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Classification and Generic Keys

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For many people, the word 'fungus' suggests the fructifications of various forms and colours found chiefly in the autumn in the forests and nearby areas. These are the carpophores, essentially of Basidiomycetes (e.g., *Amanita*, boletus, chanterelle) and sometimes of Ascomycetes (e.g., morels, truffles).

Apart from these commonly seen forms, there are many other fungi that are often microscopic.

The Deuteromycetes are among these and represent the phase of asexual multiplication (anamorph) of the higher fungi (mostly Ascomycetes, and to a lesser extent Basidiomycetes).

They represent the second group of fungi in numerical significance (around 2400 genera and 20,000 species) after the Ascomycetes.

Whether one studies the fungal flora of the air, litter, soil, or any other substrate (faeces, diseased plants), it is these, primarily, that are observed, *in situ* or isolated on nutritive media.

From this omnipresence arises also their **economic importance**. We can cite, for example, the case of the genus *Acremonium*, of which certain species live in the stems of Gramineae as endophytes toxinogenic to cattle. These toxicoses lead to losses (lower production of meat and milk, even abortion) estimated at 760 million dollars a year in the United States.

The work we present here is based on the modern classification of this group. Barring some tropical examples, it covers essentially genera found in the temperate zone of the Northern hemisphere, and we hope it will help English-reading users to identify them.

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FOREWORD

The world of fungi, which includes moulds and yeasts, is vast. Some 76,000 species are known, but it is estimated to comprise 1,500,000 species.

This world is understood, by the nature of its characters, to be a living world apart, a kingdom apart among the living kingdoms, a kingdom that is not plant or animal, but fungal. One of the important characters that distinguishes fungi from plants is the composition of their cell walls, made for the most part of chitin, of a type similar to that of Arthropoda. Being heterotrophic, like animals, the fungi have, like animals, four modes of life: parasitism on other living beings (animals, plants, fungi, or protists), symbiosis with plants and animals, association with other living beings that can become predatory, and saprophytism, or life that is dependent on the degradation of dead organic matter.

Our knowledge of fungal diversity is based on observation, taxonomy, nomenclature, classification, and identification.

Taxonomy is the characterization and distinction of taxa (species) based on the observation of precise characters. It is the recognition of individuals that resemble each other to the point of forming a homogeneous group having certain common characters and differing from other groups of individuals on the basis of other characters. One individual is chosen in this homogeneous group (taxon) as a specimen of reference, the type. A proper name is given to this type individual representing the taxon and constitutes an essential part of the name of the species.

Classification is the placing of species in a hierarchical system of morphological and biological resemblance. The species is classed in a genus and is given the name of the genus. The species name along with the genus name forms the binomial, the name that designates the species.

Nomenclature regulates the constitution of names, their validity, their legitimacy, and their priority or synonymy, and maintains a single correct name for each taxon.

Identification is the decision to consider an individual as belonging to a known taxon and attributing to it the name of this taxon. If no identification can be made, the specimen can represent a taxon not yet described, a new species.

Taxonomy, classification, nomenclature, and identification therefore depend on the observation of the characters of individuals. These characters are morphological and biological. According to Linnaeus, the classification of plants is based on the morphology of their organs of sexual reproduction.

Among the fungi, as among other cryptogams, sexual reproduction was long unknown and is still unknown in a good number. The taxonomy and classification are therefore based, in a Linnaean system, on all other forms of reproduction. The great diversity of forms and reproductive organs in the fungi thus form the origin of the distinction of a large number of species. After the first discoveries of sexuality in the fungi around the 1860s, the forms of reproduction could be recognized as asexual or sexual. The asexual species were grouped by Fuckel in 1869 in the category of *Fungi Imperfecti*, imperfect fungi (*unvollständiger Pilze*) and the sexual species in the Fungi Perfecti, perfect fungi (*vollkommene Pilze*). Saccardo picked up the name *Fungi Imperfecti* around 1879 and modified it to '*Imperfectae* Fuckel' or *Fungi Inferiores*. In 1899, Saccardo introduced the denomination *Deuteromycetae*, for the *Fungi secondarii vel inferiores* (deuteros = secondary), otherwise called the *Fungi Imperfecti*.

Apart from the Deuteromycetes, Saccardo classed the fungi without any known mode of reproduction other than surviving mycelial organs in a category that he called *Mycelia sterilia* in 1881. This group was later called Agonomycetales and considered part of the Deuteromycetes.

The brothers Louis-René and Charles Tulasne in 1851 to 1865 and Anton de Bary in 1866 to 1884 demonstrated that the two types of reproduction, sexual and asexual, could coexist, simultaneously or successively, in many fungi. It was then realized that the names of asexual species were only names given to the secondary forms of reproduction (imperfect forms) belonging to the fungi otherwise given a name typified by sexual reproduction (perfect form). There arose thus two parallel nomenclatures for the fungi that were simultaneously sexual and asexual and the fungi that were sexual or asexual.

This double nomenclature was accepted by the International Code of Botanical Nomenclature around 1906, as a tolerated exception to its principle of 'one and only one name for an organism'. The tolerance was motivated by two reasons. One was the necessity of classifying in a coherent manner all the fungi known only in the asexual form (*Fungi Imperfecti*), which cannot be classified among the higher fungi (called *Perfecti*), and, in order to help in their diagnosis, of classifying them together with the asexual forms already named among the higher fungi. The other reason, which is practical, was to ensure a classification enabling the identification of any fungus, perfect or imperfect, that presents, at the moment of its observation, only an asexual reproduction. This

tolerance of a double nomenclature is currently regulated by article 59 of the Code of Botanical Nomenclature.

In order to avoid this anthropomorphism of designating certain fungi as imperfect because they do not manifest sexuality in their spore production or, to be honest, because they are imperfectly known, the terms 'anamorph', 'holomorph', and 'teleomorph' were introduced in 1977. Anamorph to designate the secondary form (*ana* = near) of a fungus denominated Deuteromycete for its asexual or imperfect reproduction; teleomorph for the form of sexual reproduction of the same fungus; and holomorph to designate the fungus denominated Ascomycete or Basidiomycete in its entirety. As early as 1863, the Tulasne brothers distinguished different names given to the same fungus in names designating 'the imperfect fungus, conidial' on the one hand, those designating 'the perfect fungus, ascophore' on the other, and the name of the 'entire fungus'.

Since then, more and more species of Ascomycetes and Deuteromycetes have been recognized as being organically related and thus constituting a single species (holomorphic) in place of two or three, and therefore having only one name. These organic connections of forms of reproduction are now reinforced with genomic identity of the teleomorph and of a corresponding anamorph or anamorphs.

Also, the current trend is to analyse the technical possibilities of integrating the two parallel fungal taxonomies, those of sexual fungi (Ascomycetes and Basidiomycetes) and those of asexual fungi and the anamorphic forms of sexual fungi (Deuteromycetes), into a single taxonomy and a single nomenclature.

Nevertheless, this prospect of integration does not detract from the intrinsic and practical value of the taxonomy of Deuteromycetes based on a characterization of asexual forms of reproduction. On the contrary, whether or not this taxonomic and nomenclatural integration is achieved, the characterization of asexual forms and the contribution of taxonomic criteria of Deuteromycetes will be useful for taxonomy and the classification of sexual forms of Ascomycetes and Basidiomycetes.

It is also important to develop works such as these, which, from a viewpoint that is more extensive and deeper than possible in the morphological characterization of forms of asexual reproduction of fungi, can contribute to the taxonomy even of higher fungi.

The Deuteromycetes comprise 1700 genera of Hyphomycetes and 700 genera of Coelomycetes that cover some 20,000 known species. Their identification, traditionally done by means of characters drawn from the morphology of fruit bodies and conidia, is much refined by the observation of modes of conidiogenesis.

The morphological characters of fruit bodies and conidia have been used for ages and were well exploited by Saccardo. But they are not enough. As early as 1910, Vuillemin sought to refine the taxonomy of

Saccardo by the observation and characterization of conidiogenesis, in which he recognized several modes. In 1953, Hughes described, in a coherent system of classification of Hyphomycetes, eight generic modes of conidiogenesis, some with several modalities. Tubaki, in 1958, added a ninth mode. Since then, as intermediate modes of conidiogenesis have been discovered, this system of characterization remains of major importance. It was used by Sutton for the Coelomycetes and by Samson for the yeasts (Blastomycetes).

As has been shown by recent authors, the system can be refined further. This necessitates a detailed study of successive events that make up conidiogenesis and the establishment of an appropriate terminology for the description of each of these particular and united events. But that is the domain of research.

This work, which integrates the progress of research, is a tool for the identification of the diverse world of microfungi. It is also an excellent technical manual that proposes a unified taxonomic system of the Deuteromycete group, integrating Hyphomycetes and Coelomycetes, and based on the morphology of the conidial apparatus and of conidiogenesis with a view to their generic identification. This system also reflects the personal views of the authors on the phenomena of conidiogenesis and thereby has some originality in comparison with the interpretations of other authors.

The conidiogenetic system proposed also has certain peculiarities. It distinguishes the two basic modes of conidiogenesis, the blastic and the arthric, and recognizes an intermediate mode presently denominated 'arthroblastic' as 'meristem arthrospores'. By this the authors extend the concept of the meristem arthrospore mode of Hughes, producing a progressive basipetal chain of arthroblastic conidia, to a retrogressive conidiogenesis from a preformed conidiogenous hypha. It is true in fact that in retrogressive conidiogenesis, a certain progressive growth is observed on account of the swelling of the future conidium.

Another peculiarity is the grouping of the blastosporous fungi producing blastic conidia in acropetal chains under the denomination of Acroblastoporae (Blastosporae *sensu stricto*), as did Hughes, without distinguishing those that produce several, ramified chains by a sympodial process from those that produce a single and non-ramified chain.

Finally, another characteristic of the system is the distinction between Annellosporae and Annelloblastosporae (holoblastic) and Annellidae (enteroblastic), the former producing a succession of holoblastic conidia on a conidiogenous cell each time renewed by percurrent proliferation, and the latter producing enteroblastic conidia by renewal of the single tip of the same conidiogenous cell. It is true, according to the classified genera, and even in the authors' opinion, that it seems difficult in certain cases to distinguish something that is here named an annellophore from

an annellide on the one hand and to recognize the conidiogenesis by percurrence when the conidia remain attached by a lateral fragment of the wall of the mother cell, giving it the appearance of a sympodula. The light microscope in fact does not always enable us to elucidate the mysterious plasticity of conidiogenesis. But this difficulty does not diminish the authors' attempt to present a refined system.

The value of this work lies also in the integration of all the asexual fungi in a conidiogenetic system without giving a discriminatory priority to the organization of fruit body that separates the classic groups of Hyphomycetes and Coelomycetes. The system proposed puts on a second plane the organization of conidiophore hyphae in fruit bodies. The authors present various conidial apparatuses from the most simple (hyphal) to the most complex (conidiomal) in a quasi-continuous series from the micronematous conidiophore, to the macronematous conidiophore, the coremium, the sporodochium, the acervulus, the cupule, the thyriopycnidium, the pseudopycnidium, and the pycnidium. Such an option no longer really justifies the distinction of the taxonomic groups Hyphomycetes and Coelomycetes, more so because in particular conditions, in culture for example, the complexity of the fruit body may be simplified.

The recognition of the complex phenomena of conidiogenesis is certainly a great step towards a more natural classification of these secondary forms of reproduction. It is only by the presentation of increasingly extensive classification systems, such as that presented in this work, that we can progress towards a natural phylogeny of these forms of fungi and their relation to sexual fungi.

Finally, the great appeal of this work lies in the production of keys and simple diagrams for the identification of a great many genera. The authors have achieved their objective of presenting a practical and accessible tool of identification.

This work, because it is so abundantly illustrated, cannot but stimulate and encourage more minute observations and their precise representation by its design as much as, if not more than, the text. The Swede Elias Fries said as early as 1849 that 'it is greatly desirable that illustrators (of fungi) clearly demonstrate to our eyes the metamorphoses of all genera of fungi, since words cannot explain everything.' And Louis-René and Charles Tulasne, whose illustrations of these fungal metamorphoses are of an extraordinary quality, wrote in 1861 at the end of their work: 'No doubt, in order to study the hidden marvels of these fungi, one must devote a great deal of labour and patience, but in gazing upon them when one discovers them, how much greater is the joy!'

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IMPACT AND DISTRIBUTION OF DEUTEROMYCETES

Practical role of Deuteromycetes

Biodegradation

In the natural environment, Deuteromycetes contribute, along with other organisms, to the biodegradation and recycling of organic matter (e.g., litter, wood). They are of various kinds:

- Cellulolytic (*Malbranchea, Stephanosporium, Oidiodendron, Chrysosporium...*)
- Lignolytic (*Arthrographis, Ptychogaster...*)
- Ligninolytic (*Geniculosporium, Spiniger, Sporotrichum pulverulentum...*)

The Deuteromycetes are a fascinating part of the succession of groups of organisms that cause degradation. They also play a role in the treatment of certain raw material, waste treatment, and the breaking down of pesticides.

Food and industry

Certain Deuteromycetes are important in nutrition and in industrial production.

- Some species of *Penicillium* are used in cheese production (*P. camembertii, P. roquefortii*). *Botrytis cinerea* is the 'noble rot' which leads to the production of sweet wines.
- *Aureobasidium pullulans*, present in the merrains of oak seasoned in the open air, improves the gustative qualities of wine in new barrels.

• Some species of *Aspergillus* and *Penicillium* produce organic acids (citric, gluconic) and pigments. Certain pigments are also produced by some species of *Helminthosporium* and *Fusarium*. Fungal biomass is produced from *Penicillium chrysogenum* to be used as fertilizer (Biosol), or as cattle feed. This same fungus is one component of Biosorbant M, which enables the extraction of uranium and radium from atomic industrial waste water.

Biomedicine

In the field of biomedicine, Deuteromycetes are among the producers of **antibiotics**, of which the penicillins (antibacterial agents produced by *Penicillium chrysogenum*) are among the best known examples. Among the antifungals, the best known is the griseofulvin, produced by *Penicillium griseofulvum*. Several antitumorals and antivirals of fungal origin are always under investigation.

Among the **immunoregulators**, one can cite the cyclosporines produced by various Hyphales, of which cyclosporine A is the most often used on account of its powerful immunosuppressant activity.

Forty per cent of the **enzymes** produced industrially are of fungal origin, most of them from Deuteromycetes, and they represent an economically very significant market.

Biocontrol

Since the success of **entomopathogens** (e.g., *Beauveria bassiana*), the industrial production of bio-insecticides is in full swing. Genera such as *Arthrobotrys, Dactylella, Dactylaria* and *Monacrosporium* are **predators** used against pathogenic nematodes. Among the numerous **mycoparasite** genera or fungal antagonists, some are used in biocontrol (*Trichoderma viride* and *Verticillium biguttatum* against *Rhizoctonia* in soil; *Scytalidium* against *Phellinus weirii*, which causes rot of telephone poles, in the USA; and *Sporothrix* against *Oidium* of hothouse cucumber or against fungi that cause wood to turn blue). We can also cite the sophisticated method of biocontrol of canker in chestnut trees by application of hypovirulent colonies of *Endothiella*.

Fusarium oxysporum ssp. *cannabis* is used as a **bioherbicide** for suppressing marijuana plants. In a more general way, *Colletotrichum gloeosporioides* and *C. truncatum* are also used as bioherbicides.

Harmful effects of Deuteromycetes

Medicine and veterinary medicine

In the field of medicine and veterinary medicine, Deuteromycetes are significant because of immunodepression in cases of transplants. The defence mechanisms of the organism are considerably diminished, and various microorganisms that are normally harmless become pathogenic.

— **Profound mycoses:** pulmonary aspergillosis (*Aspergillus*), lymphatic sporotrichosis (*Sporothrix schenckii*), equine lymphatic histoplasmosis (*Histoplasma*).

— **'Superficial' mycoses:** onychomycosis (*Scytalidium, Graphium*), chromomycosis (*Phialophora), ringworm (dermatophyte), fusariosis in crayfish (Fusarium*).

— **Allergies:** pulmonary, epidermal. Among a group of 15 fungi presently tested in this field, 11 are Deuteromycetes. They are all the more noxious as their conidia are carried, in houses, by animals such as the acarid *Tyrophagus putrescentiae*. Occupational pulmonary diseases: cheese industry (*Penicillium roquefortii*), breweries (*Aspergillus clavatus*), mushroom farms (*Doratomyces*). Skin allergies of cane harvesters of Provence (*Arthrinium*). Respiratory allergy in public parks in certain years (*Cryptostroma corticale*).

— **Fungal toxins:** these are numerous and induce various sicknesses in humans and animals. The best known are aflatoxins (produced by various species of *Aspergillus* and *Penicillium*), some of which are powerfully carcinogenic.

Phytopathology

In the field of phytopathology, Deuteromycetes cause a very large number of plant diseases that manifest themselves in various symptoms:

— **Tissue necroses**, limited or extensive, on leaves, flowers, fruits, stems, and roots (apple scab from *Spilocaea pomi*; anthracnose of plane tree from *Discula nervisequa*; peach shot hole from *Stigmina carpophylla*; canker of chestnut tree from *Endothiella* sp.; seedling wilt from *Fusarium* spp.; black spot of rose from *Marssonina rosae*; blossom blight of cherry tree from *Monilia laxa*; green and blue mould of citrus fruits from *Penicillium digitatum* and *italicum*; black rot of roots of numerous plants from *Chalara elegans*; needle cast of pines from *Lophodermium seditiosum*; silver scurf of potato from *Helminthosporium solani*).

— **Vascular wilting** (dutch elm disease from *Graphium ulmi*; verticilliosis of numerous herbaceous and woody plants from *Verticillium albo-atrum* and *V. dahliae*).

Alterations

Practically all foods and organic matter can be altered to the point of toxicity by Deuteromycetes. But their ravages extend to non-organic matter as well: for example, glass is damaged by *Penicillium citrinum*, metals such as aluminium and steel by *Aspergillus* and *Trichoderma*, and paints by *Phoma violacea*.

HOW TO USE THIS BOOK

You know little or nothing about the Deuteromycetes, or you wish to update your knowledge about this group.

- Definitely read chapter I, essentially from pp. 1 to 24. The basic concepts and terminology are explained in these pages (and the terms can be found again in the glossary).

You know the group, but you have under the microscope a member of the group in which you do not know the mode of conidiogenesis.

- The essential point is to determine how the fungus produces its conidia (conidiogenesis). Chapter I will help you, pp. 24–35, Figs. I.16 to I.30 and Table I.H.

You know the mode of conidiogenesis, or chapter I serves to clarify it.

- Refer to the corresponding chapter (which will enable you to confirm the character), then use the identification keys and the tables to arrive at the identification of the organism.

You do not know the meaning of a term.

- Consult the glossary, which often indicates as well where one can find an illustration of the term in the body of the work.

You wish to know what a given genus looks like, and/or you seek some information about it.

- The alphabetic index of taxa will lead you to the illustration of the genus. Brief information about it can be found here (number of species, geographic location, mode of life and substrate; then, if need be, the name of the teleomorph, recent bibliography in short form, existence of molecular study).

After finding information concerning a genus, you look up a bibliographic reference in short form that is difficult to understand.

- Look up the list of abbreviations used in the additional references.

Note

The **references to tables** within the keys to identification do not repeat the Roman numeral of the chapter, e.g., **C2, C4** (except in chapters containing a single table). It is only when we refer to a table outside the chapter that we specify the chapter number (e.g., VII A 12).

In the **body of the work**, we use the terms 'conidia' and 'spores' interchangeably when we speak of the mitotic conidia, which are asexual spores, of Deuteromycetes.

Similarly, some **abbreviations** of current usage are used here: SEM (scanning electron microscope), TEM (transmission electron microscope), LM (light microscope).

Regarding the **legends** accompanying the tables illustrating the genera, we have combined a certain number of data available at the time of publication of this work:

— in particular, the additional references mention selective studies that are not found in the general bibliography;

— in the column 'teleomorphs' the indicated sexual stage(s) are noted for at least one of the species of the anamorph genus (which does not imply that all the species of the latter are linked to this teleomorph genus or genera).

— most of the teleomorphs of the Deuteromycetes belong to the Ascomycetes; a B following the name of the genus indicates that it belongs to the Basidiomycetes.

— in the last column, 'Bio. mol.', the presence of an X indicates the existence of a study or studies of at least one species of the genus considered with the help of molecular biological techniques.

Etienne Kiffer, the illustrator, has designed the **illustrations** to give a synthesized view, which is rather general and diagrammatic, of the genera.

I

INTRODUCTION

The Deuteromycetes or Mitosporic Fungi (Fungi Imperfecti) make up the higher fungi, with Ascomycetes and Basidiomycetes.

The higher fungi are **eukaryotic** organisms (organisms having a true intracellular nucleus, limited by a double membrane) that have chitinous cell walls. Their vegetative system is a thallus that is well developed, filamentous (= **mycelium**), and haploid or dikaryotic (cf. infra). They produce only non-motile spores (not zoospores that move by means of flagella). They are **heterotrophic**, that is, dependent for their energy needs on pre-formed organic matter that is dead (**saprophytism**) or living (**parasitism, symbiosis**).

The Deuteromycetes constitute an artificial group. They comprise:

— higher fungi that can live and multiply seemingly without a sexual phase, and

— most of the asexual or 'imperfect' forms (**anamorphs**) of Ascomycetes and Basidiomycetes. (Arbitrarily, the anamorphs of Basidiomycetes that cause rust (Uredinales) and smut (Ustilaginales), parasites of vascular plants, are not included in Deuteromycetes.)

Among the Ascomycetes and Basidiomycetes, **sexual reproduction** takes place during a stage of the biological cycle called the 'perfect stage' or **teleomorph**.

During their sexual phase, the Ascomycetes produce reproductive cells, the **ascospores**, in parent cells or **asci**.

The main stages in the life cycle of an Ascomycete are shown in Fig. I.1a and occur as follows:

The **haploid** ascospores (having a nucleus with n chromosomes), released when the ascus matures, germinate when they are in a substrate with conditions favourable for the formation of a vegetative mycelium with haploid, uninucleate hyphae.

Then, two mycelia of different polarity undergo a fusion of their cytoplasm (**plasmogamy**) while the parental haploid nuclei remain, separately, in a common cytoplasm. This plasmogamy can occur in

various ways: the fusion of an **ascogonium** (female sex cell) and a **spermatium** (male gamete) is shown in Fig. I.1a.

It is at the end of the dikaryotic phase (*di* = double, *karyon* = nucleus), characterized by a binucleate mycelium (reduced to an ascogenous filament), that the ascogenous cell is formed. At this point the haploid nuclei fuse (**karyogamy**) to form a diploid nucleus (a nucleus with 2n chromosomes).

In the ascogenous cell thus transformed into an ascus, meiosis occurs, which results in four haploid nuclei, around which the ascospores are differentiated (numerous variations exist around this type of base, particularly by abortion or division of the meiotic nuclei. The number of ascospores thus varies from 1 to *n*, and most commonly it is 8).

A comparable sexual reproduction occurs among the Basidiomycetes: in this case, the parent cell is the **basidium**, which produces exogenous **basidiospores** (Fig. I.1b). When they germinate, these basidiospores produce a haploid or **primary** mycelium. The fusion of two primary mycelia of different polarity produces a dikaryotic or **secondary** mycelium, which may remain in the vegetative stage for a long time, unlike what happens with the Ascomycetes (cf. supra).

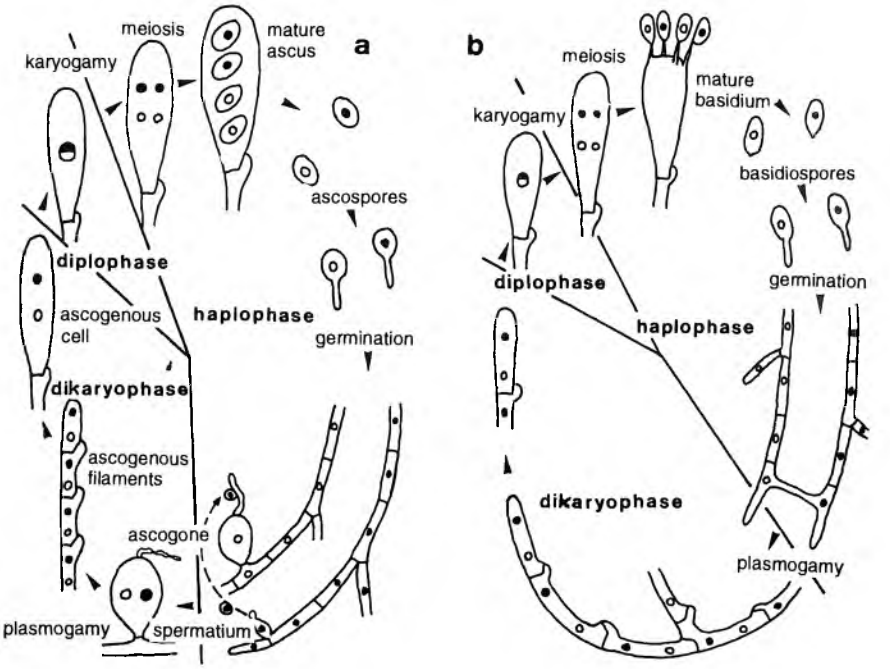


Fig. I.1. Life cycles of the higher fungi.

The Deuteromycetes, in contrast, are characterized by **asexual multiplication** by **mitosis**, considered secondary to sexual reproduction, from which the name of this group (*deuteros* = secondary, *mukes* = fungus) is derived. Most often, this multiplication occurs by production of mitotic spores or **conidia**, from a specialized hypha called **conidiophore** (Fig. I.4). The conidiophore is formed from a mycelium produced by dispersal units (ascospore, basidiospore or conidium, cf. Table I.Aa). The conidiophores are single in **hyphal forms**, or grouped on or in various structures: the **fruit bodies**, in **conidiomal forms**. The production of conidia, or **conidiogenesis**, occurs by various means and on various structures (cf. Table I.H at the end of the chapter). These enable us to classify and identify them, and constitute the subject of this work. Certain Deuteromycetes, however, do not produce conidia, but only mycelial forms or forms of resistance (Table I.Ad, Fig. I.29). These are the *Mycelia Sterilia* or Agonomycetes discussed in chapter XIII.

In some cases, in the life cycle of a fungus, a phase of sexual reproduction (teleomorph) can coexist with a phase of asexual multiplication

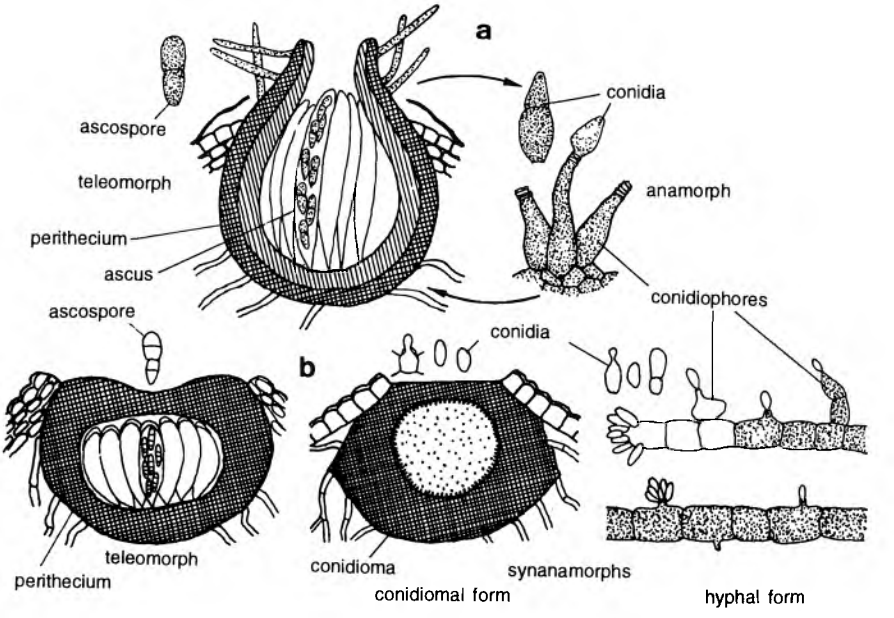


Fig. I.2. Examples of teleomorph-anamorph alternation.
a: life cycle of an Ascomycete (*Venturia inaequalis*, teleomorph) with its anamorph (*Spilocaea pomi*); **b:** an Ascomycete (*Sydowia polyspora*, teleomorph) with two anamorphs (synanamorphs) in its life cycle, a conidiomal form (*Sclerophoma pythiophila*) and a hyphal form (*Hormonema dematioides*).

Teleomorph, anamorph, holomorph

There are several possibilities:

— The fungus cycle is complete and described, that is, the characteristics and relationships of teleomorph and anamorph are established.

— The teleomorph and anamorph(s) are described separately, but their relationships are not established.

— Anamorph does not exist or is not described.

— Teleomorph does not exist or is not described.

— The same fungus can produce two (rarely several) different anamorphs or **synanamorphs** (Hughes, 1979), e.g., Fig. I.2b.

The terms 'teleomorph', 'anamorph', and 'holomorph', used hereafter, are given by Hennebert and Weresub (1977). These terms were questioned by Sutton (1993), who proposed to replace the first two with, respectively, meiosporic fungus and mitosporic fungus. This proposal was criticized by Korf and Hennebert (1993).

(anamorph): see, for example, Fig. I.2a. In such cases, the term **holomorph** is used to designate the fungus considered in all its phases, including teleomorph and anamorph (see box).

Etymology: *ana* = from the bottom up (development phase), *teleos* = end (end phase), *holos* = entire (complete), *morph* = form.

As regards nomenclature, the two types, teleomorph and anamorph, have generally been studied separately and thus have been given different **binomials** (*binomial* = a term consisting of generic name and species adjective). For example, *Stemphylium botryosum* is the anamorph of *Pleospora herbarum*, an ascosporate teleomorph. The two forms can also have the same species name, for example, the anamorph *Pollaccia mandshurica* and its teleomorph *Venturia mandshurica*, which are otherwise described together. More rarely, the anamorph does not have a specific name; we say, for example, 'the anamorph *Dicyma* of *Ascotricha distans*'. When the life cycle of a fungus is complete and known, the holomorph should have the name of the teleomorph, e.g., Fig. I.2b, in which the fungus comprising the teleomorph *Sydowia polyspora* and the synanamorphs *Hormonema dematioides* and *Sclerophoma pythiophila* has the name of the teleomorph *Sydowia polyspora*. It is only when referring specifically to an anamorph that one uses its name.

The sexual forms are sometimes massive, especially the carpophores of Basidiomycetes, and also of certain Ascomycetes.

The asexual forms, characteristic of the Deuteromycetes, are on the contrary generally small or even microscopic.

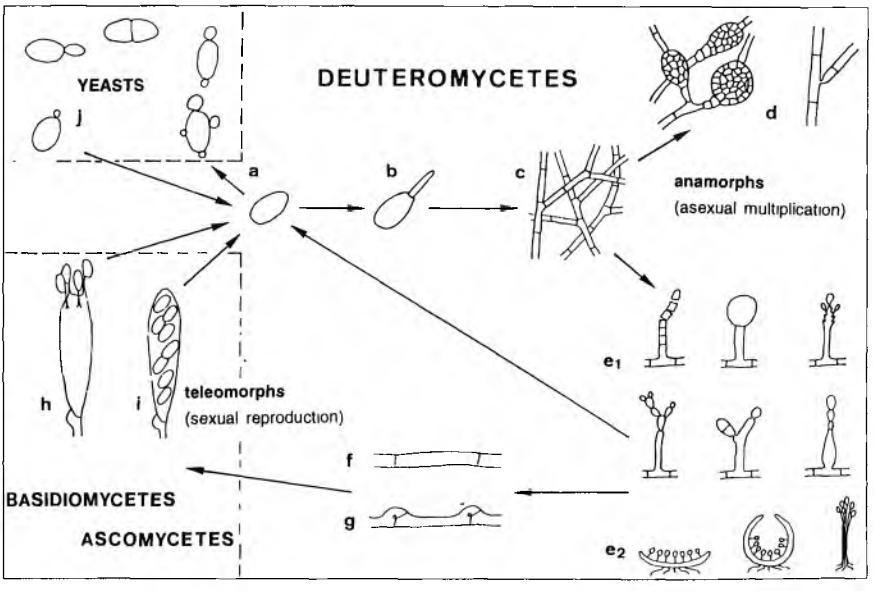
The teleomorphs of Deuteromycetes are most often Ascomycetes, and more rarely Basidiomycetes.

We mention later, in the introduction to each chapter, and along with each generic table, the known links between anamorphs and teleomorphs, as drawn from the compiled references, i.e. Kendrick (1979), Sutton and Hennebert (1994). With regard to the Ascomycetes cited in these lists, we have adopted the nomenclature proposed by Eriksson and Hawksworth (1993).

Even if the teleomorph of a Deuteromycete is unknown, it can sometimes be established as belonging to Ascomycetes or Basidiomycetes, particularly by the characteristics of the septa of the filaments or **hyphae**. They are simple in the Ascomycetes, and have a central pore that can close up if necessary by means of a special organelle called **Woronin body** (Fig. I.3a). In the Basidiomycetes, the pore, with a bulging edge, is named the **dolipore:** on each side of it is a hemispherical **parenthesome** that issues from the endoplasmic reticulum (Fig. I.3b). The study of this characteristic requires the use of an electron microscope. But one can also establish this relation by techniques of molecular biology.

According to Muller (1981), the anamorphs of Ascomycetes are always haploids, while those of Basidiomycetes can be haploid (primary mycelium) or dikaryotic (secondary mycelium). In the latter case, one can often observe clamp connexions characteristic of secondary mycelium (Table I.Ag).

Table I.A. Stages of the life cycle
a: dispersal unit: basidiospore, ascospore (produced by the teleomorph) or conidium (produced by the anamorph); **b:** germination of the dispersal units; **c:** mycelium arising from the germination; **d:** mycelium not producing conidia (chapter XIII); **e:** production of conidia by conidiophores (chapters II-XII); **e1:** single conidiophores carried by the mycelium; **e2:** conidiophores grouped in a fruiting body arising from the mycelium; **f:** simple mycelium of Ascomycetes and certain Basidiomycetes; **g:** dikaryotic mycelium with clamp connexions of certain Basidiomycetes; **h:** basidium with exogenous basidiospores; **i:** ascus with endogenous ascospores; **j:** unicellular yeasts (multiplication without production of mycelium). N.B. The groups in the box (**h, i, j**) are not dealt with in this work.



Other fungus groups, apart from Ascomycetes and Basidiomycetes, have anamorphs, but they are not grouped among Deuteromycetes. They are mainly Oomycetes and Zygomycetes. The unicellular yeasts, which multiply by budding or fission (Table I.Aj), are not discussed here.

Table I.A attempts to summarize and group the ideas that we will discuss and especially to place the Deuteromycetes in the life cycles of the higher fungi.

The different classifications

The taxonomy of Deuteromycetes is artificial: it does not constitute a system of classification such as a genealogical tree representing the natural relationships of these fungi, but rather a nomenclature and means of identification. From this perspective, we adopt here a taxonomy that uses inputs from different phases in the evolution of knowledge.

The first coherent system of classification of Fungi Imperfecti was proposed by Saccardo (1880, 1884). It was a morphological system, taking into account:

— the mode of grouping of conidial apparatus (Table I.B) in Hyphomycetes, Coelomycetes, etc.;

— the colour, form, and septation of the conidia produced (Table I.C).

Such a purely morphological system leads us to bring together Fungi, which a careful observation reveals as producing their conidia by different mechanisms: such observations were done on a small number of samples till the middle of the twentieth century.

In 1953, Hughes proposed a coherent, generalized classification of the Hyphomycetes. He divided them into eight sections (the suprageneric sections of Saccardo, families, etc. were abandoned and the sections designated simply by an order number). The 'characters of conidiophore and conidium development' are the basis of this classification (Table I.D).

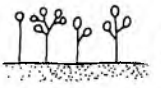
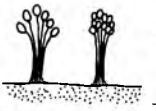
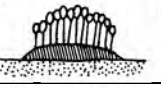
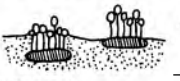
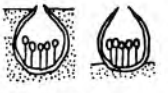
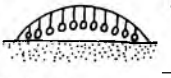
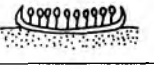
This publication gave rise to a great number of works and some of them are cited in the bibliography at the end of this chapter. The sections of Hughes were given names and Barron (1968), whose system we generally follow, established the equivalents given in Table I.E. We have also indicated in this table the illustrations given in chapter I, and the chapter that discusses this group, followed by the name we have adopted.

Conidial ontogeny, the relationships between the conidium and the conidiogenous cell, evolution of the conidium and conidiophore, and the mode of secession of spores—the bases of modern classification—must be examined very carefully, especially at the level of the walls (see box). The light microscope is insufficient for the study of these phenomena, and the electron microscope is used for a certain number of observations. We have proposed interpretations of published photomicrographs, partly in this introduction, and then at the beginning of each chapter discussing

Unitary parameters of conidiogenesis

Hennebert and Sutton (1994) proposed 20 parameters, the combination of which should enable us to characterize perfectly the genera and species of anamorphs. The authors try to propose the largest number of parameters possible in each case, and if this system is adopted, each genus and species described or studied must be characterized according to these criteria.

Table I.B. Fungi Imperfecti.
Classification based on the mode of grouping and the pigmentation of spores (mainly from Saccardo and Grove).

HYPHOMYCETES	AGONOMYCETALES	sterile mycelium 	AGONOMYCETACEAE
	HYPHOMYCETALES	conidiophores dispersed in the substrate 	DEMATIACEAE (dark colour) MUCEDINACEAE (hyaline or brightly coloured)
	STILBELLALES	conidiophores grouped in coremia 	STILBACEAE
	TUBERCULARIALES	conidiophores grouped in a globular stroma (sporodochium) 	TUBERCULARIACEAE
COELOMYCETES	MELANCONIALES	conidiophores grouped in a thin, submerged stroma (acervulus) 	MELANCONIACEAE
	SPHAEROPSIDALES	conidiophores grouped in a complete pycnidium 	SPHAERIOIDACEAE (dark colour) NECTRIOIDACEAE (hyaline or brightly coloured)
		conidiophores grouped in an incomplete pycnidium 	LEPTOSTROMATACEAE
		conidiophores grouped in a pseudo-pycnidium in the shape of a dish 	EXCIPULACEAE