Smith's Introduction to Industrial Mycology

Seventh Edition

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Preface to the Seventh Edition

The intention of this book is to produce a modern successor to Mr George Smith's book *An Introduction to Industrial Mycology*. As in the previous six editions, the aim is to assist non-specialist workers in the industrial field to identify the moulds and other fungi which are of importance in industry, either as useful organisms or as organisms causing damage. Many of the moulds described also cause food and grain spoilage and produce mycotoxins. It is hoped the book will help with the identification of some of these latter fungi, but we do not intend it to be a manual for the identification of mycotoxin fungi. This is only able to deal very superficially with the broader aspects of industrial mycology.

The first half of the previous volumes consisted of descriptions and illustrations of the moulds most regularly occurring in industrial products, with greater detailed consideration of the genera of most importance. The moulds involved have changed little over the years with perhaps a few additions. However, the study of taxonomy and nomenclature has increased considerably in the last few years. The treatment has been updated to follow these modern concepts and it is hoped we have included enough general mycology to enable the student to find and understand the more recent standard texts. The broad classification of Ainsworth (1966) (see References, p. 25) is followed as far as possible and the new approach to the identification of Hyphomycetes, based on methods of spore production, is introduced. Descriptions of laboratory methods are still included but not in such detail as in previous editions. Some chapters on other aspects have been reduced or omitted being now well documented elsewhere – for example the chapters on 'Mycology of Soil', 'Actinomycetes' and 'Microscopy' have been omitted. However, it was felt that the wood rotting Basidiomycetes should have a chapter in a book which includes spoilage fungi.

The chapter on industrial uses of fungi has been completely remodelled to cover modern appects of the subject including biochemical syntheses, harnessing of biodegradation and upgrading of materials, but this is now such a wide field that the treatment can only be an introduction. The chapter on control of mould growth has been rewritten and becomes 'Biodeterioration and its Prevention'.

G. Smith always maintained that figures from photographs were more suitable than line drawings for the use of beginners. However, line drawings have been introduced as it is felt that they often assist in interpretation of the photographs. Many of Smith's original photographs have been retained but some, through loss, damage or other causes, have been replaced and, as before, these replacements come from original photographs. For permission

for their inclusion we are indebted to the Commonwealth Mycological Institute and in particular to the Institute photographer Mr D. W. Fry for his assistance with those of higher technical standard.

The authors wish to thank our many colleagues for help in producing this work: in particular Dr R. R. Davenport of Long Ashton Research Station for the chapter on Yeasts; Mr A. R. M. Barr of Catomance Ltd, Mr W. J. Irvine of Carreras Rothmans (Research Divison) and Dr B. Jarvis of the Food Research Association for advice on preservatives; Professor T. A. Oxley of the Biodeterioration Centre, University of Aston in Birmingham for contributing the section on water activity and Mr R. Young, also of the Biodeterioration Centre, for finalizing the chapter on industrial fungi.

In the taxonomy section we thank Dr A. F. Bravery of the Building Research Laboratories for examining the chapter on Basidiomycetes and are most grateful to our colleagues at the Commonwealth Mycological Institute who read and advised on much of the manuscript, especially Dr B. C. Sutton who examined many chapters, Dr D. L. Hawksworth the Ascomycetes, Mr P. Kirk the Zygomycetes, Dr P. M. Stockdale several chapters and all our other colleagues for support and interest, not least of all our ever patient typists, especially Mrs M. Rainbow who typed the taxonomic section.

1981

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Introduction

We may rest assured that as green plants and animals disappear one by one from the face of the globe, some of the fungi will always be present to dispose of the last remains.

B. O. Dodge, *Rep. 3rd Int. Congr. Microbiol.*, 1940

1.1 Mycology

Mycology is concerned with the study of the Fungi, the term being derived from the Greek word *mykes*, meaning a fungus. The Fungi were, until comparatively recent times, regarded as members of the Plant Kingdom, and certainly, in general aspects, the majority of them bear a superficial resemblance to plants. Even at the present day nearly all the teaching in mycology in this country is carried out as part of courses in botany in our schools and universities, though there is an increasing number of courses in microbiology in which mycology forms a part.

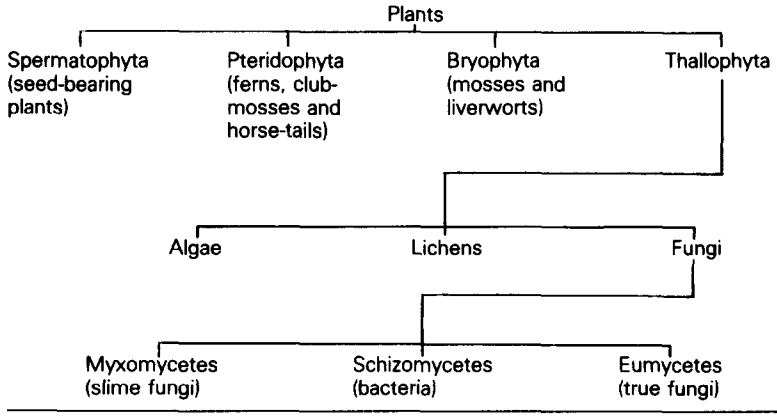
1.2 The place of Fungi amongst living things, old and new theories

The supposed relationship of the Fungi to the various types of true plants has, until recently, usually been set out somewhat as in Table 1.1. In this system algae and fungi were regarded of the same phyletic origin and placed together as plants in the Thallophyta (Gr. *thallos*, a young shoot; *phyton*, a plant) which were plants which show no differentiation into root, stem, leaf etc., the vegetative structure being known as a *thallus*. This might be unicellular, as in some of the simplest fungi, or might show considerable specialization of structure with corresponding specialization of function.

The view that fungi and algae were derived from a primitive form of protozoa was originally put forward by Haeckel in 1866. Various classifications based on the derivation of fungi from this primitive kingdom have been favoured by many modern authors including Ramsbottom (1941), Langeron (1945) and Ingold (1959) and are fully discussed by Martin (1968).

However, it was still felt that fungi and algae were distinct and in 1969 Whittaker proposed his theory of classification of living things in which he separated the simplest prokaryotic organisms (Monera) from the eukaryotic organisms (Protista). From the latter he suggested three lines had developed with separation based on their nutrition: (1) the plant kingdom in which the

Table 1.1 The supposed relationship of the Fungi to the various types of 'true' plants and some other groups of organisms as usually set out before the more recent re-classifications.



organisms manufacture their own food by photosynthesis; (2) the animal kingdom characterized by ingestive nutrition, devouring organisms; and (3) the fungi which absorb nourishment from living or dead organisms or organic matter. This theory was adopted by Ainsworth (1973) who discusses the whole phylogenetic development in his book, *Introduction to the History of Mycology* (1976).

It is agreed, however, that whatever the origin of the fungi, they are a very distinct and separate group.

1.3 Separation of Fungi from other organisms

1.3.1 Algae

The fungi are distinguished from the algae in that they lack the green pigment which enables plants to bring about photosynthesis, i.e. the building up of complex organic compounds from carbon dioxide and water in the presence of sunlight.

1.3.2 Lichens

The lichens are compound organisms, consisting of algae and fungi in intimate association. Their study is a special branch of botany, since the alga-fungus association is so close that the lichens may be classified into genera and species just as if they were single organisms, and many of the fungi are unknown apart from their algal associates. Those who are interested in this group should consult the excellent text by Hale (1974).

1.3.3 Myxomycetes

The Myxomycetes (Gr. *myxa*, slime; *myketes*, pl. of *mykes*), the slime moulds, are a puzzling group of organisms and have been claimed by both mycologists and zoologists. However, Ainsworth (1973) included them with the fungi. No matter how they are classified their study does not come within the province of industrial mycology. The excellent monograph of the British Mycetozoa by Lister (1925) is still valuable and has only recently been replaced by the works of Gray and Alexopoulos (1968) on the biology, Martin and Alexopoulos (1969) on the taxonomy and a shorter key to the families and genera by Alexopoulos (1973).

1.3.4 Bacteria

The bacteria (Schizomycetes), comprising one of the three classes of fungi in Table 1 bear little resemblance to true fungi. Modern developments in microscopic techniques and molecular biology are presenting a clearer picture of their structure and nature, and the study of bacteria has now become a separate and important branch of science, with a technique of its own – their consideration is outside the scope of this book.

The only organisms listed in Table 1.1 which come within the province of the industrial mycologist are, therefore, the Eumycetes, or true fungi.

1.4 Numbers of Fungi

The number of species of fungi is a matter of speculation. Ainsworth (1968) reckoned that there were already 50 000 known species based on morphology and well over 100 000 specific names, and that this number was largely dependent on the number of working mycologists. He considered that there were at least 100 000 species and as there may be as many or more species of fungi than flowering plants this number could be as high as 250 000. The number of fungi depends on the understanding of an individual, but their range of habitat is wider than for flowering plants and many species are of world-wide distribution.

1.5 The activities of Fungi

As is to be expected of such a large group of living things, the fungi show great differences in size, structure, and metabolic activities. Some, such as yeasts, grow as loose aggregates of single detached cells, whilst others, such as the mushrooms and toadstools, form large fruit-bodies of complicated structure, with elaborate mechanisms for propagation. Some of the larger fungi are prized by the epicure whilst others are shunned as amongst the deadliest of poisons. The majority of the known fungi live on dead organic matter, performing a useful service in returning to the soil nutrients originally extracted by plants, but there is a large group of species which are inimical to

man's activities through their habit of parasitizing plants which are grown for food and clothing, and a smaller group which are parasitic on animals, including man himself. Many fungi attack manufactured products of all kinds including foodstuffs, fabrics, leather, timber, cosmetics, pharmaceuticals, aviation fuel, and even glass. On the other hand a number of species are capable of synthesizing, under suitable conditions, substances useful to man, with an economy of effort which the chemist cannot emulate.

1.6 Fields of study

In mycology, as in other sciences, increased knowledge has resulted in complexity, and eventually the division of the science into a number of branches in which individual workers tend to specialize. What is usually termed pure mycology concerns the detailed structure, cytology, and modes of development of fungi. Field mycologists are interested in the fungi which are to be found in fields and woods, both the larger forms, known as mushrooms and toadstools, which grow on the ground or as parasites of forest trees, and the microscopic forms found on plant debris or as parasites of plants. The taxonomist studies structure with a view to classifying fungi, so as to show relationships and facilitate identifications by others. Although plant pathology is not a branch of mycology since it is concerned with the study and prevention of all kinds of abnormalities in cultivated plants, the plant pathologist nevertheless must have a good knowledge of mycology, for many diseases of plants are caused by fungi. Medical mycology deals with the fungi which cause disease in man. The study of toxins (mycotoxins) harmful to man and animals produced by fungi growing on deteriorating feedstuffs, in particular grains, is causing concern at the present time and is becoming an important branch of the science. Another somewhat specialized branch of the science is the study of the wood-destroying fungi, both those which attack standing trees and those which rot felled and worked timber.

1.7 Industrial mycology

The field of industrial mycology includes both the harmful activities of fungi in rotting or spoiling industrial raw materials and manufactured goods, and the uses of fungi in industrial fermentations. Their biodegradative activities are now being harnessed to assist in breakdown of organic waste and even upgrading of such waste for recycling or use as feedstuffs. The fungi concerned are commonly known as 'moulds'. They show considerable diversity of structure and are placed by the taxonomist in a number of widely separated groups. Although they are commonly visible to the naked eye, they all produce minute fruiting structures which cannot be studied without the aid of a microscope. One great advantage which industrial mycology has over some branches of the science is that the moulds are readily grown in the laboratory and can be studied quite independently of season or weather.

The various species of moulds differ in their responses to environmental conditions, in their abilities to attack various types of material, in toleration

to preservatives and in synthetic activity. Hence little can be accomplished in the field of industrial mycology without a working knowledge of the moulds themselves, and the ability to recognize at least the more common species. Even in fermentation industries, which may use a single species of fungus, contaminants are likely to cause trouble unless they are recognized at an early stage. In addition, it is essential to be able to distinguish a highly active strain from other less useful strains of the same species, and to be able to recognize the species when searching for new and more active strains. A large proportion of this book is therefore devoted to descriptions and illustrations of most of the common species of moulds, and to the methods used in studying them for the purposes of identification.

The study of taxonomy has increased and undergone enormous change in approach and concept in the last 20 years. An attempt has been made to introduce the new ideas and to give enough new references to guide the reader to the extensive and expanding modern literature. However, descriptions of the fungi are based on culture characteristics and morphology and separation is by traditional keys – methods readily available to workers in industry. No effort is made to include the new, complex, and at present expensive, methods of electronmicroscopy, biochemical differentiation, electrophoresis, serology and numerical taxonomy.

The chapter on prevention of biodeterioration is given in such a way as to introduce the reader to the subject, as workers in this area are often new to industrial mycology, while it is now felt there have been such advances in the fermentation industries that workers will require no introduction to the technical aspects of the subject though they may still find information on fungi useful.

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2

A Brief Introduction to Morphology, Ecology and Physiology

2.1 Basic definitions and fungal morphology

When a mould begins to grow, whether it is on a natural substrate, on some manufactured material, or on a culture medium in the laboratory, there is an initial period during which nothing is visible to the naked eye. The time taken for visible growth to appear may vary from a few hours to many days, depending on a number of factors, the most important of which are the particular species of mould, the availability of any nutrient material present, and the relative humidity of the air. When the mould **colony** (as it is usually termed) has grown sufficiently to be readily seen, examination with a good hand-lens or low-power microscope will show the presence of a network of fine filaments. Each individual filament is termed a **hypha** (Gr. *hyphe*, a tissue), and the hyphae collectively are called **mycelium** (Gr. *mykes*, a fungus; *elos*, a wart). Some of the hyphae grow along the surface of the substrate, some may penetrate to a degree depending on the texture of the substrate, whilst others may stand above the surface, in some cases giving a hairy or fluffy appearance.

If the material on which the mould is growing is poor in nutritive value the mycelium spreads slowly and usually changes little in appearance, except that any aerial growth tends to collapse after a time. When, however, there is a reasonable amount of available food, and external conditions remain favourable, there is usually a gradual change in the appearance of the colony. Frequently there is a distinct change in colour, first manifested in the central and older parts of the mycelium. Microscopic examination at this stage will show the presence of fruiting structures, which are readily recognized as quite distinct from the ordinary hyphae. The individual reproductive bodies are called **spores** (Gr. *spora*, a seed). For example, the green mould usually found on leather (*Penicillium*) has more or less erect hyphae terminating in miniature broom-like structures, the individual bristles of the broom consisting of long chains of small roundish spores; the hairy-looking mould on bread (*Rhizopus*) bears small round, dark heads on erect hyphae, and if a head is crushed on a microscope slide it will be found to be full of small oval spores; a mould commonly found on jam (*Aspergillus*) produces spores of two kinds, one kind arranged in radiating chains, arising from the tops of erect hyphae, the other enclosed in yellow spherical bodies which are big enough to be seen without a lens. Other moulds form spores in a variety of ways, but, however they are formed, and whatever their appearance, they are almost always readily recognizable as distinct from the mycelium.

The spores of a fungus are designed for dissemination and reproduction,

just as seeds are produced as a means of propagation by green plants. A spore, however, differs from a seed in that it never contains a germ, or plant embryo. It may consist of a single cell, or be a compound structure of several cells, each consisting of a mass of protoplasm surrounded by a firm containing wall. Spores of different species show considerable variation in size, ranging from a little over 1 μm, as in some species of *Penicillium*, to about 200 μm in greatest dimension in certain species of *Helminthosporium*. However, even the largest spores are light enough to be transported considerable distances by air currents, with the result that it is rare to find the atmosphere, either inside a building or outside, free from mould spores.

When a spore eventually alights it may remain dormant for a long period if conditions for growth are not favourable. As soon as the relative humidity of the air becomes sufficiently high (the actual figure varies for different species), germination occurs. It should be noted that although the term 'germination' is always used in reference to spores of fungi, the process has nothing in common with the process of germination of a plant seed. The first stage in spore germination is the absorption of water, with a consequent increase in size of the spore. One or more **germ-tubes** then emerge from points on the surface and rapidly elongate. Even a single-celled spore may give rise to more than one germ-tube, whilst in the case of many multicellular spores any cell may germinate separately. Figure 2.1 shows two spores of

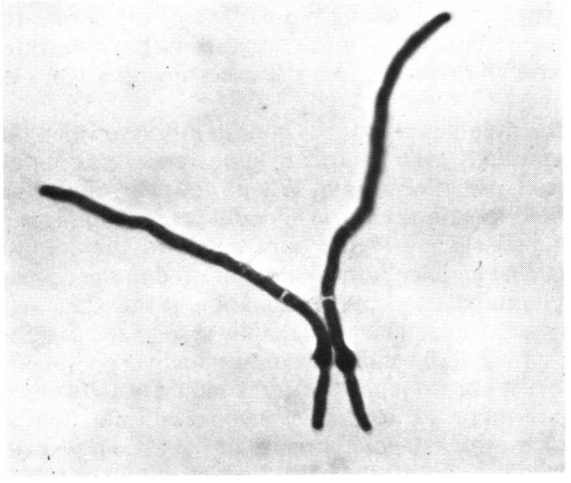

Fig. 2.1 *Penicillium notatum* Germinating spores, ×250.

Penicillium notatum which have been allowed to germinate on cellulose sheet and subsequently stained (for the method see Chapter 13). Note that each spore has put forth two germ-tubes and that these have issued successively, not at the same time. If a supply of suitable nutrients, as well as sufficient moisture, is available, the germ-tubes rapidly increase in length and soon branch repeatedly, covering the surface of the substrate with a radiating