

Nomenclatural considerations in naming species of *Aspergillus* and its teleomorphs

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Abstract: The nomenclature of *Aspergillus* is important in many fields of research and therefore the strategies for stable and efficient naming are important. The conservation of species names as accepted by the *Aspergillus* community is described. Published lists of accepted names provide that people who use *Aspergillus* and *Penicillium* taxonomies need no longer fear the overturning of names currently used. *Aspergillus* is a good example of a genus where the naming of both anamorph and teleomorph has been applied and arguments are given for maintaining the system of dual nomenclature. A protocol for describing new taxa in *Aspergillus* and their teleomorphs is proposed, including the availability of living ex type cultures, deposit of type cultures in at least two recognised culture collections, deposits of sequence data in specialised data bases and registration of the new names in MycoBank.

Key words: accepted *Aspergillus* names, conservation of names, dual nomenclature, protocol for species description.

INTRODUCTION

Aspergillus is one of the most studied fungal genera and has a great impact in many applied areas. The nomenclature of the species has always been an important issue because applied researchers do not like to see changes in species names, in particular for those which are common. Like all other fungi the naming of *Aspergillus* species must follow the Rules of the International Botanical Code. In the past however taxonomists have neglected these rules and for example Raper & Fennell (1965) only used *Aspergillus* names for sexual taxa and refused to use the correct names for the teleomorph.

In recent years, strategies for maintaining a stable *Aspergillus* nomenclature have been in the forefront of *Aspergillus* taxonomy including proposals for the correct anamorph-teleomorph nomenclature, for subgeneric taxa and for a list of accepted names. In the following paper the conservation of species names and dual nomenclature are discussed. Furthermore a proposal for recommended procedure for the description of new species is set out.

Conservation of species names

For a long time, the International Code of Botanical Nomenclature (ICBN) has had provisions for the conservation of names. Conservation is a process that enables the use of a name – or more usually the continued use of a name – for a particular taxon that for one reason or another is not the name having priority, i.e. is not the earliest validly published name. Under the ICBN, it is mandatory to use the earliest valid name for any taxon. The purpose behind, and justification for, conservation is almost always to permit the continued use of a popular or important name, and thus to promote taxonomic stability. Examples of conservation include that of the yeast genus *Candida* Berkhout 1923, which includes

the important pathogenic species *C. albicans*, against the older, validly published genus *Syringospora* Quinquaud 1868 and three others. Conservation avoided the need to transfer *C. albicans* to an essentially unknown genus, with consequent confusion among users of taxonomy. Many other examples exist of well known fungal genera that have been conserved, including *Alternaria*, *Drechslera*, *Mucor* and *Rhizopus*.

For a long time, the provisions for conservation in the ICBN extended only down to genus level. Until recently, it was not possible to conserve species names. When Pitt (1979) revised the taxonomy of *Penicillium*, the generic name was not in dispute, but a number of species names were. It became clear that some of the species names used by Thom (1930) and Raper and Thom (1949) were predated by earlier valid names. Examples are *P. cyclopium* Westling 1911 which is predated by *P. aurantiogriseum* Dierckx 1901, and *P. nigricans* Bainier 1930 (published by Thom 1930) by *P. janczewskii* K.M. Zalesky 1927. Nothing could be done about those situations, and the earlier valid names were taken up. However, the calamitous loss of *P. chrysogenum* Thom 1907, clearly predated by *P. griseoroseum* Dierckx 1901, was avoided by placing the two species in separate subgenera (Pitt 1979).

In due course the International Botanical Congress agreed to permit conservation of species names of “major economic importance” (the Berlin Code, Greuter *et al.* 1988). The problem of keeping the name *P. chrysogenum* was then able to be solved by conserving it (Kozakiewicz *et al.* 1992). The next meeting of the International Botanical Congress (the Tokyo Code, Greuter *et al.* 1994) made possible the conservation of any species name.

Conservation is a slow and often tedious process. It requires careful documentation of the problem, and establishment of the reasons for conservation. Any proposal must be approved by the Special Committee on Fungi and Lichens of the ICBN before ratification by a full Botanical Congress, a body that meets only every six years. Approval by the Special Committee is by no means automatic. A proposal for the conservation of the commonly used

name *Aspergillus nidulans* – not a valid name for reasons that do not concern us here – was not approved in 1992.

The advent of molecular taxonomy enormously increased the importance of conservation of species names. Old herbarium specimens, unrecognisable by traditional techniques, can nevertheless often be recognised by DNA analysis. The case of species in *Aspergillus* is particularly serious. European herbaria contain many old *Aspergillus* specimens. These are long dead, so that cultural methods cannot be used to obtain a recognisable species, but they may still contain DNA of analysable quality. It can be safely stated that many of the names in use in *Aspergillus* are predated by names validly applied to specimens and recognisable by molecular techniques.

A solution to this type of problem by the validation of commonly used names was proposed by US botanists many years ago, but it was not acceptable to the wider botanical community. Dr Morten Lange, a distinguished Danish mycologist, took up this idea at the International Botanical Congress in Montreal, in 1959, but again without acceptance (D.L. Hawksworth, pers. comm.). In 1988, Dr David Hawksworth, then at the International Mycological Institute, Kew, Surrey, U.K., organised a meeting there to again put forward this proposal (Hawksworth 1988). This led to a Symposium at the Royal Botanical Gardens, Kew that he organised, covering all groups of organisms and several publications (Hawksworth 1991a, 1991b, 1992, 1993). In these works, he and others proposed that lists of “Names in Current Use” (NCU) be established. These would be developed by appropriate experts, circulated widely to obtain general agreement and then sanctioned by a Botanical Congress. Names in an NCU would in a sense be cast in stone – they should not be subject to nomenclatural challenge from earlier names, if earlier valid names were subsequently located. At the same time, taxonomy would not be affected – names in an NCU could be split or combined by taxonomic decisions, but could not be overturned by nomenclatural findings. This was a brilliant concept, as at a stroke it would provide taxonomic stability to species in genera such as *Aspergillus*, *Penicillium* and their teleomorphs.

At Dr Hawksworth's request, we prepared an NCU list of all the names in the fungal family *Trichocomaceae*, including of course *Aspergillus* and *Penicillium*. That list was published (Pitt & Samson 1993) and presented to the Tokyo Botanical Congress in 1993, along with the overarching concept of Names in Current Use. Unfortunately, the concept failed to gain Congress approval, and the whole idea has gone into abeyance, though it has not been abandoned. However, as reported in the Preface to the Tokyo Code (Greuter *et al.* 1994), the Nomenclature Section of that Congress “was particularly impressed by the utility of the list of species names in *Trichocomaceae*” and so “urges taxonomists not to adopt names that would compete with or change the application of any names on that list.”

This concept appears to have met with general approval among the specialist taxonomists who work with *Aspergillus*, *Penicillium* and related genera in *Trichocomaceae*, and has provided the stability which has long been sought. People who use *Aspergillus* and *Penicillium* taxonomies need no longer fear the overturning of names currently used.

The conflict between dual nomenclature and “one name, one fungus”

The concept of “dual nomenclature”, which simply means the use of more than one name for a single taxon, was established in the

International Code of Botanical Nomenclature (ICBN) in 1910, to accommodate the problem of naming fungi that exhibit pleomorphic life cycles (Cline 2005). Article 59 of the ICBN governs the naming of these fungi. The Article has implication for many common fungi that are holomorphic, i.e. that produce both a teleomorph and an anamorph. Dual nomenclature has permitted the use, for any taxon, of either the teleomorph or the anamorph name as appropriate.

Aspergillus is a good example of a genus where dual nomenclature has been applied. Five of the six subgenera in *Aspergillus* include one or more species that produce a teleomorph, and many more that do not. Teleomorph – anamorph relations in *Aspergillus* are complex, because *Aspergillus* is associated with eight teleomorph genera. Molecular evidence to date indicates that these are all phylogenetically related (Peterson 2000). However, the major teleomorph genera with *Aspergillus* anamorphs are quite distinct from each other, with large differences in both morphology and physiology. *Eurotium* species are xerophiles, and cause spoilage of essentially any low water activity (dry or concentrated) material. Ascospores are only produced on media with increased sugar concentrations. *Neosartorya* species are thermophiles, and are not xerophilic, inhabiting decaying vegetation. Ascospores are readily produced and have exceptional heat resistance, causing spoilage of pasteurised products. *Emmericella* species are neither xerophiles nor thermophiles, and are soil inhabiting fungi seldom found elsewhere.

Neosartorya species are classified in section *Fumigati*, and related to *Aspergillus fumigatus*, a species of great importance in medical mycology. Species related to *Emmericella* are classified in section *Nidulantes*, and this section includes a number of species which consistently produce teleomorphs. However, in both of these *Aspergillus* sections, a larger number of species never make ascospores, or any body that resembles an ascocarp.

One teleomorph genus, *Petromyces*, classified in section *Flavi*, includes only one or two species that have ever been shown to produce ascospores, and production has been observed only rarely. However, many species in section *Flavi* are clearly related both morphologically and molecularly to *Petromyces* (Peterson 2000). For example, *Aspergillus flavus* commonly produces black sclerotia analogous to, and undoubtedly related to, the ascocata of *Petromyces*, but none of the many thousands of isolates examined around the world has ever been recorded to produce ascospores.

So throughout *Aspergillus* there are some species that produce teleomorphs and these are clearly related to many species where teleomorphs are unknown. Dual nomenclature has provided a simple means for distinguishing those that make ascospores from those that do not, and that has been of great practical importance.

A similar situation exists with *Penicillium*. Some species classified in *Eupenicillium* include naturally occurring isolates that may (a) produce both the teleomorph and the anamorph; (b) produce sclerotial bodies (like *A. flavus*) that have never been known to differentiate into ascospores; and (c) make only the anamorph, with no hint of a teleomorph connection. A classic example is the species *Eupenicillium cinnamopurpureum*. Isolates are encountered that belong to each of these three categories, and where only the anamorph is produced the fungus is correctly known as *Penicillium phoeniceum*, the earliest valid name for the anamorph (Pitt 1979). Other similar examples of the presence or absence of the teleomorph and/or sclerotial state are *E. hirayamae* and *E. pinetorum*. It appears that evolution in both *Aspergillus* and *Penicillium* is towards production of the anamorph alone, but of course the speed of this evolution is unknown.

The system of dual nomenclature has worked well, and has been of particular importance in food mycology. Because the presence of

a teleomorph tells so much about physiology, spoilage capabilities and potential for mycotoxin production, food mycologists have used the teleomorph names for species known to produce teleomorphs for more than 20 years. Species where teleomorphs are not known, and that includes the great majority of *Aspergillus* species, as well as species in many other important genera including *Penicillium*, *Fusarium*, *Paecilomyces* and *Alternaria*, are called by their anamorph names. This has proved to be a sensible and practical approach to taxonomy, where the name used provides the maximum amount of basic knowledge about a species. If a species is reported as a *Eurotium*, people in the food industry know immediately they are dealing with a xerophilic organism, if as a *Neosartorya* or a *Byssosclamyces*, the spoilage problem they confront will be due to heat resistant ascospores.

A proposal to abandon dual nomenclature – termed “one name one fungus” – has a great deal of appeal to the theoretical mycologist. Why should a fungus have more than one name when genetic studies will often determine that it is a single species based on DNA analysis? This topic has been debated at length elsewhere (Gams *et al.* 2003; Hawksworth 2004; Rossman & Samuels 2005; Gams 2005). It is pertinent here because *Aspergillus* happens to be one of the hardest genera to see a way forward. One group of scientists says “The teleomorph name has precedence in the ICBN, so all species should be named according to the teleomorph with which molecular science indicates they are associated”. That approach is simplistic. First, it is not clear to what teleomorph genus some anamorph species may be associated. This is not a serious problem in *Aspergillus* but becomes very complex with species of *Trichoderma* or *Paecilomyces*. Second, many industrial users of taxonomies are now well familiar with the fact that a teleomorph name on a fungus means ascospores: use of teleomorph names for species without ascospores can only cause loss of information. Third, that approach requires hundreds and perhaps thousands of name changes. It is most unlikely that practical users of taxonomies would ever accept those new names, and confusion would result.

An alternative is to apply the well known anamorph names, like *Aspergillus* and *Penicillium*, to both teleomorph and anamorph species. Again, this is a retrograde step, as applying anamorph names to *Eurotium* or *Neosartorya* species also results in loss of information. Ascosporic *Aspergillus* species are known to have special properties in many cases, and users rely on teleomorph names to alert them to those properties. Moreover, the number of name changes needed, and the resistance to those new names, would lead to confusion once more.

This very difficult nomenclatural problem will only be resolved when a practical compromise is reached. The most obvious and sensible one is to follow the lead given by the food mycologists. Teleomorph names should be used where these are known, and anamorph names for those species that have no teleomorph. Food and industrial mycologists – probably the most numerous users of dual nomenclature – have been applying this principle for the past 20 years, with a notable improvement in understanding and communication with users Pitt & Hocking, 1997, Samson *et al.* 2004). This system is totally consistent with that of the ICBN system, that also provides precedence to teleomorphs when they exist.

There is one further important point. If this particular approach to “one name, one fungus” was put into practice, dual nomenclature could be laid to rest, for it is only occasionally that *any particular species* has more than one name in common use for it. As noted above, *E. cinnamopurpureum*, *E. hirayamae* and *E. pinetorum* are examples of that. However, the loss of information from using a single name for these species would be a small price to pay.

Proposal for describing new taxa in *Aspergillus* and their teleomorphs

The taxonomy of *Aspergillus* has evolved from a simple morphological species concept in which morphological characters of the conidiophores and conidia together with colony colours and patterns were used, into a polyphasic approach with strong molecular and biochemical characters. This means that the traditional rules following the Botanical Code are insufficient. For the comparison with newly proposed species dried herbarium specimens of holotypes or iconotypes are not suitable anymore.

The following procedure is proposed:

- For species descriptions, a polyphasic approach is preferred including morphological, physiological, molecular and/or ecological data
- Type cultures of new *Aspergillus* and teleomorph species should be deposited in at least two international recognised culture collections
- Type cultures should be available directly after the description has been published. If type cultures are not available for the scientific community within six months after the description the species will be considered invalid
- Latin descriptions can be short indicating differences with related taxa
- Good morphological and physiological descriptions are essential
- Media used for the description should be Malt and Czapek based and exact formulations indicated
- The new species name should be registered at MycoBank (see www.Mycobank.org)
- Sequence data should be deposited in recognised genetic databases

The following procedure was extensively discussed at the International workshop “*Aspergillus* systematics in the genomics era” (Utrecht, 12–14 April 2007) and agreed upon with general consensus (Samson *et al.* 2007).

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