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Biodiversity of emerging pathogenic and invasive fungi in plants, animals and humans in Italy

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Abstract

In the last 30 years, the spread of emerging and invasive fungal pathogens has had a profound impact on plants, animals and humans, causing crop losses and damaging their health with economic and social impact. Awareness of the biodiversity of these pathogens is essential for their detection, identification and control. In this article, their diversity in Italy is reviewed taking into consideration the international context. Fungal endophytes, important ecological agents whose lifestyle can be switched by stochastic events from beneficial/neutral to pathogenic, are included in this review.

Keywords: Emerging pathogenic fungi, endophytes, animals, humans, plants, Italy,

Introduction

Biological invasions by non-native species are considered among the most serious threats to local biodiversity and ecosystem function in terrestrial ecosystems. They result in: (1) profound changes in indigenous population structure; (2) alteration of evolutionary processes; (3) change in the ecological relationships between plants and animals; (4) reduction of primary productivity in agrarian and forestry systems; (5) loss of native species; (6) reduction or loss of important functions such as water filtration, soil stabilization, the containment of diseases, etc. In particular, explosive non-native pathogen reproduction and consequent proliferation in new areas are linked to three factors: (1) host-tracking; (2) host-jump; (3) enemy release. According to Celesti Grapow (2010 Celesti Grapow, L, Alessandrini, A, Arrigoni, P V, Assini, S, Banfi, EBarni, E. 2010. Non native flora of Italy: Species distribution and threats. *Plant Biosyst*, 144: 12–28. [Taylor & Francis Online], [Web of Science ®]), the number and density of introduced species is highest in artificial land use types,particularly in urban areas. Moreover, the troublesome non-native is not followed into its new territory by natural hyperparasites present in the origin area (Keane & Crawley 2002 Keane, R M and Crawley, M J. 2002. Exotic plant invasions and the enemy release hypothesis. *Trends Ecol Evol*, 17: 164–170. [CrossRef], [Web of Science ®], [CSA]). With the advent and widespread use of immunomodulating biologic agents, new medicosurgical techniques and the HIV epidemic, emerging invasive fungal infections in man are being increasingly reported.

In a recent paper, Anderson et al. (2004 Anderson, P K, Cunningham, A A, Patel, N G, Morales, F J, Epstein, P R and Daszak, P. 2004. Emerging infectious diseases of plants: Pathogen pollution, climate change and agrotechnology drivers. *Trends Ecol Evol*, 19: 535–544. [CrossRef], [PubMed], [Web of Science ®]) applied the definition of emerging infectious diseases (EIDs) used in the medical and veterinary fields to plant pathology and highlighted a series of emerging plant diseases including EIDs of cultivated and wild plants, some of which are of significant conservation concern. Their economic impact and socio-economic consequences were underlined by Vurro et al (2010 Vurro, M, Bonciani, B and Vannacci, G. 2010. Emerging infectious diseases of crop plants in developing countries: Impact on agriculture and socio-economic consequences. *Food Secur*, 2: 113–132. [CrossRef], [Web of Science ®]). Many EIDs are caused by pathogens that have: (1) increased in incidence, geographical or host range; (2) changed in pathogenesis; (3) newly evolved or (4) been discovered or newly recognized (Daszak et al. 2000 Daszak, P, Cunningham, A A and Hyatt, A D. 2000. Emerging infectious diseases of wildlife: Threats to biodiversity and human health. *Science*, 287: 443–449. [CrossRef], [PubMed], [Web of Science ®], [CSA]). Some EIDs are caused by fungal endophytes, important ecological agents whose lifestyle can be switched by stochastic events such as climatic factors from beneficial/neutral to pathogenic (Desprez-Loustau et al. 2007 Desprez-Loustau, M L, Robin, C, Buee, M, Courtecuisse, R, Garbaye, JSuffert, F. 2007. The fungal dimension of biological invasions. *Trends Ecol Evol*, 22: 472–480. [CrossRef], [PubMed], [Web of Science ®]; Moricca & Ragazzi 2008 Moricca, S and Ragazzi, A. 2008. Fungal endophytes in Mediterranean oak forests: A lesson from *Discula quercina*. *Phytopathol*, 98: 380–386. [CrossRef], [PubMed], [Web of Science ®]).

As part of an overview of fungal diversity in Italy (Onofri et al. 2011 Onofri, S, Anastasi, A, Del Frate, G, Di Piazza, S, Garnero, NGuglielminetti, M. 2011. Biodiversity of rock, beach and water fungi in Italy. *Plant Biosyst*, 145: 981–990. ; Persiani et al. 2011 Persiani, A M, Tosi, S, Del Frate, G, Granito, V M, Guglielminetti, MLunghini, D. 2011. High spots for diversity of soil and litter microfungi in Italy. *Plant Biosyst*, 145: 972–980. ; Saitta et al. 2011 Saitta, A, Bernicchia, A, Gorjón, S P, Altobelli, E, Granito, V MLosi, C. 2011. Biodiversity of wood-decay fungi in Italy. *Plant Biosyst*, 145: 961–971. ; Varese et al. 2011 Varese, G C, Angelini, P, Bencivenga, M, Buzzini, P, Donnini, DGargano, M L. 2011. Ex-situ conservation and exploitation of fungi in Italy. *Plant Biosyst*, 145: 1000–1008.[Web of Science ®]; Venturella et al. 2011 Venturella, G, Altobelli, E, Bernicchia, A, Di Piazza, S, Donnini, DGargano, M L. 2011. Fungal biodiversity and in situ conservation in Italy. *Plant Biosyst*, 145: 953–960.[Web of Science ®]), this article reviews the diversity of emerging pathogenic and invasive fungi on plants, animal and humans and of fungal endophytes.

Diversity of emerging pathogenic and invasive fungi on plants

Emerging fungi in Europe were called “alien fungi” in the recent publication by Desprez-Loustau et al. (2009 Desprez-Loustau, M L, Courtecuisse, R, Robin, C, Husson, C, Moreau, P ABlancard, D.

2009. Species diversity and drivers of spread of alien fungi (*sensu lato*) in Europe with a particular focus on France. *Biol Invasions*, 12: 157–172. [CrossRef], [Web of Science ®]), who listed 688 alien species, mostly and almost equally represented by *Ascomycota* (46%) and *Basidiomycota* (40%). Every national sub list encloses nearly 90 species, most plant pathogens. Global changes are resulting in strong impacts on both terrestrial and aquatic ecosystems, particularly in the Mediterranean area, considered by the Intergovernmental Panel on Climate Change as a "Climate Change Hot Spot Zone" (Intergovermental Panel on Climate Change (IPPC) 2007).

Italy seems to be one of the most important sites of fungal immigration with an increase of arrivals from Africa, Asia and the USA. The following key emerging fungi have entered Italy as plant pathogens in their host-plants: *Ceratocystis platani* (J.M. Walter) Engelbr. & T.C. Harr., *Cryphonectria parasitica* (Murrill) M.E. Barr, *Mycosphaerella pini* Rostr. exMunk, *Mycosphaerella* sp., *Ophiostoma ulmi* (Buisman)Nannf., *O. novo-ulmi* Brasier, *Sphaeropsis sapinea* (Fr.) Dyko & B. Sutton. In addition, on the *Cupressaceae* there are *Lepteutypa cupressi* (Nattrass, C. Booth & B. Sutton) H.J. Swart, *Seiridium cardinale* (W.W. Wagener) B. Sutton & I.A.S. Gibson and *S.unicorne* (Cooke & Ellis) B. Sutton. There are also the basidiomycete *Cronartium ribicola* J.C. Fisch. and species of the Straminipila genus *Phytophthora* DeBary. That genus includes some of the most important pathogens causing diseases in agricultural, forest, ornamental and natural systems world-wide. In many cases, the most destructive *Phytophthora* spp. are non-native, highly invasive and directly influenced by climate change (Rizzo et al. 2005 Rizzo, D M, Garbelotto, M and Hansen, E M. 2005. *Phytophthora ramorum*: Integrative research and management of an emerging pathogen in California and Oregon forests. *Annu Rev Phytopathol*, 43: 309–335. [CrossRef], [PubMed], [Web of Science ®]). Two notable examples are the soil-borne *P. cinnamomi* Rands, able to destabilize entire local ecosystems such as native jarrah forest in Australia (Shearer & Tippett 1989 Shearer, B L and Tippett, J T. 1989. "Jarrah dieback: The dynamics andmanagement of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia". In *Research Bulletin 3*, 76Perth: Department of Conservation and Land Management.) and oak stands in the Iberian Peninsula (Brasier 1992 Brasier, C M. 1992. Oak tree mortality in Iberia. *Nature*, 360: 539[CrossRef], [Web of Science ®]; Sánchez et al. 2002 Sánchez, M E, Caetano, P, Ferraz, J and Trapero, A. 2002. *Phytophthora* disease of *Quercus ilex* in south-western Spain. *Forest Pathol*, 32: 5–18. [CrossRef], [Web of Science ®], [CSA]), and *P.ramorum* Werres, De Cock & Man in't Veld, which has had an impact on nursery trade and forest ecosystems in Europe and North America (Rizzo et al. 2005 Rizzo, D M, Garbelotto, M and Hansen, E M. 2005. *Phytophthora ramorum*: Integrative research and management of an emerging pathogen in California and Oregon forests. *Annu Rev Phytopathol*, 43: 309–335. [CrossRef], [PubMed], [Web of Science ®]; Brasier 2008 Brasier, C M. 2008. The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathol*, 57: 792–808. [CrossRef], [Web of Science ®]).

The last few years have also seen a significant incidence of "ink disease" of sweet chestnut, caused by *Phytophthora cambivora* (Petri) Buisman and *P.cinnamomi*, which has resulted in devastating epidemics in southern Europe (Robin et al. 1998 Robin, C, Desprez-Loustau, M L, Capron, G and Delatour, C. 1998. First record of *Phytophtora cinnamomi* on cork holm oaks inFrance and evidence of pathogenicity. *Ann Sci Forest*, 55: 869–883. [CrossRef], [Web of Science ®]; Vettraino et al. 2001 Vettraino, A M, Natili, G, Anselmi, N and Vannini, A. 2001. Recovery and pathogenicity of *Phytophthora* species associated with a resurgence of ink disease in *Castanea sativa* in Italy. *Plant Pathol*, 50: 90–96. [CrossRef], [Web of Science ®]). Several other *Phytophthora* species have recently been found also to be associated with this disease (Vettraino et al. 2005 Vettraino, A M, Morel, O, Perlerou, C, Robin, C, Diamandis, S and Vannini, A. 2005. Occurrence and distribution of *Phytophthora* species in European chestnut stands, and their association withInk Disease and crown decline. *Eur J Plant Pathol*, 111: 169–180. [CrossRef], [Web of Science ®]). There is a possibility of hybridization between different *Phytophthora* spp. with consequent spread of more virulent new species (Brasier 2000 Brasier, C M. 2000. The rise of the hybrid fungi. *Nature*, 405: 134–135. [CrossRef], [PubMed], [Web of Science ®], [CSA]). A prominent example is *P. alni* Brasier & S.A. Kirk subsp. *alni* which is killing native alders across Europe, and has been considered an emerging natural disaster (Jung & Blaschke 2004 Jung, T and Blaschke, M. 2004. *Phytophthora* root and collar rot of alders in Bavaria: Distribution, modes of spread and possible management strategies. *Plant Pathol*, 53: 197–208. [CrossRef], [Web of Science ®]). Several *Phytophthora* spp. were strongly involved in European oak (*Quercus robur* L.) decline (Jung et al. 1996 Jung, T, Blaschke, H and Neumann, P. 1996. Isolation, identification and pathogenicity of *Phytophthora* species from declining oak stands. *Eur J Forest Pathol*, 26: 253–272. [CrossRef], [Web of Science ®]; Hansen & Delatour 1999 Hansen, E and Delatour, C. 1999. *Phytophthora* species in oak forests of north-east France. *Ann Sci Forest*, 56: 539–547. [CrossRef], [Web of Science ®]; Vettraino et al. 2002 Vettraino, A M, Barzanti, B P, Bianco, M C, Ragazzi, A, Capretti, PPaoletto, E. 2002. Occurrence of *Phytophthora* species in oak stands in Italy and their association with declining oak trees. *Forest Pathol*, 32: 19–28. [CrossRef], [Web of Science ®], [CSA]). Recently, in Sardinia various *Phytophthora* spp. have been involved in the aetiology of severe mortality of holm oak (*Quercus ilex* L.) in natural stands (Franceschini et al. 2010). *P. cambivora*, *P. cinnamomi*, *P. pseudosyringae* T. Jung & Delatour are emerging species important for Italian forest ecosystems. *Phytophthora citrophthora* (R.E. Sm. & E.H. Sm.) Leonian, *P. palmivora* (E.J. Butler) E.J. Butler, *P. cactorum* (Lebert & Cohn) J. Schröt. have damaged horticultural heritage trees and fruit trees (Cristinzio 1994 Cristinzio, G. 1994. Il marciume bruno dei frutti di limone da*Phytophthora* spp. nella penisola sorrentina. *Petria*, 4: 123–130. ; Cacciola et al. 2007a Cacciola, S O, Giudice, V, Magnano di San Lio, G and Raudino, F. 2007a. *Phytophthora* spp. in citrus groves, one disease with several symptoms. *Inf Agr*, 63: 44–50. ,b; Garibaldi & Gullino 2010 Garibaldi, A and Gullino, M L. 2010. Emerging soilborne diseases ofhorticultural crops and new trends in their management. *Acta Hortic*, 883: 37–47.). Dramatic changes are expected in ornamental and forest nurseries: *P.cryptogea* Pethybr. & Laff., *P. nicotianae* Breda de Haan, *P. palmivora*, *P. niederhauserii* Z.G. Abad & J.A. Abad and *P. ramorum* (Pane et al. 2006 Pane, A, Cacciola, S O, Badalà, F, Martini, P and Magnano di San Lio, G. 2006. Il marciume radicale da *Phytophthora* nei vivai di piante ornamentali. *Terra Vita*, 18: 24–28. ; Scanu et al. 2011 Scanu, B, Linaldeddu, B T and Franceschini, A. 2011. A new *Phytophthora* sp. causing root and collar rot on *Pistacia lentiscus* in Italy. *Plant Dis*, 95: 618.1[CrossRef], [Web of Science ®]) have been reported as invasive throughout Italy. Their occurrence in nurseries might pose a threat to natural ecosystems in Italy or in any other country receiving imported plants (Brasier 2008 Brasier, C M. 2008. The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathol*, 57: 792–808. [CrossRef], [Web of Science ®]; Moralejo et al. 2009 Moralejo, E, Perez-Sierra, A M, Alvarez, L A, Belbahri, L, Lefort, F and Descals, E. 2009. Multiple alien *Phytophthora* taxa discovered on diseased ornamental plants in Spain. *Plant Pathol*, 58: 100–110. [CrossRef], [Web of Science ®]).

Because it includes some of the most damaging plant pathogen and toxin producing species, *Fusarium* Link is an actively researched genus in Italy. Studies have been made on *F. oxysporum* f.sp. *raphani* J.B. Kendr. & W.C. Snyder, an emerging pathogen recognized to be the causal agent of wilt on both cultivated and wild rocket (Garibaldi et al. 2006 Garibaldi, A, Gilardi, G and Gullino, M L. 2006. Evidence for an expanded host range of *Fusarium oxysporum* f.sp. *raphani*. *Phytoparasitica*, 34: 115–121. [CrossRef], [Web of Science ®]). It is represented by different races and only a few rocket varieties available in Italy are resistant. *Fusarium circinatum* Nirenberg & O'Donnell has been recognized as the causal agent of the pitch canker in Italy, observed since 2005 in Apulia on numerous trees of Aleppo pine (*Pinus halepensis* Mill.) and Italian stone pine (*Pinus pinea* L.) in urban parks and gardens (Carlucci et al. 2007 Carlucci, A, Colatruglio, L and Frisullo, S. 2007. First report of Pitch Canker caused by *Fusarium circinatum* on *Pinus halepensis* and *P.*

pinea in Apulia (Southern Italy). *Plant Dis*, 91: 1683[CrossRef], [Web of Science ®]). In Sardinia, *F. nygamai* L.W. Burgess & Trimboli has been reported for the first time as the causal agent of seedling blight and foot rot on rice (*Oryza sativa* L.) (Perrone et al. 2002 Perrone, G, Mulè, G, Susca, A, Stea, G, Ritieni, A and Moretti, A. 2002. AFLP and toxin analysis of *Fusarium nygamai* and *Fusarium oxysporum* from rice, in Sardinia. *J Appl Genet*, 43A: 91–102.). Often associated with other species (including *F. verticillioides* (Sacc.) Nirenberg, *F. proliferatum* (Matsush.) Nirenberg ex Gerlach & Nirenberg, *F. oxysporum* Schltdl., *F. solani* (Mart.) Sacc., *F. graminearum* Schwabe, *F. equiseti* (Corda) Sacc. and *F. andiyazi* Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie) (Perrone et al. 2002 Perrone, G, Mulè, G, Susca, A, Stea, G, Ritieni, A and Moretti, A. 2002. AFLP and toxin analysis of *Fusarium nygamai* and *Fusarium oxysporum* from rice, in Sardinia. *J Appl Genet*, 43A: 91–102. ; Alberti et al. 2006 Alberti, I, Vibio, M, Sella, L, Prà, M, dal Pisi, A and Pancaldi, D. Study on the presence of *Fusarium* spp. on rice reproduction seeds in Northern Italy. Phytopathological Meeting 2006. March27–292006, Riccione, Italy. pp.327–332. ; Amatulli et al. 2010 Amatulli, M T, Spadaro, D, Gullino, M L and Garibaldi, A. 2010. Molecular identification of *Fusarium* spp. *associated with bakanae disease of rice in Italy and assessment of their pathogenicity*. *Plant Pathol*, 59: 839–844. ; Dal Prà et al. 2010 Dal Prà, M, Tonti, S, Pancaldi, D, Nipoti, P and Alberti, I. 2010. First report of *Fusarium andiyazi* associated with rice bakanae in Italy. *Plant Dis*, 94: 1070[Web of Science ®]), *F. fujikuroi* Nirenberg has since 2003–2004 occurred in northern Italy rice fields as an endemic pathogen, causing the gibberellin phytohormone-induced “bakanae disease”. Good levels of fertility have been observed *in vitro* within the *F. fujikuroi* population isolated from infected plants, confirming the possibility of sexual recombination under field conditions as well as an altered mycotoxin producing capability (Picco et al. 2006 Picco, A M, Rodolfi, M, Somma, S and Moretti, A. *Fusarium fujikuroi* and related species from rice plants affected by Bakanae disease in Northern Italy. 12th congress of the Mediterranean phytopathological union. June11–152006, Rhodes Island, Greece. pp.387–388. ; Moretti et al. 2007 Moretti, A, Somma, S, Picco, A M, Rodolfi, M and Ritieni, A. Biological, molecular and toxin characterization of *Fusarium* species isolated from bakanae diseased rice plants. 4th international temperate rice conference. June25–282007, Novara, Italy. pp.164–165.).

From the dawn of civilization, species of the genus *Puccinia* Pers. have caused catastrophic epidemics ofcereal rust resulting sometimes in destruction of entire crops. Among artefacts found at an archaeological site in Israel was a jar over 6000 years old containing wheat infected by *Puccinia graminis* Pers. (Anikster & Wahl 1979 Anikster, Y and Wahl, I. 1979. Coevolution of the rust fungi on Gramineae and Liliaceae and their hosts. *Annu Rev Phytopathol*, 17: 367–403. [CrossRef], [Web of Science ®]). Currently, the agent of black rust of wheat, *Puccinia graminis* f.sp. *tritici* Erikss. & Henning, in Italy in particular and in Europe in general is controlled by use of resistant wheat lines. It is however considered an emerging and invasive pathogen in Burundi, Congo, Ethiopia, Kenya, Ruanda, South Africa and Uganda, where it is present with the new virulent genotype UG99 (Pretorius et al. 2010 Pretorius, Z A, Bender, C M and Visser, B. 2010. First report of a *Puccinia graminis* f. sp. *tritici* race virulent to the *Sr24* and *Sr31* Wheat stem rust resistance genes in South Africa. *Plant Dis*, 94: 784–785. [CrossRef], [Web of Science ®]). In Europe, Italy included, varieties of soft and hard wheat containing the genes Sr31 and Sr38 for resistance against *P. graminis* f.sp. *tritici* are cultivated – varieties that in Africa have been infected by the UG99 race. The population of the pathogen present in Italy is different from this race. Given its high ability to evolve based on its great phenotypic plasticity (Pasquini et al. 2009 Pasquini, M, Nocente, F, Sreni, L, Matere, A, Casini, FIori, A. 2009. Quali grani potrebbero resistere alla ruggine nera in Italia. *Inf Agr*, 18: 54–56.), continuous monitoring of the evolution and virulence of this agent are necessary.

In respect of forest trees, devastating rust epidemics were recorded in Italian pine plantations during the period 1960–1972. The infections by *Melampsora pinitorqua* Rostr. and, particularly, by *Cronartium flaccidum* (Alb. & Schwein.) G. Winter have affected the whole peninsula, Sardinia and Sicily included. These epidemics are correlated with other factors: the huge extent of the pine plantations, the periods with favorable temperature and humidity, the closeness of the intermediate host *Vincetoxicum hirundinaria* Med. to susceptible pines, and the high presence of the pathogen (in the form of uredinia) on *Vincetoxicum* (Ragazzi et al. 2007 Ragazzi, A, Moricca, S and Dellavalle, I. 2007. *Ruggini di piante arboree forestali ed ornamentali*, 199Bologna: Pàtron Editore, Italy.). Detailed attention must also be turned to *Melampsoridium hiratsukanum* S. Ito ex Hirats., cause of frequent outbreaks in Europe (Hantula et al. 2009 Hantula, J, Kurkela, T, Hendry, S and Yamaguchi, T. 2009. Morphological measurements and ITS sequences show that the new alder rust in Europe is conspecific with *Melampsoridium hiratsukanum* in eastern Asia. *Mycologia*, : 622–631. [CrossRef], [PubMed], [Web of Science ®]; Moricca & Maresi 2010 Moricca, S and Maresi, G. 2010. *Melampsoridium hiratsukanum* reported for the first time on grey alder in Italy. *New Dis Reports*, 21: 17[CrossRef]) and a new agent of rust on gray alder (*Alnus incana* (L.) Moench) in Italy, and to *Puccinia horiana* Henn., the agent of white rust on *Chrysanthemum* L., a quarantine pathogen in the USA and included in the A2 list of European Plant Protection Organization (EPPO) in Europe and in Italy.

Some fungal pathogens fitting the "emerging" description, are involved in the disease described as "esca complex" of grapevine (*Vitis vinifera* L.). Currently, in the Mediterranean area, at least three fungi have been implicated in this disease: *Fomitiporia mediterranea* M. Fish., *Phaeomoniella chlamydospora* Crous & W. Gams and *Phaeoacremonium aleophilum* W. Gams, Crous, M.J. Wingf. & Mugnai. During the last few years, the incidence of the disease has increased in all areas where grapevine is cultivated in European countries, Italy included, California and South Africa. The disease also hits two- to three-year-old plants (Mugnai et al. 1999 Mugnai, L, Graniti, A and Surico, G. 1999. Esca (black measles) and brown wood-streaking: Two old and elusive diseases of grapevines. *Plant Dis*, 83: 404–418. [CrossRef], [Web of Science ®], [CSA]; Graniti et al. 2000 Graniti, A, Surico, G and Mugnai, L. 2000. Esca of grapevine: A disease complex or a complex of diseases. *Phytopathol Mediterr*, 39: 16–20. ; Surico 2009 Surico, G. 2009. Towards a redefinition of the disease within the esca complex of grapevine. *Phytopathol Mediterr*, 48: 5–10. [Web of Science ®]). In Apulia, large areas are involved (Ciccarone 2006) and some studies have been carried out on fungi associated with esca-like symptoms. A dozen members of the *Hymenochaetaceae* (*Phellinus* Quél., *Inonotus* P. Karst., *Fomitiporia* Murrill genera) were isolated and appear to be widespread on grapevine (Ciccarone et al. 2004 Ciccarone, C, Graniti, A, Schiaffino, A and Marras, F. 2004. Molecular analysis of *Fomitiporia mediterranea* isolates from esca-affected grapevines in southern Italy. *Phytopathol Mediterr*, 43: 268–272.).

Diversity of fungal endophytes in plants

Plants in natural ecosystems establish symbiotic relationships with fungal endophytes (mainly *Ascomycota* and *Basidiomycota*), and those fungi, for all or part of their life cycle exist as asymptomatic infections (Wilson 1995 Wilson, D. 1995. Endophyte: The evolution of a term and clarification of its use and definition. *Oikos*, 72: 274–276. [CrossRef], [Web of Science ®]). Two main groups of fungal endophytes, clavicipitaceous and non-clavicipitaceous, distributed in functional classes, are generally recognized on the basis of host range, colonization and transmission patterns (vertical/horizontal), tissue specificity and fitness benefits (Rodriguez et al. 2009 Rodriguez, R J, White, J F, Arnold, A E and Redman, R S. 2009. Fungal endophytes: Diversity and functional roles. *New Phytol*, 182: 314–330. [CrossRef], [PubMed], [Web of Science ®]). In Italy, several studies have been made on the fungal endophytic community of both grasses and forest trees.

Picco and Rodolfi (2004) reported a three years microscopic investigation on the incidence of *Neotyphodium* Glenn, C.W. Bacon & Hanlin sp. in 18 ryegrass (*Lolium perenne* L.) ecotypes of northern Italy. A higher frequency (22–48%) of the endophyte was found in grazed pastures where the benefits of the association, exemplified by protection from herbivores and other plant eaters, overcame the cost of maintaining the fungi within the plant. The effect of grazing pressure, the influence of which on plant richness and floristic composition of the pastures has been already assessed (Škornik et al. 2010), seems also to impact on the fungal endophytic community.

Angelini et al. (2011 Angelini, P, Rubini, A, Gigante, D, Pagiotti, R, Reale, L and Venanzoni, R. 2011. "Diversity of fungal endophytes associated with common reed (*Phragmites australis*) from Trasimeno Lake (Perugia, Italy)". FEMS Microbiol Ecol, in press.) evaluated diversity of fungal endophytes associated with leaves and roots of the common reed grass (*Phragmites australis* (Cav.) Trin.) Trasimeno Lake, in central Italy. Endophytes were recovered from 887 (61.59%) of the 1440 samples, with a total of 1541 isolates. *Fusarium* sp. and *Gibberella fujikuroi* (Sawada) Wollenw. were the most frequently isolated fungi. A greater diversity of endophytes was found in roots than in leaves.

Further research has detected endophytic fungi in cultivated plants and, in particular, rice (*Oryza sativa* L.). Investigation of endophytic colonization of rice seeds belonging to 100 Italian cultivated varieties showed the latent presence of some seed-borne pathogens (especially *Fusarium* spp.) and of various toxigenic strains of *Aspergillus flavus* Link (Rodolfi et al. 2006 Rodolfi, M, Picco, A M, Menghini, L, Epifano, F, Musti, A and Cocco, R. Detection and toxigenic evaluation of endophytic strains of *Aspergillus flavus* from Italian rice seeds. 12th congress of the Mediterranean phytopathological union. June11–152006, Rhodes Island, Greece. pp.419–421. ; Rodolfi & Picco 2007 Rodolfi, M and Picco, A M. Fungal endophytes of Italian rice (*Oryza sativa* L.) seeds. 4th international temperate rice conference. June25–282007, Novara, Italy. pp.360–361.).

Research in 2003–2004 in natural areas and urban areas of northern Italy on endophytes inhabiting needles of Norway spruce (*Picea abies* (L.) H. Karst) (Lorenzi et al. 2006 Lorenzi, E, Lorando, E and Picco, A M. 2006. Microfunghi endofitici edepifitici di *Picea abies* (L.) Karst. in ambiente naturale ed antropizzato in Lombardia. *Forest*, 3: 426–436. [CrossRef]) showed differing distributions of endophytic *taxa*, some species being mostly isolated in natural areas, others in urban ones, suggesting the presence of different clusters. *Zythiostroma pinastri* (P. Karst.) Höhn. and *Tiarosporella parca* (Berk. & Broome) H.S. Whitney, J. Reid & Piroz. were the most frequent endophytes in natural areas, while *Sphaeropsis sapinea* (Fr.) Dyko & B. Sutton was more common in urban areas. Biodiversity differs in urban areas but, as concluded by Sabovljević and Sabovljević (2009 Sabovljević, M and Sabovljević, A. 2009. Biodiversity within urban areas: A case study on bryophytes of the city of Cologne (NRW, Germany). *Plant Biosyst*, 143: 473–481. [Taylor & Francis Online], [Web of Science ®]) in the specific case of bryophytes in a European urban area, urbanization does not necessarily means drastic diversity reduction. In 2010, in the context of the project PRIN 2008, monitoring was established in Bagni di Masino (Sondrio province) to investigate whether effects of global climate change on plants could be accompanied by changes in this fungal endophyte community. Preliminary data suggest *Z.pinastri* remains dominant, unlike *T. parka* which is isolated very infrequently.

Much research has been focused on differences in fungal endophytic assemblages of *Quercus* L. spp. in relation to plant health and environmental conditions (Ragazzi et al. 2003 Ragazzi, A, Moricca, S, Capretti, P, Dellavalle, I and Turco, E. 2003. Differences in composition of endophytic mycobiota in twigs and leaves of healthy and declining *Quercus* species in Italy. *Forest Pathol*, 33: 31–38. [CrossRef], [Web of Science ®], [CSA]; Franceschini et al. 2005 Franceschini, A, Linaldeddu, B T and Marras, F. 2005. Occurrence and distribution of fungal endophytes in declining cork oak forests in Sardinia (Italy). *IOBC/wprs Bull*, 28: 67–74. ; Gonthier et al. 2006 Gonthier, P, Germaro, M and Nicolotti, G. 2006. Effects of water stress on the endophytic mycota of *Quercus robur*.. *Fungal Divers*, 21: 69–80. [Web of Science ®]). Results revealed that oak fungal endophyte communities include both mutualistic and pathogenic species. Some endophytic pathogens appear to be reactive to host changes due to adverse environmental factors, suggesting their role in the rapid decline of stressed trees (Gonthier et al. 2006 Gonthier, P, Germaro, M and Nicolotti, G. 2006. Effects of water stress on the endophytic mycota of *Quercus robur*.. *Fungal Divers*, 21: 69–80. [Web of Science ®]; Vannini et al. 2009 Vannini, A, Lucero, G, Anselmi, N and Vettraino, A M. 2009. Response of endophytic *Biscogniauxia mediterranea* to variation in leaf water potential of *Quercus cerris*.. *Forest Pathol*, 39: 8–14. [CrossRef], [Web of Science ®]; Linaldeddu et al. 2011 Linaldeddu, B T, Sirca, C, Spano, D and Franceschini, A. 2011. Variation of endophytic cork oak-associated fungal communities in relation to plant health and water stress. *Forest Pathol*, 41: 193–201. [CrossRef], [Web of Science ®]). Among them, *Biscogniauxia mediterranea* (De Not.) O. Kuntze, *Botryosphaeria corticola* Phillips, Alves et Luque and *B. dothidea* (Moug.) Ces. & De Not. are the most virulent and widespread species. They are able to latently colonize all canopy oak tissues, also causing cankers, dieback and imbalance of some metabolic processes. The area of distribution of *B. mediterranea* is constantly expanding, suggesting invasive behavior. Following a first report from Morocco, it has been identified in Europe in Slovenia on Turkey oak (*Quercus cerris* L.) (Jurc & Ogris 2005 Jurc, D and Ogris, N. 2005. First reported outbreak of charcoal disease caused by *Biscogniauxia mediterranea* on Turkey oak in Slovenia. *Plant Pathol*, 55: 299[Web of Science ®]), France, Spain and Portugal (Luque et al. 2000 Luque, J, Parladé, J and Pera, J. 2000. Pathogenicity of fungi isolated from *Quercus suber* in Catalonia (NE Spain). *Forest Pathol*, 30: 247–263. [CrossRef], [Web of Science ®], [CSA]). Increasing incidence of *B.mediterranea* is favored by plant water stress and high temperatures, and represents a classic example of the effects of the climatic changes on the forest plant pathosystems (subsystem, in the specific one *B.mediterranea*/oak stands, of an ecosystem characterized from parasitism phenomena) and, consequently, on ecosystems. Until 1990, *B. mediterranea* had not been reported in Italy. With an increase in temperature and with the thermal line being moved from the south of the Italian peninsula to regions of the north, its distribution has increased. From the first report in the Lazio region, it has diffused both southwards and, particularly, northwards, affecting oak species at over 1000 m altitude (Ragazzi & Moricca 2011 Ragazzi, A and Moricca, S. 2011. "Il patosistema "endofita/specie arborea forestale" e i cambiamenti climatici". Micologia Italiana, in press.). The cork oak (*Quercus suber* L.) is particularly susceptible, with a lot of damage in Sardinia where it forms part of the Mediterranean maquis (Franceschini et al. 2000 Franceschini, A, Corda, P and Marras, F. 2000. "Fungi involved in oak decline". In *Decline of oak species in Italy, problems and perspectives. Accademia Italiana di Scienze Forestali*, Edited by: Ragazzi, A and Dellavalle, I. 101–113. Firenze: Tipografia Coppini.). The pathogen is occasionally also isolated from other forest trees, including chestnut (*Castanea sativa* Miller), beech (*Fagus sylvatica* L.) and ash (*Fraxinus excelsior* L.) (Ragazzi, pers. com.).

Botryosphaeria corticola A.J.L. Phillips, A. Alves & J.Luque is an endophytic pathogen of the *Botryosphaericeae*, an important fungus family including several pathogenic species present in various ecosystems (Slippers & Wingfield 2007 Slippers, B and Wingfield, M J. 2007. Botryosphaeriaceae species as endophytes and latent pathogens of woody plants: Diversity, ecology and impact. *Fungal Biol Rev*, 21: 90–106. [CrossRef]). In oak woods of Mediterranean countries (Alves et al. 2004 Alves, A, Correia, A, Luque, J and Phillips, A JL. 2004. *Botryosphaeria corticola* sp. nov. on *Quercus* species, with notes and description of *Botryosphaeria stevensii* and its anamorph *Diplodia mutila*. *Mycologia*, 96: 598–613. [CrossRef], [PubMed], [Web of Science ®]; Linaldeddu et al. 2009 Linaldeddu, B T, Hasnaoui, F and Franceschini, A. 2009. First report of *Botryosphaeria corticola* affecting *Quercus afares* and *Q. canariensis* in Tunisia. *J Plant Pathol*, 91: 234[Web of Science ®]) and, more recently, in California (Lynch et al. 2010 Lynch, S C, Eskalen, A, Zambino, P and Scott, T. 2010. First report of bot canker caused by *Diplodia corticola* on coast live oak (*Quercus agrifolia*) in California. *Plant Dis*, 94: 1510[CrossRef], [Web of Science

®]), *B. corticola* has become an emerging pathogen. In this regard, climatic changes occurring in these environments over the past decades have probably played a decisive role.

Diversity of emerging pathogenic and invasive fungi in animals

There is a growing awareness of fungi as potential agents of pandemic and panzootic disease in animals. Disturbance resulting from natural causes or from some activities of humans, such as global transport and changes in agricultural practice, have triggered fungal outbreaks in diverse host populations.

The global emergence of the amphibian chytrid pathogen *Batrachochytrium dendrobatidis* Longcore, Pessier & D.K. Nichols, now recognized as a proximate driver of global decline in amphibian diversity, is one of the most compelling and troubling examples of a panzootic disease. The pathogen infects over 350 species of amphibians and is found on all continents except Antarctica (Fisher et al. 2009 Fisher, M C, Trenton, W, Garner, J and Walker, S F. 2009. Global emergence of *Batrachochytrium dendrobatidis* and amphibian Chytridiomycosis in space, time, and host. *Annu Rev Microbiol*, 63: 291–310. [CrossRef], [PubMed], [Web of Science ®]). However, the processes that have led to the global distribution of *B. dendrobatidis* and the occurrence of chytridiomycosis remain unclear. InEurope, it is known to be broadly, but focally, distributed across the continent (Garner et al. 2006 Garner, T WG, Perkins, M W, Govindarajulu, P, Seglie, D, Walker, SCunningham, A A. 2006. The emerging amphibian pathogen *Batrachochytrium dendrobatidis* globally infect introduced populations of North American bullfrog *Rana catesbeiana*. *Biology Lett*, 2: 455–459. [CrossRef], [PubMed], [Web of Science ®]). In Italy, *B. dendrobatidis*-related declines or mortality events have been recently reported in southern Sardinia for the endangered Sardinian newt (*Euproctus platycephalus*; Bovero et al. 2008 Bovero, S, Sotgiu, G, Angelini, C, Doglio, S, Gazzaniga, ECunningham, A A. 2008. Detection of chytridiomycosis caused by *Batrachochytrium dendrobatidis* in the endangered Sardinian newt (*Euproctus platycephalus*) in Southern Sardinia, Italy. *J Wildlife Dis*, 44: 712–715. [PubMed], [Web of Science ®]) and the painted frog (*Discoglossus sardus* Tschudi); infections have been described in introduced North American bullfrogs (*Rana catesbeiana* Shaw), native Apennine yellow-bellied toads (*Bombina pachypus* Bonaparte), pool frogs (*Rana lessonae* Camerano) and the Italian agile, or Lataste's, frog (*Rana latastei* Boulenger) (Garner et al. 2006 Garner, T WG, Perkins, M W, Govindarajulu, P, Seglie, D, Walker, SCunningham, A A. 2006. The emerging amphibian pathogen *Batrachochytrium dendrobatidis* globally infect introduced populations of North American bullfrog *Rana catesbeiana*. *Biology Lett*, 2: 455–459. [CrossRef], [PubMed], [Web of Science ®]; Simoncelli et al. 2006 Simoncelli, F, Fagotti, A, Dall'Oloi, R, Vagnetti, D, Pascolini, R and DiRosa, I. 2006. Evidence of *Batrachochytrium dendrobatidis* infection in water frogs of the *Rana esculenta* complex in Central Italy. *EcoHealth*, 2: 307–312. [CrossRef]; Bovero et al. 2008 Bovero, S, Sotgiu, G, Angelini, C, Doglio, S, Gazzaniga, ECunningham, A A. 2008. Detection of chytridiomycosis caused by *Batrachochytrium dendrobatidis* in the endangered Sardinian newt (*Euproctus platycephalus*) in Southern Sardinia, Italy. *J Wildlife Dis*, 44: 712–715. [PubMed], [Web of Science ®]).

Another important EID is white-nose syndrome (WNS) affecting hibernating insectivorous bats. Since its first detection in bats near Albany (NewYork, 2006), WNS has been confirmed in 10 additional US states and 2 Canadian provinces and has caused a mortality approaching 100% among some hibernation colonies. The most likely infectious agent of WNS is the newly described psychrophilic fungal species *Geomyces destructans* Blehert & Gargas (Gargas et al. 2009 Gargas, A, Trest, M T, Christensen, M, Volk, T J and Blehert, D S. 2009. *Geomyces destructans* sp. nov.

associated with bat white-nose syndrome. *Mycotaxon*, 108: 147–154. [CrossRef], [Web of Science ®]), however, there is still scepticism regarding the role of this species as the primary pathogen involved in WNS. Its distribution, infection dynamics and effects on hibernating bats inEurope are largely unknown. The problem may expand to a global scale, as *G. destructans* was reported in France in March 2009 (Puechmaille et al. 2010 Puechmaille, S J, Verdeyroux, P, Fuller, H, Gouilh, M A and Bekaert, M. 2010. White-nose syndrome fungus (*Geomyces destructans*) in bat, France. *Emerg Infect Dis*, 16: 290–293. [PubMed], [Web of Science ®]). At the moment, at least eight further countries have confirmed or supposed presence of *G.destructans* in bat populations, but, as reported in France, those bats have remained healthy (Wibbelt et al. 2010 Wibbelt, G, Kurth, A, Hellmann, D, Weishaar, M and Barlow, A. 2010. White nose syndrome fungus (*Geomyces destructans*) in bats, Europe. *Emerg Infect Dis*, 16: 1237–1242. [CrossRef], [PubMed], [Web of Science ®]). However, according to Martìnková et al. (2010), the occurrence of *G. destructans* in Europe is widespread in certain localities and could be associated with skin lesions. There has been only one report about this topic from Italy (Voyron et al. 2011 Voyron, S, Lazzari, A, Ricucci, M, Calvini, M and Varese, G C. 2011. “First mycological investigation on Italian bats”. Hystrix 22: 189–197.) related to the finding during summer 2009 of several dead bats (10% of an estimated population of 500–600 individuals) extensively colonized by fungi in a cave in southern Italy (Palummaro cave, Cosenza province). Twenty bat carcasses belonging to the genera *Myotis* Kaup, *Miniopterus* Bonaparte and *Pipistrellus* Gray were investigated and, among the 14 species isolated from bat carcasses, the most abundant were *Mucor hiemalis* f. *hiemalis* Wehmer, *M. racemosus* Fresen., *Fusarium equiseti* (Corda) Sacc. and, for the first time in Italy, *Trichosporon chiropterorum* Sugita, Takshima & Kikuchi. Further analyses of three healthy live bats showing white fungal growth and two dead bats collected in a cave in Piedmont (unpublished data) showed fungi belonging to the same species or genus as those found on dead bats (Voyron et al. 2011 Voyron, S, Lazzari, A, Ricucci, M, Calvini, M and Varese, G C. 2011. “First mycological investigation on Italian bats”. Hystrix 22: 189–197.). Results show that the high rate of bat mortality observed in the Palummaro cave was not caused by WNS, and neither *G.destructans* nor any other *Geomyces* species were found.

In the case of larger animals, in May 2010, a flock of Italian Merinizzata race sheep in Potenza province was affected by skin lesions and facial eczema diagnosed as pithomycotoxicosis of ruminants (vanWuijckhuise et al. 2006). Mycological analysis confirmed the presence of *Pithomyces chartarum* (Berk. & M.A. Curtis) M.B. Ellis both in faeces and on forage samples, supporting the idea that the fungus, a major constituent of the saprobic mycota in late summer and autumn, can reach levels which render pasture dangerous for grazing in Italy (Agnetti et al. 2010 Agnetti, F, Garaguso, M, Prestera, G, Manuali, E, Rodolfi, MLepri, E. 2010. Isolamento di *Pithomyces chartarum* da ovini con eczema facciale allevati in Italia. *Large Anim Rev*, 16: 54).

Isolation into pure culture of the Oomycete *Aphanomyces astaci* Schikora and its subsequent molecular identification confirmed the presence of Crayfish Plague in Italy (Cammà et al. 2010 Cammà, C, Ferri, N, Zezza, D, Marcacci, M, Paolini, ARicciuti, L. 2010. Confirmation of crayfish plague in Italy: Detection of *Aphanomyces astaci* in white clawed crayfish. *Dis Aquat Organ*, 80: 266–268.). Acquiloni et al. (2011 Acquiloni, L, Marin, M P, Gherardi, F and Diéguez-Uribeondo, J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the Oomycete *Aphanomyces astaci* in Italy. *Biol Invasions*, 13: 359–367. [CrossRef], [Web of Science ®]) demonstrated, using molecular tools, the presence of *A. astaci* also on *Procambarus clarkii* Girard, the most widespread alien crayfish in Italy, thus demonstrating that it is an active carrier of this oomycete in our Country. Further mycological investigations of *P. clarkii* in Pavia using cultural techniques revealed the presence on the alien crayfish of numerous other fungal species, many of which could be responsible for damages to agriculture and man (Dörr et al. 2011 Dörr, A JM, Rodolfi, M, Scalici, M, Elia, A C, Garzoli, L and Picco, A M. 2011. "*Phoma glomerata*, a potential new threat to Italian inland waters". J Nat Conserv. doi:10.1016/j.jnc.2011.06.006.).

Diversity of emerging pathogenic and invasive fungi in humans

Over the past 20 years, fungi have emerged as major causes of human disease. They are favored by new therapeutic methods (antibiotics, corticosteroid, immunosuppressors), new medicosurgical techniques (catheters, monitoring in intensive-care units, open-heart surgery, solid-organ transplantation), the HIV epidemic and international tourism and other mass movement of people. New and emerging fungal pathogens include species of *Candida* Berkhout and *Aspergillus* P. Micheli ex Haller other than *C. albicans* (C.P. Robin) Berkhout and *A. fumigatus* Fresen., opportunistic yeast-like fungi (e.g. *Trichosporon* Behrend and *Rhodotorula* F.C. Harrison species), the Zygomycetes, hyaline moulds (e.g., *Fusarium* and *Scedosporium* Sacc. ex Castell. & Chalm. species) and a wide variety of dematiaceous fungi (Pfaller & Diekema 2004 Pfaller, M A and Diekema, D J. 2004. Rare and emerging opportunistic fungal pathogens: concern for resistance beyond *Candida albicans* and *Aspergillus fumigatus*. *J Clin Microbiol*, 42: 4419–4431. [CrossRef], [PubMed], [Web of Science ®]; Nucci & Marr 2005 Nucci, M and Marr, K A. 2005. Emerging fungal diseases. *Clin Infect Dis*, 41: 521–526. [CrossRef], [PubMed], [Web of Science ®]).

In Italy, the National Society of Medical Mycology (Federazione Italiana di Micopatologia Umana e Animale, FIMUA) has organized region-wide surveillance, using the hospital laboratory network operative in Lombardy, to characterize the epidemiological features of candidaemia and the overall distribution of *Candida* species involved in bloodstream infections. Results appear similar to those recently reported in the USA, Canada and elsewhere in Europe. *Candida albicans* was the most common species recovered (58.5%), followed by *C. parapsilosis* (Ashford) Langeron & Talice (14.6%) and *C.glabrata* (H.W. Anderson) S.A. Mey. & Yarrow (12.8%). (Tortorano et al. 2002 Tortorano, A M, Biraghi, E, Astolfi, A, Ossiz, C, Tejada, MFarina, C. 2002. European Confederation of Medical Mycology (ECMM) prospective survey of candidaemia: Report from one Italian region. *J Hosp Infect*, 51: 297–304. [CrossRef], [PubMed], [Web of Science ®], [CSA]). *Candida parapsilosis* isolation is on the rise worldwide, it is an emerging major human pathogen that has dramatically increased in significance and prevalence over the past two decades. It is now one of the leading causes of invasive candidal disease (Trofa et al. 2008 Trofa, D, Gácser, A and Nosanchuk, J D. 2008. *Candida parapsilosis*, an emerging fungal pathogen. *Clin Microbiol Rev*, 21: 606–625. [CrossRef], [PubMed], [Web of Science ®]), being a facultative human pathogen with an extensive distribution in nature.

Trichosporonosis is an uncommon but frequently fatal mycosis in immunocompromized patients. A multicenter retrospective study has been conducted to characterize cases of proven or probable invasive trichosporonosis diagnosed over the past 20 years inItalian patients with haematological diseases (Girmenia et al. 2005 Girmenia, C, Pagano, L, Martino, B, D'Antonio, D, Fanci, RSpecchia, G. 2005. Invasive infections caused by *Trichosporon* species and *Geotrichum capitatum* in patients with haematological malignancies: A retrospective multicenter study from Italy and review of the literature. *J Clin Microbiol*, 43: 1818–1828. [CrossRef], [PubMed], [Web of Science ®]). Of the 52 cases identified, 17 were classified as *Trichosporon* Behrend spp. infections and 35 were attributed to *Geotrichum capitatum* Diddens & Lodder. This confirms the emergence of *G. capitatum* as a predominantly European pathogen, particularly in certain Mediterranean areas.

Aspergillosis encompasses a broad spectrum of diseases caused by members of the genus *Aspergillus* (Baddley et al. 2001 Baddley, J W, Stroud, T P, Salzman, D and Pappas, P G. 2001.

Invasive mold infections in allogeneic bone marrow transplant recipients. *Clin Infect Dis*, 32: 1319–1324. [CrossRef], [PubMed], [Web of Science ®], [CSA]; Perfect et al. 2001 Perfect, J R, Cox, G M, Lee, J Y, Kauffman, C A, de Repentigny, LChapman, S W. 2001. The impact of culture isolation of *Aspergillus* species: A hospital-based survey of aspergillosis. *Clin Infect Dis*, 33: 1824–1833. [CrossRef], [PubMed], [Web of Science ®], [CSA]). *Aspergillus* species are cosmopolitan and their conidia are ubiquitous in air, soil and decaying matter. Within the hospital environment, *Aspergillus* species may be found in air, showerheads, water storage tanks and potted plants (Anaissie et al. 2002 Anaissie, E J, Stratton, S L, Dignani, M C, Summerbell, R C, Rex, J HMonson, T P. 2002. Pathogenic *Aspergillus* species recovered from a hospital water system: A 3-year prospective study. *Clin Infect Dis*, 34: 780–789. [CrossRef], [PubMed], [Web of Science ®], [CSA]; Lass-Flörl et al. 2000**)**. Since aspergillosis is not considered predictive for AIDS, its incidence in such patients has not been clearly established. A study in Italy between January 1986 and April 1997 (Libanore et al. 2002 Libanore, M, Prini, E, Mazzetti, M, Barchi, E, Raise, EGritti, F M. 2002. Invasive aspergillosis in Italian AIDS patients. *Infection*, 30: 341–345. [CrossRef], [PubMed], [Web of Science ®], [CSA]), highlighted the outcome of invasive aspergillosis in AIDS. Aspergillosis was diagnosed in 54 of the 2614 patients admitted with AIDS (2.1%).

In other superficial mycoses, for instance onychomycosis, it is possible to observe an increase in infections due to fungi commonly present in the environment, but never or rarely involved in human pathology. Onychomycosis, represent about 50% of all nail disorders and 30% (Moreno & Arenas 2010 Moreno, G and Arenas, R. 2010. Other fungi causing onychomycosis. *Clin Dermatol*, 28: 160–163. [CrossRef], [PubMed], [Web of Science ®]) of all superficial skin fungal infections diagnosed (Gupta et al. 2007 Gupta, M, Sharma, L N, Kanga, A K, Mahajan, V K and Tegta, G R. 2007. Onychomycosis: Clinico-mycologic study of 130 patients fromHimachal Pradesh, India. *Indian J Dermatol Ve*, 73: 389–392. [CrossRef]). The fungi involved in this type of mycoses are typically dermatophytes and yeasts. However, during the past few decades onychomycosis have often been caused by opportunistic fungi defined as non-dermatophyte fungi (NDF) and the percentage of these cases is increasing, accounting from 2 to 22% of all onychomycosis (Gupta et al. 2007 Gupta, M, Sharma, L N, Kanga, A K, Mahajan, V K and Tegta, G R. 2007. Onychomycosis: Clinico-mycologic study of 130 patients fromHimachal Pradesh, India. *Indian J Dermatol Ve*, 73: 389–392. [CrossRef]). Among NDF, the most common genera are *Scopulariopsis* Bainier, *Aspergillus*, *Fusarium* and *Acremonium* Link with high variable incidence depending on the environment conditions, the population and the geographic area studied (Moreno & Arenas 2010 Moreno, G and Arenas, R. 2010. Other fungi causing onychomycosis. *Clin Dermatol*, 28: 160–163. [CrossRef], [PubMed], [Web of Science ®]; Aghamirian & Ghiasian 2010 Aghamirian, M R and Ghiasian, S A. 2010. Onychomycosis in Iran: Epidemiology, causative agents and clinical features. *Nippon Ishinkin Gakkai Zasshi*, 51: 23–29. [CrossRef]).

The genus *Aspergillus* seems to have an emerging role as an agent of onychomycosis and a significant number of its species are involved. The most frequently identified species related to nail infections are: *A. niger* Tiegh., *A. flavus*, *A. terreus* Thom, *A.nidulans* (Eidam) G. Winter, *A. fumigatus* and *A.versicolor* (Vuill.) Tirab. (Mügge et al. 2006 Mügge, C, Haustein, U F and Nenoff, P. 2006. Causative agents of onychomycosis – A retrospective study. *J Dtsch Dermatol Ges*, 4: 218–228. [CrossRef], [PubMed]; Aghamirian et al. 2010 Aghamirian, M R and Ghiasian, S A. 2010. Onychomycosis in Iran: Epidemiology, causative agents and clinical features. *Nippon Ishinkin Gakkai Zasshi*, 51: 23–29. [CrossRef]; Veraldi et al. 2010 Veraldi, S, Chiaratti, A and Harak, H. 2010. Onychomycosis caused by *Aspergillus versicolor*. *Mycoses*, 53: 363–365. [PubMed], [Web of Science ®]). Nail infections cases due to *Aspergillus tritici* B.S. Mehrotra & M. Basu, A. *ochraceus* K. Wilh., *A. sclerotiorum* G.A. Huber, *A. sydowii* (Bainier & Sartory) Thom & Church and *A. tamari* Kita have been occasionally observed (Kristensen et al. 2005 Kristensen, L, Stenderup, J and Otkjaer, A. 2005. Onychomycosis due to *Aspergillus tamarii* in a 3-year-old boy.

Acta Derm-Venereol, 85: 261–262. [PubMed], [Web of Science ®]; Takahata et al. 2008 Takahata, Y, Hiruma, M, Sugita, T and Muto, M. 2008. A case of onychomycosis due to *Aspergillus sydowii* diagnosed using DNA sequence analysis. *Mycoses*, 51: 170–173. [CrossRef], [PubMed], [Web of Science ®]). More recently a new species, *Aspergillus persii* A.M. Corte & Zotti (Zotti & Montemartini Corte 2002 Zotti, M and Montemartini Corte, A. 2002. *Aspergillus persii:* A new species in section Circumdati. *Mycotaxon*, 83: 269–279. [Web of Science ®]) was isolated and described at the University of Genoa. As it was observed in different patients (Zotti et al. 2010 Zotti, M, Machetti, M, Perotti, M, Barabino, G and Persi, A. 2010. A new species, *Aspergillus persii*, as an agent of onychomycosis. *Med Mycol*, 48: 656–660. [Taylor & Francis Online], [Web of Science ®]), *A. persii* can be considered a likely fungal pathogen agent of onychomycosis. Another interesting identified species is *A. nomius* Kurtzman, B.W. Horn & Hesselt. (Zotti et al. 2011 Zotti, M, Machetti, M, Persi, A, Barabino, G and Parodi, A. 2011. "Onychomycosis: First case due to *Aspergillus nomius*". Acta Derm-Venereol. doi:10.2340/00015555-1118.) never previously associated with onychomycosis.

The third leading cause of invasive fungal infection following aspergillosis and candidosis is zygomycosis, caused by various members of *Zygomycetes*. A recent study performed in Italy (Pagano et al. 2009 Pagano, L, Valentini, C G, Posteraro, B, Girmenia, C, Ossi, CPan, A. 2009. Zygomycosis in Italy: A survey of FIMUA-ECMM. *J Chemotherapy*, 21: 322–329. [Taylor & Francis Online], [Web of Science ®]) underlined that *Rhizopus* Ehrenb. spp., *Rhizomucor* Lucet & Costantin spp., *Absidia corymbifera* (Cohn) Sacc. & Trotter, *Cunninghamella* Matr. spp. were the most common species in immunocompromized patients and in patients with penetrating trauma.

Finally, the isolation in Italy of *Scedosporium apiospermum* (Sacc.) Sacc. ex Castell. & Chalm. in a case of keratomycosis (Mancini et al. 2005 Mancini, N, Ossi, C M, Perotti, M, Carletti, S, Gianni, CPaganoni, G. 2005. Direct sequencing of *Scedosporium apiospermum* DNA in the diagnosis of a case of keratitis. *J Med Microbiol*, 54: 897–900. [CrossRef], [PubMed], [Web of Science ®]), deserves to be mentioned, since the fungus is an emerging and opportunistic pathogen, especially in organ transplant recipients and in patients with acquired neutropenia.

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