feather	nail	hoof	horn	hedgehog spine	human plantar callus
Fusarium xylarioides Steyaert			+						
Geomyces pannorum var. pannorum (Link) Sigler & Carmichael			+	+				+	
Geotrichum candidum Link	+		+						
***Gliocladium catenulatum* Gilman & Abbott**			+			+			
Gliocladium nigrovirens Beyma			+						
Gliocladium solani (Harting) Petch			+						
Gliocladium viride Matruchot			+						
Gymnascella citrina (Massee & Salmon) Orr et al.	+		+						
Gymnascella marginispora (Kuehn & Orr) Currah			+						
Gymnoascoideus petalosporus Orr et al.			+						
***Gymnoascus arxii* Cano & Guarro**		+							
Humicola fuscoatra Traaen			+						
Humicola grisea Traaen			+	+	+				+
Lecanicillium psalliotae (Treschow) Zare & Gams			+						
Madurella grisea McKinnon et al.			+		+			+	+
Madurella mycetomi (Laveran) Brumpt					+			+	+
Malbranchea arcuata Sigler & Carmichael			+						
Malbranchea aurantiaca Sigler & Carmichael			+						
Malbranchea chrysosporioidea Sigler & Carmichael	+		+						
Malbranchea cinnamomea (Libert) Van Oorschot & de Hoog			+						
Malbranchea fulva Sigler & Carmichael			+						
***Malbranchea anamorph* of Uncinocarpus reesii Sigler & Orr**	+		+						
Malbranchea sp. (strain GPCK 535)			+						
Memnoniella echinata (Rivolta) Galloway			+					+	
Metarhizium brunneum Petch	+								
Microascus cirrosus Curzi		+							
Microsporum audouinii Gruby			+						
Microsporum boullardii Dominik & Majchrowicz			+						
***Microsporum canis* Bodin**	+		+						
***Microsporum cookei* Ajello**	+		+	+					
Microsporum fulvum Uriburu		+	+	+					
***Microsporum gallinae* (Megnin ex Guéguen) Grigoraki**				+					
***Microsporum gypseum* (Bodin) Guiart & Grigorakis**	+	+	+	+	+	+	+		
Microsporum nanum Fuentes et al.			+	+					
Microsporum persicolor (Sabouraud) Guiart & Grigorakis			+						
Microsporum racemosum Borelli			+						
Microsporum ripariae Hubálek & Rush-Munro			+	+					
Monodictys castaneae (Wallroth) Hughes	+								
Monographella cucumerina (Lindfors) Arx			+						
Mortierella alpina Peyronel			+						
Mortierella mutabilis Linnemann			+						
Mucor circinelloides van Tieghem	+		+						
Mucor genevensis Lendner			+						
Mucor hiemalis Wehmer			+	+					
Mucor mucedo Fresenius			+						
Mucor piriformis Fischer			+						
Mucor plumbeus Bonorden	+								
Mucor racemosus Fresenius	+		+						
Mucor ramosissimus Samoutsevitch				+					
Mucor saturninus Hagem			+						
Mucor strictus Hagem			+						
Myceliophthora vellerea (Saccardo & Spegazzini) Van Oorschot			+	+					
***Myceliophthora* sp. (strain BBT 41, CBS 116055)**		+							
***Myrothecium verrucaria* (Albertini & Schweinitz) Ditmar**	+		+						
Nectria haematococca Berkeley & Broome	+		+						
Nectria ventricosa Booth			+						
Neosartorya fischeri (Wehmer) Malloch & Cain		+	+						
Oidiodendron griseum Robak			+						
Onygena corvina Albertini & Schweinitz	+								
Onygena piligena Fries	+								
Paecilomyces carneus (Duché & Heim) Brown & Smith			+						
Paecilomyces farinosus (Holmskjold) Brown & Smith			+						
Paecilomyces lilacinus (Thom) Samson	+		+	+					
Paecilomyces marquandii (Massee) Hughes			+						
Paecilomyces variotii Bainier		+	+						
Papulaspora sepedonioides Preuss			+						
Penicillium aurantiogriseum Dierckx			+						
Penicillium brevicompactum Dierckx			+						
Penicillium canescens Sopp		+	+						
Penicillium chrysogenum Thom	+	+	+	+	+			+	+
Penicillium citrinum Thom			+	+	+			+	+
Penicillium cyclopium Westling		+							
Penicillium daleae Zaleski			+						

(*continued on next page*)

Table 4 (*continued*)

Species name	Keratinous substrate[a] from which fungus was isolated and/or which it degraded								
	wool	textile	hair	feather	nail	hoof	horn	hedgehog spine	human plantar callus
***Penicillium expansum* Link**	+		+						
Penicillium funiculosum Thom	+		+						
Penicillium glabrum (Wehmer) Westling		+	+						
Penicillium glandicola (Oudemans) Seifert & Samson		+	+						
Penicillium griseofulvum Dierckx			+						
Penicillium herquei Bainier & Sartory			+						
Penicillium islandicum Sopp			+						
Penicillium italicum Wehmer			+						
Penicillium janczewskii Zaleski			+						
Penicillium janthinellum Biourge			+						
Penicillium oxalicum Currie & Thom	+		+						
Penicillium paxilli Bainier		+							
Penicillium purpurogenum Stoll			+						
Penicillium rubrum Stoll			+						
Penicillium rugulosum Thom			+						
Penicillium simplicissimum (Oudemans) Thom		+	+						
Penicillium soppi Zaleski		+							
Penicillium spinulosum Thom		+							
Penicillium thomii Maire			+						
Penicillium variabile Sopp			+						
Penicillium verruculosum Peyronel	+								
Penicillium vulpinum (Cooke & Massee) Seifert & Samson			+						
Pestalotia bicolor Ellis & Everhart	+								
Phialophora cyclaminis Beyma			+						
***Phoma glomerata* (Corda) Wollenweber & Hochapfel**	+		+						
Phoma humicola Gilman & Abbott			+						
Pithomyces sacchari (Spegazzini) Ellis			+						
Pleospora herbarum (Fries) Rabenhorst	+								
Pseudallescheria boydii (Shear) McGinnis et al.	+		+						
Pythium oligandrum Drechsler				+					
Rhizomucor pusillus (Lindt) Schipper	+		+	+	+	+	+		
Rhizopus oryzae Went & Prinsen Geerligs			+						
Rhizopus stolonifer (Ehrenberg) Lind	+		+						
Rutola graminis (Desmazières) Crane & Schoknecht			+						
Scopulariopsis acremonium (Delacroix) Vuillemin			+						
***Scopulariopsis brevicaulis* (Saccardo) Bainier**	+	+	+	+		+		+	
Scopulariopsis brumptii Salvanet-Duval		+	+						
Scopulariopsis candida (Guéguen) Vuillemin	+		+						
Scopulariopsis koningii (Oudemans) Vuillemin			+						
Sepedonium chrysospermum (Bulliard) Fries			+						
Setosphaeria rostrata Leonard	+								
***Sordaria fimicola* (Roberge) Cesati & de Notaris**	+								
Sporothrix schenckii Hektoen & Perkins			+						
***Sporotrichum pruinosum* Gilman & Abbott**				+					
Stachybotrys chartarum (Ehrenberg) Hughes	+	+	+		+				+
Staphylotrichum coccosporum Meyer & Nicot			+						
Stemphylium macrosporoideum (Berkeley & Broome) Saccardo		+							
Stilbella fimetaria (Persoon) Lindau					+			+	+
Stilbella sp. (strain QM 833)	+								
Syncephalastrum racemosum Cohn ex Schroeter			+						
Talaromyces luteus (Zukal) Benjamin			+						
Talaromyces trachyspermus (Shear) Stolk & Samson			+						
Thamnidium elegans Link	+								
Thermoascus aurantiacus Miehe	+		+						
Torula herbarum (Persoon) Link	+		+						
Trichoderma virens (Miller et al.) von Arx				+					
***Trichoderma viride* Persoon: Fries**	+		+	+				+	
***Trichophyton ajelloi* (Vanbreuseghem) Ajello**	+		+	+	+			+	
Trichophyton equinum (Matruchot & Dassonville) Gedoelst			+						
Trichophyton mentagrophytes var. *interdigitale* (Priestley) Georg	+		+						
***T. mentagrophytes* (Robin) Blanchard**	+		+		+			+	
***Trichophyton rubrum* (Castellani) Sabouraud**	+		+		+			+	
Trichophyton schoenleinii (Lebert) Langeron & Milochevitch			+						
***Trichophyton terrestre* Durie & Frey**	+		+	+	+			+	
***Trichophyton tonsurans* Malmsten**			+						
Trichophyton vanbreuseghemii Rioux et al.			+						
Trichophyton verrucosum Bodin			+						
Trichophyton violaceum Sabouraud			+						
Trichosporiella cerebriformis (de Vries & Kleine-Natrop) Gams			+						
Trichothecium roseum (Persoon: Fries) Link	+		+						
Ulocladium alternariae (Cooke) Simmons	+								
Ulocladium atrum Preuss	+								
Ulocladium botrytis Preuss			+						
Ulocladium chartarum (Preuss) Simmons			+						

Table 4 (*continued*)

Species name	Keratinous substrate[a] from which fungus was isolated and/or which it degraded								
	wool	textile	hair	feather	nail	hoof	horn	hedgehog spine	human plantar callus
Ulocladium consortiale (Thümen) Simmons			+						
Ulocladium tuberculatum Simmons	+								
Verticillium albo-atrum Reinke & Berthold			+					+	
Verticillium chlamydosporium Goddard			+	+					
Verticillium lecani (Zimmermann) Viégas			+						
Verticillium luteoalbum (Link) Subramanian	+		+						
Verticillium nigrescens Pethybridge			+						
Verticillium nubilum Pethybridge			+						
Zygorhynchus moelleri Vuillemin				+					
Number of species	108	44	225	58	23	6	4	23	19

[a] Only those substrates are listed, on which fungi were reported at least three times.
[b] Bold indicates the most active fungi and the kind of substrate(s) towards which they showed the strongest action.

Onygenales and the other 30 to the Eurotiales. Among 299 species described, 298 lie within bio-safety levels (BSL) 1 and 2; thus, they are described as being non-hazardous to human life. However, those within BSL group 2 include the dermatophytes responsible for dermatomycoses. There is one highly worrying fact—a representative of BSL class 3, *Cladophialophora bantiana* (Table 3) was isolated from animal hair. It is a neurotropic pathogen causing the usually fatal disease of cerebral phaeohyphomycosis in humans. The pathogens belonging to BSL 3 are potentially capable of causing acute, deep systemic mycoses in healthy individuals (Baran, 1998; De Hoog and Guarro, 1995).

6. Conclusions

The decay of keratinous substrates results from mechanical and biochemical processes caused by specialized fungal groups. Keratinolytic strains are found not only among the Onygenales, but also in other taxonomic groups, including the Mucorales. The rate and degree of deterioration of the material depends on the type of substrate and on its cystine concentration. Thus the hair of humans, dogs, horses, and cats degrades more slowly than that of rodents or sheep's wool or feathers; the resistance level of nails and horns is much lower.

References

Abdel-Gawad, K.M., 1997. Mycological and some physiological studies of keratinophilic and other moulds associated with sheep wool. Microbiological Research 152, 181–188.

Abdel-Kareem, O.M.A., 2000. Application of Fungicides and Polymers in Preservation of Linen Textiles. PhD thesis. Krakow University of Economics, Faculty of Commodity Science, Krakow, Poland.

Agarwal, P.N., Puvathingal, J.M., 1969. Microbiological deterioration of woollen materials. Textile Research Journal 39, 38–42.

Agrawal, S.C., 1995. Biodeterioration of wool: efficacy of some fungicides in controlling the deterioration. In: Aranyanak, Ch., Singhasiri, Ch. (Eds.), Biodeterioration of Cultural Property 3. Proceedings of the Third International Conference on Biodeterioration of Cultural Property, Bangkok, pp. 202–208.

Ajello, L., 1968. A taxonomic review of the dermatophytes and related species. Sabouraudia 6, 147–159.

Al Musallam, A.A., Radwan, S.S., 1990. Wool colonizing microorganisms capable of utilizing wool lipids and fatty acids as sole sources of carbon and energy. Journal of Applied Bacteriology 69, 806–813.

Asquith, R.S., 1977. Chemistry of Natural Protein Fibers. Plenum Press, New York.

Ali-Shtayeh, M.S., Arda, H.M., Hassouna, M., Shaheen, S.F., 1988a. Keratinophilic fungi on the hair of goats from the West Bank of Jordan. Mycopathologia 104, 103–108.

Ali-Shtayeh, M.S., Arda, H.M., Hassouna, M., Shaheen, S.F., 1988b. Keratinophilic fungi on the hair of cows, donkeys, rabbits, cats and dogs from the West Bank of Jordan. Mycopathologia 104, 109–121.

Ali-Shtayeh, M.S., Jamous, R.M.F., 2000. Keratinophilic fungi and related dermatophytes in polluted soil and water habitats. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 51–59. Bilbao.

Ali-Shtayeh, M.S., Khaleel, T.K.M., Jamous, R.M., 2002. Ecology of dermatophytes and other keratinophilic fungi in swimming pools and polluted and unpolluted streams. Mycopathologia 156, 193–205.

ATCC, The global bioresource center, 2008. http://www.lgcpromochem-atcc.com/common/catalog/fungiYeast/%20fungiYeastIndex.cfm.

Bagy, M.M.K., Abdel-Mallek, A.Y., 1991. Saprophytic and keratinolytic fungi associated with animals hair from Riyadh, Saudi Arabia. Zentralblatt für Microbiologie 146, 305–310.

Bahuguna, S., Kushwaha, R.K.S., 1989. Hair perforation by keratinophilic fungi. Mycoses 32, 340–343.

Baran, E., 1998. Outline of Medical Mycology. Volumed, Wroclaw (in Polish).

Batko, A., 1975. Outline of Hydromycology. PWN, Warszawa (in Polish).

Baxter, M., Mann, P.R., 1969–1970. Electron microscopic studies of the invasion of human hair *in vitro* by three keratinophilic fungi. Sabouraudia 7, 33–37.

Benny, G.L., Humber, R.A., Morton, J.B., 2001. Zygomycota: Zygomycetes. In: Esser, K., Lemke, P.A. (Eds.), The Mycota. A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research. vol. 7A. In: McLaughlin, D.J., McLaughlin, E.G., Lemke, P.A. (Eds.), Systematics and Evolution. Springer, Berlin, pp. 113–146.

Błyskal, B., 2005. The Influence of Dyes on the Degree of Biodeterioration of a Woollen Textile. PhD Dissertation. Krakow University of Economics, Faculty of Commodity Science, Krakow, Poland (in Polish).

CBS Filamentous fungi database, 2008. http://www.cbs.knaw.nl/databases/index.htm.

CBS List of cultures, 1994. Fungi and Yeasts, 33rd ed. CBS, Baarn and Delft.

Chesters, C.G.C., Mathison, G.E., 1963. The decomposition of wool keratin by *Keratinomyces ajelloi*. Saboraudia 2, 225–237.

Chmel, L., Hasilikova, A., Hrasko, J., Vlacilikova, A., 1972. The influence of some ecological factors on keratinophilic fungi in the soil. Sabouraudia 10, 26–34.

Crewther, W.G., 1955. Pretreatments which affect the susceptibility of wool to proteolysis. The effects of pH, wetting agents and solvent extraction. In: Crewther, W.G. (Ed.), Proceedings of the International Wool Textile Research Conference. Morris and Walker Pty. Ltd., Melbourne, pp. 227–256.

Cruickshank, C.N.D., Trotter, M.D., 1956. Separation of epidermis from dermis by filtrates of *Trichophyton mantagrophytes*. Nature 177, 1085–1086.

De Hoog, G.S., 1996. Risk assessment of fungi reported from humans and animals. Mycoses 39, 407–417 (Review article).

De Hoog, G.S., Guarro, J., 1995. Atlas of Clinical Fungi. CBS, Baarn and Delft.

De Hoog, G.S., Guarro, J., 2000. Atlas of Clinical Fungi, second ed. CBS, Utrecht.

Denizel, T., Jarvis, B., Onions, A.H.S., Rhodes, A.C., Samson, R.A., Simmons, E.G., Smith, M.T., Hueck van der Plas, E.H., 1974. A catalogue of potentially biodeteriogenic fungi held in the culture collections of the CBS (Centraalbureau voor Schimmelcultures), CMI (Commonwealth Mycological Institute) and QM (U.S. Army Natick Laboratories). International Biodeterioration Bulletin 10, 3–23.

Deshmukh, S.K., Agrawal, S.C., 1982. In vitro degradation of human hair by some keratinophilic fungi. Mycosen 25, 454–458.

Deshmukh, S.K., Agrawal, S.C., 1985. Degradation of human hair by some dermatophytes and other keratinophilic fungi. Mycosen 28, 463–466.

De Vries, G.A., 1962. Keratinophilic fungi and their action. Antonie van Leeuwenhoek 28, 121–133.

De Vries, G., 1964. Keratinophylic fungi. Annales des Societes belges Medecine tropicale 44, 795–802.

Dix, N.J., Webster, J., 1995. Fungal Ecology. Chapman and Hall, London.

Domsch, K.H., Gams, W., Anderson, T.H., 1993. Compendium of Soil Fungi. IHW-Verlag, Eching.

Dozie, I.N.S., Okeke, C.N., Unaeze, N.C., 1994. A thermostable, alkaline-active, keratinolytic proteinase from *Chrysosporium keratinophilum*. World Journal of Microbiology and Biotechnology 10, 563–567.

English, M.P., 1963. The saprophytic growth of keratinophilic fungi on keratin. Sabouraudia 3, 115–130.

English, M.P., 1965. The saprophytic growth of non-keratinophilic fungi on keratinized substrata and a comparison with keratinophilic fungi. Transactions of British Mycological Society 48, 219–235.

Filipello Marchisio, V., 2000. Keratinophilic fungi: their role in nature and degradation of keratinic substrates. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 86–92. Bilbao.
Filipello Marchisio, V., Fusconi, A., Rigo, S., 1994. Keratinolysis and its morphological expression in hair digestion by airborne fungi. Mycopathologia 127, 103–115.
Filipello Marchisio, V., Fusconi, A., Querio, F.L., 2000. *Scopulariopsis brevicaulis*: a keratinophilic or a keratinolytic fungus? Mycoses 43, 281–292.
Flannigan, B., Samson, R.A., Miller, J.D., 2001. Microorganisms in Home and Indoor Work Environments. Taylor and Francis, London.
Geiser, D.M., LoBuglio, K.F., 2001. The monophyletic Plectomycetes: Ascosphaerales, Onygenales, Eurotiales. In: Esser, K., Lemke, P.A. (Eds.), The Mycota. A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research. vol. 7A. In: McLaughlin, D.J., McLaughlin, E.G., Lemke, P.A. (Eds.), Systematics and Evolution. Springer, Berlin, pp. 201–219.
Ghawana, V.K., Shrivastava, J.N., 1995. Morphological changes induced during the biodeterioration of wool by soil-borne fungus. In: Aranyanak, Ch., Singhasiri, Ch. (Eds.), Biodeterioration of Cultural Property 3. Proceedings of the Third International Conference on Biodeterioration of Cultural Property, Bangkok, pp. 693–697.
Griffin, D.M., 1960. Fungal colonization of sterile hair in contact with soil. Transactions of British Mycological Society 43, 583–596.
Gugnani, H.C., 2000. Nondermatophytic filamentous keratinophilic fungi and their role in human infection. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 109–114. Bilbao.
Hawks, C.A., Rowe, W.F., 1988. Deterioration of hair by airborne microorganisms: implications for museum biological collections. In: Houghton, D.R., Smith, R.N., Eggins, H.O.W. (Eds.), Biodeterioration 7. Elsevier Applied Science, London, pp. 461–465.
Hawksworth, D.L., Kirk, P.M., Sutton, B.C., Pegler, D.N., 1995. Ainsworth and Bisby's Dictionary of Fungi, eighth ed. CAB International, Wallingford.
Hsu, Y.C., Volz, P.A., 1975. Penetration of *Trichophyton terrestre* in human hair. Mycopathologia 55, 179–183.
Hubalek, Z., Rush-Munro, F.M., 1973. A dermatophyte from birds: *Microsporum ripariae* sp. nov. Sabouraudia 11, 287–292.
Jennings, D.H., 1995. The Physiology of Fungal Nutrition. Cambridge University Press, Cambridge.
Kamalam, A., Thambiah, A.S., 1980. Growth pattern and constituents of dermatophytes in varied substrates. Mycosen 23, 141–150.
Kantarcioglu, A.S., Yucel, A., de Hoog, G.S., 2002. Case report. Isolation of *Cladosporium cladosporioides* from cerebrospinal fluid. Mycoses 45, 500–503.
Katiyar, S., Kushwaha, R.K.S., 2002. Invasion and biodegradation of hair by house dust fungi. International Biodeterioration and Biodegradation 50, 89–93.
Kirk, P.M., Cannon, P.F., David, J.C., Stalpers, J.A., 2001. Ainsworth and Bisby's Dictionary of Fungi, ninth ed. CAB International, Wallingford.
Klich, M., 2002. Identification of Common *Aspergillus* Species. CBS, Utrecht.
Kornillowicz, T., 1991–1992. Studies on the mycoflora colonizing raw keratin wastes in soil. Acta Mycologica 27, 231–245 (in Polish).
Kornillowicz, T., 1994. Methods for determining keratinolytic activity of saprophytic fungi. Acta Mycologica 29, 169–178.
Kornillowicz-Kowalska, T., 1997. Studies on the decomposition of keratin waste by saprotrophic microfungi. I. Criteria for evaluating keratinolytic activity. Acta Mycologica 32, 51–79.
Kornillowicz-Kowalska, T., 1999. Studies on the decomposition of keratin waste by saprotrophic microfungi. III. Activity and properties of keratinolytic enzymes. Acta Mycologica 34, 65–78.
Kowalik, R., Czerwinska, E., 1956. Microorganisms concerned in decaying cotton and wool fibers. Acta Microbiologica Polonica 5, 291–297 (in Polish).
Kunert, J., 1972. Tiosulphate esters in keratin attacked by dermatophytes *in vitro*. Sabouraudia 10, 6–13.
Kunert, J., 1989. Biochemical mechanism of keratin degradation by the actinomycete *Streptomyces fradiae* and the fungus *Microsporum gypseum*: a comparison. Journal of Basic Microbiology 29, 597–604.
Kunert, J., 1992. Effect of reducing agents on proteolytic and keratinolytic activity of enzymes of *Microsporum gypseum*. Mycoses 35, 343–348.
Kunert, J., 2000. Physiology of keratinophilic fungi. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 77–85. Bilbao.
Kushwaha, R.K.S., 2000. The genus *Chrysosporium*, its physiology and biotechnological potential. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 66–76. Bilbao.
Mahmoud, A.L.E., 1995. Dermatophytes and other keratinophilic fungi causing ringworm of horses. Folia Microbiologica 40, 293–296.
Malviya, H.K., Rajak, R.C., Hasija, S.K., 1992a. Purification and partial characterization of extracellular keratinases of *Scopulariopsis brevicaulis*. Mycopathologia 119, 161–165.
Malviya, H.K., Rajak, R.C., Hasija, S.K., 1992b. Synthesis and regulation of extracellular keratinases in three fungi isolated from the grounds of a gelatin factory, Jabalpur, India. Mycopathologia 120, 1–4.
Mandels, G.R., Stahl, W.H., Levinson, H.S., 1948. Structural changes in wool degraded by the ringworm fungus *Microsporum gypseum* and other microorganisms. Textile Research Journal 18, 224–231.
Mathison, G.E., 1964. The microbiological decomposition of keratin. Annales des Sociétés belges de Médecine tropicale 44, 767–792.
McCarthy, B.J., Greaves, P.H., 1988. Mildew – causes, detection methods and prevention. Wool Science Review 85, 27–48.
McQuade, A.B., 1964. Microbiological degradation of wool. Dermatologica 128, 249–266.
Mercantini, R., Marsella, R., Prignano, G., Moretto, D., Marmo, W., Leonetto, F., Fuga, G.C., Serio, G., 1989. Isolation of keratinophilic fungi from the dust of ferry boats and trains in Italy. Mycoses 32, 590–594.
Michalska, I., 1957. Fungi and bacteria as a factor in decaying of wool fiber. Acta Microbiologica Polonica 6, 171–189 (in Polish).
Midgley, G., Hay, R.J., Clayton, Y.M., 1997. Medical Mycology. Czelej, Lublin (in Polish).
Mitola, G., Escalona, F., Salas, R., Garcia, E., Ladesma, A., 2002. Morphological characterization of *in vitro* human hair keratinolysis, produced by identified wild strains of *Chrysosporium* species. Mycopathologia 156, 163–169.
Moubahser, A.H., El-Naghy, M.A., Abdel-Fattah, H.M., Maghazy, S.M., 1992. Keratiolytic fungi in Egyptian soils. I. Baited with hair and wool. Zentralblatt für Microbiologie 147, 529–535.
Mulcock, A.P., 1959. Discoloration of wool fibres by a fungus. Nature 183, 1281–1282.
Mulcock, A.P., 1965. *Peyronellaea glomerata* – a fungus growing within the fibres of the unshorn fleece. Australian Journal of Agricultural Research 16, 691–697.
MycoBank, 2008. http://www.mycobank.org/MycoTaxo.aspx.
Nigam, N., Kushwaha, K.S., 1992a. Biodegradation of wool by *Chrysosporium keratinophilum* acting singly or in combination with other fungi. Transactions of Mycological Society of Japan 33, 481–486.
Nigam, N., Kushwaha, R.K.S., 1992b. Biodegradation of keratinous substrates. In: Toishi, K., Arai, H., Kenjo, T., Yamano, K. (Eds.), Biodeterioration of Cultural Property 2. Proceedings of the Second International Conference on Biodeterioration of Cultural Property, Yokohama, pp. 180–185.
Nigam, N., Dhawan, S., Nair, M.V., 1994. Deterioration of feather and leather objects of some Indian Museum by keratinophilic and non-keratinophilic fungi. International Biodeterioration and Biodegradation 33, 145–152.
Oyeka, C.A., 2000. *Trichophyton mentagrophytes* a keratinophilic fungus. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 60–65. Bilbao.
Page, R.M., 1950. Observations on the keratin digestion by *Microsporum gypseum*. Mycologia 62, 591–602.
Parbery, D.G., 1974. Biodeterioration in Australia. International Biodeterioration Bulletin 10, 63–74.
Parbery, D.G., 1977. Isolation techniques and identification of fungal biodeteriogens from soil. In: Walters, A.H. (Ed.), Biodeterioration Investigation Techniques. Applied Science Publishers Ltd, London, pp. 123–148.
Pugh, G.J.F., Mathison, G.E., 1962. Studies on fungi in coastal soils. III. An ecological survey of keratinophilic fungi. Transactions of British Mycological Society 45, 567–572.
Pugh, G.J.F., Evans, M.D., 1970a. Keratinophilic fungi associated with birds. I. Fungi isolated from feathers, nests and soils. Transactions of British Mycological Society 54, 233–240.
Pugh, G.J.F., Evans, M.D., 1970b. Keratinophilic fungi associated with birds. II. Physiological studies. Transactions of British Mycological Society 54, 241–250.
Rajak, R.C., Parwekar, S., Malviya, H., Hasija, S.K., 1991. Keratin degradation by fungi isolated from the grounds of a gelatin factory in Jabalpur, India. Mycopathologia 114, 83–87.
Rajak, R.C., Malviya, H.K., Deshapande, H., Hasija, S.K., 1992. Keratinolysis by *Absidia cylindrospora* and *Rhizomucor pusillus*: biochemical proof. Mycopathologia 118, 109–114.
Ramesh, V.M., Hilda, A., 1999. Incidence of keratinophilic fungi in the soil of primary schools and public parks of Madras city, India. Mycopathologia 143, 139–145.
Ruffin, P., Andrieu, S., Biserte, G., Biguet, J., 1976. Sulphitolysis in keratinolysis. Biochemical proof. Sabouraudia 14, 181–184.
Safranek, W.W., Goos, R.D., 1982. Degradation of wool by saprotrophic fungi. Canadian Journal of Microbiology 28, 137–140.
Salata, B., Rudnicka-Jezierska, W., 1979. Ascomycetes. In: Kochman, J., Skirgiello, A. (Eds.), Mycota, vol. 12. PWN, Warszawa (in Polish).
Samson, R.A., 1974. *Paecilomyces* and some allied *Hyphomycetes*. In: Studies in Mycology, vol. 6. CBS, Baarn.
Samson, R.A., Pitt, J., 2000. Integration of Modern Taxonomic Methods for *Penicillium* and *Aspergillus* Classification. Harwood Academic Publishers, Amsterdam.
Samson, R.A., Hoekstra, E.S., Frisvad, J.C., Filtenborg, O., 2002. Introduction to Food- and Airborne Fungi. CBS, Utrecht.
Seifert, K.A., Gams, W., 2001. The taxonomy of anamorphic fungi. In: Esser, K., Lemke, P.A. (Eds.), The Mycota. A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research. vol. 7A. In: McLaughlin, D.J., McLaughlin, E.G., Lemke, P.A. (Eds.), Systematics and Evolution. Springer, Germany, pp. 307–347.
Shipper, M.A.A., 1976. On *Mucor circinelloides, Mucor racemosus* and related species. In: Studies in Mycology, vol. 12. CBS, Baarn.
Simpanya, M.F., 2000. Dermatophytes: their taxonomy, ecology and pathogenicity. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 1–12. Bilbao.
Simpanya, M.F., Baxter, M., 1996. Isolation of fungi from soil using the keratin-baiting technique. Mycopathologia 136, 85–89.
Stahl, W.H., McQue, B., Mandels, G.R., Siu, R.G.H., 1950. Studies on the microbiological degradation of wool. Digestion of normal and modified fibrillar proteins. Textile Research Journal 20, 570–579.

Stefaniak, H., 1969. Protection of textiles against microorganisms. Postepy mikrobiologii 8, 157–160 (in Polish).
Straus, D.C. (Ed.), 2004. Sick Building Syndrome. Advances in Applied Microbiology, vol. 55. Elsevier Academic Press, London.
Summerbell, R.C., Kane, J., Krajden, S., 1989. Onychomycosis, tinea pedis and tinea manuum caused by non-dermatophytic filamentous fungi. Mycoses 32, 609–619.
Szostak-Kot, J., Błyskal, B., Sygula-Cholewinska, J., 2004a. Biodeterioration of dyed woollen textiles by fungi. In: Rong, W., Changju, Y., Min, J., Jianghua, L., Xuzhe, F., Liqin, L., Jiajie, L., Zhenwang, K., Song, Ch., Yan, Z. (Eds.), Proceedings of the Fourteenth IGWT Symposium, Focusing New Century: Commodity – Trade – Environment. China Agriculture Press, Beijing, pp. 197–201.
Szostak-Kot, J., Błyskal, B., Sygula-Cholewinska, J., 2004b. Influence of *Myceliophthora* sp. on tensile properties of woollen textiles. In: Zuchowski, J. (Ed.), Science of Commodities and Integration with European Union. Wydawnictwo Instytutu Technologii Eksploatacji, Radom, pp. 589–592 (in Polish).
Tan, S., Hoekstra, E.S., Samson, R.A., 1994. Fungi That Cause Superficial Mycoses. CBS, Baarn.
The Index Fungorum, 2008. http://www.indexfungorum.org/Names/Names.asp.
Timar-Balazsy, A., Eastop, D., 1998. Chemical Principles of Textile Conservation. Butterworth-Heinemann, Oxford.
Ulfig, K., 2003. Factors influencing the occurrence of keratinolytic and keratinophilic fungi in sewage sediments. In: Zeszyty Naukowe, vol. 932. Politechnika Lodzka, Lodz, pp. 1–146 (in Polish).
Vanbreuseghem, R., 1952. Keratin digestion by dermatophytes: a specific diagnostic method. Mycologia 44, 176–182.
Van Oorschot, C.A.N., 1980. A revision of *Chrysosporium* and allied genera. In: Studies in Mycology, vol. 20. CBS, Baarn.
Vidal, P., de los Angeles Vinuesa, M., Sanchez-Puelles, J.M., Guarro, J., 2000. Phylogeny of the anamorphic genus *Chrysosporium* and related taxa based on rDNA internal transcribed spacer sequences. In: Kushwaha, R.K.S., Guarro, J. (Eds.), Biology of Dermatophytes and Other Keratinophilic Fungi, Revista Iberoamericana de Micologia, pp. 22–29. Bilbao.
Wawrzkiewicz, K., Wolski, T., Lobarzewski, J., 1991. Screening the keratinolytic activity of dermatophytes *in vitro*. Mycopathologia 114, 1–8.
Wawrzkiewicz, K., Ziolkowska, G., Wawrzkiewicz, J., 1997. In vitro biodegradation of hair from different animal species by *Microsporum canis*. International Biodeterioration and Biodegradation 39, 15–25.
White, W.L., Mandels, G.R., Siu, R.G.H., 1950. Fungi in relation to the degradation of woollen fabrics. Mycologia 62, 199–223.
Zare, R., Gams, W., 2001. Nova Hedwigia 73, 21.