C. H. Kauffman.
Dec. 1905.

Minnesota Plant Diseases.

A Wound Parasite (*Pleurotus ulmarius*) on the Trunk of a Maple Tree.
Original.

MINNESOTA PLANT DISEASES

by

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Preface.

IT is probably safe to say that millions of dollars are lost in Minnesota yearly by the ravages of plant diseases. Agriculturists and horticulturists all over the world have of late years directed a great deal of attention toward the study of plant diseases and the methods of combating them. The Department of Agriculture of the United States has done vastly more than any other institution in the world along this line and the results have been well worth the efforts, for many efficient methods of fighting these pests have been devised.

In many cases where cure is impossible an intelligent understanding of the conditions and effects of a disease will aid in prevention. The dissemination of such knowledge is of very great value. It is a very evident fact that all agricultural pursuits are taking great strides, and the education of those boys and girls who are about to cultivate or manage the cultivation of lands is becoming more and more imperative.

The possession of an accurate knowledge of plant diseases and their causes is not only of commercial use to the farmer, both in cure and prevention, but also, by making him an intelligent observer, adds hosts of assistants to the small corps of men who are devoting their time to this study of botanical science. The advantages of such a condition amongst agriculturists would far surpass those where the mere knowledge of present methods of prevention and cure obtains. In fact it is only with the intelligent and hearty co operation of farmers that such work can successfully go forward.

It is not the aim of this work therefore to catalogue all of the ills that Minnesota plants are heir to, but its chief object is to disseminate knowledge of the destructive parasites of the useful plants of this state, to assist all concerned in the cultivation of plants to a more intelligent and thorough understanding of the habits of these parasites, and to point out established methods of combating such diseases. Recipes are not the aim of such a work — these are of value and as such are introduced; but by far the most valuable effort should be the inculcation of the knowledge of the habits and life-stories of those organisms which are the causes of disease. Upon such knowledge, widely disseminated, can be built a substantial system of disease prevention. In short, the aim of this work is rather *educational* than *immediately practical*, for in the former feature the author hopes that it will be ultimately most useful.

It is to be regretted that a systematic survey of the plant diseases of the state, sufficiently thorough to determine the full extent of the damage due to these diseases, has not been possible. The Minnesota Agricultural Experiment Station has never employed a special plant pathologist, and the records of the station on plant diseases are therefore only fragmentary. The author has, in the pursuit of his studies on the fungi of Minnesota under the Geological and Natural History Survey of the state. become more or less acquainted with many of the plant diseases, and this volume is in part the result of such observations as were made in that work.

The omission of some diseases is naturally unavoidable, and on the other hand it has been deemed advisable to include many diseases which are doubtfully of much importance in this state. These have been added either because their prevalence is to be expected on account of their existence in neighboring states, or on account of their general importance in other parts of the country. While not wishing to borrow trouble from the future, it is well to be forewarned. The old adage, "a stitch in time saves nine," is peculiarly appropriate. Again, plant diseases are here described which are economically of minor importance, but which are illustrative of certain important classes of diseases, and, as it has been pointed out that this work pretends to be chiefly educational, such diseases become, secondarily at least, of considerable importance.

I wish to express my thanks to the following for assistance in various ways, as in the use of plates, photographs, material or literature: Mr. F. K. Butters, Professor E. W. D. Holway, Mr. H. Cuzner, Professor F. L. Washburn, Miss D. Hone and Dr. H. L. Lyon of the University of Minnesota; Mr. C. J. Hibbard of Minneapolis; Dr. Francis Ramaley of the University of Colorado; Professor G. F. Atkinson of Cornell University; Professor R. S. MacIntosh of the Alabama Experiment Station; Dr. G. P. Clinton of the Connecticut Agricultural College; Professor H. Marshall Ward, F. R. S., of the University of Cambridge; Professor Roland Thaxter of Harvard University; Professor F. C. Stewart of the New York Experiment Station; Mr. F. J. Seavers of the University of Iowa; Mr. M. A. Carleton of the United States Department of Agriculture; Professor H. L. Russell of the Wisconsin Agricultural Experiment Station; Professor B. M. Duggar of the University of Missouri; Mr. S. A. Sirrine of the New York Experiment Station; Professor J. C. Blair of the Illinois Agricultural Experiment Station; Mr. C. G. Loyd of Cincinnati; Dr. J. C. Arthur of Purdue University; Dr. W. A. Kellerman of Ohio State University; Professor H. L. Bolley of the North Dakota Agricultural College; Professor B. D. Halsted of Rutgers College; Professor B. O. Longyear formerly of Michigan State Agricultural College;

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To the following Experiment Stations I am indebted for the loan of plates for illustration: Kansas, Connecticut, New York (Geneva), New York (Cornell), Illinois, New Jersey, Massachusetts, Michigan, Rhode Island, Maryland. My thanks are also due the Goulds Manufacturing Co. of Seneca Falls, N. Y., for the loan of several electrotypes.

Amongst the many well-known general works consulted, the following have proved particularly useful and have been freely used; I wish here to acknowledge my indebtedness: Diseases of Plants, Tubeuf and Smith; Pflanzenkrankheiten, Hartig Diseases of Trees, Hartig (translated by Somerville and Ward); Zerzetzungserscheinungen des Holzes, Hartig; Spraying of Plants, Lodeman; A Textbook of Plant Diseases, G. Massee; Die Natürlichen Pflanzenfamilien, Engler and Prantl; and the older general works of Sorauer, von Tavel, Frank, Zopf and De Bary.

I have made free use of the great literature of the bulletins and reports of the United States Agricultural Experiment Stations and especially of Connecticut Experiment Station Bulletin No. 142 and the Connecticut Report for 1903, both of which were written by Professor G. P. Clinton.

Where illustrations have been taken from other works credit is given in the proper place; I desire here to acknowledge my indebtedness to the following publishers, for permission to copy illustrations: Julius Springer, Berlin; Eduard Trewendt, Breslau; Gustav Fischer, Jena; The Clarendon Press, Oxford; Longmans, Green & Co., New York; The Botanical Gazette, Chicago; Macmillan & Co., London and New York; Wilhelm Engelmann, Leipzig.

For the chapter arrangement of the descriptions of specific diseases in Part II, I am indebted to the suggestion of Professor MacMillan.

All figures designated as original were made by Mr. C. J. Hibbard under the Geological and Natural History Survey of Minnesota. The great majority were made under the direction and with the co-operation of the author; the remainder under the direction of other members of the survey staff.

To the Board of Regents of the University of Minnesota is due the credit for making financially possible the collection of material and illustrations and the publication of this work.

I am particularly indebted to Professor Conway MacMillan, at whose suggestion the work was undertaken, and without whose advice and assistance the publication would have been impossible.

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Introduction.

The diseases of plants and their causes may be grouped as follows:

Organic diseases, i. e., those caused by living organisms such as:

Fungi.
Bacteria.
Slime molds.
Flowering plants.
Insects and other animals.

Inorganic diseases, i. e., those due to other causes than living organisms:

Unfavorable conditions of soil, etc.
Unfavorable conditions of weather, etc.

It is not the purpose of this work to consider *all* of the diseases of Minnesota plants. The attack of insects furnishes a vast field of research which is best left to the entomologist. By far the most widely distributed and most destructive of Minnesota plant diseases are organisms belonging to the plants known as fungi. Bacteria are responsible for a considerable number and the fungus-like animals, known as slime-molds, are responsible for a few. In addition the flowering plants cause several diseases. There are also to be considered those diseases which are caused by inorganic agencies as drought, heat, wind, hail, lightning, frost-cracks, sunscalds, etc. This work will not admit of a discussion of the latter group.

It is well at the outset to note that disease cannot be easily defined. One might consider any variation due to the derangement from the most favorable conditions of the life of a plant as a disease. The most favorable conditions in all respects are seldom, if ever, realized. When the favorable conditions of life are so seriously interfered with by any agency, so that the life of a part of a plant or of the whole plant is threatened, we recognize disease in that plant. The change in favorable conditions may be so slight that the shortening of the life of the plant or its parts is not apparent. One does not recognize disease in such a case, although it is essentially similar to that of well-recognized diseases. There are, then, between health and disease in plants imperceptible gradations and no sharp lines of demarcation. A farmer who intelligently strives for all of the most favorable conditions of his crop is in reality combating disease. A great loss to agriculture annually occurs which does not usually pass for disease. When the grower of plants realizes this, and when he joins his efforts with those who are seeking methods of combating diseases, then more rapid strides will be possible in methods of investigation and prevention. The more knowledge a farmer possesses of the conditions favorable and unfavorable to the numerous diseases which affect his crop, just so much more successful will he be in his efforts toward preventing disease. Agriculture really resolves itself into one great problem, the prevention of plant disease in the broader sense.

There are three factors to be considered in a plant disease:

(1) The immediate cause of a disease, e. g., fungi, bacteria, insects, etc., as enumerated above.

(2) The immediate effect in the anatomy, form and physiology of the host plant and the effect in inheritance.

(3) The previous condition and disposition of plants which may seriously affect the susceptibility of those plants to a certain disease; in other words, the predisposition of plants toward disease.

It is therefore apparent that one must study not only the immediate cause of a disease but the predisposition or immunity of plants toward that disease. An appreciation of these principles finds expression in the selection of varieties for specific purposes and in the more detailed study of the life-histories of diseases. By such study an exact knowledge of the habits of a parasite are obtained and it is only by means of this knowledge that we can intelligently devise methods of prevention. Too much stress cannot be placed on the necessity for accurate work in the observations of the habits of a parasite and of its life-history. All of those diseases which are at present successfully combated have been dealt with only after a thorough knowledge of their habits. The treatment of oat smut, for instance, is based on the knowledge that infection of the oat plant takes place when the plant is in the seedling stage and from spores found usually clinging to the oat grains.

The predisposition of plants toward disease is a subject which at this point is to be dealt with only in passing, and will receive more detailed attention in later chapters.

Part I. of this work will deal *in general* with those groups of plants, particularly the fungi, which furnish the causes of diseases in plants and with general methods of combating diseases, etc. Part II. will be given up to a consideration of *specific* diseases of Minnesota plants.

PART I.—GENERAL.

Chapter I.

Fungi. Nutrition.

What the fungi are. As understood today, the plants known as fungi do not include the bacteria and the slime molds. The bacteria are plants which find their closest affinities with the blue-green algae. Slime-molds possess fructifications which have at least great superficial resemblance to those of the fungi, but their vegetative life is similar to that of the lowest order of animals. They are therefore known appropriately as fungus-animals.

The fungi are all devoid of leaf-green. They hold this character in common with bacteria, slime-molds and many flowering plants. The lack of leaf-green is the result of a different habit and nutrition method from that of leaf-green-bearing plants. The latter can utilize constituents of the air and water, together with mineral salts from the soil, and build them up. with the power of sunlight, first into starch and then into the more complex substance known as protoplasm or living substance. The loss of leaf-green indicates that a plant has no longer any use for a starch-forming apparatus, but since it still needs starch it must obtain such material in a manufactured condition. Fungi are therefore dependent upon other plants or animals or upon the products of these organisms for food. Although lack of leaf-green is not characteristic of fungi alone but is shared by certain other plants or groups of plants, we find that the fungi do possess a distinguishing mark in the structure of the vegetative portion of their bodies.

That portion of the plant which is concerned with the building up of the individual plant itself is known as the vegetative portion, while that which is concerned with the production of cells for the development of offspring is reproductive. The vegetative portion of a fungus is known as a mycelium and has a characteristic structure and method of growth. This mycelium is composed of fine microscopic threads, more or less branched and densely interwoven to form loose, woolly masses, as in bread mold, or may even be compacted to form solid bodies. All fungi reproduce in some form by means of microscopic cells, more or less spherical in shape, and often as small as 1/2000 of a millimeter in diameter. They are usually, however, larger. These tiny cells are known as spores and have various forms and methods of production, which are character-

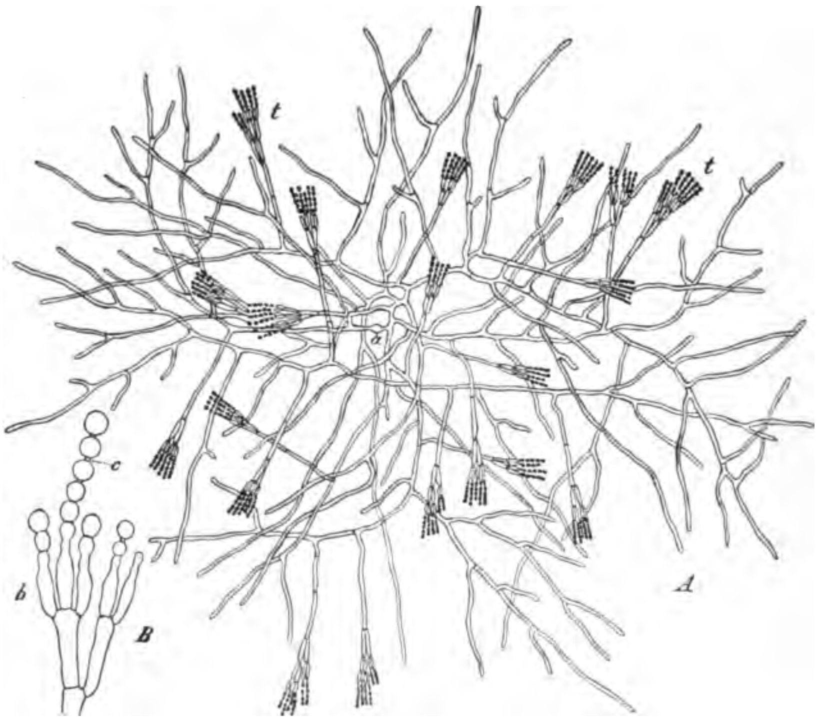


Fig. 1.—The mycelium of a food-mold fungus (Penicillium). A. Mycelium which is entirely absorptive and tufts (t) of spores (reproductive tract). The original spore from which the mycelium grew is seen at a. B. Highly magnified view of spore tuft. After Zopf.

istic for different groups of fungi. There is, however, no spore form or spore receptacle which is common to all fungi, nor are spores themselves confined to fungus plants.

Plants as well as animals can usually be best understood by their ancestry. The fungi have all descended from the algae, probably not, however, from one, but from several groups, e. g., from the flower-pot algae, the green felts and the pond scums, and possibly from the red sea-weeds.

The fungi therefore comprise low forms of plant life which have descended from algal stock and which by a change in their nutritive methods have lost their leaf-green and have come to possess a vegetative mechanism, composed of more or less branched threads known as a mycelium.

The number of fungi in Minnesota is undoubtedly very large. It has been estimated at between 2,500 and 3,000, out of a total number of 7,000 Minnesota plants. The minute size of many of these fungi,—some of the entire plants cannot be seen without the aid of a hand-lens,—the difficulty of observation, the great resemblances of forms and the complex methods of life make the determination of these plants a slow task, and the exact number of Minnesota fungi will probably not be known for some years. The rate of constant additions of new forms is sufficient indication of the very large number which exists in the state and points towards a confirmation of the above estimate.

The fungus method of obtaining nutrition. It was stated above that fungi had lost the leaf-green of their algal ancestors and were therefore unable to make starch from water, soil and air constituents but compelled to derive their elaborated food from other sources. Two methods have been adopted. In one the fungus derives its nutritive material directly from living plants. Such are parasites, and the plants upon which they feed are known as host plants. In the other method the fungus derives its prepared food from the dead products or remains of animals or plants, as leaf-mold, bread, preserves, etc. Such plants are known as saprophytes. In both of these cases the food obtained is at least partially prepared.

How the nutritive method is expressed in structure. It is a law which covers all living things, plants as well as animals, that the complexity of the structure of an organism depends on the amount and kinds of work which it can perform. When an organism has its food prepared by no effort of its own, it soon shows the loss of power to do that work. This loss of power is usually expressed in loss of certain structures, or in the simplifying of such structures. Such an effect is commonly described as degeneration. It is a noteworthy fact that such a plant may be very well adapted for obtaining food in its own way, and in this respect may be highly specialized. The wheat-rust, for instance, is very highly organized and is very closely adapted to its own manner of life. The fungi are specialists along certain lines of obtaining food and are in these lines more highly specialized than leaf-green-bearing plants. Plants with such a habit of life do not need the elaborate starch-making machinery of higher plants, as of ferns and flowering plants. It is easier and more economical for fungi to reduce their vegetative areas and hence to simplify their structure. It is a case of economy on the part of the plant. In general, all plants, whether fungi or flowering plants, when devoid of leaf-green, are efficient specialists in their absorptive methods while at the same time the vegetative area may be comparatively simple. It must therefore be understood that when these plants are called degenerate it is only in this one aspect of vegetative structure that they are correctly so called. In absorptive power and in reproduction they may be fairly complex.

It is also well known that parasitism in animals also results in degeneration of structure. There are a large number of worms, such as tapeworms and thread worms, numerous insects, such as fleas and bird lice, and even vertebrates, as the hag fishes, which are parasitic in their habits. In all of these cases simplification or degeneration of the animal body results. Organs of locomotion, sense organs, digestive tracts are all profoundly affected; either very much reduced or lost entirely. Many flowering plants have also adopted either parasitic or saprophytic habits. Familiar examples are found in the dodder and coral-root orchid. The dodder is usually found in swampy places or in clover fields and is a confirmed parasite. It has lost its leaf-green except in very early life and is consequently in later life yellowish in color. The coral-root orchid grows on leaf mold in the deep woods and is a saprophyte in habit; it has also lost its leaf-green; and its leaves, as in the case of the dodder, are reduced to small scales, useless for starch-making purposes. On the other hand, all parasites and saprophytes, whether plants or animals, have well developed systems of absorption and reproduction. The fungus system of absorption, at least in higher forms, is highly organized. In lowly forms of fungi, where the plant body is but a single, small, more or less rounded cell of microscopic size, absorption takes place over the entire surface of the little plant and there is no specialized region for the performance of this function. In all of the higher forms absorption takes place through a system of much-branched, fine threads of microscopic size.

In a mushroom, for instance, these threads penetrate the soil for a considerable distance, often for feet and even yards.

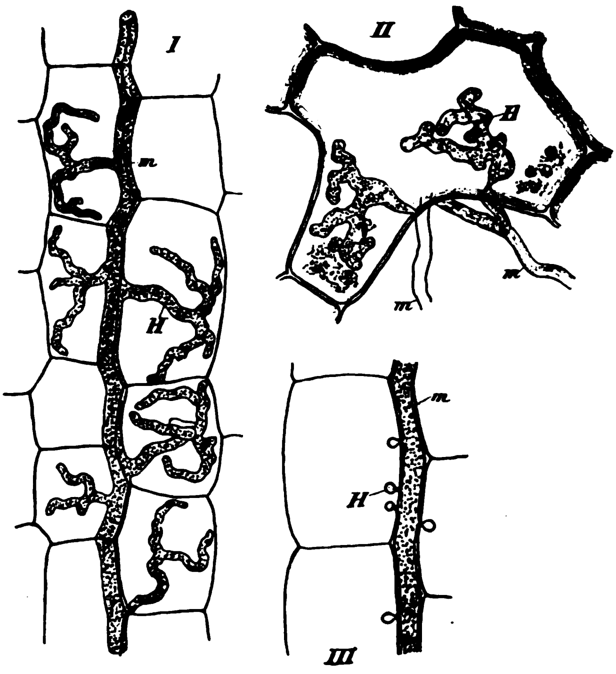


FIG. 2.—Various special absorptive or sucker threads of parasitic fungi. m. The mycelial threads. The sucker threads (H) are seen in the host plant cells. I. A downy mildew. II. Rust fungus. III. Protomyces (a fungus with a doubtful systematic position). Highly magnified. After Zopf.

The absorptive area is built upon a similar physiological principle to that of the root system of flowering plants, for in these absorption takes place at the surface of very fine hairs, which are borne on the surface of the younger roots. True root hairs and fungus absorption threads embody the same advantage in the presentation of a large absorbing area. In the fungus the threads branch profusely and are of great length, and thus a greater area of soil is drained of its nourishment. Root hairs of flowering plants never branch, but new ones are constantly being formed near the tip of the growing rootlets, thus effecting a similar result to that of the branched mycelium of the fungus. The absorptive system of parasites often consists of a similarly branched mycelium which runs between the cells of the plant upon which it feeds. Some of the branches of these fungus threads are of a special kind and penetrate into the cells of the host plant. Parasitic plants may not have such a richly developed absorptive system as a mushroom, but in other respects may be more highly specialized. The mycelium of a highly organized parasite is usually only able to obtain nourishment from certain species or groups of species of plants. For instance, certain rusts are capable of getting nourishment only from one kind of grass plant. It will be seen from these considerations that the absorptive system of this group of plants, whether parasites or saprophytes, is, in general, well developed.

Parasitism and saprophytism. Parasites are usually described as those plants which obtain their nourishment directly from living plants or animals. They are so organized that, when their nourishing threads come into close contact with certain living plants or parts of plants, they answer to certain impulses, sending special branches directly into the living tissues and there absorbing nutrition. Saprophytic plants, on the other hand, are not reacted upon by living plants and are compelled to get their nourishment from the dead products of plants or animals. The real substances which are absorbed by parasites and saprophytes may not be different in their chemical natures but the methods of obtaining them differ. The parasite has learned to respond to certain impulses, which it receives when it comes near to another plant, and by this response obtains nutrition. True saprophytes never respond to such an impulse. They live on ground rich in leaf mold or in decaying wood, or on dung of animals, on remains of animal life or on still other products of living plants or animals, but never upon the organism when the latter is still alive.

Parasites are limited in their size by the size of their host-plant, hence they are usually very small—often microscopic in size. Being limited in size, they often live for a long period through which they produce their reproductive bodies and thus compensate for lack of size. In some cases they produce different kinds of spores at different seasons. Such is the case in the fungus which causes rust diseases of grains. The saprophyte, on the other hand, has often an unlimited supply of mate-

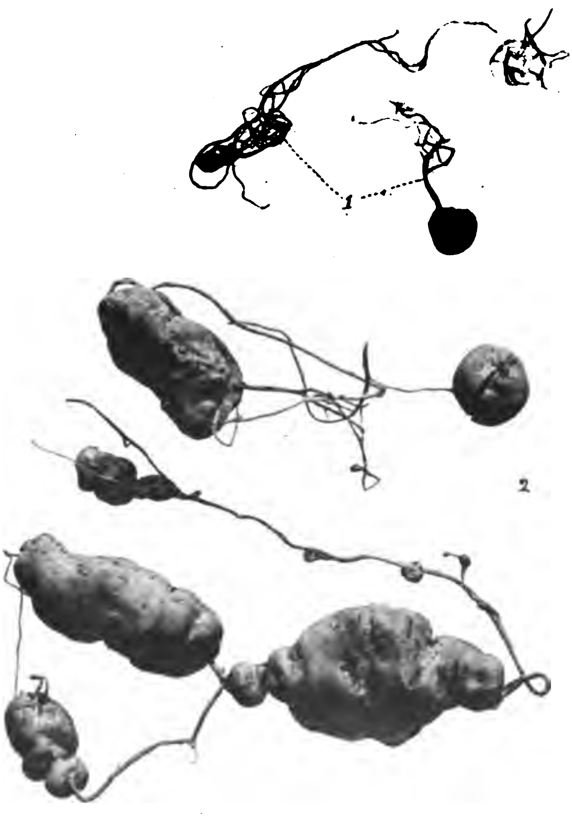


FIG. 3.—Strands and storage organs. 1. Strands of a stalked puff-ball (Tylostoma) with young fruiting bodies attached. 2. Strands and storage organs of a carrion fungus (Dictyophora ravenellii). Original.

rial at its disposal. Moreover, this food material is easily available and large plant bodies can thus be built up. Such is the case with a great many saprophytes, especially those of the mushroom group, puff-balls, etc. Only one effort a season may be made by the plant to produce reproductive bodies and then one grand effort is made. A single mushroom may produce millions of spores and shed them all in a single day. Not all parasites, however, are small; but in some cases, as in the wound parasites, they may produce large shelf-like fruiting bodies. These plants are often saprophytic at first, becoming parasitic later.

Storage organs. Most fungi use the food materials which have been absorbed from their various sources, for the immediate production of fruiting bodies. Consequently the fungus consists almost entirely of these two regions, the absorptive myce-

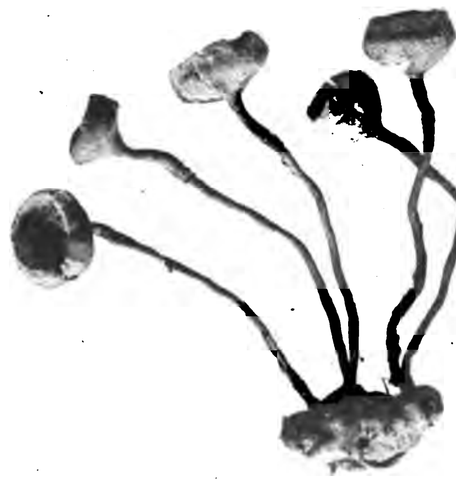


Fig. 4.—Storage organ of a cup fungus (Sclerotinia) with fruiting bodies (stalked cups) which have grown from the storage organs. Original.

lium and the reproductive organs. Some fungi, however, have learned to store food for future use and are thus able to collect considerable material, before attempting the formation of spore-bearing organs. The ergot of rye is such a storage organ, formed by a fungus parasitic on the rye. The fungus appropriates the nutrient material of the young grain and builds up a solid elongated or roundish body which, when mature, becomes dark violet colored or blackish. This body is composed of parallel threads of the fungus tightly compacted together and

Fig. 5.—Strands of mycelial threads of the dry-rot fungus (Merulius lacrymans). See also Figs. 120, 121 and 122. Original.

contains nutrient material in the form of oils and other compounds. This ergot remains dormant through winter and in the spring produces reproductive bodies. Certain carrion fungi form storage organs. They are found under the ground, developed on strands of the mycelium. In this case the storage organ has packed up its food material in the form of a starch peculiar to fungi and known as fungus starch. Certain pore fungi produce very large underground storage organs. Such is probably the "Tuckahoe Indian Bread" of the southeastern states. This storage organ is often about the size of a small cantaloupe and of heavy doughy consistency. A certain pore fungus of Australia produces storage organs of immense size and these are used by the natives for food. The caterpillar fungus furnishes an example of a storage organ of some interest. The fungus attacks living caterpillars and the mycelium finally gains entrance to the interior of the insect body. By continued growth of the fungus the caterpillar is killed. Its substance is absorbed and appropriated by the parasite, which finally replaces all insect parts with densely woven threads packed with nourishment. There is thus produced a complete cast of all parts of the caterpillar, life size, composed of the threads of the fungus. After a rest period, this mummy or storage organ produces a stalked reproductive body. In New Zealand certain very large caterpillars are thus attacked and the resulting storage organs are used as a food by the natives. They are known as vegetable worms.

Fungus Shoestrings or Strands. One often finds in decaying logs or in soil where an abundance of woody material is present, cord-like strands, often whitish in color, or in other cases very dark. By tracing them along one finds them connected with puff-ball fruiting bodies, or carrion fungi or gill fungi. Those strands formed by the puff-ball or carrion fungus are whitish in color and branch considerably; some of the branches are very small and occasionally meet each other, fusing together to form a network. These threads are not absorptive in their function, although the smaller branches connect directly with the absorptive mycelium. They serve probably in part to store up a certain amount of nourishment, but their chief purpose is to distribute as widely as possible the fruiting bodies and to enlarge the territory from which the fungus draws its nutrition. In respect to the enlargement of the spore distribution such strands function as do the runner stems of higher plants.

Perhaps the most common of these strands and those to which the name shoestring more properly applies, are the gill-fungus strands, particularly those of the honey mushroom, which is abundant everywhere in the fall. These strands are found both in the ground and under the bark of trees. They are dark-colored exteriorly and branch profusely and, like those of the puff-balls, may form elaborate networks. The older strands look somewhat like shoestrings. They may attack roots of trees, penetrate the bark and spread under the latter to form an absorptive mycelium which is parasitic, and which may finally kill the tree. Under the bark of such dead trees one finds large networks of shoestring strands and at the base of the trunks will arise the honey-colored mushroom, which usually occurs in great clusters.

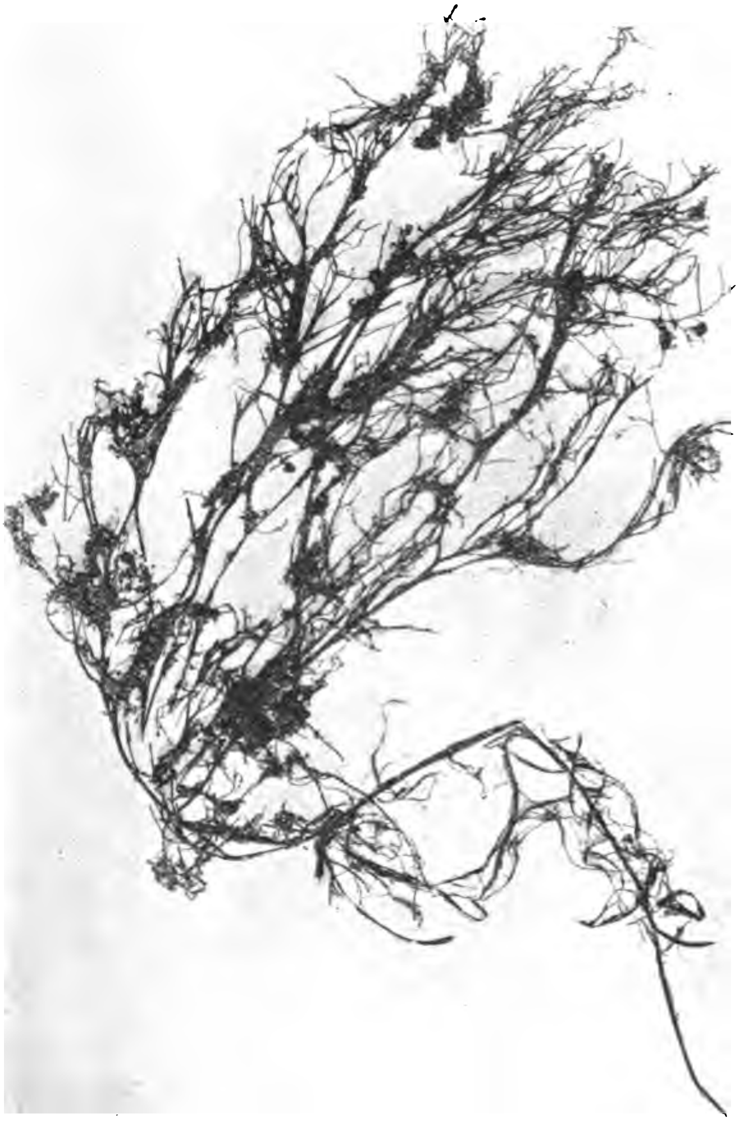


Fig. 6.—"Shoestring" strands of mycelial threads of the honey-colored mushroom (Armillaria mellea). (See also Fig. 128.) Original.

Physiology of the Mycelium. The mycelium arises from the spore by the germination of the latter. The spore sends out one or more little tubes which elongate and finally, by branching, produce numerous threads; the spore is then seen at the center of a system of radiating threads, like the hub of a wheel and its spokes. These threads soon branch profusely and now a circular, densely interwoven network is produced which keeps on enlarging, thus encroaching upon new areas of nutrition. If the spore should be placed in nutrient jelly, where its environments in all directions are alike, the resulting mycelium would be ball-shaped in outline; but if the mycelium is produced in such a place as the mold soil on the forest floor, the symmetry of the form is interfered with by various obstacles. In general, a mycelium would tend to become circular in outline as seen from above. Such a mycelium is often seen in the production of what are called fairy rings. Many gill-fungus mycelia grow from year to year and at the proper season of each year produce a crop of fruiting bodies at the surface of the ground. These are formed at the end of the mycelium and hence come to stand in a circle. One circle appears each year, becoming larger year by year.

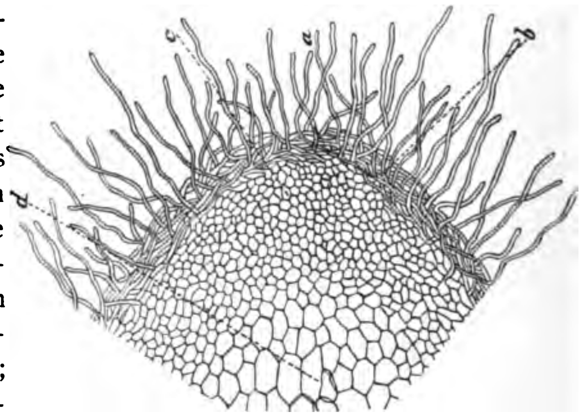


FIG. 7.—Highly magnified view of section through end of mycelial strand of honey-colored mushroom, showing compactness of central portion (c and d) and loose threads at the surface (a and b). Highly magnified. After Zopf.

The peculiar life habits of many fungi bring with them peculiarities in the development. Many fungus spores will germinate between temperatures a little above freezing, 1.5°-2°C., and 40°-43°C., but best at about 25°C. Such as are required to pass through the alimentary canal of certain animals before germinating demand, in general, higher temperatures. One of the gaseous constituents of the air, oxygen, is necessary to the germination of spores of fungi. Every housewife knows that if *all* of the air is excluded from a jar of preserves no molds will develop.

The spores of parasitic fungi will usually germinate if placed in water. They often require to be kept for a certain time and are often adapted for certain seasons. For instance, the black rust spores of wheats and grasses usually will not germinate until the following spring. A germinating spore of a true parasite must be brought into contact with its proper host, or it will soon die for lack of food. When brought into contact it commences very soon its parasitic life. The spores of many saprophytes, on the other hand, require nutrient substances before they will germinate. It is often a matter of very exact requirements as, for instance, in the case of the common commercial mushroom. It is only within the last few years that the commercial mushroom spore has been observed germinating. The continuation of the growth of the mycelium takes place at about the temperature of the germination. Light is not a necessary condition for growth, for it is not an essential in the building up of starch in fungi, as it is in the case of any of the leaf-green-bearing plants. Hence one finds fungi developing luxuriantly in caves and cellars. Light, however, sometimes influences the formation of the fruiting bodies. The food material of most saprophytic fungi is required to be of a slightly acid composition. The concentration of compounds found in the nutritive substances affect profoundly the development of the fungus. Certain fungi which develop well in a weak solution of sugar, cannot grow in a very concentrated solution, a principle which is utilized in the preserving of fruits.

Such fungi as the wood-inhabiting and insect-inhabiting forms illustrate well the method of attack of many fungi. The timber parasites and saprophytes exude from their threads a chemical substance which attacks the wood tissues and destroys the woody properties. The wood is thereby reduced to punk. Insect-inhabiting forms exude a substance which attacks and disintegrates the chitinous coverings of the insect, thus gaining entrance for the fungus to the soft parts of the insect.

The age of a mycelium varies considerably in different fungi. Some live for but a few days, some live indefinitely, being limited only by the absence of nutrition, and others again are regularly perennial. The latter include both saprophytes and parasites. The fairy-ring mushrooms are good examples of the former, while of the latter, illustrations are found in those rust fungi which attack balsam fir and other cone-bearing plants and form witches' brooms. The mycelium of the fungus causing smut of grains is of a peculiar kind. It often finds its way into the host plant when the latter is very young and tender, and continues to grow in the delicate growing parts and dies

FIG. 8.—Fairy rings of a mushroom fungus (probably a Lepiota). Photographed by Dr. F. Ramaley.

behind in the mature tissues. The examination of such a plant would show a mycelium only in the growing part of the stem. When the young grains are formed the mycelium develops in their tissues, completely destroying them and forming smut spores in their stead.

The mycelia of many fungi are capable of resisting many unfavorable conditions, reviving again immediately upon the return of propitious surroundings. Evidence of such power is seen in any woods when a heavy rain follows on a long period of drought. On all sides one finds fungi improving to the fullest their opportunity of favorable weather.

Chapter II.

Fungi. Reproduction.

The fungus method of reproduction. Fungi reproduce by means of very small bodies of microscopic size, which are known as spores.* All of the spores of fungi are not similar in origin, structure or appearance, but differ in these respects very considerably. Some spores are pinched off, as it were, of special fungus threads, often in rows, as in the summer spores of mildews. Others, again, are formed in cases, as in the small black heads of black molds; or in sacs, as in the morels and cup fungi. Again, a spore may be formed as the result of a breeding act—i. e., the fusion of two sexual elements which may be both alike or may be male and female. Some spores are provided with fine thread-like processes and by whipping these about can swim around in the water. Such spores are found in the potato-blight and in many water-inhabiting forms, as fish-molds. Many spores are capable of germinating immediately while others require a long rest period and are therefore provided with thick protective coats. The summer or red-rust spores of grass rusts commence to grow as soon as they are ripe, if the conditions are otherwise favorable, and this fact accounts in part for the rapid spread of rust in certain seasons. The winter spores of rust, or black rust, have thick protective coats and usually rest over until the following spring, when they continue their further development.

In the bread-mold and its allies, in the fish molds and in the potato-blight relatives, no complex organs are formed upon which the spores, whether pinched off or in cases, may be ag-

*The term spore might better, as is advocated by many botanists, be retained for the equivalents of the spore of the moss sporogonium and all other sporophytes. This restriction would exclude the term from the realm of fungi with the exception of perhaps the sac spores of the sac fungi and certain spores of the algal fungi, and perhaps also the sporidia of the rusts. Convenience and established usage would seem to counsel here the retention of this term in the older and commonly accepted sense.

gregated together. They are found on threads more or less loosely scattered about. In many higher fungi, however, the spore cases or sacs are borne on special structures, called fruiting bodies, though, of course, this term does not imply that they are at all similar or equivalent to fruits, as the gardener or horticulturist understands that term, when applied to parts of

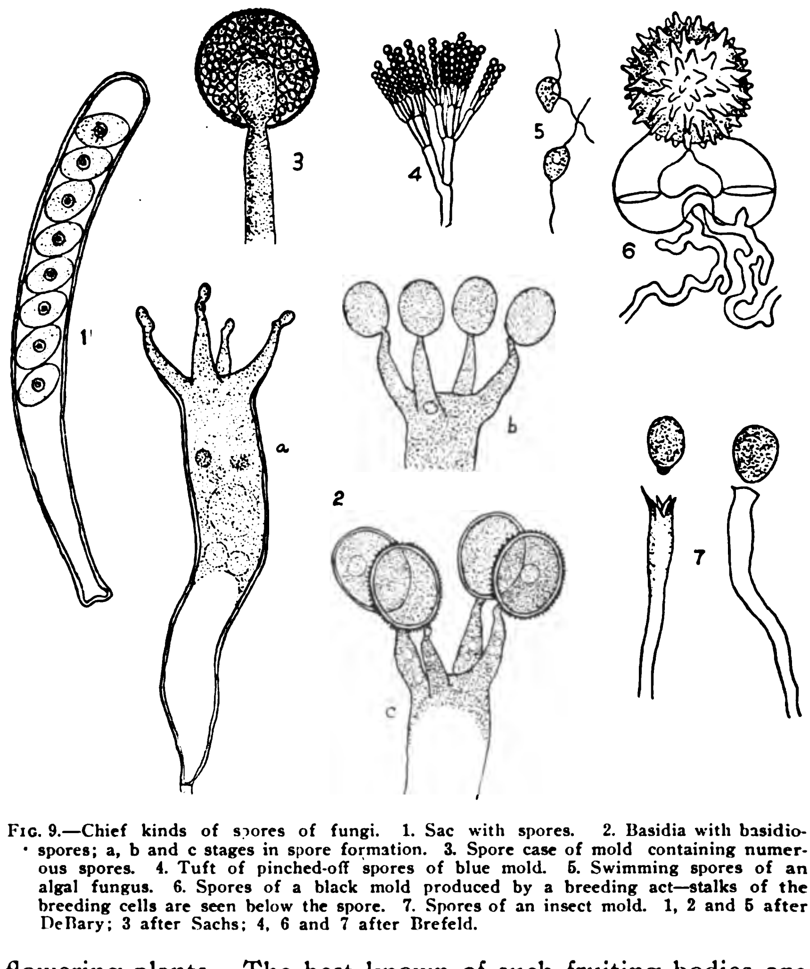


FIG. 9.—Chief kinds of spores of fungi. 1. Sac with spores. 2. Basidia with basidiospores; a, b and c stages in spore formation. 3. Spore case of mold containing numerous spores. 4. Tuft of pinched-off spores of blue mold. 5. Swimming spores of an algal fungus. 6. Spores of a black mold produced by a breeding act—stalks of the breeding cells are seen below the spore. 7. Spores of an insect mold. 1, 2 and 5 after DeBary; 3 after Sachs; 4, 6 and 7 after Brefeld.

flowering plants. The best known of such fruiting bodies are the common structures known as mushrooms and toadstools, which in typical forms are composed of a stalk and an umbrella-like cap, on the under surface of which are leaf-like plates, running from the edge to the top of the stalk. The spores are borne all over the surface of the plates, or gills, as they are termed, and the spore area is thus very greatly increased in size. Such fungi are known as gill fungi. Again, shelf fruiting bodies are produced, which have holes all over the under surface, as though pricked with a needle. The spores are formed over the entire surface of these holes or pores. These fungi are known as pore fungi. The fruiting bodies of other fungi, again, may be more or less club shaped and branched or unbranched, or they may be provided with numerous teeth as in the bear's-head fungus. The puff balls are very common objects, especially towards the fall of the year; they are closed fruiting bodies, with one or more enclosing membranes, which open by a definite hole at the top, to allow of the escape of the ripe spores. By pressing such a puff ball a dust of spores is thrown out to the wind and scattered considerable distances. Many relatives of the puff ball form fruiting bodies underground, which look somewhat like truffles. The curious little beaker-shaped structures containing egg-like objects are fruiting bodies of the "birds-nest" fungi and the fruiting bodies of the carrion fungi are still more remarkably elaborated. Here the spores are borne on the top of a very elastic stalk and are found in a sticky mass which has an odor of carrion and is much sought after by insects. The whole is enclosed in an elastic covering which ruptures only when the spores are ripe and then the stalk, previously held under pressure, is released and lifts the spore area up very quickly into the air. In the mildews, such as the common mildew on lilacs, in addition to the loosely scattered summer spores, fruiting bodies are found in the fall. They are usually very much smaller than a pinhead. Under a microscope they are seen to be little, hard, black-walled, capsule-like objects with curious appendages and containing one or more sacs of spores. The black-knots on cherry trees are fruiting bodies which contain, scattered over the surface, numerous minute, pear-shaped depressions, which are partially lined with sacs of spores. Very common in most places, on wood or on the ground, are the cups of the cup-fungi. These are fruiting bodies of various sizes with, in general, a cup or beaker shape and are often brightly colored. The inside of the cup is lined with sacs which burst open and

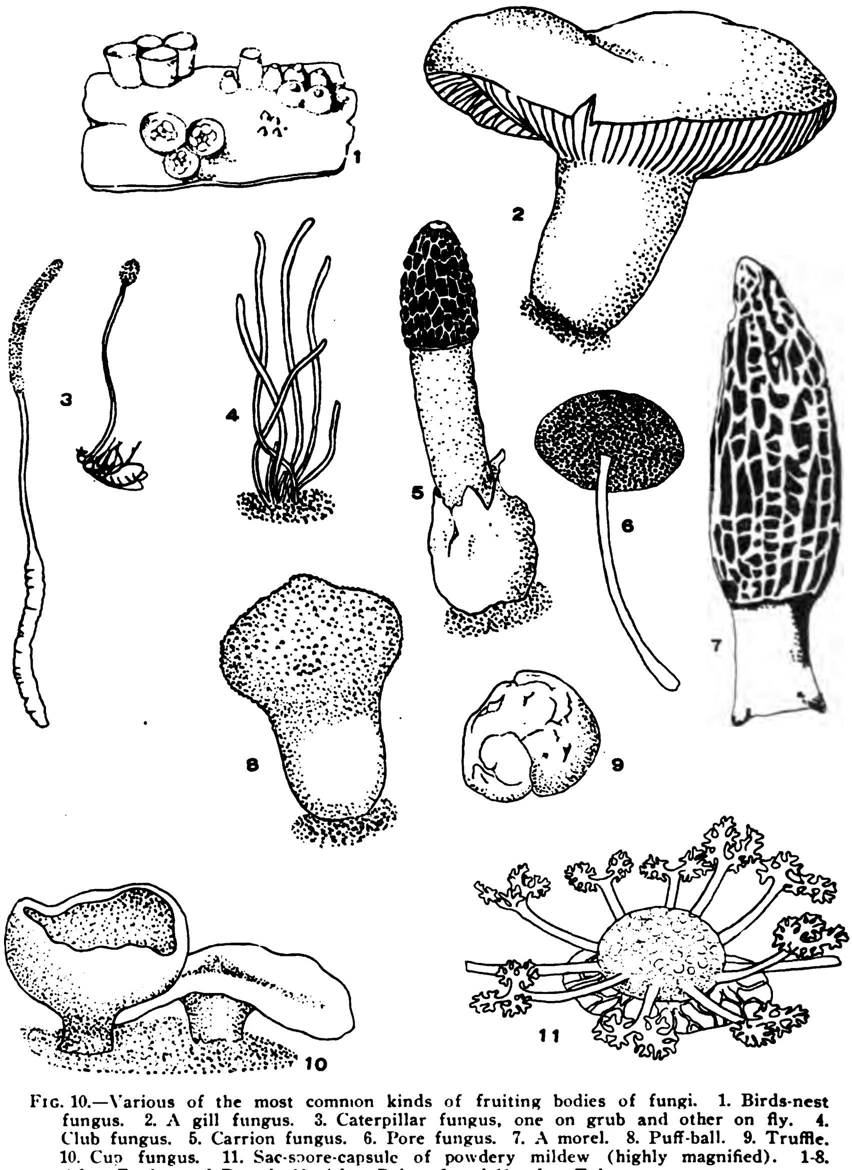


FIG. 10.—Various of the most common kinds of fruiting bodies of fungi. 1. Birds-nest fungus. 2. A gill fungus. 3. Caterpillar fungus, one on grub and other on fly. 4. Club fungus. 5. Carrion fungus. 6. Pore fungus. 7. A morel. 8. Puff-ball. 9. Truffle. 10. Cup fungus. 11. Sac-spore-capsule of powdery mildew (highly magnified). 1-8. After Engler and Prantl; 10, After Rehm; 9 and 11, after Tulasne.

forcibly eject their spores. Often by a change in the atmospheric conditions a large number of sacs burst at once and clouds of spores can be seen to ascend from the cup. The truffles have underground closed fruiting bodies which are related to the cups but never open except by decay of the walls. The morels and their allies have cups which are turned inside out, as it were, and are furthermore usually much wrinkled, and borne on stalks. Another very important phase of reproduction in fungi lies in the kinds of spores produced by a given fungus. One and the same fungus may often produce more than one kind of spore. In fact, some fungi produce as many as five or six kinds. The wheat-rust, for example, forms one or more, — commonly two,—kinds of spores in the spring, another in summer and another in the autumn and when the autumn spores grow in early spring still another kind is produced. These spore forms follow in a certain way the seasons. The mildew, for instance, has summer spores and winter spores. In other fungi the various forms may be called forth by differences in the substances upon which the fungus grows. In some fish-molds the production of the different spores can be exactly controlled by changing the food substances. Sometimes a fungus which is or has been capable of producing several spore-forms continues under certain conditions to produce only one kind of spore. Our knowledge of such a fungus is incomplete until we know the other spore-forms which it is capable of producing. There is a vast num-

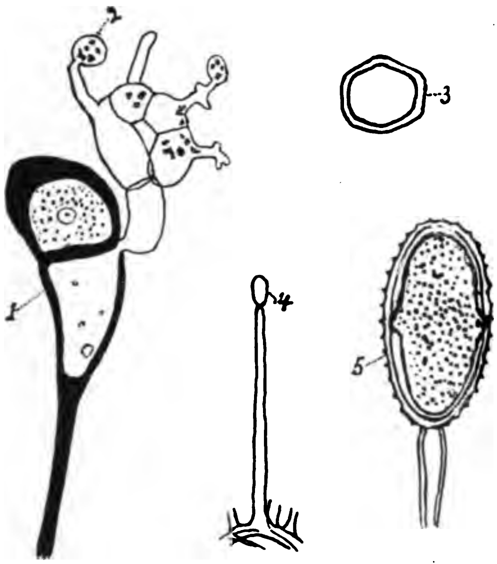


Fig. 11.—Kinds of spores produced by one rust fungus (a wheat rust) at different times. 1. Winter spore. 2. Basidiospore. 3. Cluster-cup spore. 4. Pycnidial spore (probably a functionless relic of a male sexual cell). 5. Summer spore. 1, 2, 4 and 5, after Ward; 3, after Arthur and Holway.

ber of such imperfectly known fungi, many of them being of great economic importance. They are usually designated as "Imperfect Fungi" and are classified temporarily according to a very artificial system under what are usually termed "form genera."

This selection of fungi for special substances, for the production of certain spores, and the production of different spores according to seasons, has given rise to a very remarkable phenomenon in the succession of spores. Not only may some parasitic fungi form different kinds of spores but these spores may be formed on widely different plants. The wheat rusts furnish us with the most familiar examples. The spring spores are formed on barberry or on buckthorn, or on some other plant, according to the kind of rust, while the summer and winter spores are formed on grasses. If one sows spring spores on barberry they will not develop but they must be conveyed to a grass plant before infection takes place. In a similar manner, when the winter spores germinate, the little spores which are produced on the germ threads must be borne to a barberry or buckthorn leaf before they can cause infection.

Spore distribution. Just as the seed plants utilize many agencies for the purpose of distributing their seeds over as wide an area as possible, just so do fungi utilize the same agencies for the dissemination of their spores. The fungi in general may be said to be very prodigal of their spores, so that these are produced usually in great numbers. This may be accounted for in the peculiar requirements of the spore for germination and for further development. Hundreds or thousands usually fail to develop where one or two find suitable conditions and give rise to a mature plant. A mushroom or a puff-ball produces literally millions of spores, yet from the abundance of any given kind we know that very few germinate and come to maturity. Again spores are microscopically small and hence in general cannot contain a great deal of nourishment. They cannot therefore withstand unfavorable conditions of germination for such protracted periods as can many seeds of seed-bearing plants. Many spores can pass through a very long resting period and are capable of germination at the end of this period, but after germination is begun the spore cannot usually resist unfavorable conditions; this is an important principle commonly made use of in combating fungus diseases. The spraying of fungi is most effective if carried out just after the spores germinate. Under the natural conditions of the sowing of spores, unfavorable dry periods may follow closely on a damp season, in which the spores have just germinated, and in this way undoubtedly myriads of spores come to grief.

Distribution by water. There is a great group of fungi which always live in the water or, if not actually in the water, in very moist conditions; or, as parasites of seed plants, they pass long periods in the resting condition and revive during very moist seasons, as after a rain or heavy dew. Such fungi have spores, with special mechanisms for dissemination through the water. Each little spore is provided with one or two exceedingly delicate whip-like processes which protrude from the end or side of the spore. These lashes whip about and propel the spore with comparatively great speed through the water, until it finally comes to rest and then germinates into a new plant. In this way potato blight is spread and this disease becomes epidemic only during very wet seasons. In the so-called white rust which so commonly attacks almost, if not all, of the plants of the mustard family, an enormous number of spores is found in white rust-like patches which give the common name to the fungus. These spores are formed in chains and when ripe are blown about by the wind, and are thus borne to the surface of other plants. Here they remain until very moist weather brings about their further development. They then divide up internally into numerous little swimming spores provided, as in the fish and water molds, with propelling lashes, and the chances of infection of the host plant leaves by these swimming spores are thereby many times increased. The white rust therefore uses both the wind and water in the dissemination of its spores.

Distribution by wind. The great majority of fungi utilize the wind as an agent for carrying spores. The spores of rusts and smuts are shaken out into the wind by the movement of the plants on which they grow. Their position is of advantage just as is the elevated position of the wind-distributed seeds and fruits—their radius of distribution is proportionately increased by increase of height from ground. Rust spores can be blown for great distances and still retain their power to infect plants. In this connection one sees in the structure of these spores a certain adaptation which assists in the wind sowing. The food material packed up in the spore is usually oily and is therefore light in weight. The spore-coat, moreover, has often spiny projections which enable the spore to adhere to objects with which it comes in contact. Moreover, the summer spores of rusts are often formed continuously for a long period,—throughout the summer,—that is to say, the fungus scatters its chances over a long period rather than concentrate the production into one effort. The mildews are likewise parasites with a similar habit of spore distribution. The mushrooms and their allies have learned to use the wind in sowing their spores. The stalked, unbrella-like, fruiting body raises the spores into the air and at maturity sheds them where the wind can take them up. Many shelf fungi on the trunks of trees have acquired especially elevated positions. Such fungi can be said to concentrate their efforts upon the production of an enormous number of spores for distribution in a comparatively short time and a favorable period is of course sought for this effort. The spores of mushrooms are in general smooth-coated, as they usually come to the ground before they germinate and require no special means of attachment. Puff-balls also form myriads of spores but do not shed them all at once or in such a short time. Gusts of winds, or a jar by some falling object, may force out little clouds or puffs of spores and such a puffing goes on intermittently for a long period.

Distribution by insects. Again some fungi have learned to use insects as an aid in spore distribution. A very effective device has been invented by the fungus which forms ergot of rye. Previous to the formation of the storage organ known as the ergot, the fungus forms a soft mass of much branched threads in the young grain and from these are formed summer spores. These are accompanied by an attractive sugary solution which is luring to insects and with this sugar food the latter carry off the spores, sowing them on other flowers and thus rapidly spreading the disease. The early spring spores of rusts are often accompanied by structures exuding sweet fluids that are attractive to insects and may be materially beneficial in the sowing of spores. There is a certain group of fungi, often known as the honey-dew fungi, which grow chiefly on the leaves of higher plants. They are not parasites but live on insect secretions and excreta which are deposited upon the leaves of plants. In this rich pabulum the fungi grow luxuriantly and often form very black sooty coats on the leaves. Such fungi are often specialized to the secretions of certain specific insect forms. A very curious device has been developed among the so-called birds-nests fungi—a device which has to do with the utilization of insects for the spreading of spores. The fruiting

FIG. 12.—A carrion fungus. The black head at the top of the fruiting body (lying on the leaf) is covered with a sticky solution in which spores are found. Insects, attracted by the odor, carry off this solution and thus scatter the spores. Original.

body is beaker-shaped and in the little beaker are tiny flattened egg-like bodies, in reality closed cases, the interior of which contains numerous spores. The "eggs-stalks" become gelatinous and very elastic when wetted and can be pulled out to a comparatively enormous length. These stalks probably serve to attach the "eggs" to insects' legs and later, becoming entangled in twigs or leaves, fasten the "eggs" to these objects. Germination of the spores follows immediately under favorable conditions.

Undoubted and remarkable examples of insect aid to spore sowing occurs in the so-called carrion fungi. Here the spores are found in a sticky, usually brownish mass, which is at maturity very qiuckly elevated by a sponge-like stalk to a conspicuous height. The spore-mass contains substances that emit a very strong odor as of carrion; hence the common name of these plants. This odor is very attractive to many insects and apparently the spore mass contains abundant food materiai for it very soon disappears as a result of the numerous visits of flies and other insects. In some forms of these carrion fungi pure white veil-like or lace-like mantles—in appearance much like a large-meshed Welsbach mantle — are produced. Certain tropical forms, moreover, add a phosphorescence to these mantles so that they attract nocturnal insects, and such forms open usually at or just before dusk. Certain molds inhabit the bodies of larvæ of insects, living parasitically on them. An insect thus infected may carry the fungus to a considerable distance and after death numerous spores will be formed which may infect new larvæ. The silkworm is often preyed upon by these fungi.

FIG. 13.—A birds-nest fungus. To the left are unopened fruiting bodies; to the right a section of the same; the eggs are chambers, carrying spores, and the chamber stalks become sticky when moist and probably catch in the legs of insects and are thus distributed. After Engler and Prantl, and Sachs.

Distribution by other animals. Vertebrate animals are also occasionally agents of spore distribution. Squirrels often feed on certain mushrooms thereby carrying the spores off into their holes. These fungi are the so-called wound parasites which start life as saprophytes in the dead heart-wood of trees and finally grow out into the sap-wood and kill the tree. In the well-protected shelter of such squirrel holes a wound parasite can get a good start. Rabbits and other burrowing animals often brush up against the fungus fruiting bodies of root-inhabiting forms and carry the spores in their furry coats. Truffles are probably distributed by those animals which feed on them. There is a very large class of fungi which inhabit the dung of certain animals. Such fungi often grow from spores which have passed through the alimentary canals of these animals. The near relatives of the shaggy-mane mushroom are good examples of these fungi. The common commercial mushroom also regularly inhabits dung and is therefore raised in caves from beds of manure. Many molds and many black knot allies are also constantly found upon dung. Animals are thus very potent factors in the distribution of the spores of such fungi. Woodpeckers play the same role as do squirrels, for they open holes in the bark of trees by which fungi gain entrance to a tree and boring insects are similar abettors in the attack of wound parasites.

Man is an important agent in spore distribution. In all of his commercial transactions, such as shipments of grains, introduction of plants and moving of commodities, fungi of many kinds may be introduced and spread over vast areas. The mallow rust furnishes a good example. This rust was introduced from South America less than twenty-five years ago and has since spread over nearly the whole world, becoming a great destroyer of many kinds of plants of the mallow family. The spores of many fungi lurk on the seeds of other plant parts and develop with the advent of favorable conditions. Smut spores are very good examples of such fungi for they often attach themselves to grains of grasses and when the grain germinates attain conditions favorable for their germination. This, at the same time, is precisely the best period for the infection of the grain-plant. Fungus spores or mycelia may be present in bulbs or underground parts of plants which are transported from one place to another and thus are spread over wider areas.

Explosive apparatus. In addition to these external factors of wind, insects, etc., some fungi have developed special methods of their own for hurling out spores so that these shall be scattered over larger areas or may better be caught by the wind. The cup fungi have one such device. Here the spores are formed in long cylindrical sacs. These sacs have lids at the apex and when ripe throw off the lids and spurt out the spores, together with a little drop of fluid material. Often numerous sacs blow off at once so that one sees little clouds of spores arise from the cup. The little mold fungus which causes fly cholera has also a shooting device to thrust off its spores. Each little spore is formed on the end of a thread and is finally snapped off by the protusion of the wall just underneath the spore. One sees these spores as a little halo around the fly on panes of window glass in the autumn. A very common dung-inhabiting mold has also an explosive apparatus.

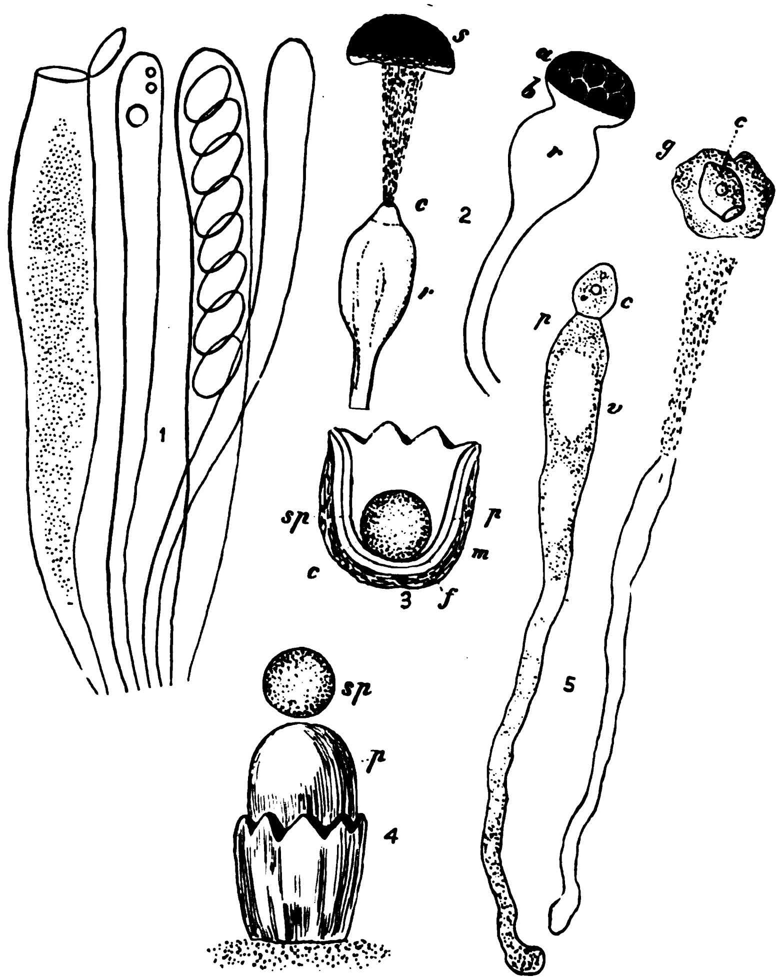


Fig. 14.—Various explosive apparatuses for distributing spores. 1. Sac fungus—spores are blown out of the sac when the lid is also blown out. 2. A black mold—the whole top of the spore case with spores is blown off; on right unopened case—on left, case is being blown off. 3. Sphere-throwing puff-ball—showing a longitudinal section with the spore mass ready to be thrown out. 4. The spore mass is ejected by the inversion of the fruiting-body coats. 5. The fly cholera fungus (an insect mold). To the right a spore has been snapped off with a small surrounding mass of sticky fluid which serves to fasten the spore to another insect. 1, after Engler and Prantl; 2, 3, 4 and 5, after Zopf.

This fungus forms numerous spores in a case on the end of a fungus thread. The thread just beneath is much swollen and under pressure, until at the ripening of the spores the whole mass of the latter breaks away and is shot off with considerable force. One of the most interesting devices is that found in the ball-throwing fungus. This is a very tiny puff-ball, little larger than a pin head. The spores are not released in a powder as is usual in the puff-balls, but cling together in a ball-like mass. The outer coats of the puff-ball burst open in star-shaped fashion and the inner coats suddenly invert, throwing the ball a yard or more into the air, reminding one of the similar methods which certain seed plants, as the common touch-me-not, utilize to cast their seeds abroad.

Spore resistance. Just as one finds great diversity in the form and method of production of fungus spores, so also may one find great differences in their powers of resistance. The presence of moisture is often a crucial factor in determining the life of a spore. The spores of many of the algal-fungi, most of which are aquatic in habit, cannot endure a dry atmosphere for any considerable length of time. This is particularly true of the swimming spores, which are peculiarly adapted to the water habit. When such spores are dried they lose their power of germination—they are dead. The great majority of fungus spores can, however, endure desiccation with perfect impunity. Such spores as smut spores have been known to retain their vitality for eight years or more in an air-dried condition. The spores of the ordinary green molds are also capable of living in dry atmospheres for a very long time. That the atmosphere of an ordinary room contains many such spores in full vigor of life can readily be demonstrated by exposing nutrient gelatine to the air, when colonies of green or blue molds will be produced in a few days. Such spores are always, after their maturity, ready for germination.

Moreover, the air-dried spores of fungi are in general capable of resisting high and low temperatures, much more so than spores in moist conditions. Blue mold spores can survive dry temperatures of several degrees above the boiling point of water. But under moist conditions they never survive this temperature; in fact, they succumb at temperatures considerably below it. The common treatment for smuts is based on this fact, for smut spores perish in water considerably below boiling water temperature. On the other hand, dry spores can endure very much lower temperatures. Very many spores of our fungi must be able to endure forty degrees below zero Fahr. to pass the winter. In fact many can undergo still lower temperatures and survive.

Conditions of spore germination. When a spore is placed under proper conditions of moisture, temperature and of other factors, it germinates, i. e., grows out into a fine thread which, if conditions remain favorable, develops directly into the fungus mycelium. By far the largest majority of fungus spores are capable of germination as soon as they are ripe, provided, of course, that such external conditions as light, moisture, etc., are favorable. Many so-called resting spores are forced to undergo a certain resting period after maturity before they can germinate. Such spores are provided with thick coats for protection. This resting period is often connected with the succession of seasons. For instance most of the rust winter spores germinate best in the following spring and cannot be made to germinate before that time. Moreover, they retain but a decreasing vitality as the following summer passes, and are usually incapable of growth in the fall. Such spores are adapted closely to the seasons. Not only resting spores but other non-resting spores may also evince such conditions. Rust summer spores are generally incapable of germination after the summer in which they are formed, though some are probably capable of surviving the winter in vigorous condition. Such adaptations are of course especially bound up in the peculiar habits of the fungus.

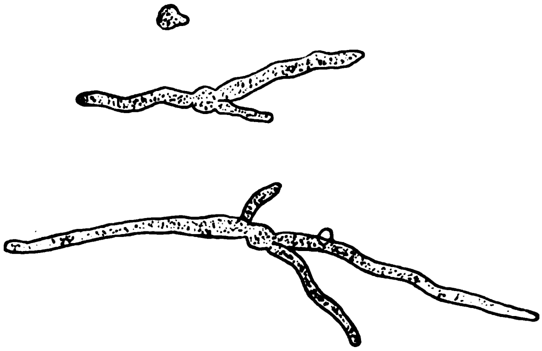


FIG. 15.—A caterpillar-fungus (Cordyceps) spore. A germinating spore at different successive stages of several hours apart. The small resulting mycelium is seen below. Highly magnified. By the author.

Chapter III.

Fungi. Fungus Life Methods.

Parasitism and saprophytism. We have already seen how fungi have adopted two methods of nutrition, the parasitic and the saprophytic. It may now be pointed out that there is associated with these methods of nutrition a further difference, viz.: that of reaction to certain impulses. When a certain parasite comes into close contact with a suitable host plant, it is attracted or reacted upon by that plant. In other words, it receives an impulse from that plant which results in certain peculiarities of growth, e. g., the sending out of sucker threads or organs, and the final result is the parasitic mode of nutrition. The saprophyte cannot respond to this impulse, no matter how closely its threads may be associated with another plant. It has not learned to respond and so is forced to obtain nutriment in other ways, i. e., in the saprophytic mode. Some plants, however, seem to have partially or imperfectly learned to avail themselves of the parasitic habit, while during the greater part of their lives they are true saprophytes. That is to say, at times in their development they may become parasitic, though they are nominally saprophytic. Such are known as half-saprophytes. Some of the blue molds and especially the wound parasites of trees furnish good examples. Again there are certain fungi which are for the greater part of their lives parasites, but which are capable of passing, even for a considerable period of time, to a saprophytic habit. Some smuts are able to do this. Such plants are known as half-parasites. True saprophytes are those whose whole life is saprophytic, e. g., most mushrooms; while a true parasite draws nourishment from its host plant throughout the life of the latter. Of true parasites the rusts furnish excellent examples.

Saprophytes. True saprophytes cannot in any way obtain their nutriment directly from living cells. But since, on account of lack of leaf-green, they are unable to manufacture starch for themselves they are forced to depend on the products of other plants or animals. Such elaborated food stuff is found in many different forms both in animal and plant remains. Saprophytes which are adapted to growth on special substances often require such materials both for development of the mycelium and also for the germination of spores. The following are the more common habits of saprophytes:

The yeast habit. The yeast are fungi which grow luxuriantly in sugar solutions of one kind or another. In nature they occur, for instance, on the ripe berries of grapes, especially where a berry has broken open and the sugary juice exudes. In this juice the yeast plant thrives. Again in the slimy fluxes of tree trunks, yeasts often grow well. The yeast plant is microscopic in size and propagates with great speed. This speed is often facilitated by the fluid condition of the medium in which the yeast is placed, because the new plants when budded off from the old can easily separate. This is not true of yeast growing in solid starch paste. The yeast usually exerts a peculiar effect upon the medium in which it lives. It exudes at the surface of its cells a chemical substance known as a ferment and this substance has the power of splitting up the sugar into two substances, carbonic acid gas, which escapes as tiny bubbles, and alcohol, which remains in the solution. The escape of these bubbles is the well known effect which is produced in fermentation, though not all yeasts cause fermentation. Preserved fruits sometimes "work," gas bubbles arising to the surface. Such may be caused by yeast plants which were allowed to get into the preserves before sealing. Two great industries are founded upon this fermenting power of yeasts. The raising of dough in bread-making is caused by the production of gas bubbles in the action of growing yeast plants upon sugary solutions, and thus bread-making is dependent upon this process. The second is the process of brewing. The ability of yeast to break up sugars into alcohol and carbonic acid gas is again utilized, but the alcohol is here the chief object of the employment of the yeast.

Water-mold habit. Almost all water molds and fish molds live in a submerged condition. Many of the fish molds are half-saprophytes, since they are capable of attacking living fish or other water animals. As saprophytes, however, the water molds obtain their nourishment from the water in which they are continuously bathed and in which organic food stuff is found in solution. In stagnant pools or ponds they may be particularly abundant. They are often sensitive to the amount of acid in the water, preferring very slightly acid water. Such plants have their food material easily accessible, absorbing it at all points of the mycelium.

Dung-dwelling habit. Very many fungi are constantly found on the dung of certain animals. Particular fungi are often to be met with only on the dung of certain species of animals and on the other hand some are almost constantly to

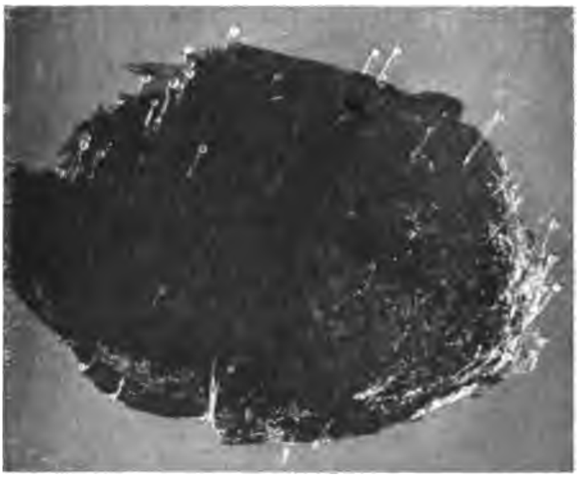


FIG. 16.—A dung-dwelling fungus (Pilobolus) of the black mold group, on horse dung. The threads, bearing spore-cases, are seen pointing in parallel directions. Photograph by F. K. Butters.

be found on the dung of these animals if placed under proper conditions. For instance, certain molds grow on fresh horse dung and almost without exception one will find this fungus if the horse dung is placed under favorable conditions of moisture and heat. There are two ways in which the fungus spores get into the dung of animals. They may fall on the dung from the air or they may be deposited with the dung, having previously passed through the alimentary canal. In the latter case they are of course taken in with the food of the animal. Many of the latter fungi have so become adapted to this passage through the canal that they require the higher temperature and the previous action of the digestive fluids of certain animals before they will germinate. Such are some of the little black "burnt-wood" fungi which always appear on horse dung when the latter is allowed to remain for several weeks under a bell jar in moist conditions. Besides these burnt wood fungi, the common inhabitants of the dung of our ordinary herb-eating animals are members of the mushroom group, the molds and the cup fungi. The specialization of many forms to the dung of certain species of animals is, of course, explained in the preference of the animal for certain foods, the remains of which in the animal dung are most favorable for the fungus.

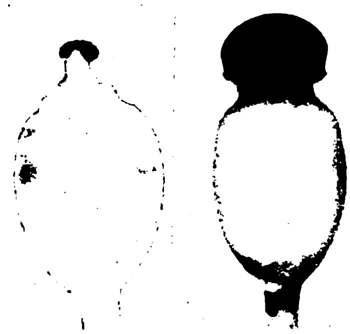


FIG. 17.—The same fungus as in Fig. 16, greatly enlarged. The spore case has a syringe-bulb thread-end, below, which throws off the spore mass. The one on the left has thrown off its spores. Microphotograph by F. K. Butters.

Earth-dwelling habit. On the forest floor or on the ground, in fields, from the thaw of early spring until snow flies in fall, one sees fungi of one sort or another. Such fungi appear to take their substance from the soil since their mycelium is branched and scattered in the earth. However, if these fungi were removed and placed in pure sand where no plant or animal remains were present, or where no substances had been leached out of dead wood, leaves or roots, and diffused through the soil, they would be utterly unable to develop. That is to say, they are unable to live in plant-free or animal-free soil, and so-called earth-inhabiting fungi in reality draw their nourishment from substances deposited in the soil or in solutions in the soil water. It is very noticeable that one finds numerous fungi in the neighborhood of old, partially decayed stumps or tree trunks, where bits of the wood have been scattered about and where the water has long been soaking through the wood. The forest floor is of course usually a humus soil, one which has been built up for inches, or even feet, by the deposit of plant debris from year to year. Often apparently earth-inhabiting fungi can be traced back to their attachment to wood lying buried in the soil, and many plants which may apparently live both on the soil and on the wood belong to this category.

FIG. 18.—An earth-dwelling fungus (Lepiota procera) of the gill fungi. Original.

Among the earth-inhabiting fungi the mushroom group is perhaps most prominent, but a host of other fungi have a similar habit. Club fungi, many pore fungi, puff balls, carrion fungi, cup fungi, and saddle fungi are found among the commoner forms.

Wood-dwelling habit. A great host of saprophytic fungi grow upon wood—on sawed timber, fallen logs and on the exposed heart wood of living trees. They constitute the great timber diseases—the chief agents of the rot of wood. Railroad ties, mine timbers, house foundation timbers, in fact, wood, wherever it is placed in continuously moist, dark places, quickly undergoes a rotting which is caused by these fungi. The wood of all our trees is subject to the attack of some of these fungi, but one kind of fungus is often confined to one kind of tree timber. For instance, the birch pore fungus is found only on birches. As a general rule, these fungi are not able to live in the bark of trees, hence they can gain entrance to the wood of living trees only through wounds in the bark. When once such an entrance has been obtained, the fungus remains in the heart-wood—which is of course dead even in healthy trees—and sets up a decay which may finally cause the tree to become hollow. Such a hollow tree may live for years, since the attacking fungi may be unable to injure the sap wood in which the living cells are found. Wood-inhabiting fungi obtain their nourishment from the wood in which the mycelium is buried. The "woody" character of wood is largely given to it by a substance known as lignin. The timber saprophyte is able to secrete a chemical which can break down this lignin just as the ferment of the yeast cell breaks down sugar. When the lignin is broken down the wood no longer gives the characteristic chemical tests for lignin. The wood has then been converted into "punk," is brittle and soft and crumbles readily. This action of the fungus is in all probability often aided by the action of bacteria. Wound saprophytes gain entrance to the

FIG. 19.—A wood-dwelling fungus (Daldinia vernicosa) on a dead stick of wood. This is a burnt-wood fungus. Original.

heart-wood through a wound in the bark but never attack the sap wood. Some half-saprophytes are capable of attacking the sapwood after an established saprophytic life—thus becoming parasitic in habit. Such fungi are known as wound parasites. They live most of their lives as saprophytes and are capable of living for an indefinite time as such. The wound parasites are dangerous enemies to forest and shade trees. The injuries and wounds through which fungi gain entrance to a living tree may be caused in numerous ways which will be more fully discussed later. Storms, hail, insects and rodents are among the more common agencies.

Leaf-dwelling habit. There is a great host of very minute fungi found on dead leaves, while the latter are still on the tree or after they have fallen. For the most part they are "burnt wood" fungi but one often finds among them small fungi of the mushroom group. In fact, most of those fungi found on the leaf mold of our forest floor are in reality leaf saprophytes. The number of such plants is very large and includes fungi of very different kinds. Most conspicuous, perhaps, are the fleshy fungi of the mushroom group which, on the undisturbed floor of the hard-wood forests in the northern part of the state, often occur in astonishing abundance. The burnt wood fungi are also very abundant.

The leaf saprophytes, as well as the wood saprophytes, are of great importance in nature's economy, for they are the agents through which the dead plant structures are gradually disintegrated or broken down until finally the constituents are again mingled with those of the soil and air. The substances are actually burned by this process until they are reduced to soil and air constituents. If this fungus and bacterial disintegration of wood and leaves were suddenly to cease all over the world the earth's surface would quickly be covered with the debris of leaf-green plants and its physiognomy would be vastly changed. Many of the plants of this day would require important alterations in their habits and form to survive such a change, as they would at present be unable to exist among the fast accumulating debris. Plants of low stature on the forest floor would probably succumb first and if one imagines the process to continue indefinitely only the taller plants would survive. These saprophytes are therefore of great economic importance in two ways. In man's narrower economy they are directly injurious in the enormous losses sustained in the decay of woods and timbers. In the broader economy of nature they are of inestimable value for they are the garbage-destroyers which keep down the accumulation of plant debris. As such their use vastly outweighs those effects detrimental to man's interest.

Bees-nest-dwelling habit and others. Certain fungi, whose near relatives are the blue molds, are often found on nests of bees and wasps. They have learned to utilize for their nourishment the material of which the nest is made and so well have they learned this method that they are unable to thrive on any other material. One therefore finds certain fungi confined to such material. Other fungi also related to the blue molds are found on horn. They are able to produce a horn-destroying substance which makes the horn material available for the fungus food. One finds such fungi on old cattle horns, or horses' hoofs, and it is only on such substances that they are found. Again, certain fungi occur on bones and still others on feathers. One of the most common of the feather-inhabiting fungi is also a blue mold relative.

Fungus-dwelling habit. A very common habit among fungi is that of living on other fungi. This is especially the case among those molds which live on plants of the mushroom group. A mushroom placed in a closed moist chamber will soon be covered with mold-growths of various kinds. These molds are for the most part truly saprophytic, though some are capable of parasitism during a part of their life history.

Honey-dew-dwelling habit. There is a great group of fungi which are known as "honey-dew" fungi and for the most part belong to the "burnt wood" groups. They are true saprophytes and live on the excretions and secretions deposited by various insects upon the surfaces of leaves and twigs. They often show an exact selection for the secretion of certain kinds of insects. A fungus of spongy appearance, for instance, always appears on the woolly aphis secretions. After the death of the insect the dead remains of the body become incorporated with the secretions and the whole forms a mass in which the fungus thrives. The mycelium of such honey-dew fungi is usually black in color and looks like partially burnt wood. These fungi are usually true saprophytes and do not attack the living leaves or plant parts on which they develop. They may, however, grow in such abundance on the surface of the leaves that they cut out the light and hence injure the plant by prohibiting the leaf in its starch-making function. The secretions of insects, especially when the latter are abundant, are often evenly distributed over leaf surfaces and hence the fungus may become very evenly and abundantly distributed over the foliage.

Food-mold habit. It is the common experience of every housewife that bread and cake, and starchy material in general, is subject to molding. Such molding is due to the presence of certain fungi known as black or bread molds. They develop on all kinds of starch foods and especially where these are kept moist, as often happens in improperly ventilated bread boxes. Such fungi will commonly grow in sugar solutions. The molds of preserves are also common enemies of the housewife. These are for the most part fungi of the blue or green mold group. When fruit is preserved in jars spores of such molds are introduced with the fruit and those near the lid have access to the included air or to air which leaks in through imperfectly fitting covers. These spores develop into the blue or green mold plants and produce the scum which is so often found under the jar covers. When paraffin is poured on preserves it forms a close-fitting, air-tight cover and does not allow any molds to develop. It is well known how cheese when allowed to remain under moist conditions for any length of time will produce, especially on the rind surface, green patches of mold which, unless removed, increase in size until they cover the whole cheese. This mold is a saprophytic fungus and the green color is due to the millions of spores produced on much-branched threads. Green molds are purposely cultivated in certain kinds of cheese to which they impart peculiar flavors.

"Mildew" of clothes. When moist clothes are left in closed, badly ventilated receptacles for any length of time they "mildew" or get moldy. This condition is due to the growth of fungi which feed on the cotton or wool fibers. It is only under moist and undisturbed conditions that such will grow. An airing dries out the cloth and the fungus perishes. Moldy clothes have usually lost their firmness because the fibers have been partially disintegrated and weakened by the fungus.

Egg-inhabiting fungi. Not all rotting of eggs is caused by fungi, as bacteria are chiefly responsible for these processes. Mold fungi, however, do occasionally penetrate, especially through the cracks in the shells, and live saprophytically upon the albumen. The latter makes an excellent nutrient material and the fungus usually thrives here though it cannot form any spores unless air is admitted. The keeping of eggs in lime or in cold storage serves the same purpose—the prevention of the development of fungi and bacteria.

Half-saprophytes. Intermediate between pure saprophytes and pure parasites are those fungi which can live under either conditions of life. Some are, however, typically saprophytes and are usually found growing under saprophytic conditions, but are capable of parasitic life under other conditions. As a rule, such fungi do not show any great specialization or exact selection in their parasitism. They are not confined in their parasitic life to certain specific kinds of host plants but often attack plants of widely related groups.

Ripe rots of fruits. Many of the fruit rots are due to fungi of this class. Some of the green molds and also of the bread molds are able to penetrate the thin skin of some fruits and attack the living cells within in the manner of a parasite. In the killed portions the fungus continues to live as a saprophyte. The living substance in most fruits is at the time of ripeness practically dormant and contains a great deal of food material, both of which conditions serve to make it easier for those fungi, which have not yet learned thoroughly, but only in an amateurish way, the parasitic life, to obtain nourishment. The low vitality of the fruit-cell protoplasm is insufficient to ward off the attack and the large amount of nourishment is an alluring reward. Hence these molds may live for a short time as parasites and then continue their saprophytic life. In fruits a great deal of sugar is stored up and this furnishes the nutrition. The fungus gains entrance through thin-skinned fruits or through cracks in the skins. Those with thick skins are capable of warding off such fungi. Bruising or crushing of berries or fruits may not only injure them so that the fungus can gain entrance, but exuding juices will often furnish nutrition where the fungus can build up a strong mycelium from which the attack upon the uninjured parts may be better carried on.

Damping-off fungi. Another half-saprophytic habit is that of the damping-off fungi. These fungi are usually found under very moist conditions and feed upon plant and animal debris in the water. One of the most common of these fungi (Pythium debaryañum) requires a very considerable amount of water for its development. When it comes into contact with seedlings, especially of the mustard family, it is capable of attacking the young plant at about the surface of the ground and kills the tissues. The plant falls over and dies. In this way whole beds of seedlings may be destroyed in a few days. This fungus is never able to attack old plants. The weakness of the seedlings lies in the fact that the living substance is not yet protected by thick coats of cork and cuticle as it is in the older plants. When the seedlings have been killed, the damping-off fungus continues to live as a saprophyte. The fungus is not a highly proficient professional in its parasitism for two reasons: First, just as do the mold fruit rots, it exercises no particular selection for special kinds of hosts, but will attack almost any plant in the seedling stage; and, second, it kills its host as soon as it penetrates, thus preventing any further service which the host might pay to its parasite. Rusts and smuts, as we shall see later, are much more proficient in this habit of life than is the damping-off fungus.

Wound parasites. Perhaps the most important of all half-saprophytes are those which have already been mentioned under wood-inhabiting fungi as wound parasites. These fungi are usually found on dead wood. The bark of trees ordinarily refuses to them entrance to the tree trunk, since the fungus threads are incapable of forcing their way through layers of cork. When, however, a wound occurs which lays bare the wood, this difficulty is overcome and the fungus thrives in the heart-wood. After building up considerable mycelial strength in its saprophytic life it proceeds to attack the growing zone of the trunk, i. e., where the sap wood joins the bark and where the living substance is protected by very thin walls. The host

FIG. 20.—A wound parasite (young specimen of Pleurotus ulmarius). The fruiting bodies are formed in a knot-hole of an unpruned tree. Original.

is thus slowly killed and the fungus continues to live on in its saprophytic way. The wounds, through which these fungi penetrate, may be caused in many ways: the breaking of branches in storms, or the wounds by falling trees, the rubbing together of trees swayed by the wind; injury by cattle and deer; lightning strokes; frost cracks; hailstones, sun scalds, holes of woodpeckers, squirrels, boring insects; injury to roots by burrowing animals. Moreover, man himself is responsible for many such opportunities for wound parasites, chief among which are the wounds of shade and orchard trees in pruning. Such wounds should be covered with tar or some other substance which will prevent the development of the fungus mycelium. Of the wood parasites by far the greater number are allies of the mushroom group. Gill fungi and pore fungi and a few burnt-wood fungi are also found in this class. The best known is the common fall- or honey-mushroom which occurs in clusters at the bases of stumps and trees in the autumn. Many of the very common "shelf fungi" are also in this class. Not all half-saprophytes are dependent upon wounds for their entrance to the tree trunk. A few such, as the honey-mushroom, may gain entrance by attacking the smaller roots with a shoestring-like strand composed of thousands of threads. The latter penetrate the bark to the growing layer just beneath. They then enter upon a parasitic life and make their way up through the roots to the stem. In this way the fungus can proceed from one living tree to another and cause epidemics.

Chapter IV.

Fungi. Plant Partnerships. Parasitism.

Equal partnerships of plants. Plants often live in very intimate relationship with each other. Sometimes this intimacy works out to the injury of one and to the benefit of the other. It may result in benefit to both partners or in what may be called an equal partnership of plants. When two plants find such an intimacy beneficial they may learn to modify their

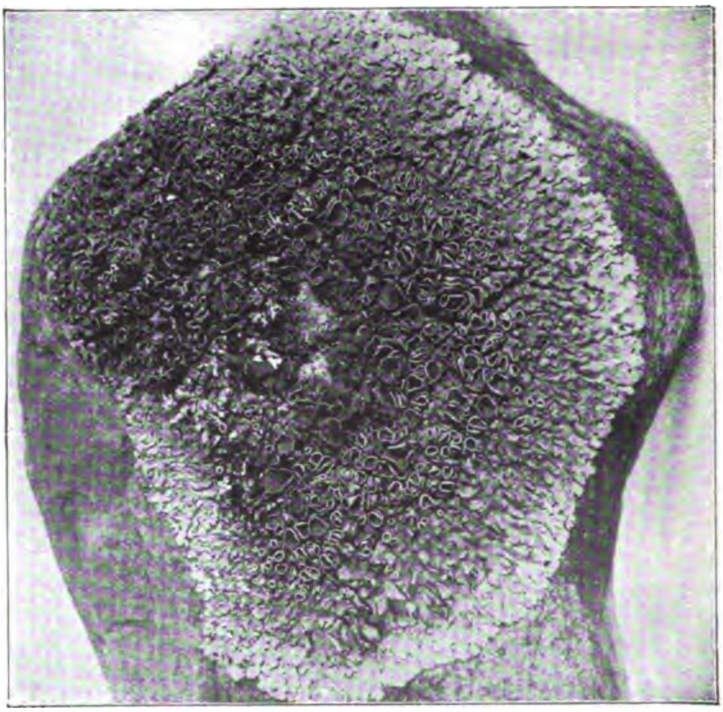


FIG. 21.—A lichen. A plant with equal partnership of fungus and alga. After Atkinson.

habits and even their structure in such a way that both may relinquish the fulfillment of some duties and will depend on the partner for the accomplishment of that work. In this way the two plants may work as one individual, one unit, though really composed of two plants. Such are the organisms known as lichens, which occur in abundance as flattened crusts on rock surfaces or on the trunks of trees. Each lichen is composed of a fungus and an alga. The algae are for the most part relatives of the flower-pot algae, while the fungi are almost all relatives of the cup fungi. The little green algal spheres are enclosed in dense wefts of the fungus threads. To the former is assigned the task of starch-making on account of the leaf green, to the latter the task of protection and also of the absorption of mineral salts from the soil. Together the two plants thrive, while, if separated, the fungus at least would perish and the alga would probably not thrive so well. This partnership is therefore of benefit to both plants and the result has been a unifying of two organisms into one. A somewhat similar living together is also encountered among certain plants and animals, e. g., the little wheel animalcule which is always found in the small cup-shaped portions of certain leaves of one of our common liverworts. The cup furnishes a protected harbor for the wheel animal and the plant probably derives nitrogenous food from the animal, and thus a living together on equal terms is effected.

Unequal partnership—host dominant. The number of equal partnerships among plants is of comparatively rare occurrence. In a vast majority of cases one partner becomes dominant and the benefits are shared unequally, if not entirely appropriated by the dominant party. In a very few of those very numerous cases when a fungus and a leaf-green plant enter an unequal partnership the leaf-green plant is dominant, and what might be termed nutrient parasitism arises. In such cases the fungus derives nourishment from the soil and transmits it to the host plant, getting, as far as one can see, no benefit in return. In other words, these fungus partners of leaf-green plants behave much as do the tiny absorbent root hairs which are commonly found on the roots of leaf-green plants. Most of our native orchid plants as well as many foreign members of the same family possess such a fungus partner. Some of these orchid plants show no external evidence of the possession of fungus partners, still retaining their leaf-green in undiminished quantity. In other cases, where the orchid plant has learned to derive more of its nutrition from the fungus partner, it may economize in its own structure and labor and dispense with some or all of its leaf-green. As a matter of course, the leaf-green organ would also be reduced. Such plants have a yellowish appearance with little or no green color and the leaves are mere bracts. The well-known coral-root orchid is an excellent example of such a plant. The little plant known as Indian-pipe is an even more conspicuous example. It is a little forest-floor plant, whose relatives are members of the blueberry family, and has formed a very effective fungus partnership. So great have its profits become that it has entirely dispensed with leaf-green and derives all its nutrition through the fungus in its roots. The leaves consequently are reduced to mere colorless scales and the whole plant has a pure white appearance. There are many other plants, however, which have fungus root-hairs but which have not yet abandoned their leaf-green apparatus for starch-making. They may also possess ordinary root hairs in addition to the fungus. For instance, many oak trees, and perhaps most plants of the heath family, possess a subservient fungus root partner. Further investigation will probably show many more plants with this same device, as the list is constantly increasing.

Bacteria and bacteria-like plants are also met with as subservient root partners of the green plants. Such are the organisms of the root tubercles which are so commonly found on the roots of plants of the pea family. These bacterioids are capable of converting nitrogen, one of the unavailable gaseous constituents of the air, into an available compound, and thus prove of great benefit to the host plant. Often special structures are formed upon the roots by the stimulation of the fungus or bacteria and in them these organisms are found. Such structures are usually tubercle-like bodies, as in the clover roots; or they may be dense, grape-like clusters of tubercles, as are found in the roots of alder trees.

In recent years it has been asserted by a French botanist that the well-known potato tubers, which are swellings of the underground stem of our common potato plant, are due to an infection by a certain fungus. This infection is said to be followed by the excessive growth of the stem at the infected points. In many of these unequal partnerships we find again the welding together of two organisms into one individual, a phenomenon comparable with that in lichens, but with a different final result, at least as far as nutrition is concerned.

Unequal partnership—fungus dominant. Parasites. An overwhelming majority of the partnerships between fungi and leaf-green plants result in exclusive benefit to the fungus, and this condition is usually designated as parasitism. The host is subservient and the fungus is dominant. It may not be the entire host, though this is so in some cases, that is robbed of nutrition, but special parts only may be attacked and forced to nourish the fungus. From the standpoint of the host plant it may be termed destructive parasitism or simply parasitism in the narrower sense. The destructive effect is the ultimate effect received by the host plant as a unit. The immediate effect of such parasitism may be very local and may be in the nature of a stimulation. Moreover, the living together of a parasite with special parts of its host often produces again, as in the lichen, an essentially new individual composed of the fungus and the host plant-part.

Witches'-brooms. Such "individuation" is best shown by the structures known as witches'-brooms. Many of our common trees are attacked by certain fungi, the latter chiefly rusts, whose mycelium becomes confined to a certain well-marked region of the host plant. This part of the host behaves in a peculiar manner. The branches are usually larger than normal, are more numerous, and often, again, profusely branched. The whole mass of branches looks like a little bush growing parasitically on the host. Moreover, the bush usually arises from one point on the host plant and the main branch of the bush, although it may be a lateral branch of the tree, behaves as though it were the leader and grows straight up in the air. This brings the bush still more into prominence and demonstrates the individualistic character of the broom. Such bushes are known as witches'-brooms. The branches usually bear leaves which fall early and are often yellowish, having lost some or all of their leaf green. This serves to point out another important feature of the broom, viz., that, as an individ-

Fig. 22.—A large witches'-broom on white pine (cause of broom unknown). Photograph by R. S. MacIntosh.

ual, it is living parasitically on the remainder of the host plant. That the broom itself is not injured, but rather stimulated, in its growth is seen by the production of such numerous and large-sized branches. But the ultimate effect upon the whole

FIG. 23.—Witches'-broom on balsam fir, caused by a rust fungus (Aecidium elatinum). The branches of the broom are vertical instead of horizontal, as are the normal, undiseased branches in the right of the picture. Original.

plant is injurious because the normal balance of nutrition and work has been interfered with for the rapid production of a group of larger but worthless branches. In a word, therefore, the witches'-broom may be described as a bush- or broom-like individual, formed by the partnership of a fungus and certain branches of the host, and living at least partially as a parasite upon the remainder of the host plant. It behaves as does a parasitic mistletoe plant and is not unlike it in appearance. Most of the witches'-brooms of Minnesota trees are due to rust fungi. One of the most common is the birds-nest broom upon red

FIG. 24.—Witches'-broom on white spruce, caused by a mistletoe (Razoumofskya pusilla). The spruce is badly affected. Numerous brooms are seen below and the whole upper part of the tree is broomed. (See also Fig. 25 and Fig. 101.) Photograph by author.

cedars. These brooms occur in great numbers in many parts of the state and look like crows' nests in the distance. The branches are very numerous and the broom stands on a lateral branch like an independent plant. The leaves are not like the ordinary leaves but are larger and very spiny, and stand out from the branches just as do the leaves on a very young plant of red cedar or in a similar fashion to those of the common juniper. At the bases of the leaves may be found in spring the brown cushions of spores. Another very common broom, especially in the northern part of the state, is that on the balsam fir. This broom is much larger than that of the red cedar and the branches are often very long and wavy and are thicker than their sister unbroomed branches. The leaves are thickish, and are yellowish in color and fall very early, never lasting as long

FIG. 25.—An enlarged view of a broom on the spruce shown in figure 24. The distorted bush-like appearance of the broom is very marked. The mistletoe plants can be seen on the smaller branches. (See Fig. 101.) Photograph by author.

as the ordinary leaves. It is clear that the broom must derive most if not all of its nourishment from the neighboring parts of the fir tree. Such brooms may become ten feet or more in diameter. The fungus partner of this broom is also a rust fungus and the spores are produced in great abundance in late spring or early summer. Another common broom is found on cherry trees. Almost any kind of cherry is subject to brooming. The broom branches are usually very numerous and the leaves do not acquire the usual regularity of form but are often distorted. This is especially noticeable where the fungus partner forms its spores. The latter are produced usually on the lower surfaces of the leaves over which a grayish filmy coat spreads. This fungus belongs to the sac fungi and is a relative of the cup fungi. Although it produces no cups yet the spores and sacs are arranged in a similar fashion. Birch trees sometimes carry brooms which are caused by fungi of the same group.

Witches'-brooms are not always caused by fungus attacks. Insects are sometimes also able to produce them, but in many cases the origin of the broom is unknown. In the latter category stand the brooms which are sometimes found on pine trees, occasionally attaining a diameter of over ten feet.

Other examples of individuation. Witches'-brooms are not the only cases of the building up of a physiological individual from a fungus and a part of its host. Swellings are often produced on pine trunks which are five times the thickness of the adjacent part of the trunk. Such swellings are caused by a parasitic fungus and may be considered again as individuals which are living luxuriantly at the expense of the host tree. Burls on trees are by no means uncommon though their origin from a fungus infection is not always clear. In many cases their origin is unknown. Again, such tubercular swellings as are found on Indian corn, where smut later arises, are in reality favored individualized parts of the corn with a fungus partner. Large galls form in allies of the blueberry plant upon leaves and stem, and these galls are also of fungus origin. A larger number of examples might be cited but enough have been mentioned to illustrate the individuation of fungus with plant parts in a parasitism which is ultimately detrimental to the host plant. In most cases of parasitism of fungi the host plant does not in any way show a stimulation of the affected parts and the absence of any difference in the action of the affected and normal parts indicates a low degree or absence of individuation. It is worthy of mention here, however, that parasitic fungi in general thrive best on healthy plants rather than on weaklings.

though some weak points in the plant organization may be responsible for the successful attack of the parasite, as has been experimentally proven within the last year. In other words, the most successful parasitic fungi are those which can stimulate the affected parts of host plants to extraordinary effort, or at least do not immediately injure those parts.

FIG. 26.—"Birds-nest" witches'-broom on red cedar caused by the birds-nest rust fungus (Gymnosporangium nidus-avis). The bush-like broom stands vertical on the horizontal branch of the host. The difference between the diseased and healthy leaves is very marked. The former are very similar to those of the common juniper. Original.

Degrees of proficiency in parasitism. The simplest modes of parasitism are undoubtedly to be met with in those half-saprophytes which are just learning the methods of parasites. Some of these have already been described in certain mold fruit-rots. Such a beginner can only obtain its food from living substance which is in a resting state and which approaches most nearly the condition of dead proteid material. Moreover, such protoplasm contains much nutrient material. The fungus kills as soon as it comes into contact. It has not acquired any particular choice for specific kinds of hosts but attacks almost indiscriminately. The damping-off fungus is another amateur parasite, though it has carried a little farther its ability to kill. It is able to attack vigorously growing parts, as seedlings, but, like the fruit molds, does not exercise any well-marked preferences in its selection of hosts, i. e., it may attack almost any seedling. The beginnings of such a preference are indicated in the great frequency with which it attacks seedlings of the mustard family. The wound parasites of trees show likewise a low degree of parasitic efficiency. They require a mycelium well established by previous growth in the heartwood before they can successfully attack the living part of the tree.

When, now, we examine the powdery mildews, e. g., the powdery mildew of lilac bushes, we find an improved method of parasitism. The fungus does not noticeably injure the host, though it is of course detrimental to it even when the results are not evident, and in some mildews the results are obviously disastrous to the host. Moreover, the parasite requires special hosts and a given mildew is found only on one kind of host, or only on plants which are very close relatives and so furnish very similar materials. In other words, the mildew is more select in its choice of food than the damping-off fungus, and its method of attack is more complicated and exact in its detail.

Now, if one considers the parasitism of the smut fungus, e. g., the smut of corn, one sees again an improvement in parasitic methods. In the first place the fungus has refined very much its selective power for food and can now only exist as a parasite on corn, and is unable to live on any other plant even of the same family. But when it has once established itself upon its host it does not immediately destroy the attacked portion of the plant, as would the damping-off fungus; neither is it a passive passenger, as is the mildew; on the contrary, it stimulates the part of the corn plants on which it lives and causes that part to grow abnormally larger at the expense of the rest of the plant. Then arise the carbuncle-like swellings of the leaves. If a kernel of the cob is attacked it increases perhaps tenfold in size. During this increase of size the fungus is also gaining strength and keeping pace with its partner plant-part, and when the proper moment has arrived for the formation of its spores it proceeds rapidly and utilizes all the extra food stored up by the swollen host plant-parts and destroys the latter rapidly. Such a parasite stimulates its host to unusual activity for a long time and at the same time prepares to use to best advantage all of the nutrient material laid up by the host, delaying its destructive effects until the most advantageous moment. Sometimes, as in oat smuts, the presence of the fungus is not determinable until harvest-time, when the fungus forms its smutty powder of spores in place of the grain. This is a very efficient method of parasitism but, in some respects at least, the fungi producing grain rusts are even more capable. The smut produces but one kind of spore on its host plant and that is a resting spore for tiding the fungus plant over the winter season. The rust fungus can produce spores from early spring to autumn and is able to do this by forming different kinds of spores at different seasons. Such a rust will produce a spring spore, a summer spore, and in autumn a so-called winter spore, the latter having the same function as the spore of the smuts. This continuous production of spores is of course a very efficient device. In addition to the multiplicity of spores the rust fungi often possess the stimulating powers already mentioned for smuts. Such have also been described in witches'-brooms of red cedar and balsam fir. In the simpler

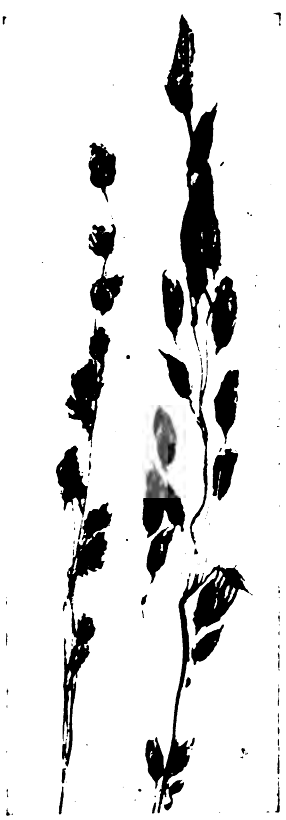


FIG. 27.—Oat smut—an accomplished parasite. After G. P. Clinton.

cases of rusts all of the spore forms are found on the same kind of host plant and it is now a well-known fact that the rusts are extreme specialists in the selection of their hosts. So exact has this selction become that certain rusts will attack one grain plant and are unable to attack other even closely related grasses. In this respect they are among the most proficient of all known parasitic fungi. Still further complications may, however, arise. A rust fungus may increase its distribution by selecting in the spring time another earlier plant for a host, and produce upon this plant its spring spores. This migration is the expression of one phase of the education of the most highly educated plant parasites known to botanists of today. In view of these and other accomplishments of these fungi one has little hesitation in pronouncing them the most proficient parasites amongst the fungi.

The modes of life of parasitic fungi. In general, there are two methods of life. The fungus may live on the surface or it may live within the tissues of the host plant. The powdery mildew of lilacs lives on the surface of the leaves while the smut of oats lives inside the tissues of the oat plant. Those fungi living in the tissues of their host, however, come to the surface when they are about to produce spores. The surface-dwelling fungus may derive its nutrition in one of two ways: it may send special threads into the living substance of the host and through these sucker-threads draw nourishment, or may merely attach itself to the surface of the plant and never send threads into the living substance. It is clear

FIG. 28.—An endophytic (internal) mycelium between the cells of a grass grain. (Fungus of Lolium temulentum.) Highly magnified. By the author.

that in the latter case the nutrient material must first pass through the walls of the host plant before it can be taken up by the fungus thread. The interior-dwelling fungi may get their nourishment in several ways. In many, special sucker-threads are sent into the living substance of the plant. In other cases the fungus threads run between the cells of the tissues without ever coming into direct contact with the living substance. On the other hand, fungi may gain entrance to the cells and live entirely within them. Such is the common method of many very minute water fungi. The sucker-threads of the various fungi differ considerably in shape and often furnish important marks of distinction, since each fungus may

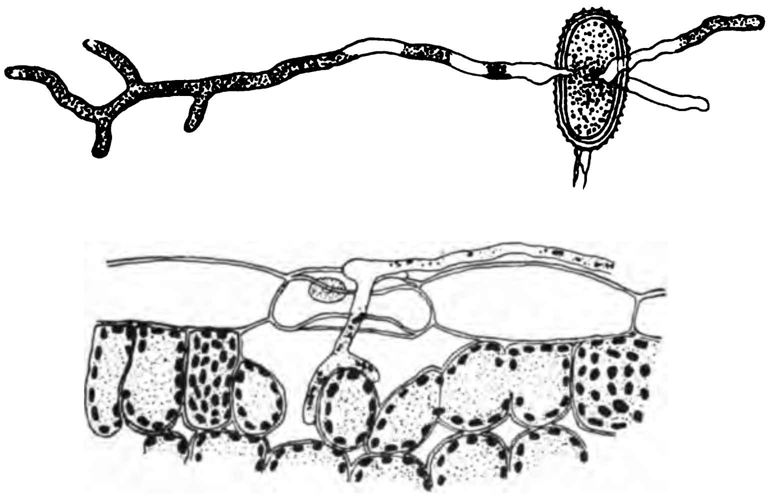


FIG. 29.—Infection of a grass leaf by a rust fungus (wheat rust). Above is a summer spore showing germ-tubes. Below is a germ-tube entering through the pore of the leaf and is reaching down in the internal part of the leaf where it soon becomes well established. After Ward.

have its own peculiar form of sucker. The simplest are little cylindrical unbranched threads. Again, they may be small tubercular hyphae; others are branched to form a stubby-fingered, hand-like system of threads. In still other cases the suckers may be very much branched and the branches may be coiled up into dense mats entirely filling the cell of the host.

Methods of attack. When the spore of a parasitic fungus falls on the leaf of a host, it awaits favorable conditions for further development. When the moisture and temperature and other conditions are most favorable the spore sends out a thread which in many cases grows directly to a ventilating pore of the leaf and enters through this pore. In many cases, however, it is able to bore its way through the walls and thus penetrate to the interior. Special threads may be developed to fasten the germinating spore to the host plant. This is accomplished by minute disk-like ends similar to little rubber vacuum cups. Abundant hairs on the surface of a host plant, or a very thick cuticle, may lessen the danger to the host of fungus attacks. Some fungi select certain periods in the growth of the host during which the latter is less able to ward off the attack. Such is seen in the oat smut and damping-off fungi, which attack seedlings, or again in the wounded trees where a fungus gains entrance before the tree has had time to close a wound in the normal manner. Since the selection for a time for attack is in many cases of great importance to the fungus, the latter usually forms its spores to coincide with this favorable time. Fungi which attack the trunks of trees are usually unable to penetrate the bark unless aided by wounds of some sort, but they may occasionally penetrate through the ventilating holes. Mention has already been made of those fungi which require previous preparation for attack, as is the case in many of the wound parasites.

The living together with special plant-parts. Parasitic fungi do not usually live together with all parts of their host plants but confine themselves to certain organs, or at least show preference for certain plant-parts.

Leaf-inhabiting parasites. Perhaps the most conspicuous and common are those which prefer the partnership with leaves. Most rust fungi are of this class; most mildews, blights, leaf-curls and that great group of imperfectly known fungi which commonly form the so-called leaf spots. The foliage leaf is usually selected by the fungus, though more rarely the scale leaves or floral leaves may also be attacked. Sometimes, as in the leaf-spot, the fungus only inhabits a small portion; in others it may pervade or cover the whole leaf. The leaf-dwelling parasites are perhaps the most destructive of all fungus parasites, both on account of their number and their effect upon the starch-making machinery of the plant. The ease with which the fungi develop in the leaf-tissues is perhaps explained by the fact that, on account of the great air-spaces inside of the leaf, the fungus can easily obtain the air gases which are necessary for its development; secondly, that these spaces are always more or less moist on account of the water vapor given off by the leaf tissues; and, lastly, they are not too highly illuminated by sunlight. The interior of a leaf, therefore, furnishes excellent opportunities for fungus development and many fungi have availed themselves of these opportunities. Moreover, the fungus can often gain easy entrance through the air pores on the leaf surface. When a leaf-fungus dwelling in the interior is about to produce spores, it forms the latter usually at the surface of the leaf. Sometimes, as in the potato-blight allies, it shoves the spore-bearing threads out through the air pores, but this is not the method in the rusts Here the leaf surface is broken open, splits out, and the interiorly formed spores reach the air through the split. Of course such an injury, minute though it may be, really injures the leaf by the interference with the leaf control of water vapor. A large number of such wounds, together with the injury by loss of nutrition to the fungi, may cause the death of the leaf. The spores of the fungi usually appear as a powder or cake uncovered by the upheaval of the leaf surface tissues. In some few leaf-fungi the spores are formed internally and are only released by the decay of the leaf.

Stem-inhabiting parasites. The stems of plants furnish another favorite abode for parasitic fungi. In the stems of herb-like plants the fungus problems of entrance and life are not very different from those of the leaf except that the tissues are firmer. Hence we find many rusts capable of living either on the leaves or stems of a given host plant. But in woody plants, as in shrubs and trees, the fungus meets with new difficulties in the nature of a thick layer of bark which must be penetrated before the living part of the stem can be reached. Moreover, the compactness of the tissues and the resultant absence of larger air-spaces do not make the stem such a congenial dwelling place as is the leaf. In such woody stems, therefore, we find almost exclusively those fungi which are capable of breaking down woody tissues and feeding on them. It has already been stated that these fungi must usually depend for entrance to the stem upon some wound, which will remove the protecting cork layer from the wood. Many burnt wood fungi inhabit stems both herbaceous and woody. On the latter are very often found the gill fungi or mushroom allies and the pore fungi. These fungi are in general long-lived, living from year to year on a tree trunk and storing up nourishment in their mycelia. Months and even years of preliminary growth are often required of such fungi before the spore-bearing organs are produced. Enormous numbers of spores are then formed and a new crop may be shed every year until the nourishment in the tree trunk is exhausted.

Root-inhabiting parasites. The root is not as popular a resort for parasitic fungi as either the leaf or the stem, but not a few find a congenial abode in these parts. They have similar difficulties to meet as the stem dwellers and are in fact mostly members of the same groups of fungi. Often the same fungus is capable of growing up into the tree trunk. The spore-bearing organs are always found either at the surface of the ground or in air-spaces in the soil, such as in the burrows of rabbits. In certain grass-like plants a smut is found in the roots and causes the formation of swollen pear-shaped bodies.

Fruit-inhabiting parasites. A very large group of fungi inhabit the fruits of flowering plants. The fruits, whether they be fleshy, like apples, or hard, like nuts, have always some protective coat, which is a serious obstacle against an invading fungus. Some fruits are better protected than others in this respect and the weaker may prove vulnerable to fungus attacks, e. g., when thin-skinned apples are invaded by mold rots. The smuts, which are commonly found in the grains of grass-plants, have devised an ingenious method for a successful attack upon the fruit of the grasses. The fungus gains entrance to the stem of the plant when the latter is in the seedling stage and then keeps pace with the growing plant without apparently affecting it at all detrimentally, until the grains are commencing to fill. Then the fungus permeates all of the grain tissues, appropriates the food material and forms its smut spores. The ergot of rye and other grains has still another device for attacking the grass fruit. It does not, as the smut, live in the point of the stem until the fruit is formed, but attacks the grain from without while the latter is still very young. It seems to be able to penetrate the grain coats at this stage and immediately proceeds to convert the grain into storage material, packing it up in the dark-coated storage organ known as the ergot. This is used in the following spring to produce the spore-bearing organs. The fruit-inhabiting fungi include members of almost every group of fungi. Fruit-mold rots, smuts and ergots have already been mentioned. There are many other burnt-wood fungi beside ergot. Plum-pocket fungi, cup fungi and algal fungi are also among the inhabitors of fruits.

Anther-inhabiting parasites. Among the smut fungi are to be found forms which have developed very strange habits. One of the most remarkable cases is that of the smut which forms its spores only in the anthers of particular kinds of plants. The latter are members of the pink family. The fungus gains entrance to the plant before the flower is completely formed and in the young flower it selects for its abode only the stamens, and particularly the pollen-bearing part or anthers. It gives no external evidence of its presence until the flower opens. When this happens one finds that, in place of pollen, the anthers give forth a violet dust of smut spores, and few, if any, pollen grains are produced. To the casual observer such flowers appear to throw off purple pollen while other flowers of the same kind of plant give off yellow pollen. The fungus has formed its spores in place of the host's pollen, and when the anthers open they shed the spores. When insects visit these flowers they carry smut spores in place of pollen from plant to plant, thus aiding in the spread of the fungus. These fungi often prove troublesome pests on plants of the pink family, such as carnations, where the flowers are grown for show plants, because the presence of the fungus cannot be foretold before the opening of the flower, and after the latter event the smut spores discolor the flowers so that they are worthless for the market. It can readily be seen that this fungus has carried to a remarkable degree of efficiency its selective power, having learned not only to repress its spore formation until a most favorable moment but also to choose a most advantageous special floral part for the spores.

Chapter V.

Fungi. Parasites on Animals.

An account of the parasitic fungi would be incomplete without some mention of those fungi which attack animals and cause disease in them. These fungi are becoming more and more of economic importance, especially in their use in combating insect invasions on agricultural crops. They are furthermore of great interest in the diseases which they cause in man and the lower animals. In general, these fungus parasites belong to the lower or algal fungi, the water molds, bread-mold-allies and insect molds; but not a few are found amongst the higher fungi, e. g., the caterpillar fungus, the green mold, and even yeast-like fungi.

Diseases of lower animals. Not even the most lowly groups of animals are exempt from fungus parasites—on the contrary, they seem to suffer to an unjust degree. Those small unicellular animals which usually inhabit the water are often attacked by the simplest of fungi, also unicellular and very minute plants. The fungus finds its way through the wall of the animal cell and draws its nourishment from the animal protoplasm. Sometimes the fungus is exceedingly minute and may confine itself to only a special portion of the protoplasm, as do nuclear parasites.

Where (as in the Coelenterates) the host animal possesses a protective coat of lime the invading parasite may bore through the lime. The resting stage of these small animalcules furnishes an especially inviting host, since here the fungus meets with less resistance. One parasitic fungus is known to live only on the eggs of the little animals known as wheel animalcules.

The pin worms are likewise subject to fungus diseases and one often finds an epidemic raging amongst colonies of these little creatures. As these worms are often greenhouse pests such a fungus may become an efficient aid to the horticulturist. The method of attack of this fungus is a very unusual one. The mycelium is built on the principle of a net in which the threads of the fungus form loops or meshes. In these meshes the wiggling pin worm becomes entangled and every effort to free itself usually results in a securer imprisonment. When the worm is held fast the fungus sends out threads which penetrate the body of the prisoner and absorb its substance.

Amongst the true worms, fungi have been reported on the common earth worm. These fungi belong to the fish or water molds. The little water flea (Daphne) is the host of a very interesting fungus. This fungus is said to be a relative of the yeast fungi which are not, as a rule, parasites, but true saprophytes. The spores of this yeast or yeast-like plant are long, pointed, almost needle-shaped, and when taken into the alimentary canal of the water daphne they penetrate the wall of the canal and get into the body cavity. Here a fight ensues between the white corpuscles and the spores. If the latter conquer they soon commence to divide in yeast fashion and rapidly use up the nutrition derived from the fluid of the body cavity. The host animal soon becomes sluggish and dies. Later the needle-shaped spores are again set free and may be swallowed by other daphnes.

The crabs have also been reported as hosts for fungi, but such occurrences have not been very frequently noted. The parasites in these cases are water or fish molds. Amongst the spiders a black fungus parasite is known. Even upon the clam fungi have been reported, but their parasitic nature has not yet been proven. Shell-boring fungi are often found on the shells of such animals.

Diseases of insects. Of all the animals the insects are by far the most popular hosts for parasitic fungi. Most of the fungus parasites attack the insects in their larval stages, when the latter, with worm-like habits, crawl through the soil or in other moist places. Hence the fungi most frequent upon them are forms of the algal fungi which are also typically aquatic in habit, though of course many have learned to live in dry situations. The fungi of insects have certain advantages. In the body of an insect there is considerable chance for aeration on account of the large number of air-tubes which traverse the insect body. This very probably accounts very largely for the popularity of the insects as fungus hosts. Of these fungi the insect molds are very abundant as is also the "burnt wood" fungus known as the caterpillar fungus, and these two groups of fungi are responsible for most of the disease epidemics of insects.

Plant lice have been known to suffer from attacks of both of these fungi. The common housefly and its relatives are destroyed in enormous numbers every fall by an insect mold causing a disease commonly known as fly cholera. Such flies are seen clinging to window panes or the ceiling or walls of a room, surrounded by a dim circular haze or halo of the fungus spores which have been forcibly snapped off from fungus threads and caught on the glass. Of course most of the spores have been thrown off into the air where they may float about until they come into contact with another fly. The fungus continues to form spores as long as there is available food material in the insect body. When spores alight on an otherwise healthy fly a fungus thread is produced which may make its way through the skin to the inside of the body and there continue to grow. The mycelium soon causes the death of the insect and later comes again to the surface to produce its spores. Other insect molds have been known to attack common house fly relatives. The mosquito may also prove a prey to fungus diseases and attempts have been made to fight it by aiding the spread and dissemination of those particular insect-molds which are parasitic upon it. One of the most remarkable groups of insect parasites are the beetle fungi, relatives, perhaps, of the black fungi. They are found

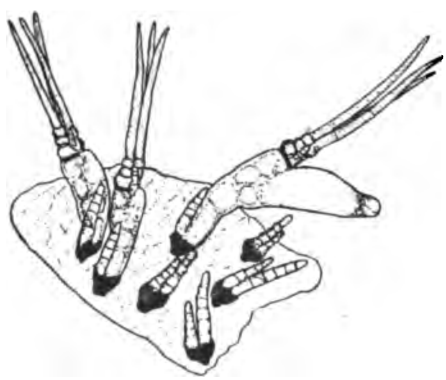


FIG. 30.—Beetle fungi attached to an insect. The black spots at the base are the attaching organs. Highly magnified. After Thaxter.

on the legs and wing covers of flies and particularly of water beetles. They are highly specialized as to their abode, often occurring constantly on a certain joint of one leg. This definiteness of position is explained in the spore distribution, as the plant sexes are often separated, growing on different plants, and the sexual cells of the fungus are brought together during the breeding acts of the insects. These beetle fungi are not, as far as is at present known, harmful to the insect which they inhabit. In form they are very minute and visible only by the aid of strong lenses. They usually have the shape of little broom brushes and are attached by a blackened disk.

The butterflies, particularly in their caterpillar stages, are also common prey for the insect mold. Perhaps more commonly, however, they are attacked by the fungus known as the caterpillar fungus, a member of the black fungus group. This fungus has learned to produce a variety of spores, each specialized for a certain purpose. Cylindrical spores are produced upon orange-colored fruiting bodies in the autumn. When a spore falls on a caterpillar it sends out germ-threads which can eat their way through the covering of the caterpillar and enter the body cavity. Here the threads immediately form long narrow spores which are pinched off into the fluid of the body cavity and can move around easily, thus rapidly spreading the fungus. These spores germinate immediately and more spores are formed. Meanwhile the threads produced by these spores branch profusely and soon permeate all parts of the insect body-cavity and invade the various organs, finally working their way even into the muscle fibers. The caterpillar gradually becomes sluggish and finally dies. After death, the fungus continues to grow and to appropriate the insect substance for food. At fist the threads are very thin and are thus able to work their way with more ease through all parts of the body. As soon, however, as the threads become very numerous they grow thicker and lay up nutrition as storage material in the form of oil and fungus starch. Finally the threads have completely absorbed all of the insect's soft parts, filling the chitinous covering, and retain in their densely compacted form, the exact shape of the larva—not only in the external form but in the form of the internal organs. In other words a mummy and model has been formed; this mummy contains a great abundance of food material, but no part of the insect can be found in it. The mummy now acts as a storage and resting organ and requires apparently considerable time—months, perhaps—to ripen. Under favorable conditions this mummy will send up an orange-colored club-shaped body, which will again produce the kind of spore which was described at the be-

FIG. 31.—Various kinds of caterpillar fungi with fruiting bodies. (Cordyceps militaris, C. stylophora and Isaria sp.) The forms of the caterpillars are preserved by the fungus storage organs and the upright clubs bear the spores. 1 and 2 bear clusters of pinched-off accessory spores; 3 and 4 bear sac-spores in capsules. (See chapter 9.) About natural size. Original.

ginning of this account. Under some conditions, however, the mummy can be made to produce a dense growth of threads from its entire surface, so that it looks like a small ball of cotton, and from these threads another kind of spore is formed. These spores are pinched off in great numbers. They have the power of germination and infection of the larva in a way similar to that of the sac spore already described. Caterpillar fungus epidemics are not infrequent and thousands of larva may be killed in a year. A caterpillar after infection can still crawl some distance before death overtakes it and thus the scattering of the fungus spores is materially aided. Attempts, made at various times to utilize this fungus to combat grubs, have met with varying success, but its use has not yet become general. Silkworms frequently suffer from these fungi and the silk growers of Europe have lost enormous sums of money through such epidemics. The beetles are very frequently the hosts of parasitic fungi, especially of the so-called "beetle fungi" which have already been mentioned. The caterpillar fungus and the insect molds are also to be found on the beetle as well as upon the dragon flies and their allies. Ants, though not very frequent hosts, have been known to harbor the caterpillar fungus.

Diseases of fish and lower vertebrates. If we now consider the vertebrate animals we find also abundant evidence of fungus parasitism. One of the most important cases is that of the fishes. Both the mature fish and its eggs may be attacked.

FIG. 32.—Dead minnow with fish mold (probably Saprolegnia thuretii). Original.

The fungi are the water or fish molds. Thousands of fish are killed off annually by these parasites. They can be seen on any minnow bait, which has died and been kept for several days. A filmy mold gradually covers the whole surface of the minnow. These fish molds are half saprophytes and live ordinarily upon dead debris in the water. When, however, they come into contact with living fish, they may attack the latter if conditions are favorable. They apparently are unable to

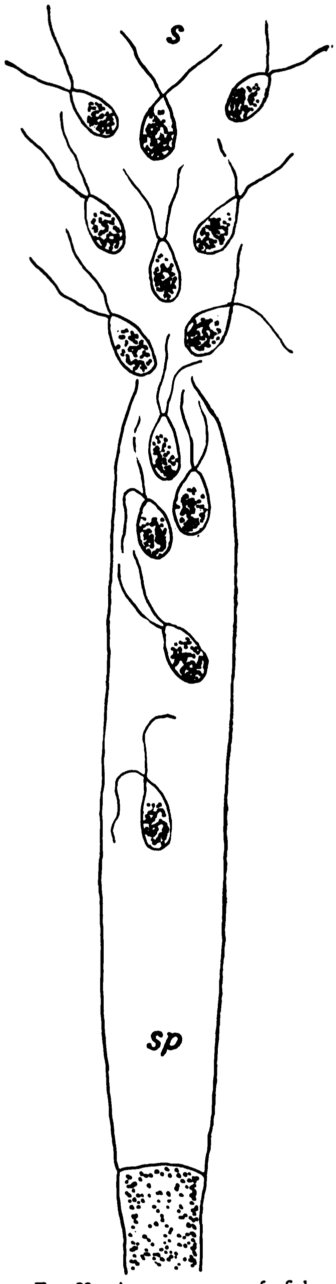


FIG. 33.—A spore-case of fish-mold showing escaping swimming spores; each of the spores is provided with two swimming lashes which whip about in the water and propel the spores. Highly magnified. After Zopf.

attack healthy fish unless perhaps through the respiratory system, but succeed if the fish are in some way injured, for instance at points where the scales have been rubbed off. When once the parasites are established they gradually spread over the body of the fish and ultimately cause its death. The fungus produces an enormous number of spores which are for the most part furnished with whip-like lashes for propelling purposes. Occasionally these fish molds cause epidemics and vast numbers of fishes may then succumb. The occurrence of several such epidemics is known. These fungi are very often the cause of the death of fish in aquaria such as common gold fish. The danger from such fungi can be lessened by keeping the aquaria scrupulously clean so as to furnish little chance for the saprophytic existence of the fungus. The infected fish should be removed as soon as possible to prevent the formation of more spores. The injuries of these fungi are not confined to the fish in lakes and streams but are sometimes a cause of great loss in the fish hatcheries where the eggs may be attacked. Some of the bread mold allies are also known as inhabitors of fish eggs. On the Amphibia, the frogs and their relatives, few fungi have been found. In this state mud puppies have been observed, which have been killed by certain fish molds. The fungus appeared on an apparently healthy mud puppy as a thin filmy spot which rapidly grew larger, coalescing with other spots until the animal was completely covered. Meanwhile the puppy gradually grew sluggish and finally died. Soon after death the fungus had formed around the mud puppy's body a dense mass of mold almost an inch thick. All the mud puppies left in the same aquarium were finally killed by this mold.

Diseases of birds. Birds are not without their fungus parasites. However, these parasites are members of a different group of fungi from those inhabiting fishes and amphibians. In the latter the parasites are adapted to aquatic habits while on the birds one finds fungi which have become adapted to aerial life. The birds offer somewhat analogous advantages to fungi which one finds among insects; that is to say, abundant aeration furnished by the bird habit of life. One fungus disease of birds is caused by forms of the green molds which affect particularly the respiratory organs causing inflammation of the affected parts. Almost all classes of birds have been reported as hosts of these parasites. Chickens sometimes suffer from a comb scab which is also of fungus origin. This fungus, when raised on gelatine plates, shows similar life habits to the yeast fungi. In this disease scabs are formed on the comb and the fungus inhabits the scab spots. The same form, or a close relative of it, may attack the crop of the chicken and form a pustule disease. Hens' eggs, as has already been mentioned, are not infrequently attacked by fungi of the green or black mold group and egg rot ensues. Such fungi may, however, be mere saprophytes living on the albumen of the egg.

Diseases of lower mammals. There are several diseases of considerable importance among the mammalians. The most serious of these is the disease of cattle known as lumpy jaw. The cause of this disease is apparently a fungus but its position in the classification of fungi is not yet known because its spores have never been observed. It occurs in little nodules which apparently multiply very rapidly. It attacks most commonly the jaws and mouth parts of cattle and the diseased animal's head becomes much swollen and presents the lumpy appearance which gives the disease its common name. The results are usually fatal. Infection apparently takes place from the food, particularly from the hay and grain foods, upon which the fungus has been found to exist. The fungus is probably introduced in cuts in the mouth made by grass blades when the animal is feeding, and from these points spreads throughout the mouth parts. Inoculation with the nodules results in the typical disease. At times the disease becomes epidemic, probably on account of the prevalence of the fungus in certain food. The same fungus, or one very closely related to it, attacks swine. It is not always confined to the mouth parts. Horses have also been known to suffer from the same disease. In the lungs of rabbits, cats and dogs the spores of green molds may lodge. Under favorable conditions of weak resistance, the spores may germinate and induce inflammation in the surrounding parts, causing the formation of tubercular growths in the lung tissues. The disease is known as a mycosis. Such fungus spores injected into the blood of animals may also give rise to mycosis in various organs of the body. The intensity of the disease seems to be proportionate to the number of spores injected or inhaled. This is of course not the cause of ordinary tuberculosis.

Bread mold allies are reported as responsible for diseases in rabbits. They gain entrance to the intestine with the food and produce diseases of the intestinal tract. When injected into the blood the spores may produce diseased conditions in the kidneys and other organs and even in the bone marrow. Death sometimes results from the attack of these molds.

An ally of the yeast fungus, and apparently also of the comb scab disease of chickens causes in the throat and mouth parts of young cats and dogs pustules and scabs similar to those produced in throats of children. The fungus is found in the scabs and pustules thus formed. Several other external scab diseases of the skin of animals are produced by these fungi, as are also the bald spots, accompanied by scabs on the external head and throat parts, often found on cattle and less often on dogs, horses, cats, etc. The latter may be identical with bald spot disease in man.

Diseases of man. Skin diseases of man, analogous to those of the lower mammals, are caused by fungi. Ring worm and some bald spots are prominent among these. They are caused by fungi perhaps identical with those of lower mammals, at any rate very similar to these in all their characters.

Cases of lumpy jaw in man, though not very frequent, are well known. The disease is similar in all respects to that produced in cattle. The fungus is similar and the results are usually fatal. Infection takes place in all probability from cuts by splinters or wounds by grass blades, or when a grass blade is drawn through the mouth or grains in the field are sampled by biting. The fungus thus appears to lurk in places similar to those of the fungus of lumpy jaw of cattle.

Green mold fungi also cause disease in man. Some diseases of the outer and middle ear canal are of this nature. Here the fungus grows as a saprophyte in the ear secretions and by its presence sets up irritation and consequent inflammation. It is doubtful if the fungus in this case is a true parasite. These molds, moreover, when inhaled into the lungs in sufficiently large quantities, may produce lung and bronchial troubles. The latter are often asthma-like in their symptoms. Children are subject to the attack of one of the yeast-like fungi, similar to the comb-scab of chickens and the throat troubles of cats and dogs. As with the last two the internal throat-parts are attacked and scabs and pustules produced in which the fungus is found, giving rise to sore throats. Somewhat similar throat troubles have been produced also in adults by a similar fungus.

Contrast of parasitism in plants and animals. A great difference is noticeable between the known number of fungi parasitic on animals and plants. The former have been estimated as less than two hundred while the latter must now exceed ten or fifteen thousand. This difference can, in part, be accounted for by certain general differences in surroundings. Fungi as a rule require neutral or acid media, while animal tissues are usually alkaline. Plants offer in their tissues more air space and thus furnish more air, which is essential to the growth of fungi. The body temperature is, in all higher animals, above that at which most fungi develop under normal conditions, and finally, the resistance of the white corpuscles of the blood is an important factor. Fungus parasitism on animals is, with perhaps the exception of lumpy jaw, an immediately destructive one, and shows no effect of mutual partnership between fungus and animal parts.

Just as with bacteria, so with fungi,—white blood corpuscles seem to form the garrison guarding against attacks. As soon as the fungus threads enter the tissues, the corpuscles gather around them and the battle begins. Moreover, the corpuscles are often produced in extraordinary numbers in the vicinity of the fungus attack. They may thus exclude air from the fungus and so materially hamper its growth. Plants have no such protection and hence suffer more. The fungus may sometimes encrust itself with lime, as in lumpy jaw, perhaps protecting itself in this manner from unfavorable conditions.

Chapter VI.

Fungi. Parasites of Plants.

Effect of parasite on host. We have already seen that parasitism, in the broader sense, of a fungus on leaf-green plants is always one of two kinds of partnership, equal or unequal, and of the latter either the host or parasite may dominate. Now, equal partnerships are rare, and those unequal associations with dominant hosts are also comparatively few, though science is rapidly adding many new examples to the list already known. The greatest number of partnerships are those in which the parasite is the profit-making partner and the host

FIG. 34.—Damping-off of seedlings, caused by a fungus (Pythium debaryanum) which immediately kills the host plant—a low, though effective, type of parasitism. After Atkinson.

the loser. It has also been pointed out that different fungi have acquired different degrees of efficiency in obtaining their profits, and that highly specialized parasites can influence the host to over-production of food stuffs for the benefit of the former.

Immediate destruction. The immediate destruction of plants or plant parts has been characterized as an amateur method. It is admittedly not as clever a method as is the delayed destruction preceded by stimulation. But the performance of even such amateur methods can be carried to a high degree of proficiency and that is what many fungi have done. The green-mold fruit-rot effects its parasitism not only according to amateurish ways, but is a beginner in this work. This is not so with the potato blight, which is an adept at its methods of killing and feeding on the potato plant. There are many special methods to be found among these parasites but they may be brought under these heads: the destroyers of small areas of plants, the destroyers of whole organs, and the destroyers of whole plants.

The destroyers of small areas. Among the simplest of the algal fungi one finds certain kinds which possess a very small mycelium so that they occupy only a single cell of the host. This cell the parasite may immediately destroy without effecting any change in the surrounding cells. In some cases, however, it may affect neighboring cells and these may grow abnormally large. Such growth results in the formation of galls. Galls vary in size from that of a pin head, or even smaller, to walnut size, and some galls are known to be even very much larger. Not all plant galls are of a fungus nature; for by far the great majority are caused by the sting of insects when the latter deposit their eggs in the plant tissues. Such are the very common galls formed so abundantly on leaves or branches of oaks, as in the nut galls of commerce.

Most small-area-destroying fungi do not confine their attacks to one cell but prey on a large group of cells. Typical examples of these fungi are found among the leaf spots. These fungi are exceedingly abundant parasites and are usually characterized by the destruction of limited, often circular, spots of the leaf which they inhabit. These spots usually turn brown and are sometimes fringed with a red or white band. The spots of strawberry leaves which are so destructive to certain varieties in our state are excellent examples of leaf spots. Many fungi of this class are very injurious if they occur in abundance, while others do not perceptibly affect the general health of the host. Certain smuts and powdery mildews may also be confined to small and limited areas. In the former case the area is converted into a smut heap while in the latter it becomes mildewed and later dotted with the very small spore cases. Most smuts and mildews, however, are not restricted to small areas. The mildews are seldom confined to small areas

FIG. 35.—Strawberry leaf-spot. The fungus (Sphaerella fragariae) destroys small areas of the leaf. Original.

of the leaf surface or even to the leaf itself, though usually this is its favorite habitation. The smuts, although often occupying a sharply delimited area, more often occupy whole plant organs, as fruits or stamens. Moreover, the smut mycelium always dwells inside of the leaf while the mildew is external in its habits, except in its sucker-threads. Rusts, though often confined to certain organs of the host, are not usually restricted to particular or limited areas.

Methods of killing tissues. There seems to be two ways by which tissues of the host plant are killed. The nutrient substance of the host tissues can be directly absorbed through the membranes of the fungus thread wall and also, in some cases, through the wall of the host cell. The substances are with-drawn before the death of the host-plant part. In the second case the fungus produces on the surface of its invading threads a chemical substance which kills the host plant tissues and the fungus absorbs its nourishment later from this killed area. It is only fungi which know the first method that can stimulate their host to extraordinary growth and over production of food material, as in the witches'-brooms. The second method is common among half saprophytes.

The destroyers of organs. Many leaf mildews attack so vigorously that the whole leaf is unfit to perform its natural function. In this case the leaf is impoverished and usually turns yellow or brown and falls. In other cases the fungus, while not withdrawing much nourishment, may cause leaves to fall prematurely. Such are often known as leaf-casting diseases. The blight of potatoes may extend over all of the foliage leaves, blighting them and causing death. The death or fall of leaves before the normal period of fall is a serious injury to the host, as every leaf lost is a fractional loss in the manufacture of starchy material. The destructive attacks of smuts on the fruit of grasses and upon the stamen of pinks have already been mentioned. Rusts of grasses never, of course, cause the fall of leaves but they may very seriously affect the starch-making power of the plant, and so very materially injure the crop. Branches are sometimes killed off by fungus parasites. Such may be the wound parasites which attack the trunks and branches of trees. The tax which a witches'-broom levies on a branch may kill off, by indirect action, the branch beyond its insertion. Whatever the attacked organs may be, if invaded in sufficient numbers their loss may cause the death of the whole plant.

The destroyers of whole plants. There are many fungi whose usual effect of parasitism is the death of the whole host plant. Conspicuous among these is the damping-off fungus which attacks seedlings. Wound-parasites of trees, when they have successfully invaded the trunk of the tree, or root-wound parasite may cause the death of the whole tree. Powdery mildews, rusts, and especially the downy mildews, such as the potato blight, very often kill the whole plants. Death is here the accumulative effect of the attack on the various organs. Sev-

eral fungi suffocate plants, causing death with or without true parasitism. A shelf fungus not uncommon in Minnesota grows on the ground and often envelopes the bases of shrubs or saplings with its dark brown fruiting body. When it meets seedlings this envelopment may prevent the further growth of the host and suffocation results. One of the black fungi attacks several kinds of grass plants and prevents the unfolding of the leaves and finally causes the death of its host plant.

Stunting of plants and plant parts. Fungus parasites in many cases do not produce death but succeed only in stunting the host plant or its

FIG. 36.—Larch tree killed by the parchment pore-fungus (Polystictus pergamenus). The entire tree was killed by this half-parasite. Original.

parts. This stunting is shown in a few cases in the leaves of plants. It may be accompanied by a stimulation of certain parts of the leaf. For instance, a very simple little fungus may attack dandelion leaves and produce tiny galls which appear as roughnesses on the surface of the leaf, while the leaf as a whole is considerably smaller than an unattacked one.

More frequently one meets with the stunting or total suppression of flowers. Some plants, for instance, which may support a parasitic fungus for many years, never produce flowers. Again, curiously deformed flowers are produced in which one or the other kind of floral leaves are missing. Sometimes the floral parts are present but strangely unlike the normal structure; petals may be green and like simple foliage leaves or like sepals. Fruits may be stunted in their growth. In cherries or plums when the fruit is attacked by certain sac fungi "pockets" are produced. These fruits, though much enlarged over the normal fruits, never produce natural seeds and the stone is also undeveloped. Not only may stunting affect the form and size of the host, but the life of parts may be shortened. The witches'-broom often furnishes examples of such age shortening. Here the leaves may fall long before the normal time.

Stimulation of host. More conspicuous and more common is the occurrence of stimulation of the host by the fungus parasite. This stimulation may result in one or more of four effects, viz.: (a) an increase in size; (b) an age stimulation; (c) the development of normally undeveloped organs; and (d) the formation of new organs.

(a) Many cases of increase in size of organs are met with as a result of fungus parasitism. The fungus galls mentioned above are the simplest cases of such enlargements. The branches of witches'-brooms are usually enlarged not only in size but in numbers. The plum and cherry "pockets" are likewise enlargements. On the leaves of Labrador tea and other heath plants may be formed large solid galls which are covered with the spores of the parasite. Rusts produce enlargements of the stems of various pines, forming huge spherical, burl-like swellings. Roots of the rushes are enlarged by the attack of a smut fungus. Moreover, floral parts are often enlarged. Petals, sepals, stamens or pistils may be stimulated by fungus parasites to extraordinary growth.

(b) Many rusts have remarkable powers of stimulation, not only in their influence on size but also in the age of parts. Although a host plant may bear the load of such a parasite the fungus may still stimulate it sufficiently to enable it to maintain its normal age relationships so that the fungus and host may live together for years. In the darnel grass lives a smut-like fungus which is parasitic and which infects the embryo in the seed before the latter is ripe, and thus this fungus lives on from year to year infecting its host without the need of spores. Such a partnership has become almost, if not altogether, an equal partnership, and approaches the degree of unification attained among the lichens.

FIG. 37.—Fungus gall on leaves of Labrador tea. The fungus (Exobasidium) is one of the gall-forming basidium-bearing fungi and causes a stimulation in the leaf which thereby furnishes additional nourishment for the fungus. The latter is an accomplished parasite. Original.

(c) Among the most remarkable effects of stimulation are the changes in the floral parts of host plants. It is well known that in some plants there are two kinds of flowers, one bearing stamens and the other pistils. This is the case in certain members of the pink family. In these plants, however, this so-called (and incorrectly) "unisexual" condition has been brought about by the failure of the beginnings of one of the floral parts to develope. Thus, we find in such flowers either the stamens alone fully developed, with the undeveloped beginnings of the pistil, or vice versa. Very often such flowers are attacked by certain smut fungi and the parasite often exerts a stimulating effect upon the undeveloped beginnings of the floral parts and excites them to growth, so that where normally only one kind of floral leaf is developed, two may be produced in the diseased flower. The stamens may be produced in pistillate flowers or pistils produced in staminate flowers. In still another case stamens may by the influence of a fungus parasite be transformed into petal-like bodies, thus producing a doubling of petals.

(d) All of the effects of parasitism mentioned thus far have been either changes in normally developed organs or the growth of undeveloped beginnings of parts. There are known at present only a very few cases where a fungus excites the formation of absolutely new organs. In these cases the organs are produced by the host only when the fungus is present and they have to do solely with aiding the parasite in the production and dissemination of its spores. Such new organs are known on a cone-bearing tree of Japan closely related to our own white cedar and the fungus causing the formation of new organs is a rust.

Effects of parasitic fungi on tissues and structure of hosts. It has already been said that fungi may cause increase in size of plant parts. This increase in size is effected in two ways: first, by an abnormal multiplication of the cells of the tissues affected which takes place under stimulus from the fungus, and second, by the enlargement of each cell. Both processes may go on at the same time.

Fungi act differently in their invasion of tissues and each has its own method of attack. This is noticeable in the effect upon the leaf-green of plants. Some fungi cause a decrease in the amount of leaf-green found in the host plant, often effecting its complete disappearance. Such plant-parts have a yellowish color. Certain rusts have such an effect upon their hosts. One may find other cases where only a partial decrease of leaf-green occurs as in the balsam-fir needles on the witches'-broom, also produced by a rust fungus. On the other hand the fungus may excite the tissues to the production of an extraordinary amount of leaf-green, or to the retention of leaf-green after surrounding parts have lost it. Such green spots on leaves have been known as green islands and are striking examples of the unification of fungus and host-parts into a virtual individual.

Fungi are even known to excite the formation of leaf-green in plant parts usually devoid of it, e. g., in petals of flowers, as is the case in the white rust on mustard plants. In this case it is very probable that we see simply the stimulation to the development of latent beginnings of the leaf-green bodies, just as the stamens and pistils are sometimes formed in flowers usually devoid of them. As leaf-green furnishes the machinery for starch-making, one sees that the amount of starch formed in a fungus-inhabited part may vary with the fungus. However, leaf-green is not the only agency of starch production. There are other agencies for the transformation of starch from other compounds. Aside from the effect of the fungus upon leaf-green, fungi react directly upon the starch, producing certain chemical substances which dissolve the starch. Some fungi use all of the available starch as soon as it can be reached, while others cause a great accumulation of starch temporarily and dissolve it in the important stages of their life history, during and just preceding the formation of spores. A great many fungi are able to dissolve starch and among them may be mentioned certain rusts, black fungi, white rusts and many wood-destroying fungi.

When tissues of plants are examined under the microscope a honeycomb-like structure of cells is seen. The walls of most cells are whitish, soft and composed of a substance called cellulose. The walls of the cells of woody tissue enclose in the youngest stages the protoplasm, but soon lose the latter. The "woody" character of wood tissues is imparted by the thickness, size and form of their cell walls, and the chemical compounds found in them. In young stages, the wall is whitish and not particularly resistant nor hard, for it is a cellulose wall. Later new substances are added, which collectively are known as lignin, and the tissues then become woody. But woods differ among themselves due to variation in the above-mentioned characters. The cellulose membranes are sometimes pierced by fungus threads in a mere mechanical fashion, just as one would force a pin or needle through them. Wood membranes offer considerable resistance to most fungi, but some of the latter have solved the problem of penetration of these walls. Such are the wood-destroying fungi already mentioned. The threads of these parasites exude certain chemicals which are able to attack the lignin of woody tissues and to dissolve out the substances which make up this lignin. These cell walls now have the same chemical constitution which they had before they became lignified. But the fungus is also able to attack the cellulose walls and the final result is a more or less complete breakdown of the walls. The wood crumbles easily and is converted into punk, which is characteristic of rotten wood. The threads make their way from cell to cell, usually by boring through the walls, whether they are wood walls or cellulose walls, and in tissues attacked by these fungi one sees large numbers of holes through the cell walls, where fungus threads

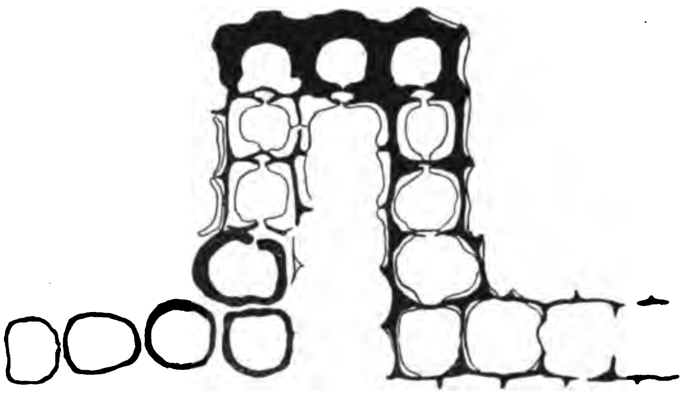


FIG. 38.—Two ways in which wood is destroyed by wood-rot fungi. On the right the wood cells are destroyed from within outwards. On the left they are destroyed from the middle of the wall toward the center of the cell. Highly magnified. After Hartig.

have passed. From these points the dissolving substance spreads over the cell wall completing the rotting process in that vicinity. Since woody tissues can be colored characteristically by using certain chemicals, one can determine by the use of these chemicals just how far the rotting has proceeded.

It is worthy of notice that fungi have different methods of attacking and rotting woods, using different substances and applying them in various ways. The study of the rotting of woods is still in its infancy, but it is now known that certain wood rotting fungi can be determined by the kind of rot which they produce. The wood-rot, therefore, often gives very definite symptoms of determinable diseases. The study of wood-rots is receiving considerable attention at the present time on account of its vast importance economically. To realize this importance one has but to think of the great losses sustained yearly by the decay of mine timbers, house-foundation and cellar timbers, of bridge-timbers, railroad ties, paving blocks, fence posts and rails—in fact, timbers wherever air and moisture can reach them. The creosoting of pavement blocks and the tarring of cedar posts are attempts to aid the wood in resisting fungus attacks. Tar and creosote are substances in which the fungi cannot live and their presence protects the wood. But as soon as the substances are washed off the fungi commence their attack. At present a considerable amount of money is being expended to find a process or substance which will protect railroad ties from fungus rot. What is wanted is some substance which when deposited in the wood will prevent the entrance of fungi and which will not readily leach out into the soil during heavy rains.

Effects of parasites on anatomy of host. The effects of fungus parasitism described above have to do with the destructive attacks upon cells and tissues, particularly in those cases where enlargement of parts is caused. One often finds other effects in tissues, viz.: changes in quality and amount of certain kinds of tissues. The covering layer is often affected by fungi which live on the surface, and may also be ruptured by the spore-producing hyphae of interior-dwelling fungi as in red rusts. Some fungi excite in certain plants an abnormal growth of cork which constitutes the outer layers of the bark. In general, in the enlarged parts of the hosts, the supporting or strengthening tissues are not as well developed as in the normal host. Many tissues, moreover, which are usually woody are not so in the diseased and enlarged parts, although there are exceptions to this generality. Sometimes the fungus attack stimulates the excessive production of resin in pines and their allies. Other products and tissues may undergo change, though no generalities can be discovered in the action of fungi. It seems, however, that, in general, those changes take place which transform the host part into a most suitable and profitable dwelling and food store for the parasitic fungus without regard to the host's needs, and often to the direct detriment of the host plant. There is usually in this connection a great amount of tissue produced which is especially fitted for storage of food materials. The cells therefore are large, thin-walled, closely crowded and contain much starch and other storage food.

Effects of hosts on parasites. In the unequal partnership of host and parasite, where the fungus is the dominant partner, the latter is often profoundly affected by the host plant. It becomes so accustomed to peculiarities in the life history of certain plants or groups of plants that it has learned to shape its own course in harmony with these peculiarities. First of all, then, one finds a parasite capable of living on but one particular kind of host—it is found on no other, and an attempt to cultivate it on even the most closely-related plants fails. Such a condition of parasitism, though by no means unknown, is not very frequent. Far more common is that condition where the parasite has learned to shape its general habits to comply with the peculiarities of each of a group of plants very closely related and is capable of infecting any of them. It is found, however, that the previous habitation of a fungus has in some rusts at least an important effect upon the spore of that rust in the infection of other host plants. In general, infection succeeds best upon the identical kind of host upon which the spores were formed, while the nearest relatives of this host are more easily infected than are distant relatives. One must infer from these facts that the effect of nutrition, etc., received during habitation on a host are far reaching and influence the fungus towards a preference for this same host.

Certain fungi, again, are able to attack any of a number of host plants which are but widely related. Such fungi show general abilities and no special education in selection of host. In other words, they are not so deeply affected as the previously mentioned specialists.

It has already been noted that certain rusts, in order perhaps to produce spores continuously throughout the season, have learned to live on different hosts at different times of the year. Such fungi may also exercise exact preference for their hosts, though, of course, two hosts are necessary. The influence of the host-effect may here be carried over through the life on the second host until the fungus again inhabits the first host plant. Such an impression must indeed be a profound one.

Host-influence on parasite may be exerted even at the time of spore germination. The spores of a great many parasitic fungi will start to grow when placed in pure water. Some fungi, however, as most of the smuts, require nutrient material before they will germinate. Again, other fungi must bring their spores into direct contact with the host plant in order to bring about germination.

After the spore has germinated the germ-tube penetrates the tissues of the host plant. In some cases, where the fungus spore is not directly influenced in its germination by the presence of the host, a spore may germinate on an unfavorable host and the germ-tube may even penetrate into the tissues, but here its progress is prevented as the host does not permit of further growth. Such a struggle may continue for some time, but is usually short if the host is at all unlike the usual host of the fungus. The preference shown by fungi for special plant parts as dwelling places, as the grass-fruit-inhabiting smuts, is but another expression of the influence of the host plant parts upon the fungus.

Chapter VII.

Fungi.. Plant Diseases.

Disease in plants. It is not always an easy matter to tell whether or not a given plant is healthy or diseased. For instance, a plant may be placed under very slightly unfavorable conditions of moisture and sunlight. If it were to obtain slightly more or less moisture or sunlight, as the case might be, it would thrive or sicken. Still the unhealthiness of such a plant would hardly be termed a disease. If, however, we were to further change the unfavorable surroundings, we might bring the plant to a condition where its life would be seriously threatened and such a plant would unhesitatingly be called diseased. We can therefore see that one may conceive of all sorts of possible conditions between so-called good health and undoubted disease in plants, and that disease and health are only conventional marks, as it were, on an artificial scale of the life conditions of organisms. No plant ever enjoys *all* of the best conditions possible for it can only approach such a condition. If it could, it would touch the top mark of the life-scale; the bottom mark is the disease-death of the plant. We might say a premature death instead of a disease-death because it must be remembered that all plants as we know them today are destined to die sooner or later. Some, as many of our common weeds, live only a year, while, on the other hand, our great forest trees live for centuries, but sooner or later their constructive powers are no longer successful in repelling the attacks of unfavorable conditions and they succumb. Such a "natural death" is not in the nature of a disease, as we commonly understand that term. Yet disease merely hastens this death, and again we might trace all conceivable conditions between an imperceptible hastening of death to a violent death from a well-defined disease. All of the efforts of agriculturists and horticulturists are summed up in saying that the conditions of growth of selected plants are artificially favored. The fertilizing of soils, the selection of various soils for certain plants, processes of cultivation, and so on, are all directed toward this end. Men engaged in these pursuits are fast learning to recognize the advantages and profits of such processes and no improvement, however small it may be, is too insignificant for notice and application. We might term such processes improvements of health.

There is another aspect which often escapes the busy practical farmer or horticulturist of today. In the absence of an analysis he recognizes in disease only those sharply marked or violent disturbances which are very obviously threatening the life of his plants. The small losses by inconspicuous diseases are often overlooked. For instance, no farmer fails to calculate his loss when a heavy rust epidemic attacks his wheat or an epidemic of smut invades his oats. Few farmers, however, realize that every year rust levies a tax of a fraction of his crop, although that fraction may be small. Why should he not be alive to these facts and to the necessity for alleviating such troubles as he is to the small improvements of cultivation and introduction? And such conditions can only be improved by a fair intelligence of the cause and spread of the diseases of plants.

It is only by such knowledge that intelligent remedies are applicable and the greatest profits attainable from the products of the soil. It is only then that our plant protégés will at all approach the highest mark of good health.

It is a well known fact that the offspring of a plant may vary considerably in their characters. If we take an extreme case we can easily imagine two offspring of one plant to be so different in character that under the same conditions one would thrive very well while the other would suffer very perceptibly. The variation in the latter case would be indistinguishable from disease for it tends under existing conditions to prematurely end the life of that plant. Of course such a plant, if placed under different conditions, might thrive exceptionally well, and man's great interest in variation is the puzzle of fitting together varieties and conditions to the best advantage.

As seen in one light the life of a plant is unlimited in time—is, so far as we know, immortal through the germ cells which contribute to the formation of new offspring. Individuals, however, have a limited life. A plant evinces two processes constantly at work, viz.: a constructive process which is building up the tissues, increasing or replacing them, and a repellant process which organizes and otherwise provides for the repulse of unfavorable conditions among which may be included the attacks of injurious weather and soil conditions as well as those of fungi and other organisms. Now in the normal vigor of youth a plant is capable not only of successfully repelling external attacks but puts much energy into the constructive work. Gradually less and less of an increase of tissues is noticeable because of the necessary replacement of lost tissues and finally we reach the mature vegetative condition of a plant where the latter has attained its greatest possible size and all of its constructive power is exerted to replace lost members or parts. If conditions were ideal, one might imagine such a mature or prime condition to last indefinitely, but now with the increase in size and complexity we find also an increase in the attacks of foreign organisms or the unfavorable conditions due to accidents, as lightning strokes or storm damage. If the repelling power of the plant does not increase, the disintegrating forces gain and the plant enters the period of old age and decline which is terminated only by the complete success of the disintegrating forces, i. e., the death of the plant. Among the shortest-lived individuals are those plants which live but a single season. Among the longest-lived are not only our giant trees but also those herbaceous plants which have creeping underground stems, that travel from year to year, carrying their reserve material as a capital for starting work again in the following spring. Such plants as iris, bloodroot and many of our grasses are good examples of such long-lived plants. The attack of some foreign organism has in general more chance of success during the old age period than during the vigor of youth and old age in a plant, therefore in general predisposes that plant towards disease.

Factors of disease. Disease in plants has these three factors: first, the immediate cause of disturbance, as a fungus or some insect or some unfavorable atmospheric agency; second, the resultant change in the life of the host; and third, the previous condition of the host plant, i. e., its predisposition in particular towards that disease. The first factor will be considered later. The second has been discussed in Chapter VI. We will now examine more in detail the third factor, i. e., peculiarities in internal and external conditions which make a plant more or less susceptible to disease.

Predisposition. This susceptibility is in almost all cases a specific one toward a certain disease and less often toward many diseases. When a plant is subject to the attack of numerous agencies we can easily imagine some change in conditions, as, for instance, transplanting from a dry to a moist atmosphere, which would favor the attack of all of these diseases. The conditions become such that fungus attacks in general are facilitated. But most predispositions are in the nature of special conditions which are favorable to only one special disease or class of diseases. This distinction is expressed in the terms general and special predisposition. An illustration may make this clear. Wheat rusts are of different kinds caused by several fungi. In general, moist warm weather in the growing season predisposes all kinds of wheat plants in many ways to the attack of rusts, and such conditions furnish general predisposition. But if a certain variety of wheat be particularly susceptible to a given rust fungus, abundant in the region into which the wheat is introduced, the new condition of position in the wheat plant predisposes it very much to that disease. Other varieties of wheat, less susceptible to that particular disease, might be unaffected so that we may have here a special predisposition.

It is a fact which must not be lost sight of, that the predisposition of the plant in itself may not be harmful to that plant, but may be a condition which might be highly recommended when considered alone. But it is the other factor, the fungus or insect, which may be the disturbing influence and which is especially favored by this condition of the host plant. Such a distinction is of very great importance to practical agriculturists and horticulturists because it is not only the immediate condition of the plant or, on the other hand, the presence of disease-causing conditions, but it is the relationship between these two factors that is all important. There is another fact of great importance that must be emphasized. No plant, as far as is at present known, ever inherits a disease—no disease passes directly from parent to the offspring plant in the germ cells. Predispositional characters may be inherited but the first disease factor is never inherited. The infection of the host plant may take place so early in life that at first sight there may appear to be an inheritance, but all such cases at present known have been shown to be simply early infections of the host plant. For instance, oat plants are infected in the seedling stage just after the little plant arises from the grain, while in the darnel grass the infection of the host plant takes place inside of the seedling before the seed is ripe—for, as is well known, the little plant is already well developed when the seed is ripe and has been growing for some time previously. That is to say, in the darnel, the plantlet (commonly called the "germ") inside of the grain is already infected with the fungus. But in neither of these cases is there an inheritance of the disease.

Kinds of predisposition. Predisposition may be therefore of two kinds, the natural and inherited condition of structure and habit due to internal causes, and the accidental or abnormal conditions which are due, not to internal inherited traits, but to the accident of external forces. Thick-skinned potatoes are known to be more resistant towards certain rots than thin-skinned potatoes, i. e., the thin-skinned forms are naturally predisposed in their structure to that disease. Again, oat grains germinate at about the same time when the oat smut spores germinate and hence the young oat plants are predisposed to smut attacks by their inherited habit of germinating in the spring. Such might be termed a natural predisposition of habit. On the other hand, a wounded plant is predisposed towards the attack of wound parasites by an external force as in pruning, or by wounds caused by cattle or deer, or a wagon wheel, and is more liable to such attacks after receiving a wound.

Again, the transplanting of plants from a dry to a moist climate may predispose such plants to disease. Here the predisposition is induced by external factors. It is noticeable that in both of these predispositions of external cause the predisposition as in a wound or in transplanting may not in itself bring about serious injury to the plant. Plants have an effective method of healing over wounds and a removal from a dry to a moist atmosphere frequently stimulates the plant to extraordinary growth. But it is in opening a new field of attack for invading organisms and other disease-causing factors that such externally caused conditions may prove dangerous to the host-plant.

Many other plants besides oats are predisposed towards disease during their youth or during the youthful stages of certain organs. The corn plant is attacked by the corn smut only in young growing parts and the fungus cannot invade mature tissues. Certain conditions of the youth of plants aid in the attack of disease; for instance, the thinness of the tissue skins, and the abundance of food material. It must not be assumed that all plants in their infancy are predisposed towards disease, but there are certain conditions which may in general tend to increase susceptibility towards disease. Perhaps the problems of old age are still more productive of predispositions. Young tissues have the advantage of vigorous protoplasm, while aged plants have reached their limit of growth and are losing ground. Again, seasons may bring predispositions, as in the oat smut, for several causes may contribute to the same predisposition. A rest period may also be productive of disease since the protoplasm is not as active in resistance when resting as in the rapidly growing condition. Such is the case of the ripe rot of fruit. Predispositions of form have already been cited in the thin-skinned potato. Immunity from certain diseases sometimes comes with wax-coated surfaces or thick cork, etc. Physiological habits of plants, as in the oat smut, are likewise productive of predisposition or immunity. Such habits as in the germinating period of grains growing in different regions may be important in assisting the plant to escape disease. This is the partial explanation of the advantage of selection of seeds growing in certain regions, e. g., northern grown seeds for northern localities.

Plants kept under peculiar conditions of moisture or temperature may acquire a predisposition towards disease. Hothouse plants suddenly planted in very dry conditions are sometimes not able to adjust their water evaporating apparatus to the dryer conditions and suffer wilting and accordingly in some cases death. Likewise, when trees grown in the protection of forest shade are suddenly transplanted to a prairie or isolated by the cutting down of surrounding trees, they may fall a prey to sun scorch.

External causes may be fertile in many other predispositions: Wounds by pruning, root injuries, insect boring, hailstone wounds and injuries by lightning strokes, frost cracks and sun scalds, etc.

It has already been explained that disease is never inherited. On the other hand, it is a fact that natural conditions, e. g., of form or of habit, which are, in reference to certain diseases, causes of predisposition or immunity, may be inherited. Such accidental conditions as wounds are of course not capable of transmission. In other words, only natural or so-called normal predispositions are inheritable.

Variation and predisposition. The selection of varieties in agriculture and horticulture is very greatly concerned with this phase of the subject. Variation in structure, form and habit give to plants different degrees of resistance toward certain diseases, some greater and some less. Of course there is likewise variation in respect of other conditions and one may select varieties for those conditions. For instance, wheat varieties may be selected for their fitness for milling, size of grains, crop yield and other characters. Fruit tree varieties are selected for size of fruit, keeping qualities, yield and so on. Now one can also select varieties of agricultural plants for the resistance which they exhibit towards a given disease. For instance, certain varieties of strawberries will resist the strawberry spot fungus more successfully than others, and where this disease is prevalent might be very desirable. Again, some apples or crabs are more susceptible to apple scab than others, and the selection of these varieties may be a distinct advantage. Of course such varieties might not be the most desirable in other respects. In other words, the intelligent grower of plants has before him a very complex problem. The object to be gained is the best crop under the existing conditions. These conditions he must know thoroughly before he can solve the problem, and the varieties must be selected accordingly. It should be emphasized that the conditions must be thoroughly understood and the difficulties appreciated. If they are not, the plant grower is working in the dark. The wheat rusts furnish a good illustration of the complexity of the problem which is presented. Wheat rust may be caused by one or more of several kinds of fungi which are very closely related but are nevertheless distinct kinds. A wheat variety which might resist one of these would be unable to resist others. Now an intelligent solution of the problem must include a knowledge of the particular rust fungus attacking wheat in certain localities and then varieties must be selected which will resist this particular fungus. If more than one fungus is prevalent in this locality the selection of a rust-proof variety becomes more difficult. In other words, rust-proof varieties may have to be selected for certain kinds of rusts and not for rusts in general, although, on the other hand, it is not conceivable that certain varieties may possibly be developed which will offer general resistances to the whole group of rusts, e. g., where they are able to withstand the predisposing effects of moisture, or in their early or late sprouting habits might dodge, as it were, the time of year when rusts' spores are most abundant. Early sowing of wheats was an attempt to evade this period of the year but not as yet with very conspicuous results. In a word, the greatest success in selection of varieties is still to be obtained, but can only be won by more knowledge of the habits and forms both of the hosts and of the fungus causing the disease. More knowledge and the hearty coöperation of the practical plant grower with the plant disease specialist are the requirements of the solution of these complex problems.

Infection of host. We have already seen that fungi use various methods and agencies for the distribution of spores and there are consequently various methods of inoculation of host plants. In the first place it must be pointed out that inoculation and infection are two different things, e. g., a plant may be inoculated with fungus spores which may even start to grow, but a successful continuance of growth does not always follow. When the fungus does succeed in living with the host, infection in the true sense is accomplished. Infection is successful inoculation.

The wind transports many fungus spores from plant to plant and some great plant epidemics are due in part to this agency. It seems possible that red rust spores may be blown from warmer climates, where they pass the winter, many miles, inoculating in the early summer or spring the plants of northern countries where the summer spores cannot be formed throughout the year. Inoculation of some fungi occurs chiefly through swimming spores and in such, only wet seasons will enable the disease to become serious. Such a parasite as potato blight will spread with remarkable rapidity on plants in low, damp situations or during excessively moist weather. Some of the algal fungi, as white rust, combine the two methods in distributing by means of the wind, spores which in subsequent rainy weather break up into swimming spores and thus act as new centers of inoculation. Insects carry spores of fungi from plant to plant and are allured by "honey dew" or by other sweet and odorous liquids. In the case of ergot of rye the insects are attracted by a honey-like fluid, which is exuded by the young grain, on which the fungus has formed an abundance of summer spores. These are then carried by the fly to other young flowers and the disease thus spreads rapidly. It is known that many other animals effect the spread of plants by distributing spores under favorable conditions. The furry coats of some rodents have already been mentioned as depositories for spores. Man is responsible for many inoculations of fungus spores on plants. All of the numerous methods of transportation and travel and commercial intercourse furnish means by which man scatters spores of fungi, often bringing them into most favorable conditions. The introduction of mallow rust from South America has already been cited. Careless pruning or wounding of trees, untidiness in horticultural and agricultural pursuits and lack of knowledge of the nature and various methods of infection of certain diseases all conspire to make man an efficient aid in the spread of fungus plant diseases. In manure heaps dangerous fungi often multiply or pass the winter. The debris of trees or other plants which have been diseased is also a menace. The various farm implements, in passing from one place to another, may carry spores and effectually scatter them. The sowing of smut-infected oats without taking the precaution to kill off the fungus is a good case in point. Finally, the fungi may actually aid by special devices the spread of disease. Such devices are seen in the sac fungi where spores are forcibly ejected and so, caught by the wind, are easily scattered. Again, infection may take place not only by spores but also by mycelium, and does so in many cases. This is noticeably true in those fungi which

FIG. 39.—A good example of an epidemic. Potato blight has, within a week, entirely destroyed the potato plants in this field. After Clinton.

attack trees and particularly root parasites. Contact between a diseased tree trunk or roots and a healthy one may offer the mycelium a chance to pass over directly from the one to the other and a successful infection may ensue. Some of these fungi have a special shoe-string-like strand of threads which are especially proficient in effecting mycelial infection.

Epidemics. When a fungus disease becomes particularly abundant and devastates great fields or forests of certain host plants there arises an epidemic. There have been notable epidemics of continental extent in historical times just as there have been famous plagues attacking man. Potatoes have many times been decimated by the blight, forests have been threatened by the honey mushroom; the mallow rust has swept over Europe and America damaging many kinds of mallow; while year after year one may read of epidemics of grain rusts and of smuts. These epidemics are more widespread in some years than in others. This last season (1904) has seen wheat-rust epidemic almost throughout the northwestern United States and Canada. In Ceylon the coffee disease has ruined hundreds of coffee plantations. A remarkable fact in these epidemics is that the fungi which produce them may have been present a long time previous to the epidemic without exciting any great amount of damage. It is well known, for instance, that potato blight, wheat rusts, mildews and smuts are always with us, but that not every year furnishes epidemics. It is therefore evident that other factors besides the immediate cause or fungus factors must be present. Of these, weather conditions are usually the most important factor. Potato blight never thrives in dry weather or on plants in sandy soil, but is at its best when the weather for days is misty and moist so that the fungus can form its swimming spores and distribute them rapidly. It is just in such weather as this, and particularly after a warm growing season, when the leaves are swollen with moisture and rich in food material, that blight strikes. Several of such epidemics of enormous extent have been known. It is also a well-known fact that wheat rust often follows upon very moist springs and early summers. In fact many people still think that the wet weather causes rust. And they are not altogether wrong, but the effect of the weather is not exactly as such people imagine. Warm, moist weather is just the kind of weather which is favorable to the development of the summer spores of the rust fungus and the fungus grows luxuriantly, producing in two weeks or less another crop of summer spores, thus multiplying an hundred or a thousand-fold in this short time.

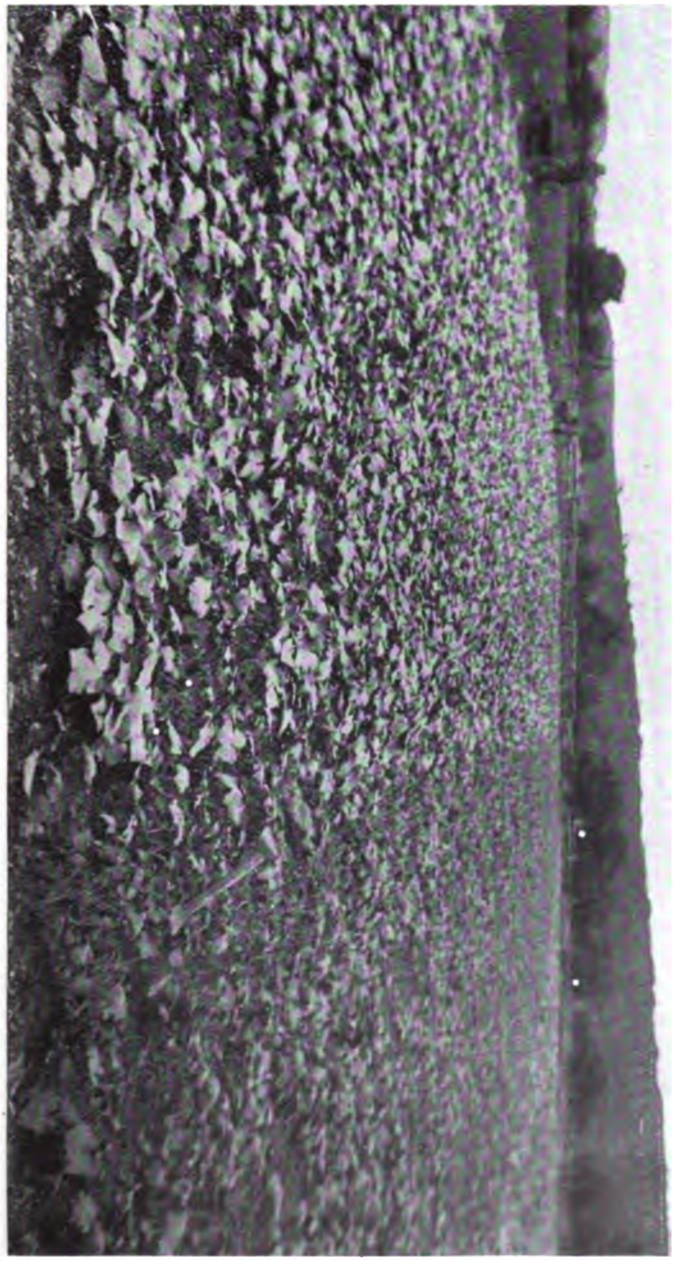


Fig. 40.—An epidemic of mildew on cucumbers checked by spraying. This field was sprayed in streaks and the sprayed regions were almost

The success of smut infection depends largely upon the ability of the spores to germinate and the germination of the spores at a suitable season for attacking the host-plant, e. g., in oats, in the seedling stage. An epidemic of smut must, therefore, be preceded by a season favorable to spore germination and also coinciding with the seedling stage of the grain. Such epidemics, moreover, are greatly favored by the clinging of smut spores to the grains since they are thus sure to be near the latter when these commence to grow.

Many other causes of epidemics might be mentioned. Under so-called normal conditions the fungus may create no extraordinary damage but under propitious conditions it becomes epidemic. One can easily understand that any disease may become epidemic if the conditions are right, and since the horticultural and agricultural changes instituted by man are so great in many cases it is to be expected that the danger of epidemic diseases is always an important and ever-present source of trouble. The older horticulturists and agriculturists took cognizance of epidemics only after they occurred, when, of course, remedial measures were impossible. Now the raiser of plants, just as does the medical practitioner among men, keeps close watch upon all kinds of diseases and attempts to *prevent* epidemics rather than to cure them. Every introduction of a plant into a new country and new surroundings, every appearance of a new hybrid opens up new fields for numerous parasites who may find in the newcomer just the right conditions for an epidemical growth. Every introduction of a new plant to a certain community may also bring new fungus diseases which may be able to attack plants of this community if the latter have not learned to withstand their attacks. Thus may result an epidemic similar to that of mallow rust. It is useless to suppose that we shall ever get rid of the plant disease question and be able to lay it aside under the weight of a few rules for spraying or other treatment. On the contrary, the more complex and advanced our agriculture and horticulture become even more so becomes the question of immunity from fungus epidemics. As the host plants vary so also may the fungi, and those parasites which are apparently harmless today may in years to come be very dangerous pests.

Chapter VIII.

Fungi. Kinds of Fungi. Algal Fungi.

The fungi are undoubtedly descended from algal stock and, as commonly understood, more than one line of descent is probable. That is to say, the ancestors of the present day fungi were all algae, though of at least several kinds. The algae comprise a group of plants which have in general a water-habit. A great many fungi still retain this water-habit but unlike the algae, which possess leaf-green, they are unable to manufacture their own food. On the other hand, a vast number of fungi have learned to live in the open air or in the tissues of other plants or on the ground; in short, have abandoned the aquatic for some terrestrial habit. With this change in habit have gone on changes in form and methods of reproduction. Botanists recognize three great groups of fungi. The lowest group is that of the algal fungi, including those of which the majority have retained the aquatic habit and in which the reproductive methods have been less strongly altered than in the two remaining higher groups. The latter groups are in general terrestrial, and have adopted two very distinct methods of reproduction. In all of the sac fungi spores are formed inside of sacs and these sacs in most forms are elongated cylinders containing eight spores each. In the stalked fungi the spores are produced externally on fungus threads, and are borne on fine and delicate stalk threads. The number of such stalked spores on each thread is commonly definite for any given species and the usual number is four. The production of spores by breeding is known to occur throughout the algal fungi and has been observed in many cases among the sac fungi and probably occurs throughout the latter group. Up to within recent times no undisputed evidence had been produced of the presence of a breeding act among the stalked fungi; but it is now known that a fusion process takes place and this has been interpreted as a breeding act by some botanists.

The algal fungi (*Phycomycetes*). It has already been stated that these fungi are for the most part aquatic in habit but that some forms, as the insect molds and black molds, have abandoned the water and taken to dryer situations. It is a noticeable fact, however, that even insect molds and black molds require very moist conditions. It is in the algal fungi, therefore, that swimming spores are commonly produced and especially, though not exclusively, in the aquatic forms. White rust of mustard produces swimming spores at certain stages, but this only occurs when an abundance of water is present, so that the fungus may be considered aquatic during a part of its life and terrestrial during the remainder. Spores are produced by a breeding act and often these are special spores for resting purposes; they are therefore provided with very thick walls. In some families, as in the black molds, large numbers of spores are produced in cases which to the naked eye look like tiny black spheres about the size of a pin-point. These spores are not provided with swimming lashes but depend upon the wind for aerial distribution. The algal fungi are structurally peculiar in that the threads have no crosswalls except when spores or spore-cases are about to be formed. The following groups are the most important among the algal fungi: Chytridines or Lowly Algal Fungi, Water Molds, Fish Molds, Sewer and Drainpipe Molds, Damping-off Fungi, Downy Mildews, White Rusts, Black Molds and Black Mold Parasites.

Lowly algal fungi (*Chytridineæ*). In this group are found, in general, very simple fungi. All of them are minute and it requires strong powers of the microscope for the observation of most of them. The simplest are tiny single-celled spheres and resemble much the Flower Pot Algae, except that they have no leaf-green. In fact, it is very probable that they have descended from these algae. Some have become elongated into simple threads and still others are even considerably branched. Spore cases and breeding spores are produced and each forms, by internal division, swimming spores. These swimming spores are the chief agents of distribution and are provided with one or two lashes which, by whipping about in the water, drive the spore forward with a combination of a hopping, whirling and swimming motion. These spores, when they come to rest, draw in their whips and immediately grow out into the mature plant. The function of the resting spores, whether a breed-spore or not, is to tide the plant over unfavorable seasons. When breeding occurs, the two breeding organs are exactly alike and indistinguishable, as is the case in some pond scum algae. These lowly fungi are found in a great variety of habitats. Most of them are parasitic, though some are saprophytes. They are found on algae as well as on lowly water animals or on the eggs of the latter. Some are found on fungi, particularly on water and fish molds, while a large number inhabit the leaves and stems of the flowering plants. In their parasitic habitat they often arouse the host to extraordinary growth and swellings or galls are thus produced. Hence they are sometimes known as gall fungi. Galls of this nature are produced on the leaves of dandelion, anemone and on garden plants such as cabbage. Few, however, produce diseases of very great importance. In that they damage algae and water animals in the waters of fish hatcheries they injure or diminish the food supply of the young fish. One species attacks and gains entrance to pollen grains of the pine when the latter lie on the surface of water or are submerged in ponds, and lives inside of the spore until it forms its swimming spores when the latter are thrown out into the water. Some have even learned to penetrate and to live in the pill-box algae, which are provided with walls of silica. (Figs. 41, 211.)

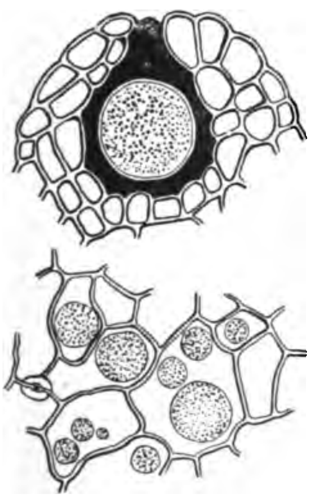


FIG. 41.—A lowly algal fungus. Above, the resting condition of a single-celled fungus in the tissues of the host plant. Below, young fungus plants are seen in the cells of the host. Highly magnified. After Schroeter.

Water molds and fish molds(*Saprolegniineæ in part*). These fungi are more highly organized than the group of fungi just discussed. In the first place they all possess a branched and well developed system of thread mycelium. They are, however, all aquatic in habit and thrive in stagnant pools where decaying animal and plant materials are particularly abundant. They are typically half-saprophytes, passing most of their life feeding on dead material in the water, but living parasitically on fish or other animals, as occasion presents itself. As water plants they utilize the swimming spores and these are usually formed in enormous numbers in spore cases of various shapes. The swimming spores are of the same general structure as those of the lower algal fungi, though in a few cases they seem to be unable to get out of their spore cases and they then grow out into threads while still inside of the case and never develop whips. All the fish and water molds develop breeding organs of two kinds, male and female. The female organs are usually spherical cases, which contain a small number of eggs, and the male organ is an elongated thread which is sometimes branched and usually arises from the same thread which produces the swollen egg case. Now the male thread penetrates the egg case and can be seen making its way between and around the eggs, but a remarkable feature lies in the fact that they never as far as has yet been observed breed with the egg cells. The latter nevertheless

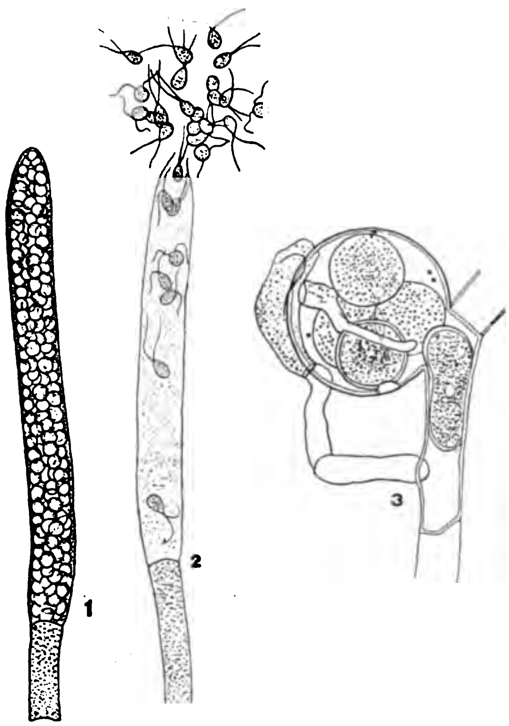


FIG. 42.—Water and fish molds. 1. A fungus thread with an unopened spore-case. 2. An opened spore-case with the escaping swimming spores. 3. An egg-case with the male threads penetrating it. The spherical bodies in the egg-case become the resting egg-spores. Highly magnified. 1 and 2, after Thuret; 3, after DeBary.

seem to be stimulated for they now become the egg spores whose special function is that of resting spores. They cannot be made to develop further until they have rested for some time. After this rest period they divide up internally into swimming spores.

These water molds grow luxuriantly on almost any kind of decaying organic matter in the water. When the bodies of dead insects, such as flies or grasshoppers, fall into the water they soon become surrounded by a halo of fungus threads from the water mold which quickly forms swimming-spore cases in countless numbers. When the nutrient material becomes scarce egg spores are produced. Dead minnows or fish are also quickly attacked by these fungi and the rapidity with which the fungus spreads is well seen in the growths on a fisherman's minnow bait. Not only are dead fish attacked. When living fish have suffered the loss of a few scales or some other slight injury, the fish mold may gain entrance through this spot and may spread rapidly as a parasite and finally kill the fish. It may even gain entrance through the gills or in the eyes of the fishes, and it very frequently attacks their eggs. The fish molds therefore may become dangerous pests in hatcheries. Numerous epidemics of these molds are known to have destroyed myriads of fishes in their native streams and lakes as well as in hatcheries. Not only fishes but other aquatic animals such as mud puppies and probably other amphibians are subject to attack, as are also many of the tiny microscopic water animals so abundant in stagnant pools and lakes, and thus the fungus preys on the food of fishes. A few forms are known which attack the pond scums. As is to be expected in such plants, the parasite is not of a high type, i. e., no exact selection of host seems probable though this simple method is highly proficient in its own way. The proficiency is due largely, no doubt, to the great number of swimming spores formed and the rapidity of their formation. (Figs. 32, 33, 42.)

Sewer and drain pipe molds (*Saprolegniineæ in part*). It is to be expected that sewer- and drain-pipes would offer favorable habitats for fungi of the general habits of the water molds and there are fungi which are constantly found in these places. A large amount of decaying organic material is always present together with constant moisture. These fungi are close relatives of the water-molds, differing from them in the long-beaded shape of their threads and in the presence of but one egg in the egg-case. Swarm-spores are again the chief means of distribution, though bits of the threads may be carried along in the pipes and become lodged. By growth these again produce another colony. In all kinds of drain-pipes, in sewers or in the drains of refrigerators these molds abound. They form dense, compact masses of mycelium which may ultimately stop up the pipe and thus cause trouble. They may also abound in streams, below factories or at the mouths of sewers, and may form large woolly masses of mycelium. (Fig. 43.)

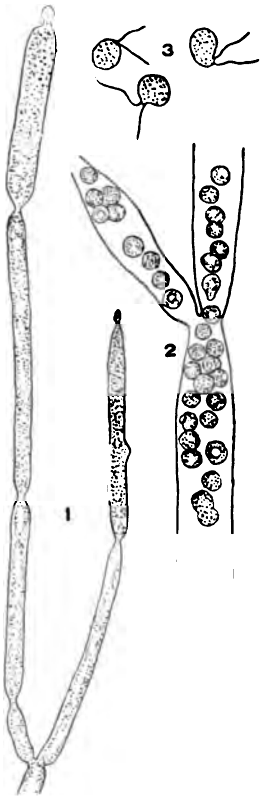


FIG. 43—Sewer-pipe fungi. 1. Fungus threads with peculiar constrictions. 2. Same (more highly magnified), with characteristic granules near constrictions. 3. Swimming spores. Highly magnified. After Pringsheim.

Damping-off fungi (*Saprolegniineæ in part*). These molds are also relatives of the water-molds but have approached more nearly to the terrestrial habit. In fact many of them are able to live comfortably in a very moist atmosphere, though typically they live in or at the surface of the water. The damping-off fungi have swimming spores and egg-spores; only one egg is produced in a case and the breeding between egg and male elements has been observed. The egg-spore is again a resting spore. Like the fish- and water-molds the damping-off fungi may live as saprophytes upon dead organic matter in the water. Many of them are, however, parasitic on algae, such as pond scums and green felts, while a few attack pinworms. By far the most common forms are, however, those which cause the disease known as damping-off. When seedlings, particularly of the mustard family, are sown very thick and are kept very moist, the damping-off fungi appear. They attack the seedlings just at the surface of the soil or below it, killing the tissues and the seedling tumbles over and is further appropriated by the fungus. In this way the fungus gains strength and large numbers of seedlings may fall. Not only mustards but clover and beet and other plants are subject to attack. In the slight preference of host, the damping-off fungus shows a slight indication of advance in parasitic methods, but the latter are still primitive and success only attends such favorable conditions as excessive moisture and crowded host plants. (Fig. 34.)

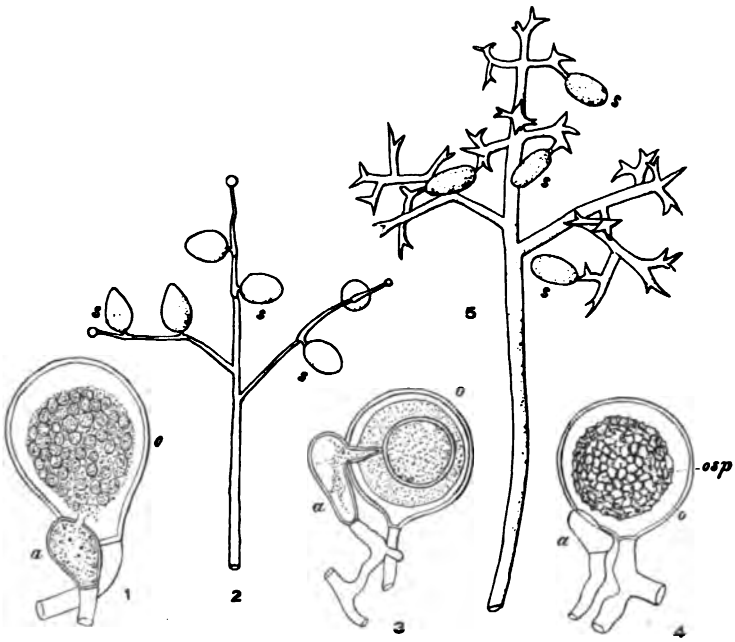


FIG. 44. —Downy mildews. 1. Downy mildew of seedlings (Phytophthora omnivora); formation of egg-spores by breeding act; a male cell and egg-cell case. 2. Potato blight (Phytophthora infestans), thread with spore-like swimming-spore-cases (s). 3. (Peronospora alsinearum.) Formation of egg-spore by breeding act in another mildew; letters as in 1. 4. Egg-spore formation in still another mildew; letters as in 1. 5. Thread of a downy mildew (Peronospora leptosperma) bearing spore-like swimming-spore-cases (s). All highly magnified. After DeBary.

Downy mildews and their allies (*Peronosporineæ in part*). Long ages ago, when the fungi had developed the saprophytic and parasitic habits, as one sees in the damping-off fungi, it became advisable to abandon the aquatic life because more opportunities are presented in aerial conditions. The damping-off fungus shows some such tendency but the blights or downy mildews show it still more clearly, for most of these fungi are parasites on common garden plants. It is a noteworthy fact, however, that they still require very damp atmospheres in which to develop well and only become epidemic in excessively moist seasons. These fungi have a very well developed system of threads which are much branched and spread through the tissues of the host plant. They are provided with little sucker-threads which penetrate the cells of the host plant and often form here very densely branched systems of threads. These sucker organs steal the nutrient material from the host plant. It is moreover a robber method similar in some respects to that of the damping-off fungus, for the host-plant parts attacked are ruthlessly and almost immediately killed. Such is the common effect of potato blight or downy mildew of vines. On the other hand, these fungi show more power of selection than do the damping-off fungi. Some are capable of attacking different and even distantly related plants but in general a given fungus of this group is quite constantly found on the same host or on closely related plants, e. g., members of the same genus or family. Wherever the threads of the fungus become abundant, the host plant is killed. The ancestral aquatic habit of these plants is still retained in the method of distribution by spores for these are swimming spores. Hence the fungus can spread rapidly only when there is a great abundance of moisture, as during excessive rains and cloudy, misty days. Under such conditions the swimming spores spread rapidly in the water drops and may be carried in these drops from plant to plant. An epidemic may thus result. On the other hand, these fungi have learned terrestrial methods of spore distribution. We find upon a close examination of the area infected by a potato blight, or false mildew, at first a thin grayish or whitish haze or shimmer spreading over the leaf, and that this fine mold-like growth is caused by an enormous number of usually much branched threads which come out of the air pores of the leaf. They pinch off of each branch end small, round, pear- or lemon-shaped bodies which look very much like spores and are commonly so-called. These bodies are light and easily carried by the wind and thus alight on other plants. In the potato blight and some of its allies this spore-like body does not betray its real nature until the conditions of moisture are favorable. Then it shows itself to be a spore-case and forms internally numerous swimming spores, which escape and spread the disease. Some of the downy mildews, however, have learned still more thoroughly the terrestrial habit and have almost entirely forgotten the ways of aquatic fungi. In these the spore-like body really acts as a spore, grows out directly into a thread and does not develop swimming spores at all, although in some forms it starts out as though it were going to form them and then abandons the attempt. We have here an excellent example of the persistence of a habit even after it is

FIG. 45.—A Downy mildew with the aspect of a white rust. Under surface of burweed elder (Iva xanthiifolia) showing dense clusters of spore-like spore-cases. Original.

ill adapted to the plant's new methods of life. Egg-spores are also formed throughout this group, though in a few cases, as in the common potato-blight, they have not yet been observed. As in the damping-off fungus, the breeding act of many forms has actually been demonstrated. The egg spores are typically resting spores and, as in the damping-off fungus, serve to tide the plant over winter or other unfavorable seasons. They are usually found in abnormally swollen parts of the host. The plants of this group are all parasites and most of the known forms attack cultivated garden plants. They live chiefly in the leaves where, in the roomy air-spaces, which are charged with moisture, they realize most nearly their preference for moist conditions. Perhaps the most famous fungus in this group is the potato blight, which causes rot of the plant in the field and a dry brown rot of the tubers in the cellar. Epidemics of this disease follow excessively moist and warm seasons and have been known to cause great damage. Tomatoes and other plants of the potato family also suffer attack from this fungus. Another very famous fungus of this group is the downy mildew of vines, which attacks the vine foliage and fruit, both of the old and new world, and causes great damage. Others exhibit habits similar to damping-off and attack seedlings. Some are found on bean plants, on grasses, and a very conspicuous one inhabits members of the carrot family. They are also found on sun-flowers and again a very important one is known on melons and cucumbers and their allies. Lettuce, beets, clovers, onions and tobacco plants, besides a large number of wild plants, as violets and anemones, are known as hosts to these parasites—in fact, almost every family of plants has its downy mildews. (Figs. 2, 39, 40, 44, 45, 166 to 171, 196 to 198.)

White rusts (*Peronosporineæ in part*). Very closely allied to the downy mildews are the white rusts. In their egg-spores and general habits they are quite similar. Just as in the potato blight, spore-like bodies are produced which later show their spore-case nature, but these spore-cases are not cut off singly from the ends of threads. They are formed in chains and these chains are arranged together in such dense clusters that they form a white rust-like mass when the host-plant skin has been broken and thrown back.

The most abundant of the white rusts is one common on the weed plant known as shepherd's purse, and found also on other mustards. Another is found on pig weed and on portulaccas, others on morning glories and on a great many other plants. As in the downy mildew the egg-spores are often found in swollen portions of the host where the fungus has excited the host plant to unusual effort. The advantage to the parasite is evident, since it is in the egg-case-producing part of the plant that much nutrition is needed. (Fig. 45.)

Black molds (*Mucorineæ in part*). These fungi are exceedingly common plants found on starchy materials and hence often called bread molds. Although they have descended from water-inhabiting plants they have retained almost no trace of an aquatic habit, with the exception of the requirement of a moist atmosphere for growth. That is to say, there is no formation of swimming spores; for all of the spores, except the resting spores, are distributed by the wind, though aided in some cases by a special explosive apparatus. The spores, as in other algal fungi, are of two kinds, viz.: the egg spores and those produced without breeding. The former are formed by a different method from that of the false mildew where an egg and a differently shaped male thread branch are found. In the black molds both breeding organs are alike in size and shape and are indistinguishable, just as is the case in the pond scums among the algae. The egg spore is a resting spore and is provided with a large, thick, resistant, usually black-colored coat. However, the most common form is that of the non-sexually produced spore. These are produced in tiny, black, spore-cases, which appear like small, black points in the mass of mold threads. Each case contains a great number of spores which escape by the breaking of the spore-case wall and are blown about in the wind. In some molds, which are particularly abundant on horse dung, there is a swelling in the thread just below the spore case and this swelling acts as a syringe bulb under pressure. When the spores are ripe the whole spore case contents are blown off at once and thrown a half-foot or more into the air.

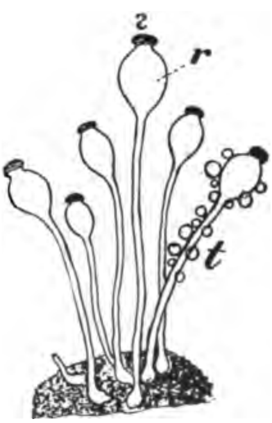


FIG. 46.—A black mold. The black spore-cases are seen on the ends of the fungus threads. Highly magnified. After Zopf.

The black molds are of very great importance on account of the damage which they cause to food stuffs, particularly the starchy foods. Bread, cake and pastry, when kept moist, will almost surely develop mold, because mold spores are to be found in the air of almost any region and at almost any time of the year. The black molds are all typically saprophytes. A few have, however, learned just the beginnings of parasitism, e. g., those black molds which attack ripe fruits through wounds or thin skins. Since the protoplasm in fruits is in a dormant condition and contains an enormous amount of food material, sugar, etc., the black mold is able to live here, amateur though it may be, as a parasite. Some animal diseases have already been mentioned as the result of black mold, though in these cases it is doubtful whether the fungus is actually parasitic, or merely saprophytic. It has in recent years been found that some molds have the power of changing the starchy material into sugars and adepts in this process have been selected and are now used to convert potato starch into sugar; from these sugar solutions, by the action of yeast, alcohol is then produced. In this process the potato starch is sterilized by heat and enclosed in perfectly clean casks, and the fungus is then introduced under perfectly clean conditions. When the starch is all converted, the yeast is introduced, also in the pure state, so that the whole process is as carefully conducted as in the culture of bacteria by an expert bacteriologist. By this process the yield of alcohol has been enormously increased. Moreover, some black molds when submerged in a sugar solution have the power of forming alcohol and carbonic acid gas just as do the yeasts; but they are not vigorous enough to be of economic use.

Some of the peculiar intoxicating drinks of Asiatic tribes are produced by the introduction of certain black molds and yeasts into starch mixtures.

Many black molds are also to be found on decaying fungi, as mushrooms, though it is not certain that they are actually parasites, they undoubtedly hasten the decay. (Figs. 14, 16, 17, 46.)

Black-mold parasites (*Mucorineæ in part*). Closely related to the true black molds are certain forms which live chiefly as parasites on other black molds. They are also found on a few other fungi. If a piece of bread with an abundance of black mold on it be left in moist conditions for some time these parasitic molds almost always appear. They are very minute plants and require high powers of the microscope for their observation. They form a delicate thread mycelium from which fine branches

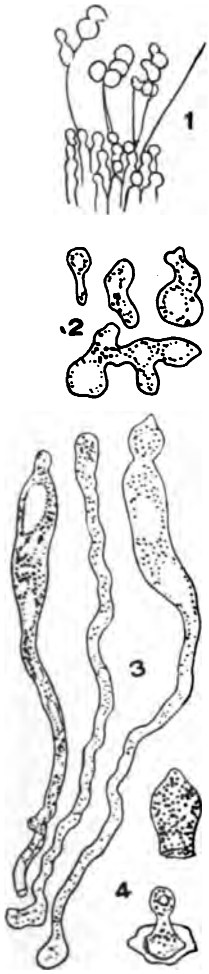


FIG. 47. — An insect mold. (Fly cholera fungus.) 1. A cluster of threads with spores clinging to hairs on the insect's body. 2. Fungus threads from the fat-body of an insect. 3. Spore-bearing threads, highly magnified. 4. Above, a single spore; below, germinating spore, forming a secondary spore. Highly magnified. After Brefeld.

are sent into the threads of the host plant where they obtain nourishment for the parasite. They are also found on certain of the blue-mold group of fungi.

Insect molds (*Entomophthorineæ*). Of all the algal fungi these are most clearly non-aquatic in their habits. Like the black molds they form breeding spores, from similar sex organs, though these spores are not of frequent occurrence. On the other hand the non-sexual spores are very abundant and are pinched off from the ends of special threads. Moreover, there is usually some device for throwing the spore to a distance. The thread is swollen just below the spore and when the latter separates from the thread the release of pressure in the swollen portion results in the forcible ejection of the spore. This is the case in the common fly cholera fungus. Most of the insect molds are parasites on insects either in the adult stage, as in the fly cholera, or on the larva.

When the fungus has gained entrance to the body of the insect it soon kills the latter and then lives saprophytically, producing a great abundance of spores. House flies are commonly attacked by fly cholera in autumn and when they die cling tightly to window panes and other objects. They are soon surrounded by a halo of spores thrown onto the pane from the fungus threads by means of the spore-throwing device described above. Many other insect diseases are caused by these fungi. Caterpillars sometimes become covered with moldy growths which completely envelop them. From the surface of these growths are thrown the fungus spores. These parasites of insects prove of great benefit to plant growers because they destroy so many insect pests of plants, as lice, locusts, etc. They are also responsible for some destruction of such common pests as mosquitos. Some insect molds are saprophytes living on dung and are apparently of no economic importance. A few attack plants and particularly the sexual plants of ferns when cultivated in greenhouses. They cause a disease similar to damping-off. The economic advantages of this group, however, far outweigh the injuries. (Figs. 14, 47.)

Chapter IX.

Fungi. Kinds of Fungi. Sac Fungi.

Sac fungi (*Ascomycetes*). The second of the three great groups of fungi is that of the sac fungi and this group is in short easily distinguished because all of its members bear at least some of their spores inside of sacs. These sacs may be spherical or pear-shaped or long-cylindrical, according to the plant, and they always contain a definite number of spores. The sacs in the simplest of these fungi are borne irregularly upon the loose weft of the mycelium but in the very great majority of sac-fungi they are borne in capsules of various shapes and often of great complexity.

Sometimes these capsules are little, black spheres, as in the powdery mildews, with or without an opening, while in others they may be borne in the fruiting bodies known as truffles or in the cups of cup-fungi. According to our present knowledge a breeding act seems to precede the formation of the sacs and in some cases one, in others, numerous, sacs may arise as the result of a single breeding. A vast number of sac fungi form more than one kind of spore—in fact many produce two or three so-called accessory spores, so that the study of such forms becomes a very difficult matter. Indeed, one may find many of these accessory forms without the main sac-form and it is then often exceedingly difficult or altogether impossible to even determine the fungus. Thousands of such fungi have been found—many causing important diseases of plants—which are thus imperfectly known and are described under provisional names until more facts are discovered about their life-stories and their proper sac forms. Not until then can they be accurately and permanently classified. Such fungi are called imperfect fungi. It is even probable that many have forgotten how to form their sacs and now produce only the accessory spore-forms and thus present an actually imperfect life-story. Again, the sac spores may be of such seldom occurrence that they have been entirely overlooked.

Conspicuous examples of accessory spore-forms are seen in the green mold growths of cheese, in the powdery mildews or summer spores of the mildew fungi and in the honey-dew spores of the ergot. The groups of fungi discussed in this and the following chapter are subgroups of the sac fungi. (Figs. 10, 14 and below.)

Yeasts and their allies (*Saccharomycetes*). Undoubtedly the simplest of all of the sac fungi, at least as far as structure is concerned, are the yeast fungi, though this simplicity is to be explained by a reduction from a more complex form, due to peculiar habits. The yeast plant consists of a single sphere-like or somewhat elongated cell, so small in size that high powers of the microscope are necessary for their examination. These cells multiply rapidly by bulging out little spherical "buds" which become separated from the parent cell and soon produce new buds in their turn. A cell may continue to bud off little plants as long as nutrient material is available. Sometimes the daughter cells do not separate from the mother cells completely but remain more or less loosely attached and thus false filaments or threads are built up. Such are often found in the scums on the surface of yeast-containing fluids. The simple method of propagation by budding suffices the yeast plant for multiplication during favorable conditions and the ordinary yeast-plant-cell is often, moreover, capable of resisting successfully very unfavorable conditions. But when

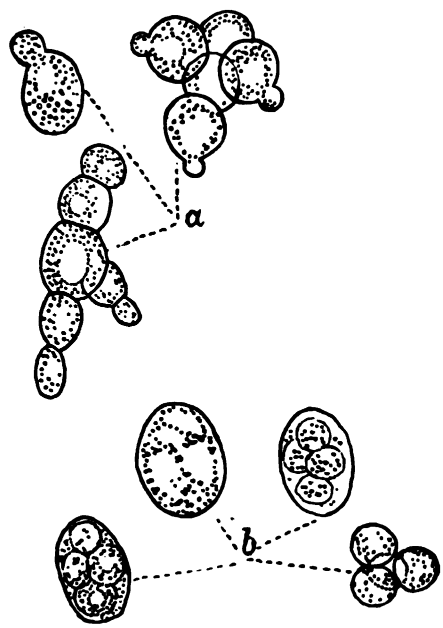


Fig. 48.—Yeast fungus cells. a. Ordinary bread yeast, showing sprouting vegetative cells. b. Spore formation in a yeast; four spores in a sac. Below are shown four free spores. Highly magnified. After Rees.

their nutrition runs low, yeast plants may prepare for unfavorable seasons by forming sac-spores. A breeding act has been described for at least two kinds of yeasts, preceding the formation of the sac-spores. The two plant cells which unite are both similar, and inside of the united cell four spores are formed. In most yeasts, however, no breeding act precedes the formation of sac-spores. The sac-spores have thick walls, are resistant and are often capable of resting for a long time before resuming growth.

Yeast plants are, in general, found growing most vigorously in liquid solutions of nutrient material for the budding habit is of peculiar advantage in such an environment. The daughter cells are easily separated from the mother cell and are carried by convection currents to other parts of the liquid where they get more nourishment. It is in sugar solutions or in closely allied substances, as starch, that the yeasts thrive best. In nature they are found in the juices exuding from ripe grapes or other fruits.

Many yeasts possess the power of breaking down the sugars into carbonic acid gas—which escapes in the form of bubbles—and into alcohol; i. e., they have the power of fermentation. This process is made use of in bread-making and in beer and wine making. In the former the carbonic acid gas is used in the raising of the bread while in the latter the alcoholic products are those sought for. Not all yeasts have the power of fermentation and many, although possessing this power, are not vigorous enough to be of commercial use. The common beer and bread yeasts have been chosen because they are vigorous fermenters. Moreover, many yeasts can ferment only certain kinds of sugars, as milk, or cane or grape sugar. One may also find several kinds of yeasts which, as far as structure and appearance is concerned, might be considered identical but which show that they are different in their powers of fermentation. Yeasts also play an important part in the production of many drinks of far eastern peoples, as of Japanese "saki," of kefir and kumys, though in these cases certain bacteria and blue molds may aid in the process. In the production of by-products, singly and in combination, yeasts may differ in the quality or tastes of the liquors thus produced, and the custom now obtains in some breweries of using only pure cultures of yeasts of a known kind, thus insuring uniform results. Certain wild yeasts and bacteria may find their way into the brew and by the formation of peculiar compounds may spoil the flavor. It has already been mentioned that certain yeast-like fungi cause several diseases of lower animals as well as thrush and sore throat in children. The systematic position of these fungi, however, is uncertain at present since the sac-spores have not been found. The power of fermentation is not confined exclusively to the yeasts since other fungi, though not many, possess this power, and it is possible that the thrush fungus is a member of some other group of fungi. As far as is known at present no yeasts can be said to cause undoubted parasitic disease in plants. It must be remembered, however, that in the exuding sugary juices of fruit under natural conditions, or from wounds, yeast cells are very commonly found, and it is not inconceivable that they work their way into the fruit and assist in fruit rot. (Fig. 48.)

Slime-flux fungi (*Endomycetaceæ*). In the slimy exudations which often flow from wounds in trees a great variety of such organisms as bacteria and fungi abound, and among them a close relative of the yeast fungi is not uncommon. This fungus differs from the yeasts in always possessing a thread mycelium and forms its spores on branches of this mycelium. It is not certain whether or not this fungus is the cause of the flux or whether it simply finds in the flux congenial conditions and appropriate food.

Leaf curls and plum pockets (*Exoascaceæ*). These fungi are of frequent occurrence on plants of the plum family such as domestic plums and cherries and peach plants. The host plant part is usually swollen. Leaves thus affected sometimes curl much and become distorted. Plum and cherry fruits when attacked by the fungus form the well-known "pockets" without stones. Both pockets and curls bear the spores of the fungus in a layer which covers the whole or a considerable part of the affected organ. This region takes on a greyish white color which is due to the presence of a great number of short cylindrical sacs, each containing eight spores. The spore-sacs stand side by side, like posts in a palisade, upon the surface of the leaf or pocket, and at right-angles to its surface. They arise just under the cuticle which is pushed up and sloughed off as the spore-sacs ripen. No breeding act has been seen to precede the spore-sac formation. The sac-spores are often capable of budding in yeast fashion when placed in sugar solutions, and in some of the fungi they bud in this fashion before they are released from the sac so that the latter may then contain a large number of spores. In addition to the effect upon fruit and foliage of plums, these fungi often cause witches'-brooms on cherries and plums as well as on birches and alders. Oaks,

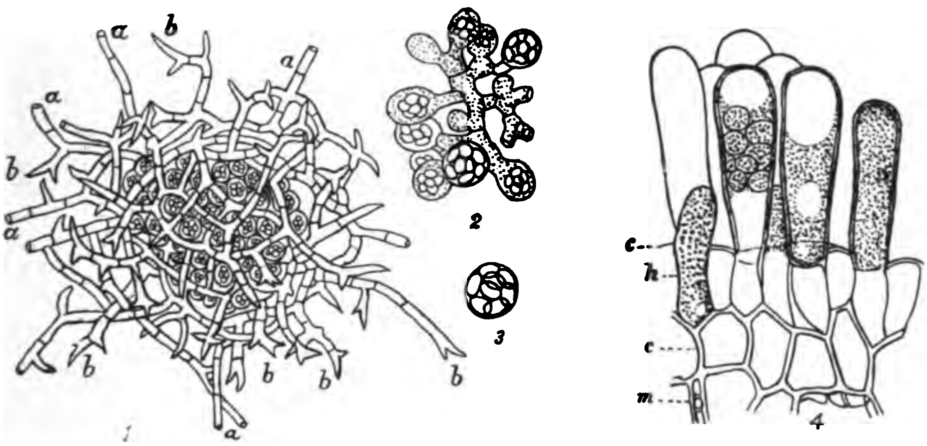


FIG. 49.—Plum-pocket fungus and loose-weft fungus. 1. A loose wefted collection of spore sacs, which is surrounded by barbed threads. A loose-weft fungus. 2. A small group of threads from 1, bearing a number of sacs. 3. Same as 2, showing a single sac with its sac-spores. 4. Plum-pocket fungus. Shows the spore-sacs of a plum-pocket fungus arranged in a palisade on the surface of the pocketed plum; c the cells of the plum; m fungus threads and h the fungus spore sacs. All highly magnified. 1, 2, 3 after Sachs; 4 after DeBary.

poplars and cottonwoods and sumacs are also attacked by them. (Figs. 49, 193.)

Loose-weft fungi (*Gymnoascaceæ*) Very closely related to the slime-flux fungi are the loose-weft fungi. The spore sacs are borne in dense clusters on a very loose weft of threads and in no regular arrangement. In some, there is a loose system of threads surrounding the cluster, forming a covering not unlike a large-holed basket. These threads are also usually armed with tiny spines. Such a covering is merely an amateurish, spore-sac capsule. The loose-weft fungi are peculiar in their habits. Many are found exclusively on feathers, some on bones, some on bees' nests, while others seem to prefer animal remains and meat extracts. They are not, however, either conspicuous in number or in size. (Fig. 49.)

Green and blue molds (*Aspergillaceæ*). The blue and green molds are amongst the best known and most conspicuous of fungi. They are the great destroyers of food stuffs and as such are well-known to every housewife. The common green or blue mold is an accessory spore stage. In this form thousands of threads stand upright side by side, each branches very profusely in broom fashion and each branch terminates in a long row of pinched-off spores which are of the characteristic green color. Millions upon millions of these spores may be produced by a small patch of mold. Such mold spores are present in great quantities in the air at almost any time of the year, so that just as soon as any food-stuff is exposed to the air it may be sown with green mold spores. These will quickly germinate and will produce in a very short time—often in a few days—another crop of mold spores. The green-mold spores, though the most common, are not the only spores produced by these fungi. There is also a sac-spore, though in most forms it does not occur frequently—in fact it is usually rare. These sacs are spherical as in the loose-wefted fungi, but are found on threads tightly woven together, and the whole spore-sac mass is surrounded by a membrane-like wall or covering, which is formed by closely united threads. These sac-capsules are often yellowish or black and are seldom larger or even as large as a pin-point. They are usually tiny spheres and of a solid structure. The spores, when ripe, are released by the decay of the capsules. There is no definite arrangement of the sacs in the capsule nor is there a special opening through the capsular membrane to allow of the escape of the spores. In some forms, at least, a breeding act precedes the formation of the capsule. The green and blue molds are especially fond of bread and other starchy materials, preserves, etc. They are also found on cheese and some varieties of mold are used to ripen the cheese, where the flavor is largely due to the green mold present. They are frequently found in preserved fruits and jells and also as simple parasites, causing mold-rots of fruits. (Figs. 1, 188, 189.)

Allies of green and blue molds. There are numerous allies of these molds which have strange habits indeed. Some, as in the loose-weft fungi, live on feathers and some live on the horns and hoofs of cattle. These fungi are of comparatively rare occurrence and have not yet been collected in Minnesota. Others, however, which resemble the powdery mildews in many respects, are found on the leaves and twigs of living plants, though seldom assuming a destructive parasitic habit.

False truffles (*Terfeziaceæ*). As is well known, the truffles are underground bodies resembling, to a small degree at least, small potatoes in appearance. Now the false truffles are very similar to the true truffles in appearance but they differ in some characters. The spore-sacs are not arranged with the same regularity which is common in the true truffles but are found in a loose weft as those in the loose-weft or blue-mold fungi. They may, in fact, be considered as huge underground spore-sac capsules of blue-mold-like fungi. Some of these false truffles are apparently the producers of fungus root-hairs in some flowering plants. They have not yet been collected in Minnesota.

Black fungi (*Pyrenomycetineæ*). These fungi constitute an enormous group of plants. They all agree in having a spore-sac capsule in which the spore-sacs are arranged in definite order and arise from the bottom of the capsule. The latter are usually, but not always, black in color and often resemble burnt wood. The spore-capsule in all, except the powdery mildews, has a definite method of opening by means of a pore which is sometimes protected by spiny processes. The simplest forms, the powdery mildews, are very similar in many respects to the blue and green mold plants and are their nearest relatives. Like these molds the black fungi possess accessory spore-forms and those of the powdery mildews, constituting the summer spores, are particularly like the green mold spores of the green mold fungi. They are not, however, green in color. The black fungi are conspicuous in the great number and variety of accessory spore-forms. Some species alone possess three or four kinds of such spores in addition to the sac-spores. The common Minnesota forms of the vast number of plants in this group can be arranged in the following ten groups.

Powdery mildews (*Erysiphaceæ*). The mildews constitute the simplest group of black fungi. The mycelium is usually to be seen on the surface of leaves as a white, moldy covering. The threads send branches into the skin cells of the host and there absorb their food and live parasitically, but the main mycelium of the fungus never lives inside of the host. In the

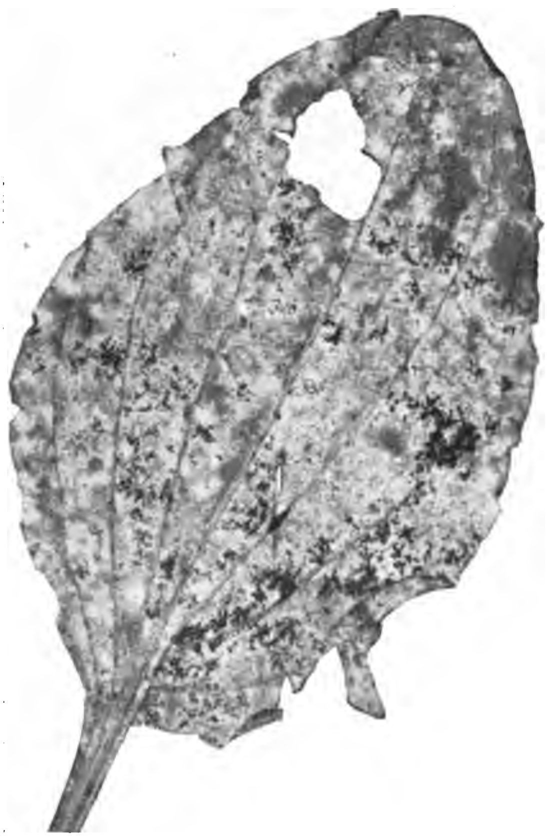


FIG. 50.—A powdery mildew on common plantain leaf. The powdery coat of the threads and the small black fruiting bodies can be clearly seen. Original.

summer, spores are produced in enormous numbers and form a dust-like covering over the leaf, whence the common name of powdery mildew for this group of fungi. These spores are pinched off in rows from upright threads, which thus become converted into chains of spores. Towards fall there arise, on the mycelium, minute spheres about the size of a pin point. They are at first white, then become yellow and finally dark brown to black. They are the sac capsules and bear one or more spherical or pear-shaped sacs with two to eight spores in each, according to the species. The capsular wall has no special method of opening but it may often possess elaborately-shaped threads known as appendages, which are often much branched and form a crown or circle around the case. Such may assist in the distribution of the whole spore-sac capsule. The powdery mildews live entirely on the outside of leaves and young branches of plants and are often dangerous parasites. A great number of our common garden plants as well as wild flowers are attacked by some sort of powdery mildew, though the conditions are not usually such as to create epidemics. Roses and grapevines are conspicuous sufferers as are also gooseberries and other garden plants. These fungi are also found abundantly on lilac bushes, all kinds of willows, birches, poplars, elms, oaks, maples, and many others, but on these do not often cause much damage. (Figs. 10, 50 to 52, 134, 135, 152, 192, 202 to 204, 210.)

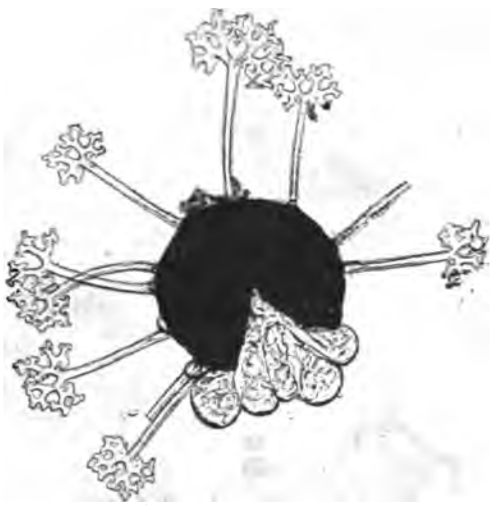


FIG. 51.—The fruiting body of the powdery mildew of black haw, showing the appendages. The sac-capsule has been broken and the sacs, each with about eight spores, are emerging from the split. Highly magnified. Microphotograph by E. W. D. Holway.

Honey-dew fungi (*Pyrenomycetineæ in part*). Structurally this group of fungi is a close relative of the mildews. The spore-sac-capsule is built on the same general plan but does not usually contain appendages while, on the other hand, it is usually furnished with a pore for the exit of the sacs and spores. Accessory spores are also found in abundance in these fungi, many being enclosed in special capsules similar in appearance to the sac-capsules. The mycelium is, moreover, often black. Many of these fungi live on leaves but not in a typically parasitic fashion. They thrive well on the excretion of certain insects and since such excretions are found abun-

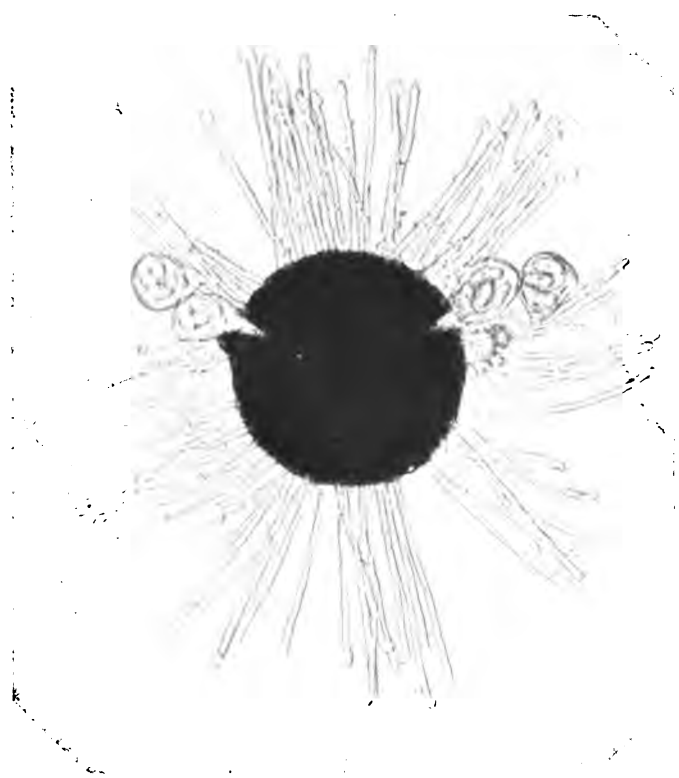


FIG. 52.—The fruiting body of the powdery mildew of willow, showing the appendages and spore-sacs. The latter have been forced out of splits in the sac-capsule. Highly magnified. Microphotograph by E. W. D. Holway.

dantly on the leaves of plants these fungi are also found on the surface of the leaves. On account of the abundance of mycelium produced and on account of its dark color a vigorous growth of mycelium may exclude sunlight from the leaves and thus injure the leaf, although the fungus may not in itself be harmful. These fungi are often known as the sooty molds on account of the soot-like mycelium which is developed.

FIG. 53.—Ergots of grasses. On left is one on a reed-grass; on right one on quack-grass; s sclerotium or "ergot," the fungus storage organ. Original.

Ergot fungi (*Hypocreaceæ in part*). The fungus which produces ergot is a member of the black fungus group, though not a very close relative of the mildews. The life-story of such a fungus is somewhat complex and we may illustrate by that of the ergot of rye. In the summer, when the youngest grains are commencing to fill, or just before that period when the grass flower opens, the spores of the ergot fungus may lodge in the flower and start to grow. The young threads are capable of attacking the growing grain and in a short time almost completely absorb the latter, forming a more or less soft, spherical or elongated mass of mycelium, at the summit of which are formed, in convolutions of the surface, thousands of summer spores. These are accessory spore-forms. The production of these spores is accompanied by the formation of sweet saccharine fluids which are very attractive to certain insects. Visiting insects become at least partially covered by summer spores in the sticky solution and in their visit to other flowers transfer these spores, just as they do the pollen, from flower to flower.

FIG. 54.—Ergot fungus on canary grass; s sclerotium or storage organ of the fungus. Original.

Now it is only in the young stages of the flower that these spores can attack the grain so that rapid spread of spores is necessary and is, moreover, readily accomplished by this insect-method of spore distribution. These spores are produced by the fungus for some time. Toward the time of ripening of the grain, the production of summer spores ceases and the fungus commences to pack up reserve nutrition in its threads. These are now compacted together in a very solid mass the exterior of which turns violet black. The whole structure becomes a storage organ or sclerotium, and often requires a rest period before it will develop further. In this sclerotium nutrient material is found in the form of fungus starch and oils. Certain violent poisons are also found in them and are extensively used in medicine, for this storage organ is known in pharmacy as the drug "ergot." Of just what use to the fungus these poisonous compounds are is not quite clear. Possibly they tend to prevent the consumption of strongly ergotized grains, thus avoiding destruction by feeding animals.

In the spring time, after their winter rest, the ergots are capable of further growth. When placed in proper conditions of moisture and temperature they send out small cylindrical stalks which bear tiny spherical heads about the size of small brown mustard seeds. These little heads become blackish in color and bear the sac spores. They are not, however, single sac-capsules but, if one examines the surface of this sphere, one finds a large number of little openings and, upon further investigation, these openings are seen to connect with pear-shaped cavities just beneath the surface. Each of these cavities is in reality a spore-sac capsule. In other words, the spore-sac capsules have been aggregated together onto a common surface and produced in abundance on account of the great amount of available storage material in the ergot. In each sac capsule are numerous very long, cylindrical sacs, and each sac contains eight long thread-like spores, which have already been divided by cross-walls into about sixty-four cells. These cells separate very readily and each is capable of growing out into a mycelium, so that each sac contains about five hundred spore cells. In addition to the spore-sacs there may be long, swollen threads in the sac-capsule, which aid especially in discharging the spores and sacs from the capsule. The spore-cells or the honey-dew spores may be carried to another flower and thus the life-story is recommenced by the new infection of the grain.

The ergot fungus is common on a great many grasses and particularly upon cultivated species as wheat, rye, barley, etc. It is found very abundantly upon wild rice in many places and is also abundant on grasses growing on railroad right-of-ways. (Figs. 53 to 55, 154, 155.)

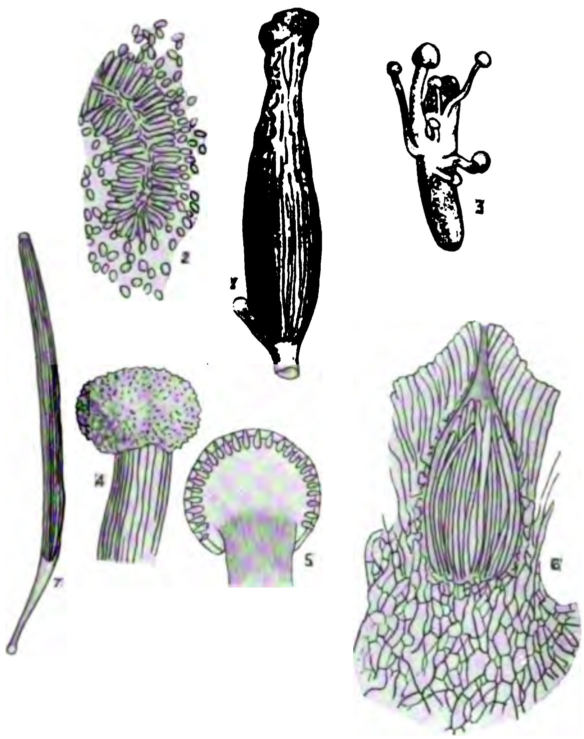
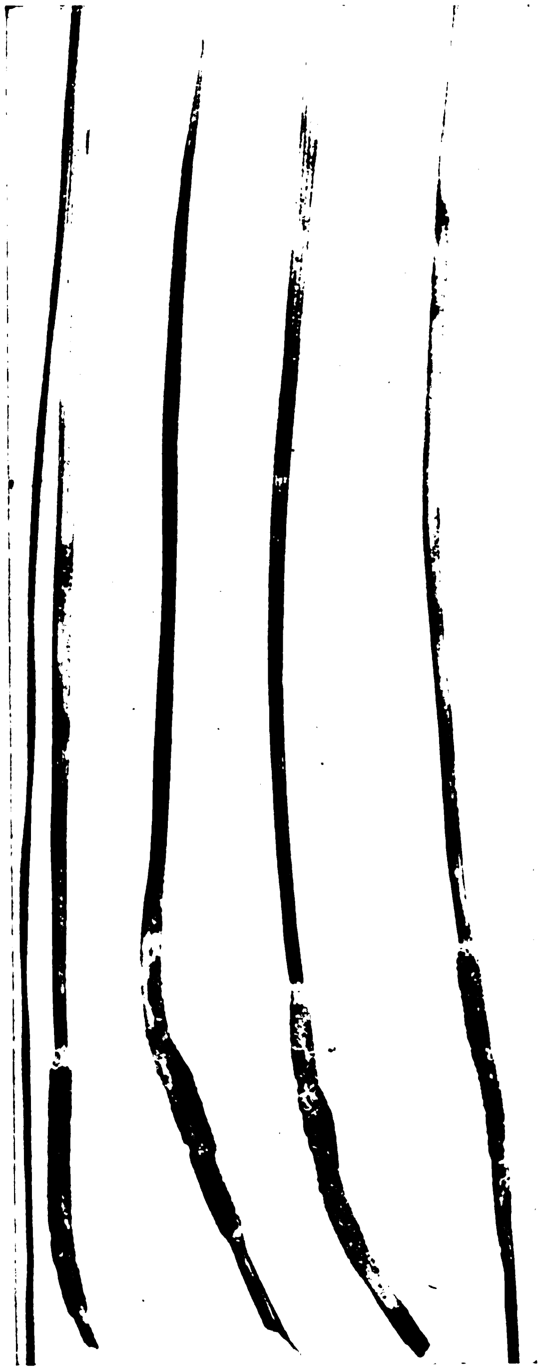


FIG. 55.—Fruiting bodies and spores of the ergot fungus. 1. Young ergot in honey-dew spore stage. 2. Small section of the top of 1, showing summer or honey-dew spores. 3. A germinated ergot with sac-capsule-bearing clubs. 4. The end of one of the clubs in 3. 5. Section of 4, showing capsules at surface of head. 6. An enlarged view of a capsule, showing arrangement of sacs. 7. A single sac showing long, thread-like spores. 1, 6 and 7 highly magnified; 4 and 5 of medium magnification. 1-6 after Tulasne; 7 after Brefeld.

Caterpillar fungi (*Hypocreaceæ in part*). A very close relative of the ergot fungus is the caterpillar fungus, the habits of which have already been described in a previous chapter. Spores of the fungus send out germ threads which penetrate the hard coat of the caterpillar or grub and, feeding on the soft parts of the insect-body, build up a mycelium which consumes all of the interior of the host except the chitinous skin. It thus stores up an enormous amount of nutrient material in the form of a storage organ or sclerotium, which is an exact cast, not only of the external form of the insect but also of the internal organs. When this storage organ has rested for some time, and when conditions of moisture and temperature are favorable, it sends up, usually one or more, rarely two, stalks, which come above ground. Here they form a club-shaped, bright-orange-colored body which may easily be mistaken for a club fungus. Close examination shows this body to contain numerous small holes just as in the head of the stalk on the germinating ergot, and these holes again communicate with pear-shaped cavities, which are the spore-sac capsules. The sacs also contain eight long, thread-shaped spores, divided into numerous cells, each of which is able to form a germ thread and thus infect other grubs or caterpillars. Sometimes the storage organ does not produce a sac-capsule-bearing stalk; but produces in one of several ways a great abundance of accessory spore forms which are pinched off from threads in enormous numbers. This happens if one places a freshly developed storage organ in a moist chamber, or it may happen in nature where one finds frayed-out branches or strands from the storage organ

FIG. 56.—A caterpillar fungus. The insect-shaped bodies are fungus casts of threads which form a storage organ; raising from these are club-shaped bodies which are covered above with fine warts. These warts are the tops of the sac-spore-capsules. Original.



giving rise to a dust of white spores at the surface of the ground. These spore-forms have all been described as of separate and independent plants. They seem to be able to infect the insects just as do the sac-spore cells. These fungi are thus seen to be very similar to the ergot fungus in all essentials but the accessory spore forms are more numerous and are found under different conditions than are those of the latter. (Figs. 10, 15, 31, 56.)

Strangling fungi (*Hypocreaceæ in part*). On a few grasses in the state occurs a fun-

FIG. 57. — A strangling fungus on grass leaves and stems. A few leaves extend above the fungus fruiting body, but the growth of the host is usually stopped. The surface of the fungus fruiting body is covered with warts which are the ends of the spore-sac-capsules. Original.

gus which is closely related to the last two groups of fungi and particularly to the caterpillar fungus. This fungus exerts a strangling action on the host plant. It appears as a whitish or light-tan-colored ring around the young leaves at the tip of the plant. The threads soon form a solid mass enclosing the young leaves and preventing them from unfolding. The branch on which the fungus is thus formed may ultimately die off. When the fungus has increased somewhat in thickness the sac-spore capsules make their appearance as pear-shaped cavities on the surface of the fungus, just as on the clubbed stalks of the caterpillar fungus. The sacs and spores are also similar to those of this fungus in appearance. The accessory spore-forms appear on the fungus preceding the sac-spore forms. The life story in this fungus is thus seen to be simpler than in either the ergot fungus or the caterpillar fungus. No storage organs are developed. (Figs. 57, 58.)

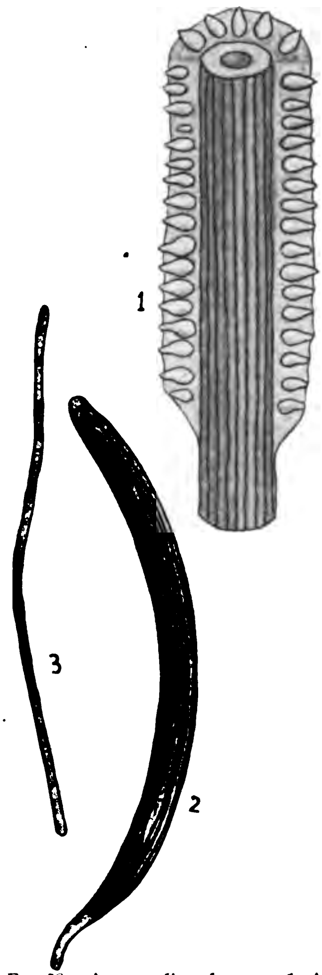


FIG. 58.—A strangling fungus. 1. A grass stem with a fungus fruiting body, part of which has been removed, showing the sac-spore-capsules in position. 2. A single sac, showing long thread spores. 3. A single spore. 2 and 3 highly magnified. 1 after Winter: 2 and 3 after Brefeld.

Other allies of the caterpillar fungus (*Hypocreaceæ in part*). Very commonly on the milk mushrooms are found fungi which cause the abortion of the gills of the host and which spread themselves out all over the latter, covering it with a bright red-orange color. On the surface reddish wart-like bodies can be seen and these are the spore-capsules which, as in the caterpillar fungus, open by pores to the surface. The sacs are also of a similar shape but the sac-spores are not as long.

Bright colored stick-fungi are also allies of these fungi and are very common on dead poplar or cottonwood sticks. On the latter, cushions an eighth to a quarter of an inch in height and breadth, are formed by the fungus and on the surface of the cushion arise the accessory spores in great abundance. After a time these spores cease to form and there is now produced from the same surface, supplanting the accessory spores, the sac-spore capsules of the fungus, which are again pear-shaped cavities with pore-like opening to the exterior. The sac-spores are short and rounded at the ends and two-celled. Some of these fungi are wound-parasites attacking orchards and timber trees through storm or hail-wounds, etc. They are sometimes known as red knot. In some of these fungi still other kinds of spores and spore-bearing organs are encountered.

Chapter X.

Fungi. Kinds of Fungi. Sac Fungi.

Black knot and allies (*Dothideaceæ in part*). One of the most conspicuous fungi of Minnesota is the so-called black-knot fungus of cultivated and wild cherries and plums. In the mature stage of the fungus, its host-plant branches carry black knot-like swellings and distortions, which are very conspicuous. These knots so interfere with the nutrition of the branch beyond that the latter usually dies off in a year or two. The fungus then gradually works its way downward to the intersection of another branch, when this is in turn killed off. The mycelium, which lives inside of the bark, causes an increase in the thickness of the latter, followed by a splitting lengthwise. There is also a swelling of the underlying wood and the fungus feeds upon this swollen, soft mass. It builds up a dense mass of the mycelium on the outside of the branch. This mass when it first appears is a light-yellow-brown and forms on its surface numerous summer spores which rapidly spread the disease. These spores are pinched off of the ends of short upright threads and are produced during the summer. In the fall the mycelial mass becomes darker until it is jet black. It looks not unlike charcoal. In this mass are formed numerous pear-shaped sac-capsules over the entire surface. These capsules open by minute pores to the exterior so that in the spring the surface of the knot appears to be covered with tiny warts, each wart indicating a spore-sac capsule.

FIG. 59.—Black knot of plum (Plowrightia morbosa). The tiny warts on the surface mark the ends of the sac-capsules. After Clinton.

The sacs are long cylinders and contain eight spores, each of which is made up of one large and one small cell. The sac spores are shed in the spring and can infect new branches or other trees. Almost all of our plums and cherries are subject to the attack of this very dangerous fungus and in the wild plants it is often found in very great abundance. It has proved a dangerous pest to cultivated plants, and in many places in the United States has ruined whole orchards and rendered aid by state laws necessary for protection.

Another very common disease which is a close relative of the black-knot is the fungus producing black spots on a great many grasses both wild and cultivated. These spots are formed on the leaves and are often mistaken for black rusts, but they can easily be distinguished from the latter diseases by the fact that the skin of the host is not split open in long lines and the spores are not produced in the way well known for rusts. The spores are formed in sacs borne in small spherical cavities or capsules. These appear in clusters at the surface of the black spots just as they are found in black-knot. The fungus is often very abundant on grasses. In such cases they undoubtedly levy a considerable tax on the starch-making apparatus of the host and thus impoverish the latter.

Similar spots are produced on the leaves of elm trees. The leaves of the common white elm are often found almost completely covered with such spots. The capsules and sacs are produced in a manner somewhat similar to that in the black spots of grasses and, though never seriously threatening the life of the elms, undoubtedly steal much nourishment from them. These black spots must not be confused with the tar spots of maple and willow which are different diseases. The latter are also sac fungi but belong to the cup-fungus group. Superficially these fungi resemble each other; in the black spots of grasses and elms, however, the sacs are found in pored capsules while in the tar spots they occur in cups. (Figs. 19, 59, 191.)

Dung fungi and their allies (Pyrenomycetineæ (in part) including Sordariaceæ and Chætomiaceæ). If horse dung be placed in a moist closed chamber and allowed to remain undisturbed for a week or two there will almost invariably arise dense crops of very small, black, thickly-crowded, pear-shaped bodies. These often bear crowns of dark tangled hairs surrounding an opening at the tip. They are sac-spore capsules and dense masses of spores can be seen collected near the opening or scattered as a dense brown or black dust around the capsules. The latter are formed singly and sometimes but not usually upon mycelial masses, as is the case in black knot, caterpillar fungus and ergot. The spores occur usually eight in a sac and often have curiously-shaped tail-like appendages. These fungi (Sordariaceæ) are very abundant and at first sight seem insignificant but are of some importance nevertheless. The dung of horses is made up largely of the indigestible woody parts of plants, e. g., the veins of the leaves of grasses, and it is on these that the fungus feeds, disintegrating them as wood-destroying fungi do timbers.

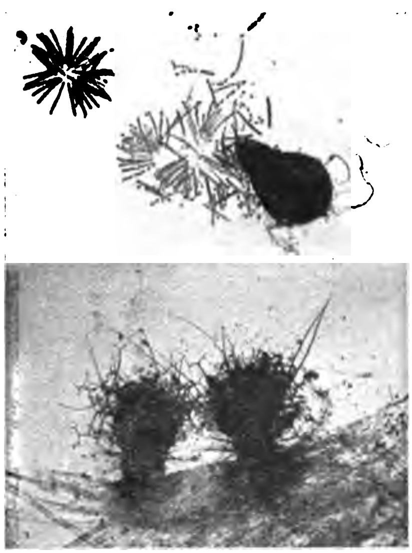


FIG. 60.—Above is seen a sac-capsule of a dung fungus (Sordariaceae) showing the escaped sacs, which are cylindrical and contain each eight spores. Broken sacs and free sac-spores are also seen. Below are two sac-capsules of another fungus of this group (Chaetomiaceae). At the summit of the fruiting body are seen great tangles of twisted threads in which the spores are caught. Magnified. Microphotograph by F. K. Butters.

Another group of forms (Chætomiaceæ) closely allied to the dung fungi is found chiefly on moldy paper. Here the sac capsule is provided with great twisted and tangled masses of crown hairs in which the spores are lodged after ejection from the sacs and sac-capsules, and are later from this point shaken out and distributed. Building paper is often rotted by these fungi. (Fig. 60.)

Sphere-fungi and their allies (*Pyrenomycetineæ* (*in part*) *including Sphæriaceæ and other families*). This is one of the very largest groups of fungi, rivalled in point of numbers only by the mushroom allies and cup fungi. It is also of great importance economically because of its numerous diseases. The sphere fungi are close relatives of the dung fungi and build similar sac-capsules which are usually tiny spheres. These are generally formed singly or are sometimes grouped on a mycelial cushion somewhat similar to black knot. The sac-capsules are very often microscopically small. These fungi are remarkable for the great numbers and variety of accessory spores produced. Most of the so-called imperfect fungi are undoubtedly merely accessory spore-forms of these fungi. Although the group is a large one the sac-capsules agree to a remarkable extent in their essential structures and vary only in such characters as hairiness, wall structure, shape and structure of sacs and spores and other minor details. The accessory spores are sometimes found on simple erect threads, from which they are pinched off in regular succession. In other cases the spore-producing threads may be bunched together into cushions, and in still other cases they may be formed in cavities or cases, quite similar to those of many sac-cases in appearance, though, of course, they do not contain sacs. Moreover, such accessory spores may vary in number and arrangement of cells. They may consist of a single cell or of a definite or indefinite number, which may be built up into a net-shaped complex or into long strings. On the characters of the sac-capsule structure and opening, on sac-spore shape, etc., and on the grouping, structure, etc., of the accessory spores, an elaborate artificial classification of the group has been built up. This system, though artificial, is nevertheless useful as a framework for collecting and describing information about this vast group of plants.

The sphere fungi inhabit almost all plant parts though they may be said to be most numerous upon the leaves of their hosts. They are also very abundant on herbaceous stems and may even be found on woody stems, on timbers, roots and fruits. Many needle-cast diseases of cone-bearing plants, as pines, are caused by sphere fungi. Certain root diseases of vines and other plants, the leaf spot disease of strawberry and many other so-called leaf-spot diseases are due to sphere fungi. Apple scabs on leaves and fruits and many other diseases of cultivated plants might be cited as further examples. In fact the great majority of plants harbor one or more of these parasites. They are not in all cases dangerous diseases. Moreover, not all of the sphere fungi are parasites; many are saprophytes as are the dung fungi, and many are half saprophytes or wound parasites. (Figs. 35, 60, 153, 183 to 187.)

Dead-stick and burnt-wood fungi. These are sphere fungi which are found in great abundance on dead sticks and branches of trees. They are saprophytes or half-saprophytes and the latter do not usually produce their sac-capsules until after the death of the host branch. The sac capsules are very often collected together with or without a black mycelial cushion, and they usually break out from beneath the bark, pushing out the latter before them. Often the mycelial cushion is of great size and thus resembles the black-knot in appearance. Such fungi occur in great abundance on oak limbs or oak fence posts and sometimes produce cushions a foot in length. These cushions become black and hard and resemble burnt or charred wood, whence their common name. They are often mistaken for such wood by those unacquainted with their true nature. Birch branches and in fact limbs and stumps, dead or fallen trunks of almost any tree may show such burnt wood fungi. They are very effective agents of decay in wood, though not as conspicuous in their action as the pore and gill fungi of the mushroom group. The highest forms of these burnt wood fungi produce cushions which are club-shaped in appearance and look like charred club fungi. A number of such forms are abundant in our state. In the spring one finds such clubs covered with a white dust of accessory spores, while in the fall the sac-cases are formed and the club is black and warted just as in black-knot.

In some of these dead-stick and burnt-wood fungi one finds sac-capsules which open, not by a pore, but by long slits or by star-shaped openings. It is in these forms that we see the transition to the cup fungi; for a cup of the cup-fungus group is merely a sac-capsule with a great wide-open top. It has a pore which has become very large so that the capsule when mature has a beaker shape, or may even become saucer-shaped or plate-like in form.

Beetle fungi (*Laboulbeniineæ*). These fungi are parasites on insects and are found in abundance on water beetles. The plants are very minute and can usually only be clearly seen under a compound microscope. On the one hand these fungi show relationships with the sphere fungi, which are undoubtedly their closest fungus relatives. They form sacs containing spores and these are contained in sac-capsules. The structure of the sac-capsule is not however very similar to those of the sphere fungi. The cases are often long pear-shaped and the sacs are produced over a considerable period of time and do not all mature at once. Moreover, the sac-cases are preceded by a breeding act which is altogether unlike that of any of the sphere fungi but can be best compared with the breeding act in the

FIG. 61.—A common cup fungus (Urnula craterium) growing on sticks sunken in the soil and appearing abundantly in the spring. Original.

group of algae known as the red sea-weeds. The structure of the mycelial threads is, moreover, very similar to that of the red sea-weeds and the beetle fungi are therefore considered by some botanists to have a common origin with that group of algae. The beetle fungus plants are usually broom-brush-shaped and are found on the legs and wings and outer parts of insects. They are often highly specialized in locality, occurring only on certain joints of the legs and on certain legs of the host. The plants are often of two sexes though some contain both female and male organs. These fungi are undoubtedly numerous in Minnesota though no attempts have as yet been made to collect or determine them. They seldom, however, are very destructive parasites, as is the caterpillar fungus or the insect molds, and hence are not, as far as is at present known, of great economic importance. (Fig. 30.)

Cup fungi (*Discomycetes*). These comprise one of the largest groups of fungi. The range of habit and structure is very great within the group. The cup fungi are very closely related to the sphere fungi, as has already been pointed out. They are all sac fungi and the sacs are always borne in structures commonly called cups. These cups may be considered as wide-mouthed spore-sac-capsules such as are common in the sphere fungi. In the early stages of many cup-fungi the cup is in fact a sphere entirely closed or with a small pore-like opening. The cups vary greatly in shape and size. In many forms it is very minute and requires a hand lens for its examination. In others it is large, reaching six inches in diameter and even exceeding this. Some forms are like long goblets, while others resemble beakers of all shapes. Many, again, are saucer-shaped and some perfectly flat or even more or less convex. Some are gelatinous in texture, others cartilaginous or waxy, still others are more or less leathery or simulate burnt wood. Few, if any, have woody cups. They may be furnished with hairs, sometimes with dense masses, and often they have eye-lash-like, hairy spines lining the edge of the cup. The cup is often a very complex organ structurally and in a great majority of cases contains between the sacs sterile threads of very characteristic shapes. The sacs are usually long cylinders and line the inside of the cup with a dense palisade, standing upright in the cup—that is, at right angles to the inside surface. The function of the sterile threads is probably that of assistance in throwing out the spores. The sacs are often provided with little lids at the apex and when the spores are ripe the lid comes

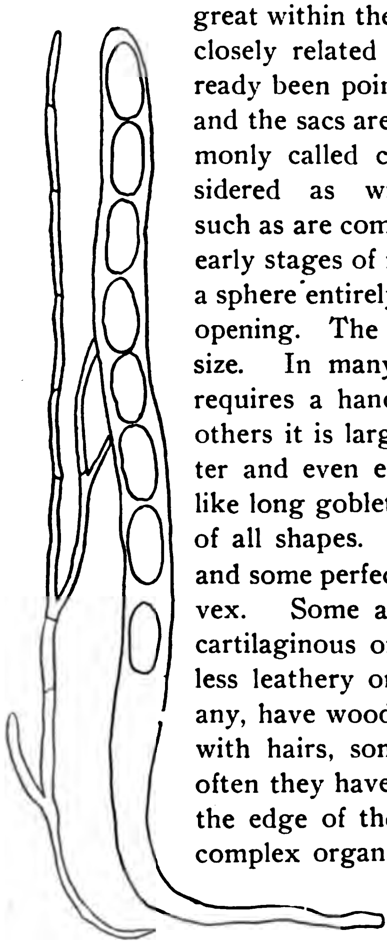


FIG. 62.—A single sac and sterile threads from the palisade of sacs of the fungus shown in Fig. 61. The sacs show eight spores. Highly magnified. After Seavers.

off and the spores are thrown out in a tiny drop of liquid. Very often comparatively large areas of sacs in a cup throw out their spores simultaneously and then one sees small dust-like clouds arising from the cup. If a little slip of glass be placed over the cup at such times the spores will be found in groups of eight in little drops of liquid on the glass. If cups be placed in a moist chamber and allowed to remain undisturbed for several hours they will often, upon the removal of the moist chamber lid, begin to send up the dust cloud of spores. The change of moisture conditions seems to initiate the expulsion of these clouds. A few cup fungi have another device by which the entire unopened sacs are thrown out. Accessory spore-forms are known in a great many cup fungi though not nearly so numerous nor in such great variety as those of the black fungi. The great majority of cup fungi live on the ground or on dead wood and are saprophytes, but not a few are parasitic and some cause serious diseases of their host plants. As agents in the disintegration of plant debris they are important economically, though not nearly so conspicuous in this effect as are the black fungi and the gill- and pore-fungus allies. The two following groups contain most of the common forms of cup fungi.

Tar-spot fungi and their allies (*Phacidiineæ and Hysteriineæ*). This group of fungi may be considered as a transitional group between those black fungi whose sac-capsules have large oval or slit-like mouths and the true cup fungi. They produce densely-woven mycelial masses which form crusts with the substrata and upon these burnt-wood-like masses arise the little cups which are similar in texture. The cups are at first closed and simulate the spore-sac-capsules of the black fungi, but the sac-bearing area is soon exposed. The sterile threads between the sacs are usually longer than the sacs and the ends come together above the sacs forming a covering. Accessory spore bodies are not uncommon. These fungi occur on leaves and branches of trees and have the habit of leaf- and dead-stick-inhabiting black fungi. They are, moreover, usually saprophytic though tree tar-spots are parasites of economic importance. The tar spots of willow and maple leaves are very abundant in Minnesota. The mycelial mass which forms on the leaves in summer and in fall looks like a drop of tar and does not show any mature cups. The latter are formed on the fallen leaves in the spring. (Fig. 133.)

True cup fungi (*Pezizineæ*). The greatest number of cup fungi belong in this group. The great variety of form and size has already been mentioned. Many have long stalks, others are sessile. While the cups vary considerably as to texture, they are usually fleshy or soft and seldom or never woody. Moreover, they are very frequently brightly colored, especially in the sac-bearing region. The color is usually contained in the ends

FIG. 63.—A cluster of cup fungi, showing cups appearing just above the ground. They are attached to long stalks, which arise underground from a storage organ. (See Fig. 4.) Original.

of the sterile threads between the sacs. The most common colors are reds varying on the one hand from bright scarlet through orange and yellowish reds to lemon-yellows or even lighter shades, and, on the other hand, from scarlet to chestnut, chocolate and violet browns. A few are lilac-tinted and many are water-colored or very dilutely brown and tan. There is a great diversity in the surface coverings. Many are perfectly smooth while others are covered with very dense hairs and numerous intermediate conditions exist showing great differences not only in the number of hairs but in the kinds produced.

Fig. 64.—A cup fungus (Plicaria repanda) on the bark of a fallen and decaying tree. Original.

The spores are usually oval in shape and single-celled, though some are somewhat elongated and many-celled. The explosive apparatus for spore or sac ejection has already been noted. It is in the true cup fungi that these devices reach the greatest degree of perfection. Accessory spore-forms are not at all common. The smaller forms of the true cup fungi abound on dead sticks or dead stems of herbaceous plants or on the ground, especially among mosses, and are often no larger than a pin head. Many grow on dung. The stick-inhabiting forms are not usually brilliant in color, though some are lemon colored. Not a few are parasitic. Most of the largest forms are saprophytes upon the ground or upon decaying tree trunks or on dung, and are often very brightly colored. Some cup fungi, and in particular parasitic forms, build storage organs, often as large as a small filbert nut, and the cups are produced in clusters upon this storage organ in the following spring. Wild anemones, cultivated clovers and plant bulbs are often attacked by such storage-organ-forming cup fungi, as are also plants of the blueberry family. In the latter case the storage organ replaces the fruit of the host plant and cases are known where the same fungus lives on two different hosts in its lifetime just as do many of the rust fungi; i. e., the fungus produces accessory spores on one host and sac spores on the other. A common disease of certain coniferous trees in the northern part of the state is due to one member of the cup fungus group. Compared with other disease-producing groups, however, the tree cup-fungi are not of very great economic importance, and this is especially noticeable since the cup fungi constitute such a very large group of plants. (Figs. 4, 10, 14, 61 to 65.)


Fig. 65.—Cup fungus (Helotium citrinum) on decaying wood. Slightly magnified. Original.

Lichen-forming fungi. It has already been stated that lichens are equal-partnership-organisms consisting of an alga and a fungus. In a vast majority of cases, the fungi are members of the cup-fungus group, as is seen by the production of cups. In some lichens, however, black fungi participate and in a very few stalked fungi are the fungus constituents. The number of lichens in Minnesota is very great, but a mere passing notice of these can be given here. The constituent fungi of lichens are in reality parasites—in the broader sense—on the algae, but the latter also derive benefit from the partnership. Obviously, therefore, this group of fungi does not produce any diseases of higher plants. The lichens attach themselves to tree-trunks or limbs where they are held in an advantageous position or they grow on the soil or as crust on rocks. In the latter case they act as the pioneers of vegetative life in the invasion of rock surfaces and are usually the first to obtain a foothold. Lichens have invented a peculiar partnership propagative body, which is merely a packet of algal cells, wrapped up in a net-work of fungus threads. When such packets come into proper conditions, they commence growth and build up a new lichen plant. In addition, the fungus produces its proper sac-spores and in many cases accessory spores, but when these germinate the resulting mycelium must soon come into contact with the proper algae or the fungus perishes. This is therefore an uncertain means of reproduction of the lichen and the packet device can easily be seen to have advantages over it in the provision for the algal constituent as well as for the fungus. (Fig. 21.)

Morels, saddle fungi and their allies (*Helvellineæ*). The saddle fungi are very common plants of our woods. They are all fairly large forms and are fleshly. Their relationship with the cup fungi is easily understood by comparison with the long stalked cups whose sac surface is flattened or turned back. Such are in reality the simplest of the saddle fungi. The stalk in some forms, however, becomes channeled and is often hollow. The cups in many, moreover, are not only turned back as one might imagine a rubber cup to be turned inside out, but the sac surface often becomes convoluted and lobed or ridged so that the sacs may thus be produced over a greater surface. The saddle fungi are usually whitish in color, or may vary from grey to greyish brown.

In the morels the cup, or as it is here termed, a cap, has very greatly increased its spore surface by the formation of ridges which join and form a network enclosing deep depressions. All over the depressions are formed the spore sacs. In some morels the cup does not extend outside of the usually broad stalk, but in others it laps over slightly at the edge. In all morels the cup is drawn out so that seen from the side it is either conical or spherical in appearance. In some forms, the cup is very much convoluted so that it gives a brain-like appearance.

Closely related to these fungi are certain "earth-tongue" fungi. Many of these are black and burnt-wood-like and look much like club fungi or like the sac-capsule-bearing branch of

FIG. 66.—Morel fungi. The ridged caps are to be regarded as everted cups, whose surface has become ridged and hollowed to afford large area for spore formation. Original.

the caterpillar fungus. The upper part of the club, however, is really a pulled-out cup and hence is like a morel which has lost its ridges and become smooth. They grow commonly in the ground among grasses and are not at all conspicuous or very large. Another relative of the morels is the spathula fungus which is so common on the mossy floors of our northern woods. Here the cup is drawn out and flattened like a spathula and is yellowish in color. Very common on the ground and amongst moss in summer and fall, can be found a peculiar little gelatinous fungus of a light to dark green color. The fungus has a stalk and a bent back cup similar to the saddle fungi, to which it is closely related, but its cup is neither wrinkled nor ridged. (Figs. 10, 66, 67.)

FIG. 67.—Saddle fungi (Helvella lacunosa). The saddle is an everted cup with the edges turned back. Original.

True truffles (*Tuberineæ*). At first sight the truffles would not be recognized as relatives of the cup fungi, but such they are nevertheless. The cup remains closed, however, and the plants are found underground, never coming to the surface as do many puff balls to discharge their spores. The spores, therefore, are only distributed after the decay of the cup by being washed away in rainwater or are scattered by the scratching or burrowing of animals. They are sought after by animals as food and they are also much prized for food by man. European truffles furnish the most highly prized mushrooms known. The closed cup of the truffles has a sac-bearing area, which is usually greatly convoluted, so that the interior of the truffle consists of a great labyrinth of pockets and canals which are lined with the spore sacs. The truffles which have been found up to the present time in Minnesota are not large, the largest reaching the size of a small walnut. They are brownish or blackish in color and regularly or irregularly spherical in shape. Two forms have been discovered and undoubtedly more exist. Many forms mature their underground cups late in autumn so that they can be found in the ground in early spring. Others mature in the summer. (Figs. 10, 68, 69.)

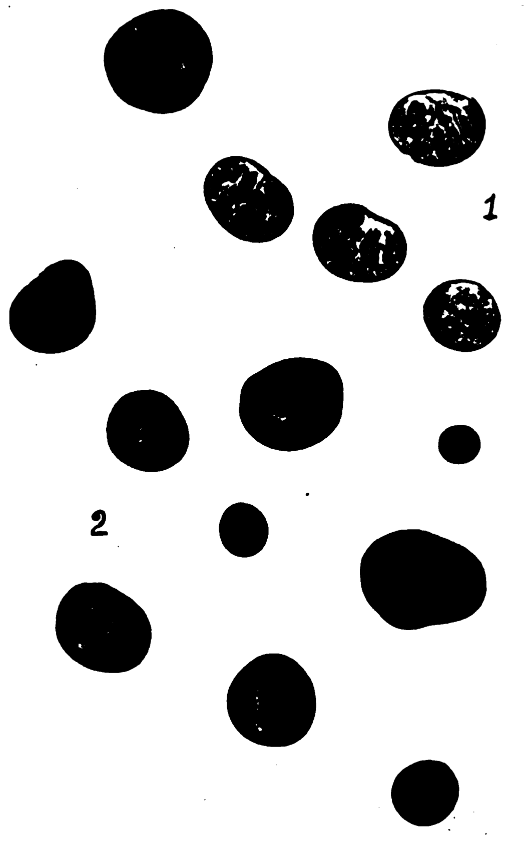


FIG. 68.—Truffles (Tuber lyoni). The truffle may be regarded as an unopened cup fungus with its internal spore-bearing surface greatly convoluted. That which corresponds to the opening of the cup fungus is seen as a furrow in 2 and in the sections 1 as a broad whitish streak. 1 shows the truffle cut open; the chambers in which the spore-sacs are formed can be clearly seen. Photograph by F. K. Butters.

Imperfect fungi and leaf spots (*Fungi imperfecti*). As has already been explained, the so-called imperfect fungi include an enormous number of plants which are as yet incompletely known. Most of them are undoubtedly accessory spore-forms of the black fungi or of the cup fungi. One can imagine that a fungus spore-form of this kind might become separated from its connection in the life-story of a black fungus, in that the mycelium arising from such a spore would give rise only to the accessory spore-form. On account of the infrequency of the occurrence of proper conditions, it might forget how to form sac-spores and would thus become independent of the sac-spore form. Both the production of different kinds of spores by one fungus plant and the production of spores on different hosts in one life-cycle would tend to furnish fungi where such a separation might occur. In addition to those forms where this actual separation and independence occurs there is a considerable assembly of spores, where the connection of apparently independent forms with sac-spore stages is known, and in such cases the term "imperfect" is in a sense a misnomer. In a vast number of forms, the connection is indicated to a certain degree by the connections of analogous forms. For instance, the accessory spore forms of the powdery mildew is of a definite type known as an Oidium, and when one meets with such isolated spore forms, if they occur in the usual habitats of mildews, one may refer them to the powdery mildew group. Indeed it may be that all so-called imperfect fungi are actually traceable in their connections with sac-spore forms, but many have, as yet, frustrated all attempts to prove such connections. We may sum up these forms in this respect into three groups: first, those isolated forms whose connection with sac-spore forms is known; second, those isolated forms whose sac-spore connection is not known, but suspected from analogy with known forms; third, those isolated forms whose sac-spore connections are not even suspected or have become actually independent.

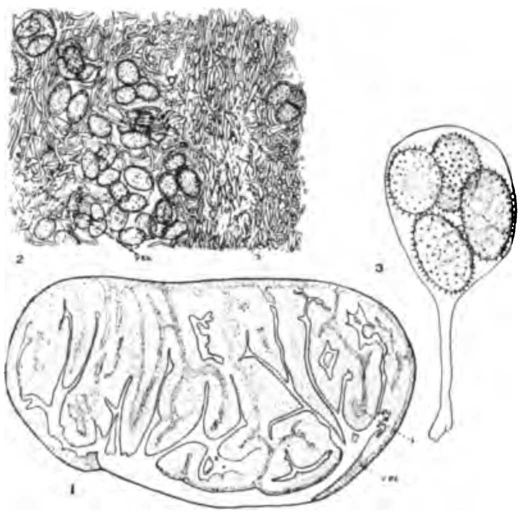


FIG. 69.—Truffle. 1. Fruiting body cut open; surface furrow which corresponds to the opening of a cup fungus is seen below and the convoluted surfaces of the cup interior above. 2. A portion of the interior showing the sacs, each with four spores (highly magnified). 3. A single sac showing four spiny spores. Very highly magnified. After F. K. Butters.

As a matter of convenience and for the collection of statistics and data, the imperfect fungi are classified in an artificial system according to the aggregation of spore-bearing threads, and each of these again into groups according to the number of cells in a spore and the arrangement of these cells. The three primary groups are: first, the loose-thread forms, i. e., those in which the spore-bearing threads are borne loosely in mold-like fashion; second, the cushion-forms, those in which the spore-bearing threads are joined together to form cushions; and third, the capsular forms, those in which the spore-bearing threads are borne in cases, often similar in appearance to the sac-capsules of the black fungi. Under each of these are sub-groups based on the color and cell structure of the spores.

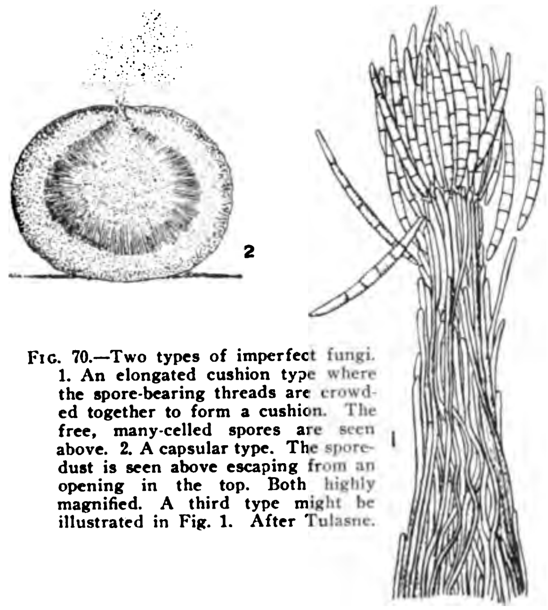


FIG. 70.—Two types of imperfect fungi. 1. An elongated cushion type where the spore-bearing threads are crowded together to form a cushion. The free, many-celled spores are seen above. 2. A capsular type. The spore-dust is seen above escaping from an opening in the top. Both highly magnified. A third type might be illustrated in Fig. 1. After Tulasne.

The imperfect fungi are of very great importance economically on account of the great number of serious diseases produced by them. These diseases often take the form of spots on leaves of the host plants and are then known as "leaf spots." Hence the fungi are often known as leaf-spot fungi. These spots may be whitish or brownish and are sometimes ringed with a whitened or reddened area. The spot is often characteristic for certain fungi. In some cases they are black, whence the disease is known as coal-spot disease or anthracnose. Sometimes the infected spot region falls out, leaving small holes which give rise to the common "shot-hole" disease of certain cultivated plants. The spots are not, however, in all cases well defined but may extend out indefinitely over the attacked organ. Many fruit rots are caused by these fungi, as the brown rot of plums and ripe rot of apples. Sometimes the influence of the fungus causes the fall of the leaves with great injury to the plants, as on currant bushes. Some imperfect fungi, moreover, attack stem portions, particularly the young stems, and then may do considerable damage. Many are, on the other hand, saprophytes and as such, just as the majority of black fungi, are important agents in the disintegration of plant debris. (Figs. 35, 70, 156 to 159, 164, 165.)

Chapter XI.

Fungi. Kinds of Fungi. Basidium-bearing Fungi.

The stalked or basidium-bearing fungi (*Basidiomycetes*). This is the third of the three great groups of fungi. The members of this group do not, as the sac fungi, bear their spores in sacs, but form them upon more or less definite stalks, which occur with some degree of regularity upon special portions, usually the ends, of the fungus threads. From these stalks the spores are pinched off just as are many accessory spores in sac fungi. They are not formed internally, as the spores are in sacs, but are externally formed in the pinching-off process. The stalks usually occur in fours at the end of the thread though they may be fewer or greater in number and may arise laterally on the stalk-bearing threads. The cell or cells of the thread which bear the stalks are known as the basidium. In the lower group of the stalked fungi, the basidium is composed of a number of cells each of which bears a stalk with its spore as in rusts and smuts, "Jews' ear," trembling and weeping fungi. In the higher forms, comprising the other groups, all of the stalks arise from a single undivided cell. The basidium may arise directly from a spore (winter spore) as in the rusts and smuts. In these forms, of course, they are often found singly, but when the winter spores are formed in crust-forming clusters they are produced in a more or less dense mass. In all other stalked fungi the basidia are borne on or in some fruiting body or on the surface of mold-like growths. The former is by far the more common form, as in the gelatinous fungi, in the mushrooms and all of their allies and the great alliance of puff balls, birds'-nest and carrion fungi. When borne at the surface of a fruiting body the basidia usually stand closely together side by side and perpendicular to the surface of the fruiting body, with occasional sterile threads between them, thus constituting a palisade, covering the entire spore-bearing surface. Such palisades are common in all of the mushroom allies, in most gelatinous fungi, "Jews' ears," etc. In many of the closed fruiting bodies, e. g., puff balls and birds'-nests, internal chambers, which are formed in the early stages of growth, are lined with such palisades. The fruiting body may assume many shapes, which apparently tend toward the increase in spore-bearing area or have to do with advantages of distribution.

The variety of forms is enormous—ranging from such simple types as the club fungi and smooth shelves to the tooth, pore and gill fungi, and from puff balls to carrion fungi. The teeth, pores and gills are the basidium-bearing regions. In the puff-ball allies, the birds' nest and carrion fungi, the spore-bearing region is in a closed fruiting body which either opens only by decay or at maturity by a special pore or other device. Inside of these closed bodies the basidia may occur in palisades lining the surfaces of chambers, or they may occur on wefted threads in no regular arrangement. The details of the fruiting bodies will be given under the various groups. In a comparatively few forms accessory spore-forms are found but they are not nearly so common in this series of fungi as they are in the sac fungi. The question of the occurrence of a breeding process is still an open one. A fusion of elements in the young basidium or in the winter spore of rusts is interpreted by many as a breeding act, and recent investigation has shown that in the rust winter-spore the fusion is the culmination of a breeding act which begins in the cluster-cup stage. The stalked fungi do not seem to show any striking similarities to either the algal fungi or to the sac fungi, so that in the light of present knowledge only an isolated position can be assigned to them. Various theories have, however, been proposed uniting this group with each of the other great fungus groups. The latest investigations indicate a relationship with the red sea-weeds.

Perhaps the majority of the stalked fungi are earth-inhabiting or wood-inhabiting saprophytes. Many, however, as the rusts and smuts, are highly specialized and destructive parasites, while not a few, as pore and other shelf-fungi, are half-saprophytes. The timber and timber-tree diseases are largely members of this group and the rusts and smuts are without doubt the most destructive disease-causing alliances of the whole group of the fungi. As food producing fungi, the stalked fungus group is very important since all of the true mushrooms, the edible pore fungi, club and tooth fungi, as well as the great variety of puff balls are found in this group.

The basidium-bearing fungi comprise the following twelve groups. Of these the last eleven possess true basidia, i. e., with a definite number of stalks and spores which are usually definitely arranged as at the summit or on the sides. In the smuts, however, the basidium, if so it may be called, bears a great number of spores which are budded off in yeast fashion from the side of the basidium cells. In other words the basidium of the smuts has not attained to the definiteness of the other basidium-bearing fungi and the smuts are often classed as a group outside of these. (For figures, see following groups.)

Smuts (*Ustilagineæ*). Though not a very large group of fungi the smuts are very important from the economic standpoint because they contain many disease-producing forms. The smuts possess the simplest form of basidium found in the stalked fungi. They are all parasitic and many of them are half-parasitic in habit, since they are able to live in certain stages for an indefinite period in culture media. They can, however, complete their life-story only as parasites on certain plants. The basidium arises directly from a resting-spore which is commonly known as the smut spore, producing the so-called smut of grain and of other plants. This smut or resting spore is usually black, dark-brown or dark-green in color and has a thick outer coat, which, under favorable conditions of moisture, breaks open and allows the inner wall to be shoved out in the form of a thread. This thread grows out to six or more times the length of the spore. It then becomes divided by cross-walls into three or four cells, each of which buds off an indefinite

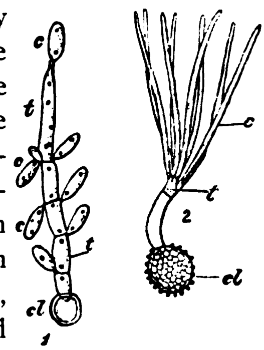


FIG. 71.—Smut spores, germinating; cl the smut spore, t the thread growing from it, and c the spore produced by the tube. 1. Wheat smut—the thread is divided up by cross walls into cells, each of which buds off spores from its side. 2. Stinking smut of wheat—the thread from the spore is undivided and produces a crown of thread-like spores at the top. Highly magnified. After Brefeld.

number of spores from its side or end. The thread thus constitutes a basidium. In one of the smut groups the basidium is not divided but consists of a single cell from the end of which the spores are produced. These spores may be known as the basidium-spores. They germinate immediately in warm, moist conditions, by sending a fine thread, which seeks the host plant and penetrates into the tissues, thus beginning the parasitic life. If the basidium-spores are placed in a nourishing solution they bud in yeast fashion and will so continue to do for an indefinite period as long as the nutrient material is present. It is still able to infect a host plant under proper conditions.

The parasitic life usually begins in some young undeveloped part of the host, e. g., the corn smut infects only young leaves or young kernels of the corn. Here the parasitic mycelium grows and builds itself up at the expense of the host plant. In the oat smut the parasite gains entrance to the oat plant only in the seedling stage of the latter. Now this penetration is accomplished in a peculiar way. In an oat field with smut the sound grains of the oat become dusted with the spores of the smut and thus at the seeding time in the spring the seed grains may have spores on their surface. Now the conditions favorable to the germination of the oats are also favorable to the germination of the smut spores and when the seedling oat appears above ground there are also near by germinating basidium-spores of the smut. The threads of these spores therefore easily reach the young seedling and rapidly penetrate to the growing-point of the stem, although this growing-point is hidden by the first leaves of the seedling. When the seedling continues to grow, the parasite also grows, always remaining in the growing point and forming patches of mycelium in the growing points of all of the branches. The oat plants thus affected do not appear very different from uninfected plants until the grains mature. When the grains are still very young the parasite invades all of them and here builds up a dense mass of mycelium at the expense of the rich food materials which the oat plant furnishes to the grains. At the time when the oat grains are ripe the fungus threads divide up into numerous cells and from each cell is formed a spore, whose wall is at first gelatinous but later is black, thick and hard. These spores are produced in enormous numbers replacing all of the grains and are then seen as a smutty powder which is familiar to every farmer who raises oats. These smut-spores are now in an advantageous position and are scattered by the wind and carried to sound grains and may, as described above, again cause infection of the oat in the seedling stage in the following spring. This life-story explains the success of the hot water method in preventing oat smut, for if the smut spores, clinging to the grains are killed by steeping in hot water, which will not injure the grain, then the chances of infection of the seedling plants from these treated grains are greatly reduced or entirely destroyed.

FIG. 72.—Loose smut of wheat. (Ustilago tritici.) The loose powder of spores has been partially shaken out; the grains of the wheat are all smutted. Original.

Smuts very often possess the power of stimulating their host plants to abnormal growth. Thus in the corn smut, the attacked part of the corn plant swells up into a tubercle many times larger than the original plant part. The advantage of this to the parasite is obvious, for it increases many-fold the area of the feeding ground as well as the spore-producing area. Such tubercles in corn smut are found on leaves, young stems and on kernels and even in the tassels.

In some smuts the stimulation is exerted on the rudiments of organs which are not normally produced in certain flowers causing the rudiments to develop into mature organs. Such is the case in certain pistillate flowers of the Pink family where the smut stimulates the rudiments of the stamens to mature development.

The smuts are parasites, chiefly of the flowering plants and particularly of the grass family. One smut, however, inhabits the capsule of the peat moss plant. The choice of organs for the establishment of the parasitic mycelium varies with different smuts. A very large number live in the grains and seeds of plants, where they get both advantage of position for spore distribution as well as an abundant supply of food material. Sometimes a whole inflorescence is destroyed. The floral parts are also attacked by smuts, e. g., certain smuts fruit only in the anthers of species of the carnation family, forming their spores in place of the pollen so that when the flower opens a violet smut dust is discharged from the anthers instead of the pollen dust. Leaves of the host plant are commonly attacked and are often swollen on account of the stimulation of the parasite. Stem parts may be attacked and one smut is known in Minnesota to produce its spores in the roots of certain rush-like plants.

Almost every cereal plant is subject to the attack of one or more smuts and many of the wild grasses are likewise invaded. The common corn, oat and wheat smuts are best known. Many garden plants such as onion and violet are subject to smut attacks and this is also true of many members of the Pink family, where the smut often lives in the anthers of the flowers.

The dock family of flowering plants is also peculiarly subject to smut attacks and this is also true of the pink family. Other flowering plants are attacked but not so commonly as the above mentioned groups. (Figs. 27, 71, 72, 146 to 151.)

Rusts (*Uredineæ*). The rust fungi constitute a larger group of plants than the smuts and exhibit more variety of structure and habit. They may be considered as relatives of the smuts in that the winter spores of the latter may be compared with

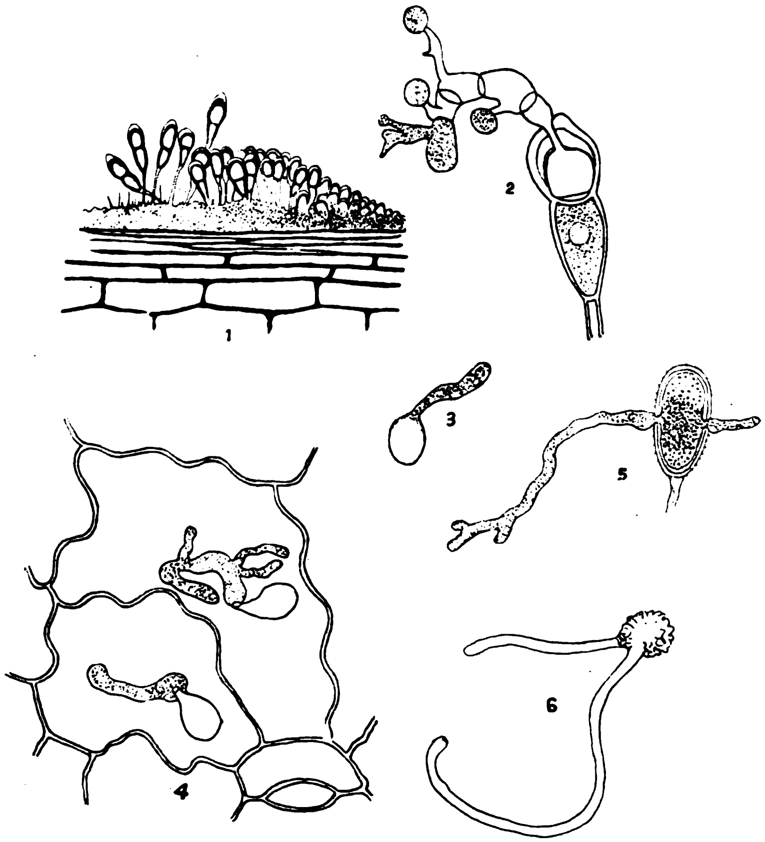


FIG. 73.—Spores of rust fungi. 1. A cluster of winter spores of wheat rust (Puccinia graminis) on wheat plant. 2. A winter spore germinating to a thread of four cells (promycelium—basidium), each of which bears a small spore (sporidium) on a stalk. The winter spore germinates in the spring while still in the straw or on the ground. The sporidia are blown by the wind to another plant and there germinate as seen in 3 and 4. 4. Shows the germination of a sporidium on a barberry leaf; here infection will soon take place. 5. A germinating summer spore of wheat rust, showing germ tubes which on a wheat plant can cause infection (as shown in Fig. 29). 6. A rare grass rust spore (amphispore of Puccinia vexans) germinating; it germinates as a summer spore, but has a thick coat and rests over winter as a winter spore. All highly magnified. 1-5, after Ward; 6, after Carleton. (See also Fig. 74.)

the smut spores. The rusts, however, exhibit a great number of accessory spore forms. They are all parasites and are of great economic importance on account of the large number of disease-causing forms. The life-story of a rust plant is often very complex. We will start with the winter spores. These spores are in a great majority of cases resting spores and, as in the case of the smut spore, are provided with very thick outer coats. These winter spores may be formed singly on stalks on the ends of short threads, where they are usually produced in dense clusters, just under the host plant epidermis and are liberated as a brownish or blackish powder by the rupture of this epidermis. This procedure is common in grass-inhabiting rusts, in the rusts of sunflower and mints. In the rusts of willow and poplar the winter spores occur in a crust-forming mass, just under the host cuticle, and are never shed but germinate in place. This is also the case with the common golden-rod rust. The winter spores in the cedar apple disease of cedars are borne in variously-shaped masses of gelatine which expand much on absorption of water and in which the winter spores germinate producing the basidium-spores at the surface of the gelatine. Some, again, as in the milkweed rust, produce long, thread-like bodies composed entirely of winter spores. In the rust of the cowberry the winter spores remain in the cells of the host epidermis and germinate there. Whatever the location or method of distribution of the winter spore may be, it always germinates in essentially the same way. There are usually thin places in the outer walls and through one of these the inner spore wall is protruded in the form of a thread. This thread increases in length as does that of the smut spores and also becomes divided, usually by three walls. Each of the resulting four cells sends out a stalk on the end of which is formed a spore. The thread bearing the four stalks and spores is the basidium and is noticeably more definite than the smut basidium in the production of but four spores, which are formed on stalks. The basidium-spores are scattered by the wind, and germinate as soon as placed under favorable conditions; they are capable of infecting host plants just as is the basidium-spore of the smut. The winter-spore is not the only spore-form produced by rusts. In the spring the mycelium, which develops from the basidium-spore, produces what is known as cluster cups. These are tiny cups scarcely as large as a pin head, usually yellowish or whitish in color and found in clusters. They are most commonly found on conspicuous yellow spots in the host plants caused by the mycelium of the fungus. The cups are at first closed and then resemble small spheres; the walls later open at the summit, roll back and expose the spores as an orange-yellow dust. The spores are formed in chains which arise in a palisade from the floor of the cup and are formed continuously for some time,

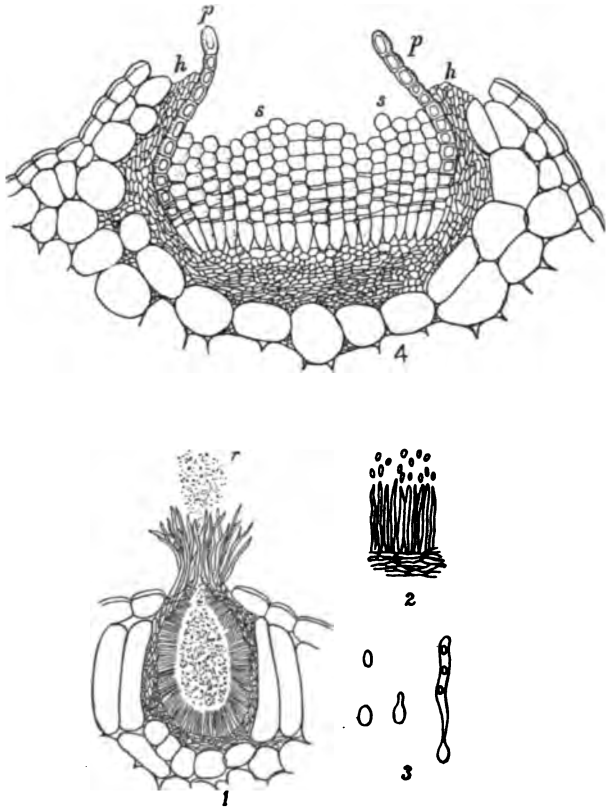


FIG. 74.—More spores of rust fungi. 1. A pycnidium (from wheat rust on barberry), a capsular spore-bearing fruiting body showing dust of spores at r. 2. Spores and spore-bearing threads from 1 greatly enlarged. 3. Same spores germinating. These spores are probably the relics of male reproductive cells which have fallen into disuse. They appear to be functionless since they do not usually germinate and have never been known to cause infection. 4. A cluster-cup of an Anemone rust; s spores, formed in chains; p, threads forming the cup of the cluster-cup. All highly magnified. After Tavel.

those at the summit being the first to mature. These cluster-cup spores are ball-shaped or have flattened sides and their outer wall is frequently provided with small warty roughnesses. The cluster-cup spores are blown about by the wind and are capable of immediate germination. When germinating they send out a germ thread which causes infection. Accompanying the cluster-cup stage or rather just preceding it one very often finds another accessory spore-form in which small spore-cases of pear-shaped structure are produced, sunken into the opposite—usually upper—side of the leaf from that on which the cluster cup occurs. Inside of these pear-shaped cases the spores are produced on long threads from which they are pinched off just as in very similar structures found in many of the accessory spore-forms of the sac fungi. These spores are often accompanied by the production of sugary, sweet fluids which are probably attractive to insects and thus aid in spore distribution. The exact use of these spores is not yet known for they have not been proven to be able to cause infection of a host plant though they will germinate under certain conditions. They have been supposed to be unused male sexual elements and recent research points to a confirmation of such a supposition.

Sometimes this pycnidium spore accompanies other spore-forms, e. g., the summer or even the winter spores. The cluster-cups are produced almost universally in spring so they are the first rust spores (excepting the pycnidia and basidium-spores) which one finds after the resumption of growth by flowering plants, after the winter has passed. In early summer or even late spring and from this time throughout the summer season and far into the autumn are found what are known as the summer spores or red rust spores. These are like the cluster-cup spores in some respects; they are orange-red or yellow in color and are often provided with external warts or spines. They are, however, not formed in closed cup cases and are not formed in chains. They arise singly on short stalks in dense clusters from which they are shed as a red-rust powder. They may be formed continuously for long periods from the same cluster, and are capable of immediate germination under favorable conditions. They germinate by sending out a fine thread in a similar manner to that

FIG. 75.—Cluster-cups of ash-leaf rust fungus, on ash twig. The cups are long cylindrical. Highly magnified. Microphotograph by E. W. D. Holway.

of the cluster-cup spore and this thread may cause infection. They are scattered by the wind and are the chief cause for the rapid spread of rusts through the fields of wheat and other cereals. Towards the end of the summer, often in the same cluster with the summer spores, the winter spores commence to develop and continue to form until late in autumn. In many cases, however, the winter spores are formed in separate clusters. The variety of habit of these winter spores has already been described. They are in general resting-spores and germinate in the following spring, thus again commencing the life-story. It may be well to summarize at this point the order of succession of these spore forms. First at the germination of the winter spore on the ground or under moist conditions anywhere, the basidium spores are produced. Soon after on a suitable host the pycnidia appear, followed closely or accompanied by the cluster-cup spore. Next in late spring commences the formation of the summer spores which may continue to form until late in fall. From mid-summer on the winter spores may be produced until snow flies in late autumn. There are thus five kinds of spores of which the winter spore corresponds to the smut spore of the smuts. In addition to these five forms a sixth is known but is of rare occurrence and seems to be very similar to the summer spores in some respects.

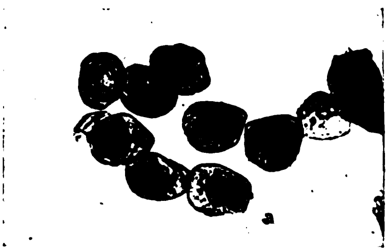


FIG. 76.—Cluster-cup spores from rust fungus of Fig. 75. Highly magnified. Microphotograph by E. W. D. Holway.

Not in all rust fungus life-stories, however, do all of these spore-forms occur. One or more may be missing so that numerous combinations are conceivable and actually occur. For instance, a rust fungus may possess no cluster-cup stage or no summer-spore stage, or both may be missing. In fact, some have apparently retained only the winter spore form, which, of course, always bears the basidium spores later.

In addition to this variety of spore-forms, rusts have further complicated their life-stories by selecting different hosts upon which to form their various spores. For instance, one of the common rusts of wheat forms its summer and winter spores on the wheat plant, but the pycnidium and cluster-cup spores are formed on the common buckthorn.

The fungus which forms its winter spores on the cedar apples of the red cedar produces its cluster-cups on apples and pears, having no summer spores in its life-history, but it produces its cluster-cups throughout the summer. The life-story of such a rust fungus which possesses five kinds of spores, four of which are produced from a parasitic mycelium and two of the latter on one host and the other two on another host, offers an exceedingly complex history. It may be remarked in passing that to combat such accomplished parasites requires an intimate knowledge of their histories.

The question of a breeding-act in the rust life-history is still, perhaps, an open one. A fusion of two elements in the young winter spore has been interpreted as such an act by some botanists. Recently, the beginning of the association of these sexual elements has been discovered just preceding the formation of the cluster-cup.

The rusts are all parasites—true parasites, unable to live except in the tissues of their hosts. The mycelium grows inside of the tissues and the spores are in almost all cases borne at the surface of the plant, whence they can best be shed; but some, buried in the tissues, depend on the decay of the host plant for their release.

The rusts vary greatly, also, in their location on the host plants. Most commonly they are found upon the leaves but in many forms the stem is also attacked and even the underground portions may be invaded. Floral parts are seldom directly attacked. The rusts also possess in some cases the power of stimulation of the host to extraordinary effort, thus increasing the available food supply for the fungus parasite. The cedar apples of the red cedar are merely enlarged twigs of the cedar tree in which a rust mycelium is at work. Some rusts on pines produce great swellings on the stem and still other cases might be cited of the deforming and stimulating effect upon the host by rust parasites. Witches'-brooms are very often of rust-fungus origin. Such is the common birds'-

nest broom of the red cedar and the great bush-like brooms of the balsam fir. These have already been described as stimulated portions of the host plant which, with the fungus parasite, live in partnership at the expense of the neighboring parts of the host. Besides this deforming power of many rusts these parasites are injurious in the stealing of nourishment which they accomplish at the expense of the host and in the wounding of plant parts. The host, as a result, becomes impoverished and may finally entirely succumb. Thus wheat rust annually robs farmers of enormous sums of money by impoverishing wheat plants.

Practically all classes and groups of flowering plants are attacked by rusts as are also certain fern plants. The lower plants as mossworts and algae seem to be free from these parasites. The favorite hosts of the rust fungi seem to be the grasses, for on these plants are found an enor-

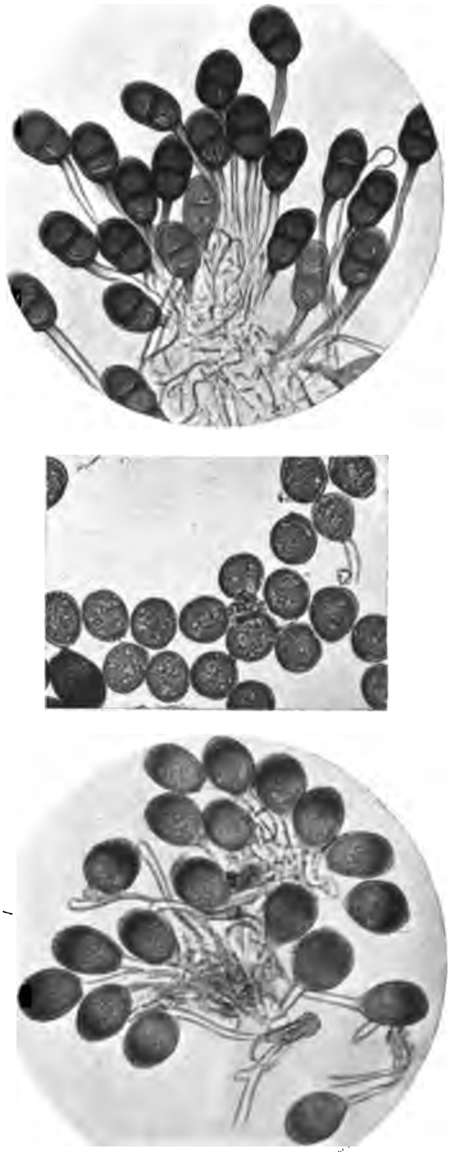


FIG. 77.—Spores of a grass rust fungus (Puccinia vexans); above, winter spores; in the middle, summer spores; below, amphispores. (Summer-spore-like in germination, but resting over winter.) Highly magnified. Microphotograph by E. W. D. Holway.

mous number of rust fungi, constituting many of the most important diseases of cultivated crops. Wheat rusts have been mentioned. The cluster-cups of the cedar apple fungus are often destructive to pear and apple trees. Of great importance are also the asparagus rust and mallow rust and the numerous rusts of beans and clover. The great rust disease of the coffee plant, though not, of course, directly affecting Minnesota plants, has been of enormous importance in its devastation of the coffee crops of India and Ceylon. In addition to these might be mentioned a host of parasitic rusts which yearly levy a tax on field and garden crops, on wild plants and greenhouse plants—in fact, they are almost universal in their distribution. (Figs. 2, 11, 23, 26, 29, 73 to 77, 136 to 145, 160 to 162, 181, 182, 199 to 201, 205 to 209.)

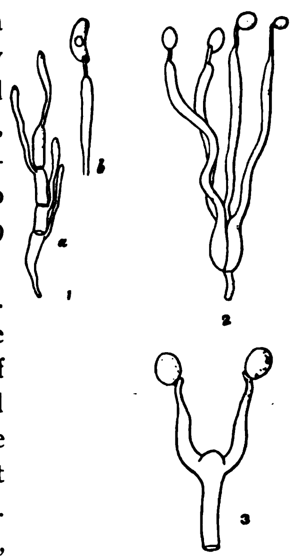


FIG. 78.—Various basidia and spores of the lower basidium-bearing fungi. 1. Jew's-ear fungus; a, a basidium; b stalk with basidiospore. 2. Trembling fungus; the basidium is longitudinally divided. 3. Weeping fungus; has an undivided and forked basidium. Highly magnified. After Brefeld.

Jews' ear fungi (*Auriculariineæ*). This group of fungi derives its name from the name of a common member of the group—a very widely distributed fungus. The nearest relatives of the Jews' ear fungi are the rusts, though at first sight this fact is not apparent. These fungi are almost all saprophytic, growing chiefly on wood, but one species is apparently a parasite upon mosses. Unlike the rusts, winter spores are not produced, but a basidium very similar to that of many rusts is formed directly on threads of the fruiting body. The basidia are long cylindrical bodies of four cells, and they stand side by side in a dense palisade, forming one surface of the fruiting body. The latter is variously shaped: club-, spoon-, shelf-, or ear-like, and is found at the surface of the log or whatever substratum may furnish the nutrient material. The vegetative mycelium is found in the log just as is the mycelium of the pore or shelf fungus in wood-inhabiting saprophytes. The fruiting body of the Jews' ear fungi is in almost all cases of a gelatinous consistency, especially in the interior, and this is due to the gelatinization of the outer portion of the fungus threads, which compose it. The threads, therefore, appear as a very loose network in a great mass of gelatine. Near the surface of the fruiting body the thread walls do not gelatinize but, by the dense network there produced, form a tough covering. The basidia usually cover a special area as they do in the common Jews' ear fungus. In the young basidium a fusion of elements similar to that in the young winter spore of rusts occurs, and has also been interpreted as a breeding act. When the fruiting body is dried, it usually becomes hard and horn-like and shrinks very greatly in size.

From each of the four cells of the basidium a stalk is sent up to the surface of the palisade area and there pinches off a single spore just as do the basidia of the rust fungi. The Jews'

FIG. 79.—Jew's-ear fungus fruiting bodies on a dead branch of balsam fir. Original.

ear fungi have also accessory spore-forms, but not in such abundance nor with such variety as they are found in the rusts. The common Jews' ear fungus, which is found almost all over the world, has been collected only in the northern part of our state, where it occurs in great abundance on dead logs of balsam fir, white cedar and other trees. (Figs. 78, 79.)

Trembling fungi (*Tremellineæ*). These fungi include forms which have a great superficial resemblance to the Jews' ear fungi and derive their common name from the gelatinous consistency which allows them to tremble, as it were, at the slightest agitation. They are all saprophytic, usually on decaying wood and logs. The fruiting body assumes in different plants a great variety of forms—usually from club-shaped or cylindrical to ear-shaped and shelf-like. Many of them are very irregular in form and much convoluted, forming brain-like masses, while still others have a surface furnished with teeth in an exactly similar fashion to those of the true tooth-fungi. They are all, however, gelatinous and this character is due to the same structure of the threads as was described for the

Fig. 80.—A trembling fungus (Tremella sp.), on the end of a log. The portion of the fruiting body near the top has partially decayed and deliquesced. (In the center of the cluster are two white caps of a gill fungus.) Original.

Jews' ear fungus. From the latter and from the true palisade fungi the trembling fungi differ in their basidium. This is formed directly from the ends of threads as in the Jews' ear, but the walls, which divide up the basidium into cells are longitudinal or oblique and the basidium itself is spherical or pear-shaped, while in the former groups the basidium was cylindrical and bore cross walls. Externally, therefore, the Jews' ear and trembling fungi and also the following group may be very similar and indistinguishable to the naked eye, but the microscope shows a difference in the structure of the basidium. Similar accessory spore-forms are also produced in the trembling fungi and a very considerable variety of such forms is found. The trembling fungi are very common in our woods, growing on dead sticks and logs, especially after heavy rains. After shedding their spores they usually liquify under the action of bacteria and other organisms, for they furnish good media for these plants. When dried the trembling fungi become hard and horn-like, resuming their gelatinous nature when again placed in water.

One of our common forms resembles a brownish, irregular or shelf-like mass of gelatine and is commonly known as witches'-butter. The brain-like forms are also very common, often producing masses weighing five pounds. Toothed forms have been found in several places in the state but are seldom abundant. These toothed forms are not unlike the true toothed fungi in appearance but are always more or less gelatinous. Economically this group of fungi is not important, though they may aid in timber rotting to a slight extent and a few forms have been pronounced edible. One very common form is tough and leathery and resembles greatly a much-branched club fungus. (Figs. 78, 80.)

Weeping fungi (*Dacryomycetineæ*). These fungi include another group of gelatinous fungi similar in apparent characters to the two previous groups. There is again a variety of shapes produced, but our commoner forms are irregularly club-shaped or brain-like. The basidia are again arranged in palisade-like areas at the surface of the fruiting bodies, but these basidia are single-celled, having no walls dividing them into several cells. The basidia are fork-like in form and each of the two tines of the fork bears at that end which comes to the surface of the gelatine a single spore. Accessory spores are also produced. The most common Minnesota form is one, which is abundant on fallen logs and stumps of larch and other soft woods. It is at first bright orange, but soon after the shedding of the spores the fruiting body liquifies, whence its common name of weeping fungus.

Chapter XII.

Fungi. Kinds of Fungi. Basidium-bearing Fungi.

The palisade fungi (*Hymenomycetes*). All of the remaining groups of the basidium-bearing fungi have one common character, viz.: the structure of the basidium. Like that of the weeping fungus the basidium is a single cell, not, however, fork-like. It usually bears its spores at the summit. The spores are commonly four in number.

The palisade fungi possess such single-celled basidia. The basidia are borne on fruiting bodies and are always arranged in a palisade which at least at maturity is exposed to the open air. This palisade of basidia lines special surfaces and only in a few cases does it cover the entire fruiting body. The fruiting body therefore exhibits a great variety of forms each of which is a special solution of the problem of furnishing large spore-bearing surfaces and exposing them to the wind for advantageous distribution. The simplest forms are prostrate and mold-like. From this to the highly-organized pore and gill fungi we find an enormous variety of fruiting bodies. Comparatively few accessory spore-forms are known though some exist. The palisade fungi constitute an enormous group of fungi and since the basidia are similar in all, the shape of the fruiting body is utilized in arranging the forms into groups. The group may be divided into the following seven sub-groups:

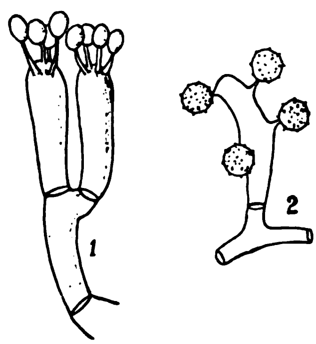


FIG. 81.—Basidia and basidiospores of all of the higher stalked or basidium-bearing fungi. 1. The usual type. 2. The basidium of a stalked puffball. Highly magnified. 1. After Brefeld; 2. After Schroeter.

Gall-producing fungi (*Exobasidiineæ*). These fungi are all parasites, chiefly of the blueberry and heath families. The mycelium stimulates the leaves or stem to excessive growth, and gall-like swellings, often reddish in color, are thus produced. On the surfaces of these galls the palisades of basidia are produced, and the basidium-spores appear to the naked eye as a fine white powder. Four spores are produced on each basidium. These spores germinate by forming a thread, which is again capable of causing infection. The galls so produced are fungus-galls and must be distinguished from the insect galls of plants which are much more common in occurrence. The most common Minnesota member of this group is one which forms galls on Labrador tea in the northern part of the state. The gall on blueberry and cranberry undoubtedly also occurs but it is not very abundant and good specimens have not been collected. (Figs. 37, 81.)

Mold palisade fungi (*Hypochnaceæ*). These comprise the simplest of all palisade fungi since no true fruiting body is formed but merely a dense mold-like mass on rotting logs or decaying wood. On the surface of this mold-like mass are the basidia arranged irregularly and only suggesting the true palisade of the higher groups of this alliance.

Smooth shelf fungi (*Thelephoraceæ*). In this group of fungi the palisade is usually the under surface of a shelf-like fruiting body. In some forms, however, the fruiting body is prostrate and closely grown to the log or substratum on which it grows and no part of it shelves out. In this case the whole upper surface is covered with a palisade. Such prostrate forms often appear as thin, grey-brown or whitish crusts on the bark of dead twigs and trunks of trees. Whatever the form of the fruiting body the palisade surface is always smooth and in this respect it differs from the pore and gill fungi. The palisade surface, moreover, is not entirely composed of basidia but may contain certain sterile cells of peculiar structure, known as cystidia. They are usually long, sharply-pointed cells which project from the surface very considerably and are frequently coated with certain salts which give to them additional rigidity. Their function is probably protection. When occurring in great numbers they give to the palisade surface a velvety appearance as seen by the naked eye or under a low-power hand lens. The smooth shelves are very common Minnesota fungi and not a few timber diseases can be traced to this group. Most forms are, however, saprophytes. The common smothering fungus which is found at the base of young shrubs and trees is a smooth-shelf fungus. (Figs. 81, 82, 117, 118.)

Club fungi (*Clavariaceæ*). As the common name implies, these fungi have club-shaped fruiting bodies. The club in some forms is single and thus simple. In other forms it may be branched and the most common of our club fungi are very abundantly branched thus forming dense tufts. The palisade surface is usually confined to the upper part of the club which is in general smooth, so that one may consider these club

FIG. 82.—A smothering fungus (Thelephora laciniata), growing on the ground. The fruiting body has narrow shelf-like divisions. Original.

fungi as but modifications of a similar scheme of fruiting body to that of the smooth shelves but of a special kind. The basidia are of the usual type and the spores vary from white to yellow. The clubs are sometimes hollow and very brittle, in other cases they are solid and fleshy. All of our club fungi are saprophytes inhabiting decaying wood or ground where wood has been scattered. They vary in size from tiny thread-like cylindrical clubs, on the one hand to large single clubs measuring six inches in length and one inch in thickness and on the other hand to clusters of branched clubs six to eight inches in diameter and even larger. One little club, not commonly, but occasionally, found in Minnesota, has a swollen and somewhat convoluted club top

Fig. 83.—Club fungi (species of Clavaria), on decaying log. (To the left below, is seen a crust of burnt-wood fungi.) Original.

which is internally more or less gelatinous and of which the entire surface is covered with the palisade of basidia. A large number of the club fungi are edible and furnish many common and abundant forms. (Figs. 10, 81, 83.)

FIG. 84.—The coral fungus—a toothed fungus (Hydnum coralloides), on the under side of a log. Original.

Tooth fungi (*Hydnaceæ*). The fruiting body of the tooth fungus is in some respects more complex than that of the smooth shelves or clubs. The palisade surface is here distributed over an area covered with teeth which thus increases the spore-bearing surfaces considerably. These teeth may be comparatively short—one-half inch or less in some forms—or they may attain a length of three inches in others. They are chiefly wood-inhabiting saprophytes and comprise some serious timber rots and diseases; some are found on the ground. The coral fungus and the very similar bear's-head fungus are exceedingly common tooth-fungi, found on logs in autumn or throughout the summer. The fruiting bodies of most of these fungi are edible. (Figs. 81, 84, 119.)

Pore fungi (*Polyporaceæ*). This is one of the largest of the groups of the palisade fungi and contains many of our most conspicuous forms. They are palisade fungi which have in common the formation of pockets or pores in the fruiting body and on the surfaces lining these pockets or pores are found the palisades. A safe position and a great increase of spore area is thus effected. There is considerable variety in these fungi in respect of the consistency and form of the fruiting body. One alliance of forms has more or less gelatinous fruiting bodies in which ridges which cross and recross each other form shallow pores. Many of these gelatinous pore fungi have single, prostrate fruiting bodies, though some form true shelves. Such gelatinous pores resemble many of the trembling fungi and their allies. To this group belongs the well known dry rot fungus which is probably the most dangerous timber-saprophyte known. They are common on rotting logs and stumps. The majority of pore fungi have tough, leathery or more or less woody fruiting bodies of a true shelf-habit. Most of our common shelf fungi belong to this group and they comprise a great many of our most common timber diseases. A variation is noticeable in the form of the pores and upon this variation is based in a large measure the classification of the numerous forms. Some pores are cylindrical pockets, others are elongated and often fuse with neighboring pores and thus form complex labyrinths; others, again, are hexagonal in outline. The pores, moreover, vary in depth, in their relationships to surrounding parts, in methods of formation, etc. Again, some shelves last but one year while others live from year to year, adding new substance to the fruiting body every year. In one alliance of forms the shelves may be branched, forming large compound shelves. The birch shelf-fungus, the sulphur fungus,

FIG. 85.—A pore fungus (a species of Boletus), growing on the ground. Pores are clearly seen on the lower surface of the cap in the fruiting body on the right. Original.

and the tinder fungus, may be mentioned as a few of the numerous common forms of these pore fungi. In addition to the gelatinous and tough and fleshy pores are the beefsteak fungi which are very soft; in these the pores with their surrounding walls are free from each other and look like small dependent tubes

FIG. 86.—A stick-dwelling gill fungus (Lenzites betulina), on a dead branch of a birch. Original.

hanging from the fruiting body. Most of these forms are edible. Somewhat similar to these are the species of Boletus, all of which are fleshy and grow on the ground, often in swampy places. The pores are here also found in tubes which separate from each other readily and the tubes are combined into a separate layer. The pores are usually large and the fruiting body always possesses a central stalk and mushroom-like cap. On the under surface of the cap are found the pores. The pore surface is sometimes enclosed in young stages by a veil-like covering below which attaches the edge of the cap to the stem. At maturity this ruptures and a part of it remains attached to the stem as a so-called ring. They are all earth-inhabiting saprophytes and most forms are edible while a few are poisonous. (Figs. 5, 10, 36, 81, 85, 120 to 127, 163.)

Gill fungi (*Agaricaceæ*). In this group of fungi the palisade layer is spread over structures known as gills. These gills are plate- or leaf-like bodies arranged on the under side of an umbrella-like cap and run from the stalk to the cap edge. When the cap is young the gills may be closely pressed together but are later spread apart to allow the spores to be shed. This group contains an enormous number of plants, being by far the largest of the palisade fungi, and it includes not a few plants of economic importance. The fruiting bodies vary in size from not larger than a large pin to umbrella-like forms more than a foot in diameter. In consistency the fruiting bodies may be gelatinous, waxy, fleshy, leathery or even woody. Some forms are stalked while others are attached directly by their cap edges. In the higher forms the fruiting body possesses veil-like structures which enclose the gills or the whole cap as long as the gills are still immature. As soon as the spores are ripe the veil breaks, leaving a cup-like

FIG. 87.—Shaggy-mane fungus (Coprinus comatus). This is an inky-gill fungus. The cap is seen to be blackened at the base, where the whole substance of the cap deliquesces and drops its black spores in an inky mass. Original.

structure at the base of the stem or a ring-like fragment on the upper part of the stem. The gills are then exposed to the air and are ready to shed their spores. If the cap of such gill fungi be cut off, placed on paper and kept thus in a closed chamber, the spores will fall in such numbers as to give a very distinct map of the gills. The spores are of various colors, white, pinkish salmon, ochre-brown, dark-purple or black, and this color difference has been used as a basis for a classification of the gill fungi. In some dung-inhabiting forms the gills liquify when the spores are ripe and the latter drip from the plant in an inky fluid mass. Some caps when broken exude milky fluids of different colors: white, red or yellow. Such are known as the milk fungi. The great majority of the gill fungi are true saprophytes. Many are earth-inhabiting or dung-inhabiting and an enormous number are wood-dwelling forms. These contain many of the chief timber-rot fungi as well as many wound-parasites. A few are parasitic on other gill fungi. The gill fungi find their chief economic importance, outside of their timber-rotting effect, and as agents in the decay of plant debris, in the food products which they furnish to man. The commercial mushroom is a member of this group and hundreds of wild forms are edible. The latter are being used more and more extensively as food by those who take the pains to hunt them up and to know them. There are likewise some fungi of this group which are

FIG. 88.—The shaggy-mane fungus. This fruiting body is in a more advanced stage of deliquescence than that shown in Fig. 87; almost the entire cap has dripped off. A ring (annulus) is seen at the base of the stalk. Original.

Fig. 89.—The common wild mushroom (Agaricus campestris). The gills are clearly seen as is also the membranous ring or annulus on the stem. Original.

exceedingly poisonous and fungus eaters must take good care that they are familiar with the poisonous varieties found in the state. (Figs. Frontispiece, 6 to 8, 10, 18, 20, 81, 86 to 89, 116, 128 to 132.)

Puff-balls and their allies *(Gastcromycctcs).* All of the remaining basidium-bearing fungi have closed fruiting bodies. The basidia are borne inside of this structure either in palisades lining the surface of chambers or in irregular fashion on loose threads throughout the fruiting body. The latter arrangement

FIG. 90.—A group of the common gemmed puff-balls (Lycoperdon gemmatum) just before opening; the position of the future opening is seen at the darkened tops of the fruiting bodies. Original.

is prevalent in the wefted puff-balls (including the first, second and third of the following groups), while the remaining groups possess the palisade arrangement of basidia. The fruiting body always possesses one or more covering membranes. These fruiting bodies may remain closed until the membranes decay, when the spores are released, or they may open in characteristic ways, by pores or by splitting, and thus allow of the escape of the spores. In most forms the interior of the fruiting body partially disintegrates, leaving only the spores in a fine dust held in a loose weft of long and strong threads which give the interior a sponge-like texture. The spores are then thrown out in dust-like clouds or puffs and are caught by the wind and may be transported considerable distances. The chambers with their palisade lining are not seen in the mature fruiting body and can only be observed when the latter is young. The interior is then fleshy, white and more or less solid, and with age gradually gets yellowish-green and soft, and even semifluid, finally producing the dust of spores in the thread weft. (Figs. 81 to 91, see also following seven groups.)

FIG. 91.—The same group as in Fig. 90, taken two weeks later; shows the opened puff-balls. Original.

Long-stalked puff-balls (Tulostomaceæ). One frequently meets in sandy places and in open fields groups of small puff-balls about one-half to three-fourths of an inch in diameter, mounted on long stalks which in some cases attain a length of six inches. At maturity the spores form a powdery dark brown mass and are thrown out through a pore in the puff-ball wall. The puff-ball is formed just under the surface of the ground and is raised up above the ground by the somewhat rapid growth and elongation of the stalk, so that the puff-ball is elevated to an advantageous position for the scattering of spores. The mycelium forms strands and the fungus is an earth-dwelling saprophyte. (Figs. 3, 81, 92.)

Hard skinned puff-balls (Sclerodermataceæ). Many of these puff-balls form their fruiting bodies at least partially underground. The coat is hard and leathery in texture and usually opens by splitting in some irregular fashion. The spores also form a powdery mass which in our common species is dark violet in color. The fruiting bodies are usually large in size, attaining a diameter of five and six inches in many cases. In their immature condition they are superficially not unlike potatoes in appearance. These fungi are also earth-dwelling saprophytes.

FIG. 92.—Stalked puff-balls (Tulostoma mammosum). The puff-balls have been raised from the sandy ground on stalks just before the opening and shedding of spores. Original.

Sphere-throwing fungi (Sphaerobolaceæ). These are very minute fungi and not easily recognized as puff-balls. The fruiting body is usually not more than three-sixteenths or one-eighth of an inch in diameter and covered with a soft whitish outer coat. Inside of this is an elastic covering which, at the maturity of the spores and after the outer coats have been split, inverts and forcibly ejects the whole mass of spores. The latter remain attached together in a solid sphere and never form a powdery mass. The sphere may be thrown as far as six feet into the air. The spores begin to germinate in the mass and thus a new mycelium is started. These fungi are wood-inhabiting saprophytes and are frequently found on pine wood, as on decaying sidewalk planks. (Figs. 14, 81.)

Underground puff-balls (*Hymenogastraceæ*). These fungi form their fruiting bodies under the ground, sometimes an inch or more below the surface. They are often thick-skinned and never open except by the decay of the walls. The interior does not develop a spore-powder mass but remains chambered to maturity, and the chambers are lined with palisades of basidia. These fungi are saprophytic. They are not abundant in Minnesota though several forms are known. They resemble very much the true and false truffles, but, of course, differ from these in the method of forming spores, for the puff-ball spores are never found in sacs but always on a basidium.

True puff-balls and earth-stars (*Lycoperdineæ*). This group includes many exceedingly common fungi which can be found in great abundance in early fall. The puff-balls are therefore very familiar objects. The fruiting body is usually spherical and is always at least at maturity found on and never below the surface of the ground. It is usually provided with at least two coats, the outer of which is shed in various ways and the inner coats peel off, undergo splitting, or open by a definite pore-like aperture. In one group of very common puff-balls, the outer coat forms small bosses, or more or less elongated spines, which at maturity fall off (Figs. 90 and 91) and leave characteristic scars on the inner coat.

One of the most familiar of this group is the gemmed puff-ball in which the short spine-bosses are grouped together in clusters. Some true puff-balls have paper-like and very thin coats and our common form of this group is almost perfectly spherical. The outer coat peels off in shreds and the inner opens by a pore. In still other forms the puff-ball's outer coat splits along the equator and the upper half then becomes inverted and looks like a saucer containing a puff-ball. The puff-ball fruiting body always contains its spores in a powdery mass which lies loosely in a cotton-like tangle of sterile threads. When jarred in any way the puff-ball emits clouds of spores which look like dust, olive-green, brown or black-purple, as the case may be. The distribution of the spores may thus continue for an unlimited period. Of course wind is the chief agent of distribution. The earth-stars are puff-balls with usually three coats in the wall of their fruiting bodies. The outer falls off and the median coat splits from the tip nearly to the base in a number of places and each lobe, so formed, bends back when it absorbs water, giving to the fruiting body the form of a star. By this bending back of the lobes the puff-ball is broken loose from its mycelium and raised up in the air. Thus the

FIG. 93.—Earth-stars. (Geaster triplex.) The uncovered strand mycelium of this fungus is seen to the right, below; in the center and to the right above are unopened fruiting bodies; above in the center is a star, just opening, and below to the left is a fully opened or vaulted star with opened puff-ball in the center. Original.

spores obtain a more advantageous position for distribution. In most earth-stars this vaulted condition is permanent but in one form (really, however, a wefted puff-ball) the coat opens and closes depending on the presence or absence of water. The bending back of the lobes is affected by the greater swelling which takes place in the inner threads of this coat while the outer threads are tough, remain somewhat rigid and are not greatly extensible. One Minnesota earth-star which in the younger stages is found just below the surface of the leaf mold is able to lift itself out of the mold and becomes vaulted directly over the hole from which it was torn loose. The puff-ball fruiting body in the very young stages is internally fleshy, more or less solid, and usually pure white, and in this condition is edible and frequently sought by mushroom eaters. Caution must be exercised to prevent mistaking for them the young button-like stages of the poisonous gill fungi, which are not at all unlike certain puff-balls. Puff-ball fruiting bodies vary enormously in size. The smallest are little larger than good-sized peas while the giant puff-ball, a form much sought for by mycophagists, has been frequently collected in Minnesota a foot or more in diameter. In the youngest stages the interior of the puff-ball is chambered and the chambers are lined with a palisade of basidia. The mycelium of certain puff-balls has been described as furnishing the mycorrhizal threads which live in partnership with roots of certain trees. These fungi are otherwise saprophytic in habit. (Figs. 10, 81, 90, 91, 93.)

Birds'-nest fungi (Nidulariineæ). This group of basidium-bearing fungi would at first sight be scarcely recognized as a close relative of the puff-balls. Such it is, however, with peculiar variations from the typical puff-ball structure. The chambering here becomes permanent and the chambers are lined as usual on the inside with a palisade; they become separated by the breaking down of the threads between. The chambers thus come to look like small hard-coated egg-like bodies, which lie loosely within the walls of the puff-ball. These walls open at the apex by a broad-mouthed opening, which in the earliest stages is closed by a parchment-like membrane, so that at maturity the fruiting body has an open beaker-like form. In the beaker or cup lie the egg-like chambers. The latter are in our commoner forms attached to the wall by thin stalks of exceedingly elastic fungus threads which are so extensible that in water they can be drawn out to a length of six inches or more from one-fourth inch or less in the dry state. This stalk may serve to attach the fungus to the legs of insects and again from here to the twigs or trunks of trees. The stalk is somewhat gelatinous which aids in the fastening of the stalk. The spores are thus distributed in packets, which are the separated chambers, and they germinate directly from the interior of the chambers. The birds'-nest fungi are saprophytes with chiefly wood- or dung-dwelling habits. They may exist as timber rots but are seldom if ever abundant enough to cause serious damage. (Figs. 13, 81.)

Carrion fungi (*Phallineæ*). More unrecognizable still as puff-ball relatives are the carrion fungi. In the very early stages of the fruiting body, however, this relationship becomes somewhat clear. The mycelium usually forms whitish strands and upon these strands arise the fruiting bodies as small spheres or pear-shaped objects and as they increase in size look superficially very much like puff-balls. These "eggs" attain a size of three or four inches in some forms, while in others seldom exceed a filbert nut. The tip of the "egg" is usually just at the surface of the ground. The outer coats of the "egg" enclose a great gelatinous mass and at maturity this swells up and the outer walls break. There then emerges from the "egg" a stalked body with a terminal cap. The stalk elongates rapidly from a compressed condition in the "egg;" the elongation is not growth but a straightening out of folds, much as a sponge enlarges when it absorbs water. The carrion fungus cap is thus raised several inches into the air in a few hours or less, so that the elongation is delayed until the spores are ready for

FIG. 94.—A carrion fungus (Dictyophora ravenellii). Below are seen the remnants of the "egg" coverings which have been broken and remain as a cup around the base of the stalk. The latter is seen to be spongy; by straightening out from a compressed condition it has lifted the cap some inches above the ground. The cap has still a considerable spore mass left; insects have, however, carried off the lower portion of the spore mass. The odor of the latter is that of badly decayed carrion. Original.

distribution. The spores are found on the upper surface of the cap and at maturity are contained in a sticky, semi-fluid olive-green mass which has a strong odor of carrion. Flies and other insects are attracted by the odor, carry off the sticky mass, and thus disseminate the spores. The attraction for insects is still further increased by the presence in some forms of a lace-curtain-like veil which hangs down from beneath the cap. In the very early stages the spore-bearing region shows a series of chambers lined with palisades and very similar to that of the puff-balls, but at maturity the chambers disappear in the disintegration of portions and only the sticky remains with the spores are left. The carrion fungi show an extraordinary amount of differentiation and complexity in the development of their fruiting bodies and the insect-distribution of spores is carried to a high degree of efficiency. In these respects the carrion fungi are undoubtedly the most highly developed of all of the basidium-bearing fungi, and it is doubtful if any other forms in the whole realm of the fungi are their equal. The carrion fungi are saprophytes and are all earth-dwelling forms. (Figs. 3, 10, 12, 81, 94, 95.)

FIG. 95.—A carrion fungus (Dictyophora duplicata), photographed just after the breaking of the "egg" and while the cap was being lifted. The "egg"-membrane remnant at the base is in sharp focus since it did not move during the exposure; but the whole top which has been lifted during the 15-minute exposure has been blurred. Below the cap is a large lace-curtain structure which serves as an additional attraction for insects. Original.

Chapter XIII.

Other Disease-causing Organisms.

Bacteria. One does not usually associate bacteria with diseases in plants, but they are nevertheless frequently agents of such disease. In recent years many diseases of bacterial origin have been discovered and described. Man's chief interest in bacteria is usually centered in the diseases of man which are so largely caused by bacterial action. The bacteria were formerly considered to be fungi but in recent years it has been recognized that they are most closely related to the blue-green algae, though they differ from the latter in important points. They resemble the fungi in their mode of nutrition—for they obtain their food in a partially elaborated condition and, with a few exceptions, are unable to manufacture starch from air, gases and water as do green plants. They are therefore devoid of leaf green just as are the fungi, and thus differ from the blue-green algae. They may possess coloring matters of various kinds but are not as a rule able to utilize these in the conversion of the sun's light to energy in starch manufacture. They differ from the fungi, however, in their method of growth and division, and in these respects and in general appearances resemble most closely the blue-green algae. The bacteria, then, may be considered as close relatives of the blue-green algae which have adopted fungus habits of nutrition.

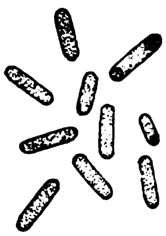


FIG. 96. — Bacteria of black rot of cabbage (Pseudomonas campestris). They are seen to be tiny cylinders. Highly magnified. After H. L. Russell.

The forms and sizes of bacteria. The bacteria are all exceedingly minute plants consisting of single cells. They may be less than one thousandth of a millimeter in length and the largest are seldom more than about ten-thousandths of a millimeter. It requires, therefore, microscopes with powers of high magnifications in order to observe and study them. The bacterial plants may differ somewhat in form and to these various forms names have been applied, and upon them the classification of the bacteria was formerly based. It is now recognized, however, that several forms may appear in the same life-story under differences of conditions, thus rendering the former classification unsatisfactory. An approximately spherical bacterium is known as a coccus, a short, rod-like form is known as a bacterium, in the narrower sense, and the long rod form is a bacillus. Some forms are, moreover, comma-shaped; others are undulate or wavy in appearance, while still others appear much like corkscrew or long-drawn spiral coils. These plants may differ, moreover, in the manner in which colonies are formed. All bacteria in the broader sense multiply chiefly by simple division of the cell into two, the resulting parts splitting away from each other—hence the name fission plants. By such divisions filaments of cells may be built up, or by division in two planes, plates of cells, or when division in three planes takes place masses of cells are produced. As the external walls of bacteria are frequently gelatinous, sheaths are formed which serve to bind the plants together in such filaments, plates or masses. A larger gelatinous colony may thus be built up and is then known as a zoogloea. One sees among the bacteria a great variety of habits; a large number inhabit fluid media. As a special means for dissemination many of such forms have lash-like projections of the protoplasm which whip around in the water and propel the plant cell about.

Multiplication and reproduction. The fission method of multiplication which is common in the bacteria is a very efficient one. It is also common to certain groups of blue-green algae. In bacteria the successive splittings into cells may follow with some rapidity, e. g., under the most favorable conditions the hay bacillus completes a division in twenty minutes. It has been calculated that if a bacillus two-thousandths of a millimeter in length were to divide uninterruptedly at the rate of once every thirty minutes, at the end of five days the volume of the resulting bacteria would fill all of the ocean beds of the globe. Competition and unfavorable conditions, of course, prevent such disastrous results, but the possible rapidity of multiplication is thus well illustrated. When unfavorable conditions confront a rapidly dividing bacterium, spore formation may take place. The spore, just as most fungus spores, provides itself with thick walls and is thus protected during the continuance of the unfavorable surroundings. These spores may be formed inside of the cells, or by the mere transformation of the ordinary cells by wall thickening and condensation of protoplasmic contents. When placed again under favorable conditions the spore may grow out in various ways into the ordinary bacterial cells. No breeding act is known among the bacteria.

Physiology of bacteria. The physiological activities of the bacteria are most varied and interesting. They are of immense economic importance for upon them are built a host of industrial processes as well as many diseases in man and in plants. Many geologic deposits, as iron ores, may possibly owe their existence to bacterial activities.

Air-loving and air-shunning bacteria. Most bacteria resemble other plants in their requirements for air gases during their life processes. Oxygen, one of these gases, is utilized in burning up certain compounds and in this combustion energy is liberated to run the protoplasmic machinery. This use of oxygen is common to animals as well as plants and the ultimate products of the burning are carbonic acid gas and water. Such bacteria may be known as air-loving bacteria or perhaps, more strictly speaking, oxygen-loving. There is another class of bacteria which is capable of obtaining such energy as the air-loving bacteria derive from combustion of compounds in a different way, viz.: by the breaking down of complex organic compounds into simpler, during which process the necessary energy is liberated. This process may take place, moreover, when no air is present, and in certain cases the exclusion of air, and particularly of oxygen gas, is necessary. Such bacteria are known as air-shunning bacteria. They have a method of breaking down complex substances different from that of the combustion method and may carry on such a process even when the air is entirely excluded.

Among the many air-loving forms the vinegar bacteria may be mentioned while the rancid-butter bacteria are examples of air-shunning kinds.

Influence of external forces as light, temperature, etc. It is a well-known fact that most bacteria do not thrive in sunlight but that the direct rays of the sun are fatal to them. Too much stress cannot, therefore, be placed upon the necessity for sunshine in thorough processes of sanitation. Waters of lakes and rivers are largely purified by direct sunshine which can fatally affect bacteria to a depth of several feet below the surface. Of course this is not the only agent of purification but is one of the most important. It is to be expected, therefore, that when bacteria cause disease in plants it is in the underground portions, as bulbs or roots or stems, or in situations where the illumination by the sun's rays is always poor. Excessive moisture may, moreover, aid in bacterial dissemination. The bacteria are easily carried about in the water currents especially if they have the whip-like swimming apparatus which is common among so many forms.

Some bacteria can live and even reproduce in temperatures near the freezing point, while the resting, inactive cells are often capable of resisting very much lower temperatures. On the other hand, heat-loving bacteria are known which thrive in comparatively high temperatures—even fifty degrees Fahr. above blood heat. The bacteria are thus seen to enjoy wide extremes of temperatures. A given species, of course, has usually a much more limited range and always possesses a favorite temperature at which it grows best. In general, bacterial cells in the dry state are capable of enduring higher temperatures than those in the moist condition,—facts which are used to advantage in combating bacterial disease germs. In the canning of fruits, for instance, boiling for a short time will destroy most germ cells though spores will often resist even such harsh treatment. The power of resistance in the dry state is an important feature, for bacterial germs may live for months and even years in such conditions, germinating again as soon as favorable conditions of moisture and nutrition present themselves. Thus germs of various diseases of man may lurk in the air or soil, becoming evident only upon the advent of suitable conditions. Strong electric currents usually destroy bacteria and this fact has led some to believe that electricity may be utilized in the purification of municipal water supplies.

Bacterial partnerships and antagonisms. Bacteria often form dense colonies of individuals developing in gelatinous masses. These bacteria may all be of one kind, but frequently are different, and may then live in a partnership apparently beneficial to each other. It is evident that such forms do not compete with each other for food stuffs. Bacteria may also form partnerships with other organisms as with yeast plants. In such cases the waste products in the nutritive processes of one may be food for the other plant and thus a beneficial partnership is established. Such is the association of bacteria and yeast in the English ginger beer "plant" and in the production of other drinks as the Asiatic kephir. Such a partnership is also explained in the fact that organisms of this kind often form waste products which, if allowed to accumulate, may prove detrimental to the organism producing them. This is a common method by which bacterial growth is limited. These compounds are in the case of bacteria often poisonous and form the toxins which in disease germs are the poisoning agents of the disease. The accompanying organism of a partnership may use up and remove these detrimental substances and thus allow the first partner unhindered development. Antagonism of bacteria in colonies may result from competition for food materials or from the production of substances by one, which are poisonous to the other organism.

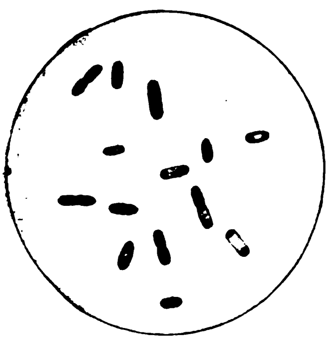


FIG. 97.—Bacteria of fire-blight of apples (Bacillus amylovorus). Highly magnified. After B. M. Duggar.

Disease-causing bacteria. One of the most useful classifications of bacteria is the arrangement of forms according to their prominent physiological effects. In such an arrangement the disease-causing or pathologic forms are of great economic importance. These are the forms which give rise to most of the well-known diseases of man and lower animals. Cholera, tuberculosis, diphtheria and typhoid are but a few of the destructive diseases of bacterial origin. By an accurate knowledge of the life-story, physiology, etc., of these organisms preventive measures of sanitation and quarantine have been made possible and an enormous saving of life effected. Modern methods of medical and surgical practice have been built upon such knowledge. Great as have been the results in the past, still greater may yet be achieved in the future by a more complete knowledge of these disease-causing bacteria. This applies as well to those bacteria-causing diseases of plants as to the diseases of man, though the former are not so numerous nor so vital to man's interests.

Dye-forming bacteria. Another great group of bacteria have the peculiar property of producing coloring matters during their nutritive processes. This coloring matter is in some cases found in the cells of the bacteria and in others is a by-product of nutrition. Red and yellow spots on bread are frequently of this nature and milk is sometimes colored red from a similar cause. The blue coloration of milk is also of bacterial origin. Certain bacteria form a beautiful "bacterial purple" and are furthermore peculiar in that, by means of this coloring matter, they seem to be able to utilize the sun's rays in a manner analogous to the leaf-green plants which convert sunlight energy by the use of leaf-green. The production of indigo dyes from indigo plants is also dependent upon the activity of bacteria; other blue colorations, as in certain kinds of cheese diseases, and again, green colorations may have bacterial origins.

Light- and heat-forming bacteria. In the conversion of energy in which bacteria are engaged, many forms exhibit still other peculiarities. Some utilize surplus energies in the generation of light and such produce phosphorescence or other illuminations. Sea phosphorescence is in part due to these bacteria. Others again dissipate energy in the production of heat and examples of these may be seen in heated manure piles, in silos, in certain methods of curing hay, and in tobacco curing. The generation of heat in all of these cases is due to the activity of heat-producing bacteria. The temperature may even be raised to such a degree that rapid combustion of the materials may take place and such occurrences are usually described as spontaneous combustion.

Fermentation bacteria. Still another great group of bacteria are capable of causing fermentation in fluids—a splitting up of compounds accompanied by the production of gases just as is effected by yeast plants in bread- and beer-making processes. These fermentation processes are of many kinds. Butter becomes rancid and milk may be broken up and soured by the action of these bacteria. Upon the action of milk-fermenting bacteria depend other processes in certain methods of curing hay and ensilage. Again, fermenting bacteria are the agents of fermentation in the production of vinegar.

Nitrifying bacteria. Of great importance in agriculture are those bacteria which live in the soil and by their action prepare crude materials for leaf-green plants. The latter require a certain gas known as nitrogen which must be furnished, however, in a particular kind of compound known as a nitrate. Leaf-green plants are unable to utilize nitrogen gas in the free state and this is the condition in which it exists in the atmosphere. Now the nitrifying bacteria are capable of using compounds unavailable to the leaf-green plants and by the united action of several bacteria finally build up the nitrates desired by the leaf-green plants.

FIG. 98.—Bacterial nodules on root of common bean. In these swollen portions of the roots are found bacteria which assist the plant in obtaining nitrogenous food material. Original.

Nodule bacteria. Certain plants such as clover and many other plants of the pea family form small nodules on their roots. In these nodules dwell bacteria, which are capable of using free nitrogen from the air. They then pass the manufactured nitrates on to the clover plant. These nodules are therefore special habitations for nitrogen-fixing bacteria, which are thus protected and fostered by the clover plant.

The latter derives its benefit in the nitrate product. A true partnership is thus effected. Clover and alfalfas and all such nodule-possessing plants are therefore valuable rotation crops because they accumulate by the aid of their bacterial partners nitrates, where wheat or other crops have depleted the soil of these compounds. These bacteria are now distributed by the Department of Agriculture in quantity for sowing on poor soils where leguminous plants as clovers, etc., are then grown. Such soils can thus be greatly enriched so that other crops which do not possess bacterial nodules can subsequently be raised.

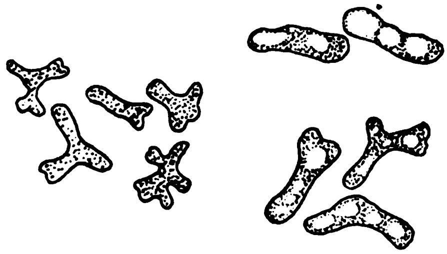


FIG. 99.—The bacteria of such root nodules of the pea family as are shown in Fig. 98. On the left of Vicia sativa (the spring vetch), on the right of Medicago denticulata. Very highly magnified. After Atkinson.

Other economic phases of bacteria. A great many other phases of bacterial life are of importance in the arts and industries and only a few may be mentioned in this short review. In tanning, in diseases of wine and beer, rennet curdling, in the manifold processes of putrifaction of organic matter, in cheese industries, in the deposition of bog iron ore, the bacteria appear in important roles. More particularly are we here concerned with those forms which attack living plants and cause disease. Such plant diseases are not numerous but investigation is steadily adding new examples and they promise to become of sufficient importance to make this brief general discussion of this group of plants justifiable. The various bacterial diseases will be considered individually in subsequent chapters. (Figs. 96 to 99. 172 to 178, 195).

Slime molds (*Myctozoa*). This group of organisms is now commonly classified with the simplest animals, though they are very fungus-like in many of their characters. Most slime molds are true saprophytes but a few have adopted parasitic habits. Some of the latter live in plants and others in animal tissues. The slime molds produce spores in structures very similar to the fruiting bodies of many saprophytic fungi. These fruiting bodies are usually very small—many are of pin-head size but a few attain a diameter of six inches. The spores are usually enclosed in cases which have definite methods of opening. The spore mass is dusty or smut-like and the spores are tiny spheres of microscopic size. If the spores be placed under favorable conditions of moisture and temperature they do not send out a fungus thread as do true fungus spores, but the wall breaks and the protoplasmic contents emerge in a naked mass, not unlike a very tiny drop of albumen in appearance. This small mass creeps about by changing form, engulfs food, and lives in all essentials as do other very simple animals. After a time a large number of these animals of the same kind meet and soon fuse together forming a larger mass of jelly-like material which is known as a plasmodium. The plasmodium is often met with on the forest floor or in other moist places and is often highly colored. Pink and yellow are common colors though many are yellowish white. The plasmodium may be cake-like or may be drawn out in various ways, as into strands. It is in reality a colony of slime-mold animals, and this colony may move and feed and otherwise behave as a simple animal. After a time and particularly as the atmosphere becomes dryer the plasmodium draws itself up into some kind of a fruiting body which is often composed of stalk and capsule. In the latter are found the spores and also sterile threads, in appearance not unlike those found in

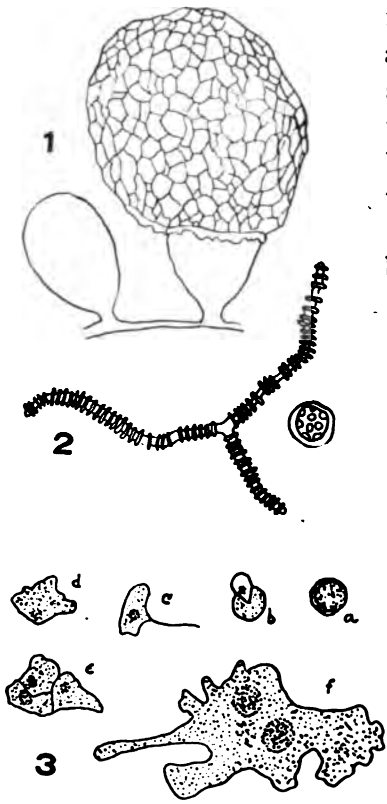


FIG. 100.—A slime mold. 1. An opened (on right), and an unopened fruiting body. From the opened fruiting body is seen a protruding fluffy mass of threads (capillitium), which encloses the spores as in a mass of cotton. 2. An isolated thread of the capillitium and a spore (highly magnified), (Arcyria serpata). 3. a, young spore (Chondrioderma difforme); b the same, germinating; contents are emerging as a naked bit of protoplasm; c same in the free swimming stage; has a single swimming lash; d same in amoeba stage; e several amoeba-like masses fusing to form a small plasmodium; f a young plasmodium. 2 and 3 highly magnified. 1 and 2 after DeBary; 3 after Cienkowski.

the fruiting bodies of puff-balls. In fact many of the fruiting bodies resemble so closely the true puff-balls that botanists formerly classified them as such and the amateur is constantly deceived by the resemblance when he first meets with these forms in the field. When the fruiting body is formed the entire plasmodium is used up in its construction and the spores are blown about by the wind and thus disseminated. The slime molds exhibit, therefore, a lowly method of animal life and a fungus-like reproduction. The slime molds, living as plant-parasites, live in the cells of the host plant and do not form fruiting bodies like those of the true wood-dwelling saprophytes. One slime mold parasite causes the club root of beets living in the cells of the swollen portions. The slime-mold parasites of animals cause various diseases. Malaria is due to a slime mold which lives a part of its life in the body of the mosquito and is transferred to man in the bite of the insect. Texas fever of cattle and several diseases of man are traceable to the action of organisms of this slime-mold group. (Figs. 100, 179,180.)

Other kinds of plants as disease-causing organisms. As has already been stated, fungi constitute an overwhelming majority of those plant diseases which are of plant origin. Besides these and the bacterial diseases, a few are known which are caused by other kinds of plants though they are with few exceptions of slight economic importance. Only a short account of them will be permissible in this work.

Algae. A number of blue-green algae live as place parasites in cavities and tissues of higher plants. Such are doubtless not true parasites in their nutrition but their position in the tissues of the host offers them protection of place and a safe harbor. Such are found in floating water-ferns, and in the roots of the greenhouse sago palms.

Some flower-pot algae are also place parasites. The possession of leaf-green enables them to manufacture their own food. A few such green algae are known on water-inhabiting seed plants, e. g., several species of the tiny duck weed. No diseases of economic importance are known in these groups.

Mosses and fernworts and lower seed plants. No Minnesota members of these groups of plants or of their alliances are known as parasites of other plants. Some of the latter groups have already been mentioned as living in an unequal partnership with root fungi in which the green plants are the dominant partners. They are not however found as parasites on other green plants.

Higher seed plants. A number of Minnesota species of the higher seed plants are known as true parasites on other leaf-green plants and a few of these are of economic importance. When a race of plants which was originally self supporting by

FIG. 101—Twig of a witches'-broom of spruce, showing the parasitic plants of the mistletoe which cause the "brooming" of the branches. The mistletoes are seen as very small plants, scarcely larger than the spruce leaves; they are tipped with an egg-shaped body which is the fruit of the mistletoe and contains a single seed. (See also Figs. 24 and 25.) Photograph by the author.

means of a leaf-green apparatus, enters upon a parasitic life, the leaf-green mechanism falls into disusè and may suffer reduction or may even entirely disappear. Hence we find in confirmed parasites of this group more or less of a bleaching of the parasite. They are often, therefore, yellowish in color and the leaves are reduced to mere scales or are wanting entirely.

Special kinds of sucker roots are frequently produced which penetrate the host plant tissues and absorb the manufactured food stuff. Some of these parasites have only half learned the parasitic habit and still retain some of their leaf-green apparatus. A typical parasite of this group of plants is the little mistletoe which occurs in great abundance on spruce trees in the northern part of the state. This little plant lives in the twigs and larger branches of the spruce and induces the formation of witches'-brooms. Badly diseased spruces therefore show a very irregular contour and may eventually be killed. The common dodder is another confirmed parasite. It starts life from the seed as a little leaf-green-possessing seedling but as soon as it comes into contact with a suitable host plant it abandons its leaf-green apparatus and coils itself closely around the support, sending in its sucker roots which also serve to fasten it to its support. The twining stem grows rapidly, bears very small and reduced leaves, and the whole plant is yellowish in color. The dodder is common on many wild swamp plants and is also occasionally abundant on clover where considerable damage may be caused. Of some interest are also those few forms which are root parasites. The toad flax, which is a common Minnesota plant, has partially learned this habit of parasitism. Here the plant is apparently a typical leaf-green herb, but its roots may be found penetrating the roots of other plants and there obtaining nourishment. Parasitism is here an auxiliary process. Other Minnesota plants, members of the broom-rape family, have completely learned the root parasite habit and have consequently lost all of their leaf-green. The stems are usually small, reaching but a short distance above the ground, and bear a few colorless reduced leaves and spikes of flowers. Several species of cancer roots and broom rapes occur in this state. They are not abundant, however, and produce no far-reaching or destructive disease in plants. (Figs. 24, 25, 101.)

Chapter XIV.

Economics. Prevention and Cure.

The economic importance of plant diseases. A few well-known figures will illustrate the great economic importance of the fungus diseases of plants. These include only estimates of epidemics. From the nature of the case it is impossible to estimate the smaller losses due to sporadic diseases which have probably caused more total loss than the great epidemics. In the kingdom of Prussia the year 1891 was particularly favorable for the rust disease of cereals. In that year the loss of wheat, rye, oats and barley from rust has been estimated at over one hundred millions of dollars. In Australia in 1890-1891 the loss by wheat rust was estimated at twelve millions. In California the grape disease from 1884-1886 caused an estimated loss of twenty million dollars. A single English tomato house has in one season suffered a loss of a thousand dollars by fungus disease. An agricultural expert has estimated the yearly loss in the United States due to loose smut of oats, before successful treatment was discovered and introduced, at eighteen million dollars. One of the most striking illustrations of the enormous losses due to fungus diseases is found in the history of the coffee leaf-rust disease which has played such havoc in the eastern hemisphere. It has practically exterminated the coffee plantations of Ceylon where the loss from about 1870 to 1886 was about five million dollars yearly and the total loss in those years from sixty to seventy-five million. India's annual loss from wheat rust has been estimated at from two to ten million. In the United States loss by wheat rust for 1891 has been placed at sixty-seven millions of dollars. In our own state Dr. Lugger, the late state entomologist, estimated the loss from wheat rust in Minnesota in 1888 as far in excess of the total loss by ravages of all insects including even the dreaded grasshopper. One can realize the enormous loss from this source in an estimate by officials of the United States department of agriculture, which placed the loss in the whole United States in 1882 on all agricultural products due to insects' ravages at 200 to 300 millions of dollars.

No estimates are readily available for losses on smaller epidemics nor on local ravages of fungus pests where conditions have favored a restricted epidemic. It is well known, however, that the potato disease in certain wet seasons causes enormous losses, particularly in eastern states and in Europe. In the few years following its introduction in about 1845 the losses amounted in many places to a complete destruction of the potato crop. Garden truck and orchards yearly suffer in almost all sections of the country. In many cases the losses are not deemed important, but though slight, amount to great sums in the aggregate. We hear of rust-free seasons for grains but no year is absolutely free and such small unnoticed loss has come to be accepted as an inevitable tax upon grain. It is against such losses as well as against the great loss by epidemics that attention will have to be directed. It must be clear from the above figures that the fight against fungus diseases is not a mere illusion entertained by a few enthusiastic specialists but is a most important and vital economic feature of all future branches of plant industries.

Prevention and cure. If there is one thing which will contribute more than any other to the relief of agriculturalists and horticulturalists from the losses incurred by the disease of plants it is knowledge. No one would hesitate to affirm that more extensive knowledge of the real nature of the diseases of man has lessened enormously the destructive attacks of those diseases. The force of this analogy is comprehended by few in its application to plant diseases. The practical plant grower wants to know only the cures,—sprays or whatever they may be,—he often does not care to study or learn the details of the disease-cause and its mode of action. But it is only with this knowledge that an intelligent application of remedial measures is possible. Probably no two occurrences of a plant disease have exactly similar conditions. The generalities which underlie them are to be found only in a knowledge of the action of the disease-causing organism. The details of treatment must necessarily differ and the judgment of the operator is always important. The value of that judgment is measured only by his knowledge. The more he knows of the causes and action of the disease the more intelligently and the more successfully will he be able to combat it. The various remedial measures—solutions, formulas, sprays and spray machinery—are all important, indispensable in fact--but they are not the ultimate object; they are the means by which relief is secured and the observant operator who knows what he is doing and why he is doing it has many more chances of success than he who is following book rule. I shall deem myself eminently successful in this work if I shall be able to contribute to such a spread of useful knowledge as shall fortify the efforts of all plant growers in the state. The solutions of these problems lie largely—I might almost say entirely—with the men who are the operators. The object of this work is to help him to an understanding which will give reason and intelligence to his efforts. It is obvious, of course, that an objection will immediately be raised, viz.: the farmer cannot hope to master all of the details of the life-stories of disease-causing organisms—his time is occupied with the practical problems and operations of plant growing. And this objection has much of truth in it. Nevertheless, success in all lines is becoming more a matter of knowledge. What the farmer can do and must do is to know more about the plants with which he has to deal—and these include not only his wheat and apples but the enemies of these plants as well. He must pick out from the results of those who have worked out and described the details of disease such facts as are of use to him and apply those results.

Successful agriculture is no longer the simple method it was of old, i. e., the planting of the seeds and the trusting to providence for favorable conditions of growth and produce. It is the scientific control of those conditions. The farmer alone stands helpless. The plant pathologist is an absolute necessity in the agriculture of today. His results must increase the efficiency of the farmers' efforts and they will if they are intelligently applied. In this specialization the plant pathologist is by no means independent. He is just as dependent upon the coöperation of the farmer as the latter is upon him. In other words, both branches of this new agricultural machinery must work together in order to achieve successful results. The facts of action and nature of diseases are useless unless applied and the application of such knowledge is in the province of the plant growers. In a word, the field of the plant pathologist is the enlargement and spread of knowledge of diseases and their causes and the field of the farmer is the application of such knowledge to the raising of plants. Both parts of the machinery of this new agriculture must work in harmony or both become useless. The successful plant grower must not only know what to do for certain diseases but why he does it, and the pathologist only can tell him why. On the other hand, the pathologist must look to the farmer for the solution of the countless problems of practical detail in the application of that knowledge.

Every one knows that the best way of fighting off disease in man—as in typhoid, tuberculosis, etc.—is to prevent infection, and just so with plant diseases. Prevention is the most successful treatment of disease. But how can a disease be prevented unless one knows the nature of the disease? It must not be supposed that no relief is possible from actual disease in plants for much can be done to furnish such relief but it needs no argument to convince a fair-minded grower of plants that prevention is more to be desired than methods of cure. It will therefore be convenient to consider the methods for combating disease under the two heads of prevention and cure.

Prevention. Since prevention is of such great importance it is obvious that a disease must be anticipated—headed off—before it can get a start. Now the first stage of a fungus disease lies in the infection. Infection, as has already been pointed out, may be effected by fungus spores, as in rusts and smuts, or by the established mycelium, as in timber and wood rots. The prevention of infection is therefore first to be considered.

Wound infection. A very common method of infection is through wounds in plants. Wounds open up passages through the outer layers of plant tissues which ordinarily resist the attack of fungus threads and through these passages the threads gain entrance. Plants have methods of covering such wounds with cork or callous tissues but these methods are slow and before they are completed the fungus has often established itself within. It is therefore obvious that wounds in shade trees and orchard trees must be covered with tar, creosote, or some other substance which will prevent infection. Many wounds are caused unnecessarily and special care should be exercised in preventing as far as possible wounding of plants. Frost, lightning and storms cause many unavoidable wounds and such should as far as possible be protected. Pruning is also a necessity and need not be injurious if the wounds are likewise protected. It has been recommended that the pruning of trees be done in winter or autumn. The tar coating is only efficient if partially absorbed by the wounded surface and this soaking-in occurs only when the tar is applied in autumn or winter. In spring or summer the tar does not enter so freely and may leave air spaces through which the fungus may enter. It should be realized, however, that the bark of trees is a necessary protection and cannot be carelessly injured without serious results. Insects cause wounds in plants and preventive methods may be employed to avoid these injuries, such as tar-ringing.

The importance of localities. Certain plants are known to suffer more from disease in one locality than they do in others. This may be due to various causes. The dampness may favor fungus growths, in which case dryer situations would be favorable. Potato-blight frequently prospers in such moist localities. Again, plants should not be placed in a region in which a dangerous disease is known to be prevalent, or at least until the disease has been eradicated. Such has been demonstrated in flax wilt. The disease germs often lurk in the soil for several years. In such plants as are subject to rusts, e. g., cereals, care must be exercised in the surroundings for such diseases may pass a part of their life on other plants and from these may infect the cereal. This is also true of apples and pears where the fungus also dwells on species of juniper. Other fungi may live on wild plants related to the crop plant. Of course it is not always practicable to select localities, but the importance of this feature should be kept in mind.

Rotation of crops and "pure cultures." The rotation of crops has several advantageous features. When wheat is rotated with clovers it is well known that the latter replenish the worn out soil by the action of the clover root tubercles. In other instances the rotation is effective in preventing disease; the latter can usually not infect the alternate crop and thus may be eradicated before a new crop is planted. This is often a very effectual method of preventing disease. By "pure cultures" are meant the great fields of one kind of plant, such as the common wheat fields of our own four neighboring states. The plants in such fields are all at about the same stage of development. When such a disease as a rust obtains a start in these fields the winds rapidly spread the spores and no obstructions are raised to the wholesale scattering. The result is a veritable epidemic. As long as large, unprotected fields of this sort are planted just so long will there be a tendency toward epidemics of rusts. The planting of such pure cultures therefore carries with it undoubted risks. This is also true in forest culture where mixed forests have in this respect advantages over pure unmixed ones.

Fertilizers. The manuring of soils may under some conditions bring dangerous diseases. In some smuts the spores may continue to live and grow for a long time in the nutrition furnished by the manure and may be introduced into the field by this means. Old manure is preferable to fresh manure, since in the former fungi may have died out or become enfeebled. The fresh manure may contain the more vigorous fungi. Of course it must not be assumed that manuring of fields is therefore always injurious, but two points must be noted: first, the kind of manure used and its source; and second, the prevalence of such diseases as thrive in manure, e. g., certain smuts of grains. In other words, manuring *may* furnish favorable disease conditions. That it does so always or even commonly is not implied.

Selection of varieties. The selection of varieties is becoming more and more important for success in plant growing. The immediate objects of such selection may be various, e. g., increase in yield, quality of yield, hardiness, etc. It has already been pointed out that plants of a given species may vary in their susceptibility toward certain diseases. The cause of such immunity or predispositoin is not understood in many cases, but certain facts of immunity are undoubted. It is possible, therefore, to select varieties of plants which may show successful resistance toward prevalent diseases—in other words, disease-proof varieties. It must, of course, be understood that a variety may be immune from one disease and not from another totally different disease. In the selection of varieties this feature must be constantly kept in mind. Moreover, there are usually other features of importance in plant growing such as annual yield, quality, and so on, which are of great importance in the selection of varieties. The best variety is, of course, that which, under given conditions, will yield the best sum total results. It is sufficient here, however, to point out the fact that plant diseases are very imporant factors in the selection of plant varieties, and that such selection can assist the plant grower in the prevention of diseases.

Prevention of spread. The methods of prevention discussed above all deal with a prevention of infection. They are attempts to prohibit the beginnings of a disease. But diseases may sometimes obtain a start and the plant grower may still be able to use preventive methods. The latter now, however, are directed towards a prevention of the spreading of a certain disease—in other words—to prevent epidemics. Such preventive methods usually consist in the burning up of infected plant parts so that the fungus spores or mycelium will be destroyed. The spread of wood rots may be prevented in this way and the infected branches of the black knot of plums and cherries should always be removed and burned. It is well known that a large number of diseases live over winter in the fallen leaves or dead branches of trees or in the stubble of wheat or straw or refuse piles. It becomes apparent that cleanliness must be an important weapon in fighting plant diseases. The only successful method of removing such refuse, fallen leaves, etc., is by burning. In the case of field crops fall plowing may also be useful in addition to the burning process. It is not recommended that all straw stacks be immediately burned. It is necessary, however, for the grower of plants to know the disease he is combating, and if it is found to winter over on straw or refuse of any kind, measures should be taken to prevent the spread of the disease by destroying its winter abode or by rendering the spread of the fungus from these places impossible. A preventive method already mentioned may be recalled here. It relates to those diseases, as rusts, which live at different times on different host plants. The careful plant grower will see to it that those plants which harbor diseases dangerous to his crops are alienated. It is known, for instance, that rusts of apples live also on red cedars. If, therefore, an apple orchard is attacked by rust, the owner should see to it that the alternate hosts, i. e., some juniper trees, in the neighborhood are closely watched and removed if necessary. Here intelligent action and knowledge of the habits of the disease are indispensable.

State aid and coöperation. Most agriculturists are acquainted with the fact that combating methods against many diseases are often of no avail unless the coöperation of all farmers in the community is obtained. If a farmer refuses to kill off the grasshoppers on his land not only does the guilty one suffer, but his neighbors suffer as well. Or if one farmer suffers injurious weeds, such as mustards, to grow on his field all of his neighbors suffer. It is just so in the fight against fungus diseases. We have in our state a state entomologist, whose duty is to aid in the combating of insect diseases of plants and it will not be many years before the farmers of our state will demand a specialist in the fungus diseases whose duty shall be to assist farmers in combating those diseases and to direct movements against the epidemics of these pests. State aid is absolutely necessary in many cases and state laws are likewise a necessity to protect the intelligent farmer from the ignorance or laziness of his neighbors and to carry on experiments on the larger scales which individual agriculturists cannot attempt. Not only does our state support the fight against insects but our forests are under the protection of a forest warden, and very rightly so, and no one questions the advisability of such protection. In combating animal disease and the diseases of man, our state board of health is an absolute necessity. Now plant diseases require quarantine and sanitation methods just as do animal diseases, and the highest success of the agricultural interests of the state will not be attainable until combative methods are supported by state aid. There should be established, therefore, a corps of specialists whose duty it should be to become familiar with the diseases of plants in this state, to investigate those not yet understood, to disseminate the knowledge of the habits and treatment of such diseases and direct the operations against disease epidemics. In connection with such a department a museum of plant disease would be found to be an excellent aid, where exhibitions of plant products, with the important diseases and graphic descriptions and illustrations of them, would assist visiting agriculturists in recognizing and understanding the diseases of his crops. Such a museum would be of great value to the farmers of the state above all in the dissemination of knowledge.

Other preventive aids. Many of the treatments described below as curative are also used as preventives and are found in very many cases to be of great service. Where the beginnings of disease are not yet demonstrated but may be strongly suspected, or where the likelihood for the occurrence of certain diseases is strong, spraying is sometimes of use in prevention.

Methods of cure. Methods of cure cannot always be sharply distinguished from preventive methods. Indeed the same method may sometimes be used with both objects in view. Curative methods in general, however, are directed toward the destruction of the parasite which has already established itself upon its host plant or which threatens such an attack, by the presence of the spores. Two courses are open in such cases. The fungus, together with the infected plant parts, may often be removed by mechanical means, or chemical poisons may be used, as sprays, dusts, etc., to kill the parasite without injuring the host plant. The first of these methods has already been considered in its important aspect of prevention, for it is properly a method of prevention against the spread of disease. The accumulation of refuse should be prevented, diseased parts of trees and shrubs and perennial herbs cut off, and burned, and the spore-producing organs of disease-forming fungi cut off and destroyed. Particular care should be taken to destroy the plant parts in which certain diseases pass the winter. Prompt action, so necessary on the first appearance of a disease which is to be treated by these methods of cutting and burning, and cleanliness in farm management are two important essentials of success. The second method of cure, viz.: the poisoning of the fungus and its destruction by means of chemicals which do not, when used in the proper proportions, injure the host plant, is one to which much study has been given. A great many formulas and processes for various diseases have been described and many of these have proven successful. In general, there are three ways of application of these substances, spraying of solutions in water, dusting in powder forms, or immersion in solutions. A number of these formulas will be considered though special references will later be made in dealing with the specific diseases of plants.

Chapter XV.

Fungicides and Spraying Apparatus.

Fungicides. By fungicides are understood those substances which are capable of destroying or prohibiting the growth of the spores or mycelium of fungi. Chemical solutions have proved of great value when sprayed upon diseased plants. Such a spray must not only not injure the plant, but must at the same time destroy or hold in check the parasite. It becomes evident, therefore, that such sprays are of greatest benefit in combating fungus parasites which live on the surface of the host plant, i. e., the epiphytic fungi, such as the powdery mildews. These parasites can be reached directly by the spray without the necessity of penetrating the leaf. But the spray may be beneficial in still other ways. For instance, where the fungus lives inside of the host plant, and comes to the surface to form its spores. Potato-blight is such a form. The use of the spray consists in the destruction of the spores and the prevention of the spread in such cases. On the other hand, a very large number of parasitic fungi produce their spores at the surface of the host, but are not affected by sprays, e. g., rusts of grains. In some cases, however, the spray is beneficial against endophytic fungi and in these cases it is because of the destruction of the spores and the prevention of the latter from germination. The internal mycelium cannot be reached

FIG. 102.—A bucket pump. (The Deming Co.)

without injury to the host plant. Only the best-known and well-established formulae will be considered here. For detailed accounts of the action on specific diseases, the special portion of this work should be consulted, as also the experiment station bulletins of the Department of Agriculture. A great many of the bulletins of the Department of Agriculture and of the various Experiment Stations have been consulted in compiling these formulae. These may be referred to for further detail.

The value of spraying in agricultural and horticultural work has been proven to be considerable. It is no longer a chance but a certainty. The kind of spray and number of applications

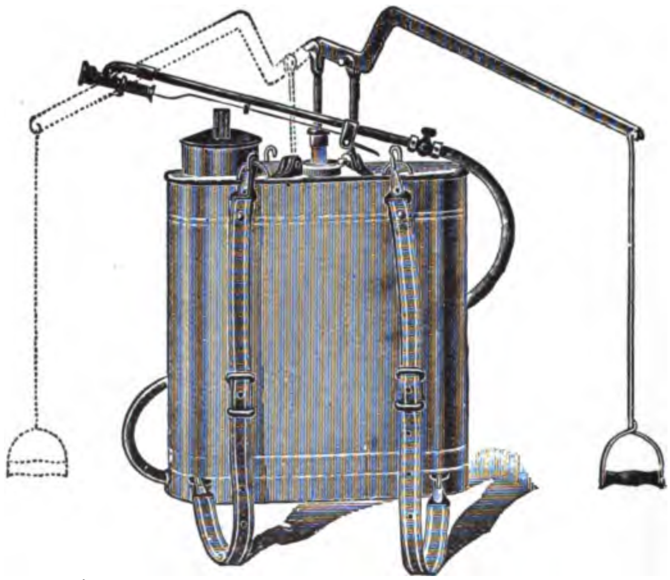


FIG. 103.—A knapsack pump. (The Goulds Mnfg. Co.)

must be left to the judgment of the operator. In general, bordeaux is of greatest use. Knowledge and intelligent judgment on the part of the agriculturalist are indispensable. He must be prompt in his action and, if possible, must extend his knowledge so as to forestall any disease and thus save time, labor and expense. It is usually best to spray too often than too seldom. Timely application may kill thousands of spores and prevent infection when a late application may be of no avail. Prevention is always to be desired. Applications must be thorough. Such a treatment usually requires but a little more attention than a careless one and must prove of much greater benefit. The matter of apparatus, as pumps, nozzles, etc., must also be left to the judgment and to the financial possibilities of the operator. Good apparatus is, however, indispensable. Whether or not this shall be expensive depends on his ingenuity and knowledge.

Effect of fungicides. The object of the application of fungicides is the destruction of the fungus pest. The substances are necessarily of a poisonous nature and the fear is often entertained by growers of plants that such applications may be injurious to the host plant or to the consumers of the crops or to domestic animals to which the crops or foliage may be fed. It has been found that the fungicides listed below, if sprayed on plants even with considerable frequency, can be made very effective and yet never injure in the least the plant foliage. It has even been claimed that copper solutions such as bordeaux are beneficial, but such an action is doubtful, or, at best, but very slight. The arsenic mixtures, such as Paris green, which are used to combat insects, likewise exercise no injurious effects upon the host plant when sprayed on in proper amounts. Copper salts in strong solutions are able to injure the roots of plants very seriously but it has been shown that by ordinary spraying absolutely no danger arises from this source, since but a very minute quantity of the salts penetrate to the roots. Sprays sometimes fall from trees onto grass beneath but experiments have proven that the quantity is not sufficient to be injurious to cattle, horses or sheep. This was demonstrated for arsenical insecticides. Still another question arises, viz., the effect of sprays on such crops as orchard crops where the fruits

Fig. 101.—A barrel pump. (The Deming Co.)

are eaten by man or used in the manufacture of wine. In the first place spraying at the time of maturity of the fruit is seldom if ever necessary. In the case of earlier sprays it has been shown that no danger exists to man from the eating of such fruits. It has been estimated that of grapes sprayed with bordeaux in the usual way an adult may eat "three hundred to five hundred pounds per day without ill effects of copper." Even in the case

FIG. 105.—A simple type of barrel pump used in the horticultural department of the Minnesota Agricultural Experiment Station. A return pipe keeps the liquid in the barrel stirred up. The fluids are strained through the brass strainer shown above when poured into the barrel. Photograph by R. S. MacIntosh.

of arsenic treatment of apples for insects it has been shown that "even though all of the poison sprayed upon the apples in making necessary treatments should remain there undisturbed a person would be obliged to eat at one meal eight to ten barrels of the fruit in order to consume enough arsenic to cause any injury." Fruits should not, however, be sprayed with arsenic within two weeks of picking. In the case of the use of corrosive sublimate for seed potatoes, however, the potatoes so treated contain sufficient poison to injure cattle, if fed to them, but in this case the potatoes are steeped in the solution. In general, therefore, the sprays, when properly applied, do not deposit upon the plants sufficient poison to injuriously affect man or his domestic animals.

SPRAYS.

Bordeaux mixture. "All things considered, it is believed that the best results will be obtained from the use of what is known as the fifty-gallon formula of this preparation. This contains: Water, fifty gallons; copper sulphate, six pounds; unslacked lime, four pounds. In a barrel or other suitable vessel place twenty-five gallons of water. Weigh out six pounds of copper sulphate, then tie the same in a piece of coarse gunny sack, and suspend it just beneath the surface of the water. By tying the bag to a stick laid across the top of the barrel no further attention will be required. In another vessel slack four pounds of lime, using care in order to obtain a smooth paste, free from grit and small lumps. To accomplish this it is best to place the lime in an ordinary water-pail and add only a small quantity of water at first, say a quart, or a quart and a half. When the lime begins to crack and crumble, and the water to disappear, add another quart or more, exercising care that the lime at no time gets too dry. Towards the last, considerable water will be required, but if added carefully and slowly, a perfectly smooth paste will be obtained, provided, of course, the lime is of good quality. When the lime is slacked, add sufficient water to the paste to bring the whole up to twenty-five gallons. When the copper sulphate is entirely dissolved and the lime is cool, pour the lime milk and the copper sulphate solution slowly together into a barrel holding fifty gallons. The milk of lime should be thoroughly stirred before pouring. The method described insures good mixing, but to complete this work the barrel of liquid should receive a final stirring, for at least three minutes, with a broad wooden paddle."

"It is now necessary to determine whether the mixture is perfect—that is, if it will be safe to apply to tender foliage. To accomplish this, two simple tests may be used. First insert the blade of a penknife in the mixture, allowing it to remain for at least one minute. If metallic copper forms on the blade, or, in other words, if the polished surface of the steel assumes the color of copperplate, the mixture is unsafe and more lime must be added. If, on the other hand, the blade of the knife remains unchanged, it is safe to conclude that the mixture is as perfect as it can be made. As an additional test, however, some of the mixture may be poured into an old plate or saucer, and while held between the eyes and the light, the breath should be gently blown upon the liquid for at least half a minute. If

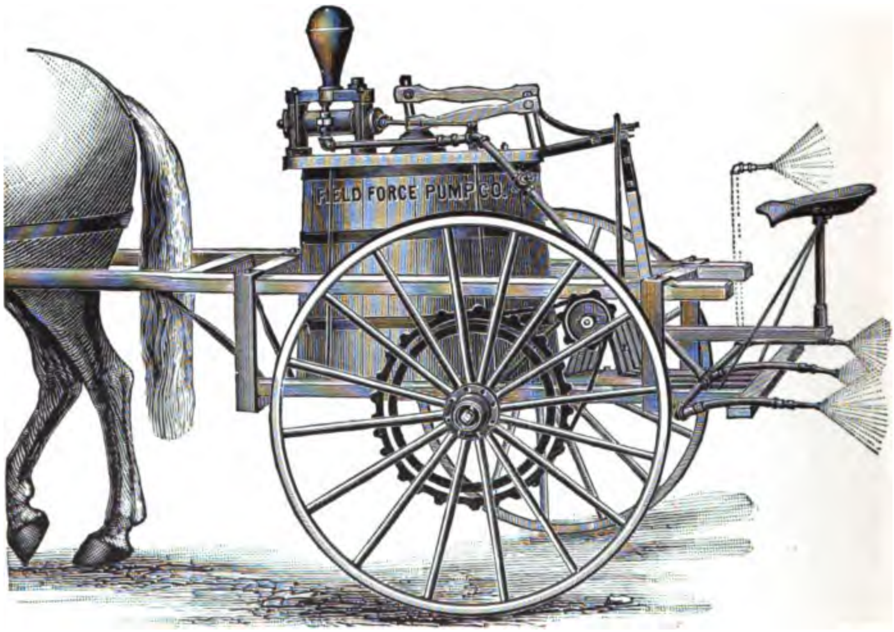


FIG. 106.—A gear-power force pump. (Victor Spraying Machine.)

the mixture is properly made, a thin pellicle, looking like oil on water, will begin to form on the surface of the liquid. If no pellicle forms more lime should be added." (B. T. Galloway.)

It is very important that good lime be used. Stock solutions of the lime and copper sulphate may be prepared, and may be kept several weeks without deteriorating. "To make stock solutions, dissolve fifty pounds of copper sulphate in fifty gallons of water. In another barrel slake fifty pounds of good stone lime and add enough water to make fifty gallons. These barrels should be tightly covered to prevent evaporation.

When it is desired to make a barrel of bordeaux mixture, stir the stock solution thoroughly, dip six gallons from each barrel and place in separate tubs. Now dilute each to twenty-five gallons and pour together as already described. The use of the lime is to combine with the copper and form a compound that will not burn the foliage. It also tends to make the fungicide adhere to the plant upon which it is sprayed and later dissolves slowly in rain and dew water to form solutions poisonous to the fungus. To test the mixture to see if all of the copper is combined with the lime, add a drop of potassium ferrocyanide solution. If it changes color upon coming into contact with the bordeaux mixture more lime should be added; if it does not

FIG. 107.—A barrel pump in action on farm of B. Hoyt, St. Anthony Park, Minn.

change color the combination is complete. In using bordeaux mixture upon peach or plum foliage it is better to use only four pounds of copper sulphate per barrel instead of six. This is the most common fungicide in use at the present time, but it must be remembered that it stains the foliage and the fruit and should therefore not be used when the fruit is approaching ripening season." Maryland Ex. Sta. Rep. 13: 67-68, 1900.

The proportion of lime and copper sulphate varies in different formulae of the bordeaux mixture; six pounds of each is frequently recommended and in weaker solutions six pounds of lime to four or three pounds of copper sulphate. The tests given above should be applied and the need of strong or weak solutions constantly kept in mind. Bordeaux can be very advantageously combined with insecticides so that the two applications can be made by one spraying. (For such combinations the reader is referred to the Eighth Annual Report of the State Entomologist of Minnesota, 1903.)

Dry bordeaux. (See under Powders.)

The following formulae are, in general, used only under special conditions, for instance, where the spotting of the foliage or other features of bordeaux are undesirable.

Bordeaux resin mixture.

"Resin	5 pounds.
Potash lime	1 pound.
Fish oil	1 pint.
Water	5 gallons."

[N. Y. (Geneva) Bull. No. 188, 1900.]

Add to bordeaux as directed below.

To prepare a stock resin solution proceed as follows:

"Place the oil and resin in the kettle, heating them until the resin is dissolved, then remove the kettle from the fire and allow the mass to cool slightly, after which the solution of lye is added slowly, the whole being stirred while adding the lye. After adding the lye the kettle should be again placed over the fire and the required amount of water added. The whole should be boiled until the solution will mix with cold water forming an amber-colored solution. Care should always be taken to have the resin and oil cool enough so that when the solution of lye or the water is added the whole mass will not boil over and catch fire.

"Dilute this stock resin solution with eight parts of water before adding to the bordeaux mixture, that is, in preparing a fifty-gallon barrel of the mixture, the copper sulphate and lime are diluted enough to make forty gallons after which two gallons of stock resin solution are diluted to ten gallons, then added to the bordeaux." [N. Y. Ex. Sta. (Geneva) Bull. No. 188—1900.]

This solution exceeds ordinary bordeaux in adhesive properties and has been highly recommended for asparagus rust.

Copper sulphate solutions. Copper sulphate is sometimes used without lime. The following formulae have been recommended:

"(A)	Copper sulphate	1 pound.
	Water	25 gallons.

For use before the buds open, the above solution is easy to prepare and to apply. *It should not be applied to any plant after the leaves burst, as it will burn the foliage.* Its action is equal to bordeaux mixture, but it does not seem as lasting.

Weak copper sulphate solutions.

(B)	Copper sulphate	1 pound.
	Water	250 gallons.
(C)	Copper sulphate	1 pound.
	Water	500 gallons."

"We have been much pleased with the results obtained from the above weak solutions. Formula (B) can be used without danger of injuring the foliage upon all except the most tender plants, but for use upon peach and other tender plants we prefer to rely upon still weaker solutions as given in formula (C)." [Mich. Bull. No. 121: 7—1895.]

The strong solution has also been used as a seed steep (10 to 12 hours) to prevent smut in oats and wheat. It is then followed by steeping the seed in a solution of lime (one pound in four to ten gallons of water) for about five minutes, which protects the grains from any injurious effects by the sulphate. [Oregon Bull. No. 75—1903].

Eau celeste (blue water.)

Copper sulphate	2 pounds.
Ammonia	1 quart.
Water	50 gallons.

Dissolve the copper sulphate in six or eight gallons of water, then add the ammonia and dilute to fifty or sixty gallons.

Ammoniacal copper carbonate.

"Copper carbonate	5 oz.
Ammonia (26° Beaumé)	3 pints.
Water	45 gallons.

Dissolve the copper carbonate in ammonia. This may be kept any length of time in a glass-stoppered bottle and can be diluted to the required strength. The solution loses strength on standing." [Mass. Bull. No. 80—1902.] Only the clear blue fluid should be used. This solution is recommended only when the staining of the foliage and fruits by bordeaux is objectionable, e. g., in fruits nearing maturity and on greenhouse plants. It has been recommended for fungus parasites as the powdery mildews which possess a conspicuous and superficial mycelium. A solution of copper carbonate (one pound to forty gallons of water) without ammonia has also been recommended for fruit rots.

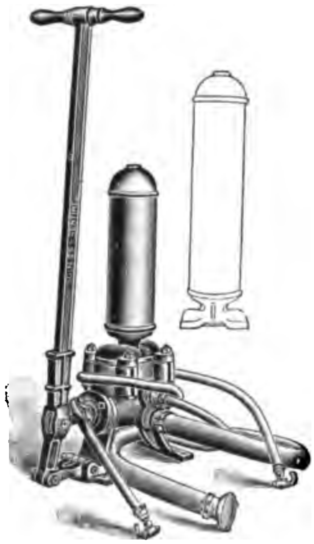


Fig. 108.—A powerful horizontal type of spray pump for orchard spraying. (Goulds Mnfg. Co.)

Copper acetate.

Copper acetate (dibasic acetate)	6 oz.
Water	50 gals.

First make a paste of the copper acetate, by adding water to it, then dilute to the required strengh. Use finely powdered acetate of copper, not the crystalline form. [Mass. Bull. No. 80—1902]. May be used as a substitute for the copper carbonate mixtures.

Saccharate of copper.

"Copper sulphate	4 pounds.
Lime	4 pounds.
Molasses	4 pints.
Water	25 gallons.

Slake four pounds of lime and dilute the same with water. Dissolve four pints of molasses in a gallon of water and mix with the lime. Stir thoroughly and let it stand a few hours. Dissolve four pounds copper sulphate in ten gallons of water and pour into it the lime-molasses solution while stirring briskly. Allow the mixture to settle. Draw off the clear greenish solution for use." [Mass. Bull. No. 80—1902.]

Potassium sulphide.

"Water	10 gallons.
Potassium sulphide	3 oz."

[Mass. Bull. No. 80—1902.]

Dissolve the potassium sulphide in a few quarts of hot water and add enough cold water to complete the solution. This has been recommended for checking powdery mildews and rust of chrysanthemums and in general for greenhouse use.

Potassium permanganate.

Potassium permanganate	1 part.
Soap	2 parts.
Water	100 parts.

Recommended in France for black rot and mildew of grape, etc. [Mass. Bull. No. 80—1902.] On account of expense can be profitably used only on greenhouse or garden plants. It has been recommended for rust diseases of hollyhocks and carnations.

Iron sulphate and sulphuric acid.

Water (hot)	100 parts.
Iron sulphate	As much as will dissolve.
Sulphuric acid	1 pint.

Prepare the solution just before using. Add the acid to the crystals and then pour on the water. Valuable for treatment of dormant grapevines affected with anthracnose, applications being made with sponge or brush. [Mass. Bull. No. 80—1902.] This solution should be made in wooden vessels. It has been recommended for disinfection of bark, ground, etc., where disease has previously existed. The solution will destroy the foliage so it must be used in late fall or early spring, or applied only to tree trunks.

STEEPS.

Formalin. (A) For oat smut and stinking smut of wheat.

Add one-half pound of formalin to thirty gallons of water and immerse the seed grain for two hours, then spread out and dry.

Or, sprinkle the grain with the formalin solution until thoroughly wet, shoveling over rapidly to distribute the moisture evenly, then place in a pile (covered with sacking) for two hours and finally spread out and dry as in the first method.

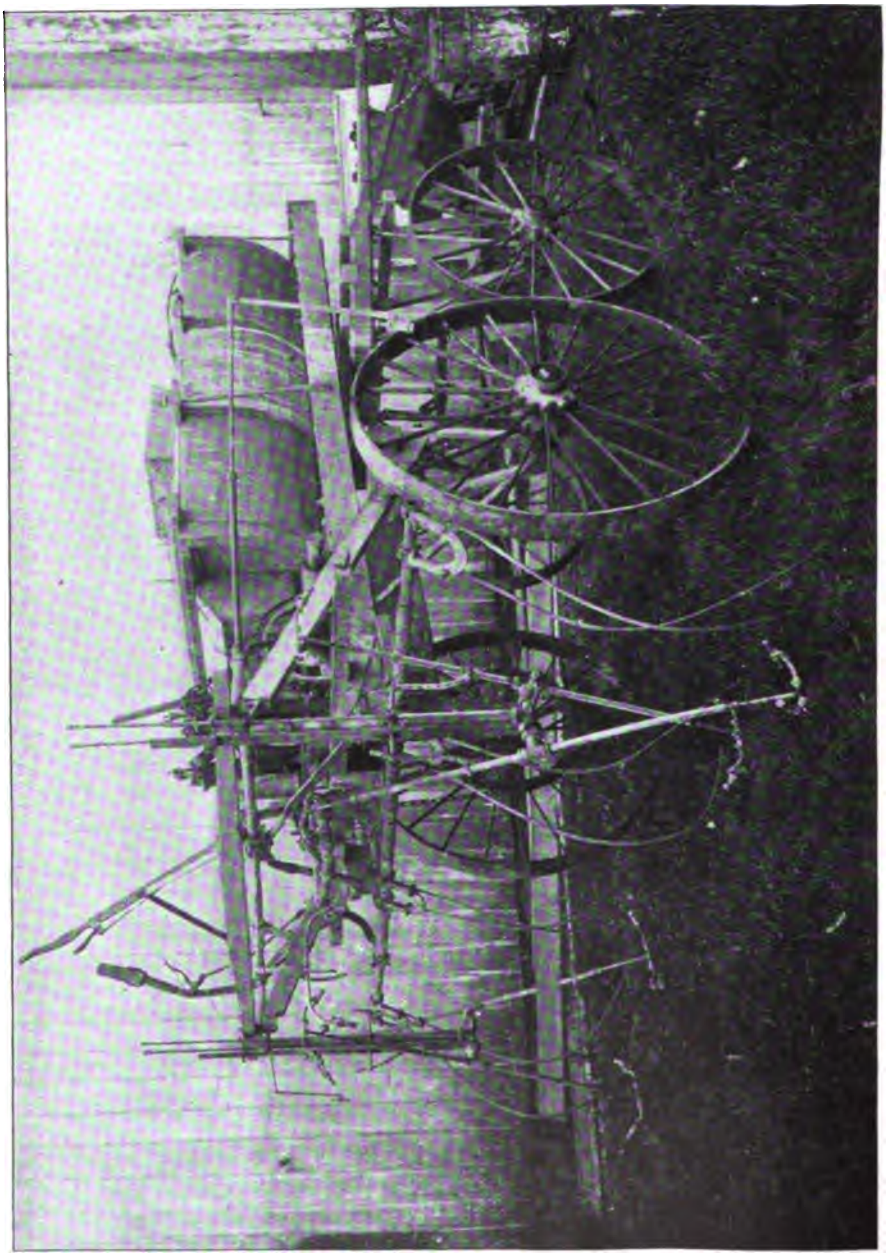


Fig. 109.—A complex type of spray pump used at the New York Experiment Station for spraying several rows of asparagus at once. After F. A. Sirrine.

Grain swollen in this manner requires the drill to be set somewhat wider to permit the usual amount of seed to be sown per acre. [Indiana Ex. Sta. Bull. 77—1899.]

This has been found a very successful, safe and cheap process for combating smut. Not all smuts are, however, prevented by this treatment. Corn smut and loose smut of wheat are not affected by it. It is undoubtedly, however, effective against the smuts mentioned above. This method has advantages over the hot-water method in the smaller degree of skill required in handling. The seed can be left in the solution an hour or more over the specified time without much injury, but the prescribed two hours are usually sufficient to kill the spores of the fungus. Oats require more of the solution than wheat since they do not give access through the hulls so readily. "If seed is kept long after treatment care must be taken that it does not heat, otherwise no harm or disadvantage will result. Professor Bolley, from some preliminary trials, estimates that when sown soon after treatment it will be necessary to set the drill for three and a half bushels of oats per acre if the equivalent of two and one-half bushels of the dry seed is desired, and with wheat must be set for one bushel and eighteen quarts per acre, if desired to sow one bushel and four quarts." [Indiana Ex. Sta. Bull. 77—1899.]

The same formalin solution can be used three or four times but the seed must be left longer in each successive treatment since the solution weakens. Formalin is not a violent poison, so that the handling of this solution or that for the potato scab is not at all dangerous for the operator. Special machines for thorough immersion and rapid handling with the formalin solution have recently been placed upon the market.

(B) For potato scab.

"The formalin treatment of seed potatoes practically frees the crop from scab, with slight expense and trouble.

"Add one-half pound of formalin to 15 gallons of water and immerse the seed tubers for not less than two hours. If the potatoes are not much sprouted a longer wetting is advantageous. After removing from the solution, cut and plant as usual." [Ind. Ex. Sta. Bull. 77—1899.]

FIG. 110.—The apparatus shown in Fig. 109 in action. After F. A. Sirrine.

Hot water method for smuts (Jensens.)

"Provide two large vessels, preferably holding at least twenty gallons. Two wash kettles, soap kettles, wash boilers, tubs, or even barrels, will do. One of the vessels should contain warm water, say at 110° to 120° F., and the other scalding water, at 132° to 133° F. The first is for the purpose of warming the seed preparatory to dipping it into the second. Unless this precaution is taken it will be difficult to keep the water in the second vessel at the proper temperature. A pail of cold water should be at hand, and it is also necessary to have a kettle filled with boiling water from which to add from time to time to keep the temperature right. Where kettles are used, a very small fire should be kept under the kettle of scalding water. The seed which is to be treated must be placed, half a bushel or more at a time, in a closed vessel that will allow free entrance and exit of water on all sides. For this purpose there can be used a bushel basket made of heavy wire inside of which is spread wire netting, say twelve meshes to the inch; or an iron frame can be made at a trifling cost, over which the wire netting can be stretched. This will allow the water to pass freely and yet prevent the passage of the seed. A sack made of loosely woven material, as gunny sack, can be used instead of the wire basket. A perforated tin vessel is in some respects preferable to any of the above. In treating stinking smut of wheat, the grain should first be thrown into a vessel filled with cold water; then, after stirring well, skim off the smutted grains that float on the top, and put the grain into the basket or other vessel for treatment with hot water. This skimming is entirely unnecessary with other grains and even with wheat, when only affected by the loose smut. Now dip the basket of seed in the first vessel containing water at 110° to 120° F.; after a moment lift it, and when the water has for the most part escaped, plunge it into the water again, repeating the operation several times. The object of the lifting and plunging, to which should be added a rotary motion, is to bring every grain in contact with the hot water. Less than a minute is required for this preparatory treatment, after which plunge the basket of seed into the second vessel, containing water at 132° to 133° F. If the thermometer indicates that the temperature of the water is falling, pour in hot water from kettle of boiling water until the right degree is maintained. If the temperature should rise higher than 133°, add a little cold water. In all cases the water should be well stirred whenever any of a different temperature is added. The basket of seed should very shortly after its immersion be lifted and drained, and then plunged and agitated in the manner described above. This operation should be repeated six or eight times during the immersion, which should be continued ten minutes. In this way every portion of the seed will be subjected to the action of the scalding water.

"After removing the grain from the scalding water, spread on a clean floor or piece of canvas to dry. The layer of grain should not be over three inches thick.

"The important precautions to be taken are as follows: (1) Maintain the proper temperature of the water (132° to 133° F.), in no case allowing it to rise higher than 135° F.; (2) see that the volume of scalding water is much greater (at least six or eight times) than that of the seed treated at any one time; (3) never fill the basket or sack containing the seed entirely full, but always leave room for the grain to move about freely; (4) leave the seed in the second vessel of water ten minutes." [Yearbook U. S. Dept. Ag., 1894.]

This method is known to be very effective if carefully followed in all details. If due care and precaution are not taken, not only will no good result but the effect of the treatment may even be harmful. In respect to the care necessary in handling, the formalin method is of greater advantage since less skill in the operation is required.

Corrosive sublimate.

Corrosive sublimate	2 oz.
Water	15 gallons.

Dissolve the corrosive sublimate in two gallons of hot water, then dilute to fifteen gallons, allowing the same to stand five or six hours, during which time thoroughly agitate the solution several times. Place the seed potatoes in a sack and immerse in the solution for one and a half hours. *Corrosive sublimate is very poisonous*, consequently care should be taken in handling it, and the treated potatoes should not be fed to stock. The solution should not be made in metallic vessels. [Mass. Bull. No. 80—1902.] This steep is very effectively used against potato scab.

POWDERS.

Sulphur. "In the dry powdered state this is known as flowers of sulphur. It may be sprinkled over plants in the dry state or it may be converted into fumes by heating. Care should be taken not to heat it to the burning point as it would thereby form a compound that would destroy green plants as well as fungi. It is usually sufficient to place it upon the hot pipes of the greenhouse." This has been recommended for powdery mildews and similar superficial parasites.

Sulphur and lime. Mix the flowers of sulphur with equal parts of powdered lime. This may be used in the same manner as the pure sulphur.

Dry bordeaux. "The new bordeaux powder can be made by any fruit grower or gardener with very little trouble, and at a very nominal expense. It can be made during the winter and stored in a dry place, where it will keep indefinitely.

"In order to make this new bordeaux powder one should first make a large quantity of air-slacked lime. This can be readily done by taking about seventy-five pounds of good quicklime, pounding up the lumps and spreading it over a large area, thus allowing it to air-slack readily. When completely air-slacked, this should then be sifted through a fine sieve; a 100-mesh sieve is the proper one to use. One can break up the lumps in this sieve so as to utilize the bulk of the air-slacked lime by rubbing it through the sieve by means of a block of wood. As this is a stock dust, to be used as a carrier in the place of water, it would be just as well to make up a much larger quantity, so as to have it on hand at a minute's notice. After it is thoroughly air-slacked and sifted, the powder should be kept in a dry place, such as the hay loft or the garret of the house.

"Dissolve four pounds of copper sulphate in two and one-half gallons of water by placing the copper sulphate in a coarse

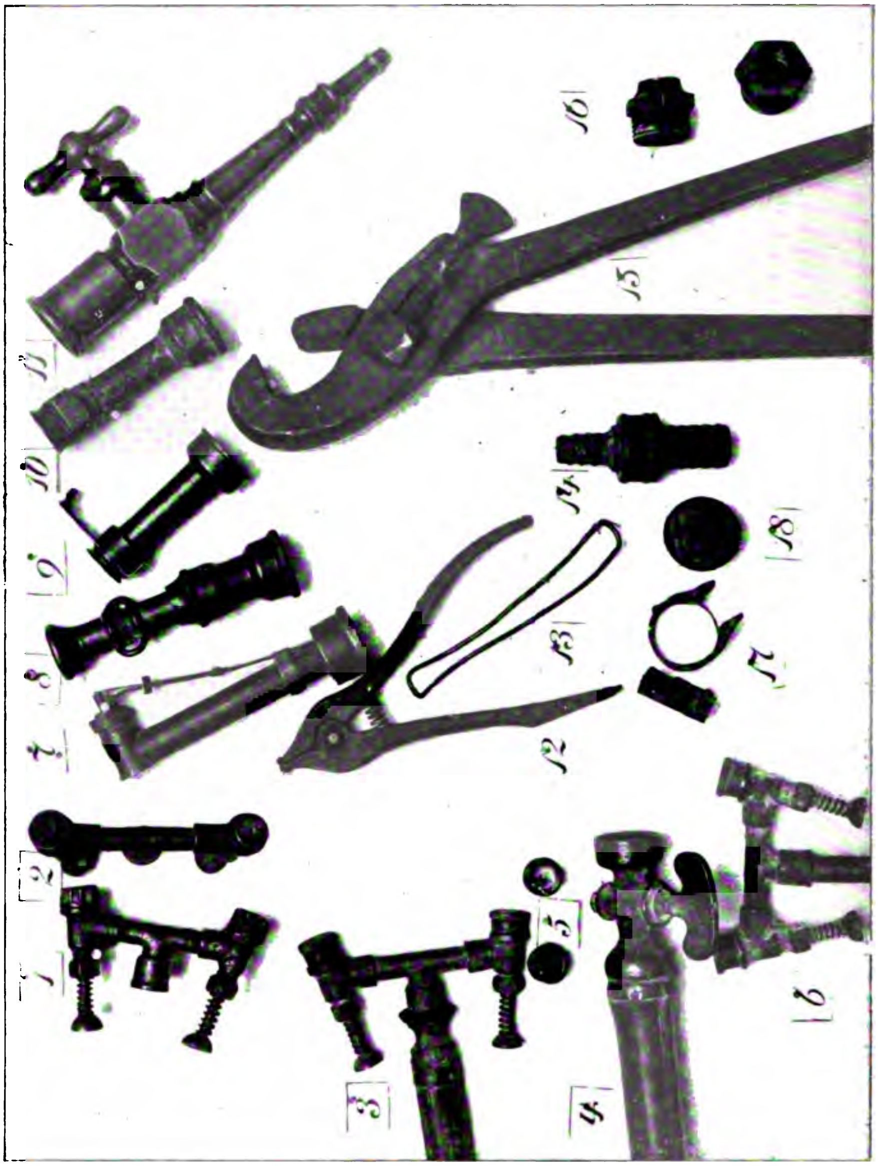


FIG. 111.—Various fixings, tools and appliances for spraying apparatus. 1. Double Vermorel nozzle (showing side). 2. Double Vermorel nozzle (showing end). 3. Double Vermorel nozzle, on bamboo extension. 4. Shut-off on bamboo. 5. Inner and outer views of reducing caps for Vermorels. 6. Vermorel nozzle attached to a brass extension rod. 7. A McGowen nozzle. 8. Gem nozzle. 9 and 10. Calla nozzle. 11. Fuller nozzle. 12. Pliers used for putting in place brass hose coupler No. 13. 14. Iron couplers to which the hose is attached when a coupling is desired. 15. A pair of pipe tongs, which are very serviceable for tightening hose couplings. 16. Two reducers, used for attaching either ⅜ or ¾ inch nozzle to hose or rod. 17. Two views of hose clamp. 18. Plug used when one attachment only of hose to pump is desired. After J. C. Blair.

bag and suspending it just below the surface of the water until dissolved. This is to be kept in a vessel by itself.

"Slack four pounds of good quicklime by sprinkling over it slowly two and one-half gallons of water in such a manner as to slack the lime to a fine powder and give as a result a milk of lime solution. This must now stand until cooled before using it.

"In a large shallow box one should then place sixty pounds of the sifted, air-slacked lime which has already been made as a stock carrier. In another vessel pour the milk of lime and the copper sulphate solution, both at the same time, and stir thoroughly until the whole is well mixed. Then turn this into a double flour sack and squeeze out most of the water.

"Empty this blue material just made into the sixty pounds of air-slacked lime, and at once work it up thoroughly with a hoe. If after this has been thoroughly mixed the material is too wet more of the lime dust should be added. This material must then immediately be rubbed through a comparatively coarse sieve while it is still somewhat damp. It should then be thoroughly mixed again by means of a stick and spread out in a dry place and allowed to dry. When this is perfectly dry it must be sifted through a fine sieve of a hundred meshes, in which case all lumps can be ground by means of a stick rubbed over the sieve. The resultant powder should have a uniformly blue color. In case it looks streaked or mottled, it should be stirred until all of the mixture is of a uniformly blue color. This powder, now completed, will keep indefinitely in a dry place, and contains copper sulphate in the same chemical combination as is found in the liquid bordeaux mixture. There is a large excess of powdered lime in this which is not in chemical combination with copper, but which is there simply as a carrying agent." [Country Gentleman, Aug. 13, 1903.]

SPRAYING APPARATUS.

The selection of spraying apparatus is a subject upon which no extensive advice can be offered here but which is best left entirely to the ingenuity of the plant grower. A few general principles as laid down by those who have paid considerable at-

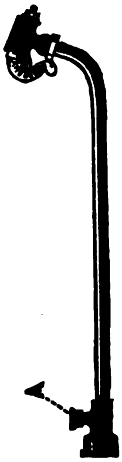


FIG. 112. A convenient nozzle for spraying the under side of leaves. (Deming Co.)

tention to this subject together with a few illustrations of common types of apparatus now in use will suffice. They are intended merely for suggestions which will lead to more careful study of the subject by those seriously interested in this matter and as a general description of modern methods of applying fungicides.

There are in general three kinds of pumps in common use. Bucket pumps are made for use with small amounts of the fluid in ordinary buckets. They are intended for small garden use and around the house but are not convenient for extensive sprayings. Knapsack pumps are suited for more extensive work and are used for low shrubs or potatoes or such crops not easily accessible to barrel-pump apparatus. The knapsack apparatus usually carries about three to five gallons of fluid and is strapped on the back of the operator in knapsack fashion. Each is furnished with a small pump and the operator works both the pump and the spray.

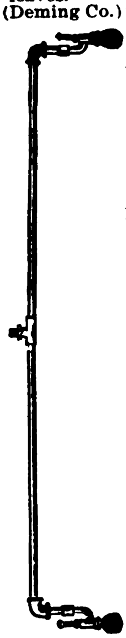


FIG. 113. Nozzle for spraying plants in rows (Goulds Mfg. Co.)

The barrel pumps are larger pumps intended for attachment to barrels and should be strong enough for spraying even fair-sized trees. They possess more general usefulness than either the knapsack or bucket pumps on account of the greater amount of fluid carried and the capacity for work. The barrel is best mounted on a farm wagon or truck and for orchards a platform for the operator is of great assistance. The following have been given by Mr. H. O. Gould of the Maryland Experiment Station as the points of greatest importance in a good pump.

"(1) The air-chamber should be sufficiently large to ensure a steady spray and be so placed on the pump that the latter will not be rendered top heavy thereby, or unduly cumbersome.

(2) Some means of keeping spraying mixture thoroughly stirred is essential, but it is not necessary that this be attached to the pump.

(3) The working parts should all be of brass and be so arranged that they can be examined without undue difficulty.

(4) The pump when mounted should not extend above the barrel more than is necessary.

(5) It is desirable to have the device for attaching to the barrel so arranged that the pump can readily be mounted or removed from the barrel.

(6) The different portions of the pump should be so constructed that they can be readily taken apart, especially those portions which enclose the valves.

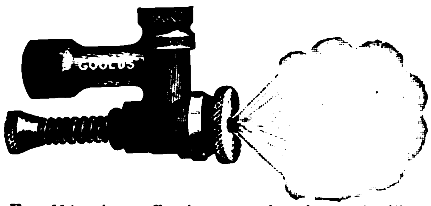


FIG. 114.—An effective nozzle for mist-like sprays. (Goulds Mnfg. Co.)

(7) All points for attachment of the hose should be cut with threads of standard size." (Maryland Ann. Rep. 13, 1899-1900.)

Horizontal pumps are also used for very extensive work in spraying. These pumps are in general more powerful than the ordinary barrel pump and can accomplish more work. They are usually of sufficient strength to operate several lines of hose.

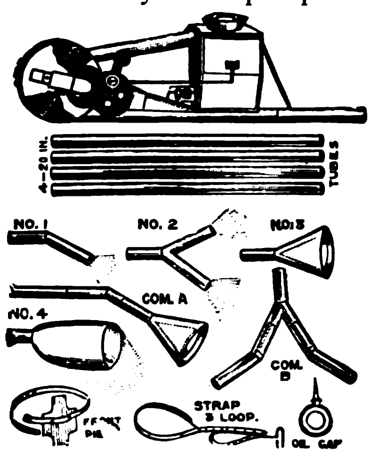


FIG. 115.—Powder gun with attachments. (Leggett.)

Various accessories are not only desirable but almost necessary to the successful use of spraying apparatus. A number of such accessories together with different kinds of nozzles are given in the accompanying figures.

Special spraying apparatus has been devised for various purposes. Asparagus spraying has been carried out successfully against rust by a very complicated machine which will spray several rows of asparagus at one time. (See N. Y. Ag. Ex. Sta. Bulletin 188.)

In barrel and all smaller pumps the power is hand power, in the larger machines wheel gears and chains transform the power from the wagon motion, while in still other cases, especially for spraying high shade trees, stationary engines have been used.

In the application of powders, apparatus is also necessary. Blow guns, pepper shakers and powder guns of various kinds are in use. Figure 115 shows a powder gun in very common use, together with various accessories and attachments.

Machines have recently been devised for the treatment of oats and other grains against smuts. Such machines aim to completely immerse the grains in the solution and to keep them agitated so that all parts of the grain surface are reached by the fungicide.

The above pretends to be only a general and elementary exposition of the general types of machinery in use at the present time. For further information and detail the reader is referred to the Minnesota State Entomologist's Report for 1904 and to other Agricultural Experiment Station literature.

PART II.—SPECIAL.

Chapter XVI.

Diseases of Timber and Shade Trees—Timber Rots.

Wound parasites and timber rots. Features of these subjects have been treated of in former chapters and little remains to be said here. These fungi include chiefly members of the palisade basidium-bearing groups, as pore and gill fungi. They are capable of attacking woody tissues, feeding upon them, and converting them into the crumbling, friable mass, known as punk. Many of these forms are entirely saprophytic and occur only on fallen logs, cut timbers or standing stumps and are simply timber rots. Others, however, are half saprophytes and are capable of attacking the living tissues of the stem or root. Such usually gain entrance through the bark, by means of wounds in the latter and, after a more or less short saprophytic life, penetrate outward to the living parts of the stem or roots and there attack the growing zone and inner bark. The ultimate result of this parasitic life is usually the death of the tree, after which the fungus continues to live on in a truly saprophytic manner. To the living forest trees, therefore, this class of fungi is a constant menace, and to the fallen trunks and broken trees almost a certain evil. The danger does not even stop here, for many of these forms attack stored timbers, and lumber, especially, if the latter is improperly kept. They even invade the standing and foundation timbers of houses. Some of the most serious problems in the construction of wooden houses lie in the prevention of subsequent rotting. The so-called dry rots are particularly harmful in this respect and are frequently found in their fruiting stages in damp cellars. Thorough seasoning is the only efficient remedy against such diseases. Application of creosote to the ends of joists and other timbers has also been recommended. Large timbers are often bored through lengthwise and ventilating holes bored at both ends at right angles to the long holes to allow of circulation of

Fig. 116.—Fruiting bodies of a gill fungus (probably Lentinus lepideus), on street railway ties. The mycelium of each of these is, of course, destroying the wood of the ties. Illustrates how prevalent the fungi may become on timbers placed under such conditions as those of ties. Photograph by Dr. F. Ramaley.

air to prevent dry rot. Other accessory cautions are also advisable and will be mentioned in the discussion of the true dry rot of timbers. Timbers in mines, tunnels and railroad ties suffer especially severe depredations from fungi of this class.

Prevention. As to the prevention of the ravages of wound parasites of this group, an avoidance of wounds is first of all advisable. Of course this is impossible in forest culture but in shade trees it is practicable. Where trees are pruned the cut surfaces should be carefully covered with creosote or some similar substance to prevent the entrance of spores and their germination. Fall and winter are preferable for this pruning since the absorption of the creosote is more complete at that time than in the spring or summer and the exclusion of the fungus threads is therefore more complete. In the second place the fruiting bodies of all disease-causing fungi should be removed as soon as discovered and burned immediately to destroy all of the spores. This is a prevention against the further spread of the disease. Badly infected trees should in most cases also be removed and thoroughly seasoned or used for firewood. Where the fungus is a root parasite traveling from root to root, as is known to be the case in a few forms, a trench is dug around the infected trees and all roots severed so as to prevent the spread to other trees. The isolated trees are carefully watched and the fruiting bodies destroyed as soon as they appear. Many valuable shade trees are annually lost as a direct or indirect result of timber diseases and such a loss can be almost entirely averted by careful attention as indicated above.

In forest culture dead trees should be immediatly cut and harvested. This saves the available timber and gives it no chance for deterioration which is sure to set in if the timber is left standing. Such treatment also prevents the formation of fungus fruiting bodies, which would spread disease to standing trees. There is an age at which trees may be said to become mature and at this age the natural forces of recuperation just balance the external destructive influences. This age varies in different trees. At this time the tree should be harvested, for in every succeeding year the chances of destruction by fungus pests increase and the tree loses in value.

The subject of timber rots has in recent years been made the object of special study by agents of the U. S. Department of Agriculture. The following abbreviated account is based largely on these reports. The importance of timber rots can be realized in the consideration of the ties, fence posts, telegraph and telephone poles, mine and ship timbers, paving blocks and bridge timber which are all subject to conditions extremely favorable for decay, in addition to all other building timbers which, though not under such unfavorable conditions, may still undergo serious rotting. Efforts have been made at different times for more than a hundred years to lengthen the "life" of such timbers by various kinds of treatments. From the nature of the case, long periods of time are necessary for carrying on experiments in this line and a great deal of progress has not yet been made. A number of satisfactory methods, however, are known at present, but on account of the cheapness of timber in this country have not until recently been introduced and are not even yet extensively employed.

In the first place seasoning of timber is an important factor. Green timber contains more moisture, which is directly favorable to the fungus growth and subsequent decay of the wood. It must also be noted that different kinds of timber require different lengths of time for seasoning. Beyond a certain point seasoning does no good but may work harm. Even wood of the same kind from different localities may require different treatments. Seasoning, therefore, is not only an important feature but is also one which is not altogether simple. Its value is beyond doubt, as has been shown by numerous experimental results. Another feature which needs mention at this point is the storage of the timbers. Close piling often results in closed moisture-laden chambers, which easily encourage the growth of fungi and the close contact of the wood admits of the rapid spread of the decay from piece to piece. The drainage of water is also seriously interfered with. Timbers, therefore, should be piled so as to admit of as complete aeration as possible, so that each piece shall have the opportunity of thorough drying out in proper season. The dangers of the storage of contaminated timbers with sound timber have already been mentioned.

The various methods of treatment of timber to prolong its usefulness consist entirely of impregnation processes. By these, chemical compounds in solution or emulsion are forced into the timbers or boiled in, so that they permeate the whole timber or at least the surface portions. These substances must be fungicides and antiseptic as well. They must prevent the germination or growth of the fungi or bacteria and thus prevent rotting. It is not always necessary that they penetrate to the center of the timber, since the surface portions, if properly impregnated, will keep out all decay-forming organisms. Of course such a substance which would penetrate to the very center would be of great advantage in the resistance towards the leaching-out process. It must be kept in mind that many common fungicides are soluble in water and hence would leach out under heavy rains. This is an important factor in the impregnation of timber. A substance must also be selected which can be injected with ease into woods. In the case of soluble salts, the easier the injection the easier the leaching out. However, in view of the cost this is an important factor. It will not be many years when the price of timber will be such as to compel the adoption of some methods of treatment for many timbers and such is already the condition in European countries. It is rapidly becoming imperative in certain classes of timber at present and particularly those mentioned above as most liable to decay, e. g., ties, poles, etc. At present, however, the cost of impregnation is one of the first factors for consideration and often of paramount interest.

The following substances have been used with considerable success. Creosote is sometimes forced hot into timbers placed in tanks from which the air has largely been removed. By this method a penetration of several inches may be effected. This process has been described as the most effective known, though on account of the considerable expense of the creosote is not generally applicable. A cheaper but less effective method is that of the use of zinc chloride. This has been more extensively used. Another process is known as the Hasselman treatment. In this the timbers are boiled in a solution of the sulphates of copper, iron and aluminum and a small amount of kainit for several hours. By this means the wood is thoroughly impregnated and the salts deposited, not only in the cavities, as with most other substances, but also in the walls of the cells. This process has not yet been thoroughly tested but has apparently many excellent features which may perhaps, in the future, make it a valuable treatment. Other processes, either new or imperfectly known, may merely be mentioned here. In one electricity is utilized and is passed through the timber in a solution of magnesium sulphate. Two things are claimed for this treatment: cheapness and a complete distribution of the impregnating salt. Another method is directed toward a saving of expense in the pure creosote method by using an emulsion of the oil in resin and a strong solution of soda lye. This has again been modified by the substitution of formalin in the place of the lye.

The following list of timber rots and timber-tree diseases is by no means complete for the wound parasites and timber rots of Minnesota; but it includes many common forms and above all is intended to give the reader an idea of the kind of organisms responsible for the rots of timbers and the deaths of timber trees. Other related forms will be readily recognized by their general similarities with these forms. The general preventive methods have been mentioned above. Only in special cases are additional measures given.

Stereum wood rot (*Stereum species*). On the dead trunks of many of our broad-leaved trees, can often be found numerous shelf-like fungi projecting in the manner of the pored shelves. In some species the upper surface is rough, hairy or silky, and the under surface is smooth. The latter does not contain pores as in the true pore-fungi. The shelves are usually of a leathery consistency and in dry weather often curl up, expanding again in wet weather. The spores are borne on typical basidia in palisades which cover the under surface. In some cases, instead of shelf-like bodies, prostrate, crust-like objects are formed which are sometimes turned back at the margins. In these cases the spores are found on the upper surface of the prostrate body. There are several species of this genus which are destructive parasites of our forest trees. Oaks are very often attacked. The fungus usually gains entrance through wounds and grows outward from that point. Fig. 117 shows an oak tree attacked by a Stereum. The progress of the myeclium upward in the stem is indicated by the size of the fruiting bodies, which are largest in the neighborhood of the wound and diminish gradually away from the wound.

FIG. 117.—A Stereum wound parasite (a species of Stereum). The fungus obtained entrance in the wound at the base of the tree (an oak), and, as shown by the fungus fruiting bodies, is gradually progressing upward. This tree died about a year after the photograph was taken. Original.

Oak attacked by Stereum hirsutum Fr. is known as white-piped or yellow-piped oak. The wood becomes brownish at first. Longitudinal white or yellow streaks then arise where, under the influence of the fungus mycelium, the wood loses its woody character. The whole block then gradually undergoes further decomposition. In a cross section of the wood these streaks are seen as whitish specks which have given the name of "fly wood" to the wood so attacked.

Partridge wood rot (*Stereum frustulosum Fr.*). This is a very characteristic rot of woods and is not uncommon in Minnesota. It attacks chiefly oak and may live either as a wound parasite or in a saprophytic manner on felled timber. The fruiting bodies are hard and crust-like, light-brown to greyish

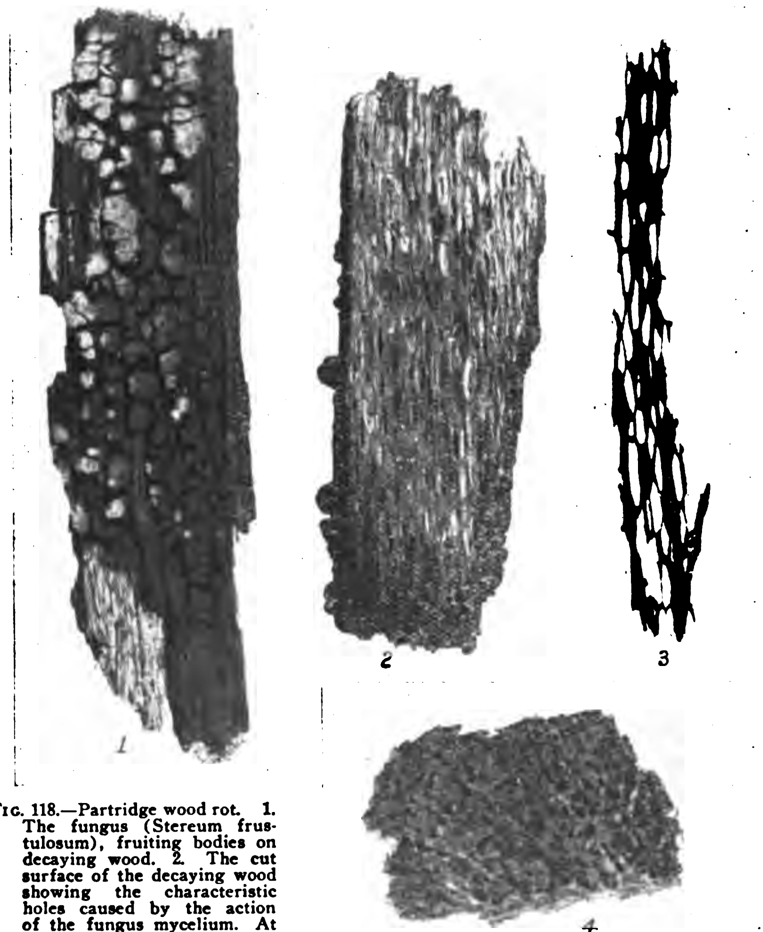


FIG. 118.—Partridge wood rot. 1. The fungus (Stereum frustulosum), fruiting bodies on decaying wood. 2. The cut surface of the decaying wood showing the characteristic holes caused by the action of the fungus mycelium. At the edge are seen a few fruiting bodies in section. 3. A thin strip of decayed wood showing holes as in 2. 4. Decayed wood seen from the end of the block. Original.

masses, and are found in dense clusters. They are usually polygonal, often five-sided, and grow from year to year, so that a section through the fruiting body exhibits a layered structure. On the upper side of the fruiting body, the spores are borne on basidia in a palisade layer similar to that of the Stereum wood rot. The fruiting bodies are very easily recognized, but the rotting wood is even more characteristic. In the early stages of rot there are seen whitish, circular or oval patches in the wood, which are more or less permeated with the mycelium of the fungus. In these patches the wood is quickly disintegrated while the wood dividing the patches remains very hard. In later stages the whitish patches become hollow by the complete destruction of the wood and a longitudinal section of such a timber would show a net-like arrangement of wood enclosing the decayed patches. Around these holes can be seen a lining of the whitish mycelium. Finally the walls between the holes also disintegrate and the entire timber crumbles.

The smothering fungus of seedlings (*Thelephora terrestris Ehrh. and T. laciniatum Pers.*). One often finds, particularly in damp situations at the bases of young saplings of hard maples and other trees, blackish, soft, leathery masses forming an irregular ring around the base of the stem just above the ground. At first sight they may seem shapeless and they are not at all conspicuous objects. A close examination shows them to be composed of numerous shelves, like the shelf fungi, and usually hemispherical in shape, jutting out from the main mass of the fungus. (T. terrestris.) Another species, Thelephora laciniatum, forms masses with irregular projections which vary from club- or tooth-shaped to fan-like in form and are usually combined into a rosette. If one examines the under surface of these shelves or clubs with a microscope one finds there numerous dark-colored spores with very rough outer walls. These spores are produced in fours on basidia which occur in palisades in the way usual for the palisade fungi.

These fungi are not truly parasitic but derive their nourishment from matter in the soil. They have nevertheless been reported as dangerous to forest culture on account of their behavior toward seedlings. The fruiting body starts as a shapeless mass lying on the ground and when it comes in contact with any upright support it grows upward a short distance and then produces the projections of the mature form described above. If this support happens to be a seedling the latter may become completely engulfed and destroyed. As this fungus is not very abundant in Minnesota it seems doubtful that any considerable damage results from it. The fungus fruiting bodies should be removed and destroyed. (Fig. 82.)

Club fungus rots (*Species of Clavaria*). There are many species of club fungi which occur on woods of various kinds in Minnesota. These fungi, however, seem to prefer those logs already in advanced stages of decay, or they may be found on the ground where wood debris is abundant. They less frequently occur on solid logs or timbers. They are not, therefore, usually counted in with the dangerous timber rots of our state. (Figs. 10, 81, 83.)

The coral fungus rot (*Hydnum coralloides Scop.*). This fungus is very abundant in the hard woods of our state. The fruiting bodies occur on the under sides of fallen logs, in hollow logs or less frequently on standing trees. They vary greatly in size. The smallest are seldom smaller than a man's hand, while the largest would fill an ordinary water pail. The fruiting body is pure white or very slightly tinged with yellow and is very much branched. From the branches arise small teeth about one-half inch in length, which are found chiefly on the under side of the branches and hang down. The whole mass is not unlike a delicate cluster of coral growths. These fruiting bodies are higly prized by mushroom eaters as choice delicacies. The mycelium, of course, lives in the wood where it causes decay of the wood tissues. The spore-bearing basidia line the whole surface of the teeth and the spores are white. The fungus is not important as a timber rot.

Closely related to the coral fungus are two other toothed fungi which are also found on wood under conditions similar to those of the coral fungus.

The bear's-head fungus differs chiefly in the possession of larger teeth and coarser texture.

The medusa-head fungus produces fruiting bodies more yellowish in color and the teeth are very much longer, often attaining a length of several inches. The teeth are usually densely packed together and the whole fruiting body presents a more nearly solid mass than either of the preceding forms. It is found on forest logs and stumps and specimens have been reported on building timbers in cellars. (Figs. 81, 84, 119.)

Dry rot or house fungus rot [*Merulius lacrymans* (*Wulf.*) *Schum.*]. This fungus is one of the most destructive of timber rots both on account of its action and its frequent occurrence. It is one of the simplest of the pore fungi, having only shallow pores on a flat prostrate fruiting body. It may almost be termed a domesticated fungus for it appears almost exclusively in the neighborhood of dwellings and is very seldom seen native in the woods. It has therefore been called by the Germans "hausschwamm" or house fungus. It is also popularly known as the weeping fungus. It attacks chiefly the soft woods of needle trees but may also destroy oak and other hard woods. This fungus is a typical saprophyte and derives its nourishment from the wood which it destroys. When the mycelium has permeated a wood tissue it leaves the latter as a spongy mass of brownish material, a common condition in timbers which are kept in moist places. Such decayed wood absorbs water readily and retains it so that the wood holds its original size and shape, but when dry the decayed portions shrink, causing cracks which form at right angles to each other,

FIG. 120.—The fruiting body of the dry-rot fungus (Merulius lacrymans). The under surface covered with shallow pores is shown in the photograph. Much reduced. Original.

FIG. 119.—The coral fungus (Hydnum coralloides), on the under surface of a log. Original.

commonly forming squares. Wood so affected is very friable and can be easily rubbed to a powder. Water passes easily through such decayed parts and further aids in the invasion of new portions and of other timbers in contact with it. In moist, dingy cellars, where the atmosphere is always more or less damp, and the timbers never have a chance to thoroughly dry out, the fungus develops a vigorous, superficial mycelium, which appears at first as a fine, thin, woolly coat of pure white threads. This soon grows into a dense sheet of white felt which can easily be peeled from the wood. In this sheet there develop later thick strands composed of threads which are packed with nutrient material. These strands are of great importance as they often grow to great lengths and may carry infection to timbers distantly located. Walls of stone or earth offer no obstacles to such progress, since the fungus strands are provided with a great amount of nutrient material. When they finally again enter the wood they establish a mycelium which supports itself upon the wood tissues.

The fungus is also remarkable on account of its ability to attack almost perfectly dry wood. It can absorb sufficient moisture from the air to keep it from drying up and may thus slowly destroy the wood. The excess of moisture absorbed by wood attacked by this mycelium often condenses out into drops on the infected parts and has given rise to the common name of "weeping pore fungus."

The fruiting bodies are flat and prostrate and never form shelves. At first they are white, then reddish and later turn dark yellow brown on account of the numerous spores produced on the surface. Wrinkles and folds form on the surface of the fruiting body and shallow pores are thus produced. The spores are dark yellow-brown and very small. It has been estimated that 65,000 millions could be crowded into a space of one cubic inch. The fruiting bodies are often five or six inches in diameter. In one end of the spore wall is a thin place through which the germ tube emerges when germination takes place. This pore is closed with a small plug and it has been claimed that this plug is removed only in the presence of alkaline material, as wood ashes, coal dust and humus materials. After the removal of the plug the germination can proceed as

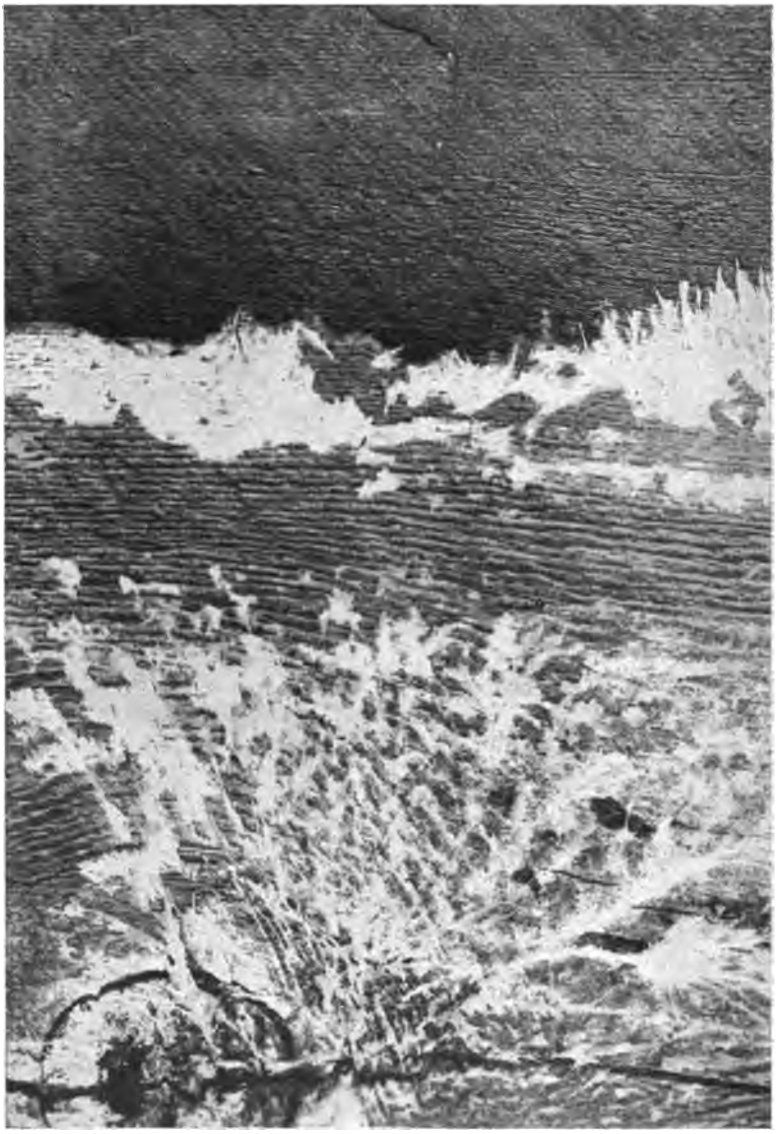


Fig. 121.—The dry-rot fungus (Merulius lacrymans). Shows the surface of a pine board which has been attacked by the dry-rot mycelium; it is not yet, however, completely converted to punk. The felted mycelium has been partially removed, showing the accentuated grain of the attacked portions. The mycelium has penetrated some distance beyond the white mycelial felt. Original.

under conditions normal to other spores. It has therefore been recommended that such substances as furnish alkaline materials be not brought unnecessarily into contact with structural timbers. The fruiting body has an agreeable odor when young but when old and in the stages of decay emits foul odors and injurious gases and an excessive amount of water may be exuded by the diseased timbers.

FIG. 122.—The dry-rot fungus (Merulius lacrymans). Later decay stages than that shown in Fig. 121. From the board shown on the left, the mycelial felt has been removed and the checked portion of the board is seen. This appearance is caused by the drawing of the tissues in drying after the decay has been well started. The removed mycelial felt is shown in Fig. 5. The board shown on the right is in a still further stage of decay and the wood under the mycelium is reduced to friable punk. Original.

As has already been stated, infection of timbers does not usually take place in the forest. It may occur where old timber is stored with fresh lumber or where old timber is used in the building of a new house. Workmen may carry spores on their clothing or tools and thus cause an infection of timbers. The evils of green lumber are here apparent, for infection takes place more readily than in well-seasoned material.

The preventive measures are indicated in the above account. The fruiting bodies should be destroyed as soon as they appear. Well-seasoned wood is preferable to green wood. The use of partially diseased wood is dangerous on account of the probable spread of the disease to other timbers as well as to the healthy parts of the diseased timber. Moist deadening material of all kinds should be avoided as also such substances which could create alkaline solutions in the presence of moisture. Ventilation of large timbers is sometimes effected by boring longitudinal holes through the center and transverse connecting holes near the ends. In general, the formation of stagnant, moisture-holding cavities should be avoided wherever possible. (See also Fig. 5.)

The false tinder-fungus rot[*Fomes igniarius* (*L.*) *Fr.*]. This is one of the true pore fungi and is a dangerous and common timber parasite. The plant gains entrance to the living stem through the bark, usually at a wound or other opening which may have been caused by such agencies as wind, hail, squirrels, birds or boring insects. When the fungus has gained entrance it attacks the growing portion of the stem, which is situated just beneath the bark and it may establish here an extensive mycelium. From this mycelium are later produced the shelf-like fruiting bodies. The latter are usually half globular when young, becoming hoof-shaped when older. The lower surface is lined with a layer of pores which are white when young, becoming dark yellow-brown with age. New layers are added in successive seasons. The upper surface of the fruiting body has usually a very hard coat. Internally it consists of a softer brownish felt-like material and numerous long tubes, which end at the lower surface. The hard skin of the upper surface of the fruiting body is usually cracked in older specimens. The wood attacked by this mycelium undergoes a white rot. It first becomes dark in color, then as the process of disintegration continues it becomes yellowish to white. The fungus threads attack the walls of the wood elements destroying their woody characters and leaving them softer and lighter in color. The chief danger of this fungus lies in the destructive parasitic habit for whole forests have been reported killed by it. It is not uncommon in this state, particularly on oaks.

Tinder-fungus rot [*Fomes fomentarius* (*L.*) *Fr.*]. This fungus is similar in its habits and characters to Fomes igniarius. Like the latter it is a true pore fungus. The pores on the lower surface are at first whitish, becoming grey-brown with age. New layers of pores are laid on each year as can be seen by the zoned character of the shelf. The upper surface of the fruiting body becomes covered with a very hard coat of greyish color. Internally the fruiting body consists of a felted, softer material above and a tinder mass, through which the long pores, built up in zones, extend to the openings on the lower surface. The age of the fungus can be approximately figured from the number of zones in the fruiting body. It may be of considerable age and of such a size as to be useful for tinder. Specimens have been observed which were almost a century old.

The tinder fungus is, like the false tinder-fungus, a dangerous parasite and gains entrance through the stem in a similar manner. The growing zone beneath the bark, chiefly upward and downward from the point of entrance, is killed and the wood beneath undergoes rotting. Wood attacked by the tinder fungus becomes yellowish. Radial patches of the white felted mycelium may often occur in such wood.

The fruiting bodies of the tinder fungus were formerly extensively used in Europe for tinder and also in the manufacture of caps, gloves, etc. The tinder has also the property of staunching blood-flow from cuts and has been used for that purpose.

The flattened pore-fungus rot [*Fomes applanatus* (*P.*) *Wallr.*]. This is a very common pore fungus on old stumps and fallen logs, less commonly found growing from wounds on living trees. The hard-crusted shelves vary greatly in size, some of the largest attaining a width of several feet. The shelf is woody and the upper surface greyish to brown. The latter is often covered with a fine dust of accessory spores of a dark reddish brown color. The upper surface is covered with a hard crust and the interior of the shelf is of a softer fibrous texture and dark brown in color. The pores are very small and cover the under surface, which is pure white, when newly formed.

The fruiting body lives from year to year, adding new growths of pores annually.

The sulphur-fungus rot [*Polyporus sulphureus* (*Bull.*) *Fr.*]. After a prolonged rainy season in spring or summer one often

FIG. 123.—The fruiting body of the flattened pore-fungus (Fomes applanatus); on a standing dead tree trunk. Original.

finds, particularly on oak trees, large masses of a tough, fleshy fungus, consisting of numerous shelves overlapping each other. The shelves are yellow to bright red above, becoming yellowish-white with age; the lower surface of each shelf, where the pores occur, is of a pure sulphur-yellow color from which the common name of the fungus is derived. In the young stages the fruiting bodies are somewhat soft, fleshy or cheesy and are often eaten by mushroom hunters. When older and especially under dryer conditions, they become tougher in consistency and paler in color. Very old masses are often found to be badly worm-eaten and much of the fruiting body is reduced to a powder. The fruiting bodies do not persist from one season to another but go to pieces each year. New crops are produced yearly.

FIG. 124.—Fruiting bodies of the sulphur pore fungus (*Polyporus sulphureus*); on a dead oak stump. Original.

The fungus is a common wound parasite. The wood, when attacked, becomes brownish red and dries out rapidly. Slits and cracks soon arise in the wood and these become filled with dense masses of the thickly felted mycelium. The wood in the last stages becomes brittle and the entire tree usually succumbs to the attack of the fungus.

Oaks in our state appear to suffer considerably from the sulphur fungus but other deciduous trees and some of the conifers may also be attacked.

The scaly pore-fungus rot [*Polyporus squamosus* (*Huds.*) *Fr.*]. This is a very common pore fungus which causes a white rot of timbers. It occurs abundantly in spring, forming large shelves, usually in groups. The fruiting bodies are soft and fleshy at first and their upper surface is conspicuously marked with dark brown or blackish scaly patches (squamae). It is attached, usually by a short stalk, which is almost always found on the edge of the fruiting body. As the latter gets older it loses its fleshiness and becomes harder, dying the same season, so that a new

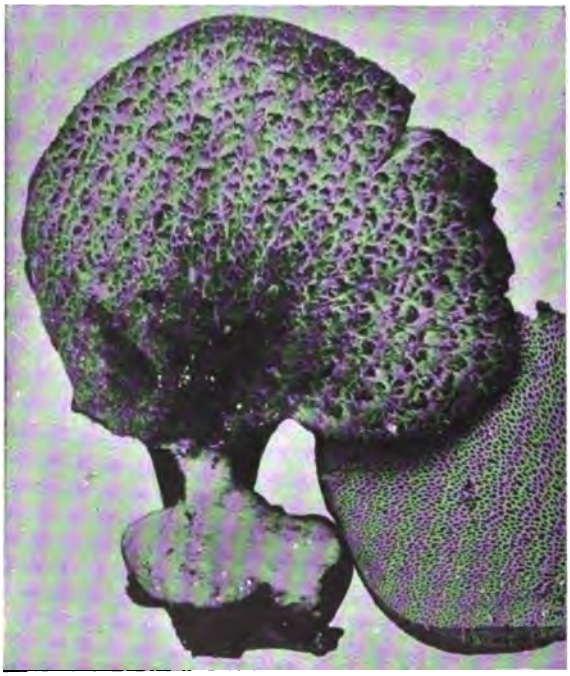


FIG. 125.—Fruiting body of the scaly pore fungus (Polyporus squamosus), seen from both surfaces. After Loyd.

crop of fruiting bodies must be formed again the following year. The pores are very large, somewhat shallow and angular and often run down some distance along the stalk. This fungus is usually found on dead logs or stumps but may also grow on dead parts of living trees.

The birch-fungus rot (*Polyporus betulinus Fr.*) This birch fungus is perhaps the most common of our pore fungi. In almost every clump of birches its fruiting bodies may be found.

The latter are annual and have a very characteristic and beautiful appearance. They are hemispherical in shape and the short stalk is always attached to the side. The upper surface is grey to light brown in color, is very smooth and covered by a thin skin. The pores on the under surface are small and rather deep and the layer in which they are found is easily separable from the rest of the fruiting bodies. The flesh of the fruiting body is pure white and somewhat spongy in texture. In old dried fruiting bodies the flesh is very commonly found to be honey-combed by the larvae of insects.

FIG. 126.—Fruiting body of the birch pore fungus (Polyporus betulinus), on a branch of a white birch. Original.

The parasitic relationships of this fungus with the birch trees have been established by several investigators and there is little doubt that the fungus causes the death of many birches in this state. The fruiting bodies are usually found on dead birches, often accompanied by other pore fungi. The mycelium in the living tree grows not only through the growing region of the stem and the inner bark but also attacks the wood. When the mycelium which may be growing for years has accumulated sufficient food material a fruiting body is formed. A new crop is produced every year, if conditions are favorable.

Trametes root-rot (*Trametes radiciperda Hartig.*). This root-inhabiting pore fungus has been very thoroughly investigated in Europe where it has done an enormous amount of damage to coniferous and broad-leaved forest trees. The mycelium of the fungus travels from root to root in the living trees and the disease is thereby rapidly spread. It later passes from the root into the stem, chiefly through the inner bark, and here attacks the wood. The affected trees soon die and the wood undergoes a red rot. The fruiting bodies are formed where they may distribute their spores into the air and are therefore usually above ground. They are irregular in shape varying according to their position; they are brown above, have white flesh, and the lower surface, upon which the pores are formed, is also white. The fungus is not infrequently found on timber in mines.

European botanists recommend for the prevention of the spread of this disease the isolation of the infected region by digging ditches deep enough to cut through all of the roots, thereby preventing the spread of the mycelium by way of the roots. In the isolated areas, fruiting bodies may develop either from the exposed roots or from the standing trunks. To prevent the spread of the disease by means of the spores so formed, the roots should again be covered with soil and the trunks and stumps burned. The formation of mature fruiting bodies should be prevented. The extent of the distribution of the fungus in Minnesota is as yet unknown.

Ring scale of pine [*Trametes pini* (*Brot.*) *Fr.*]. Ring scale is a very common parasite on pines both in Europe and in this country; it is also known on Douglass fir. The fungus gains entrance to the tree usually through wounds or broken limbs, particularly the older branches, in the heart-wood of which no protection-coat of resin has been formed. After it has gained entrance to the stem, the mycelium grows in longitudinal stripes above and below the points of entrance; in the same year's growth and in successive years it works from the interior to the exterior. In this way zones of the diseased regions are formed exteriorly (ring scale). The wood attacked by the ring scale undergoes a peculiar disintegration. There are formed in the decaying wood numerous small, isolated patches of the white mycelium of the fungus. These differ from the similar patches in the Trametes root-rot in the usual absence of black centers.

The fruiting body is brown and either forms a shelf or is diffused into a coating over the bark. It is woody and perennial, producing new pore areas successively for many years. The pore area is on the lower surface of the shelf forms and on the outer surface of the prostrate fruiting bodies.

FIG. 127.—Fruiting bodies of an undetermined pore fungus on a basswood log. Original.

The oak Dædalea [*Dædalea quercina* (*L.*) *Pers.*]. The cause of this disease is a pore fungus and is not uncommon on the dead trunks of oaks; it is one of the most common rots of oak railroad ties. The fruiting body is a thick shelf, woody in appearance but in consistency tough-corky. It is pale buff in color and the upper surface is smooth, though usually more or less zoned and sometimes ridged. The pore surface is often half-cone-shaped and the pores are elongated from the center toward the edge. The pores are more or less sinuous or wavy in outline and are especially elongated toward the point of attachment. The pore surface is of the same color as the top of the shelf.

The parchment pore-fungus rot (*Polystictus pergamenus Fr.*). This is an exceedingly abundant pore fungus found on various kinds of soft wood trees. It is very common on birch, where one frequently finds whole logs covered with the densely crowded fungus shelves. Occasionally one finds the fungus on the living trees. It has also been observed on living larch trees where it occurs in great abundance. The fruiting body is a thin, reflexed shelf which is very light tan colored above and covered with dense hairs. The pores are found on the lower surface and are shallow at the edge, increasing in depth toward the center. They are often of a purplish or violet tinge and the pore walls become, with age, so badly torn that the under surface of the shelf has the appearance of a toothed or hedgehog fungus. There is strong evidence that it has caused the death of numerous larch trees in Minnesota. (Fig. 36.)

Wood-rot of the creeping pore-fungus [*Polyporus vaporarius* (*P.*) *Fr.*]. This fungus is reported as very abundant in Europe and forms very similar to it are known in Minnesota. A description of this fungus will therefore not be out of place since it is not improbable that it exists in the state. The fungus attacks chiefly soft coniferous woods and is a wound parasite. It is found in the roots and on the stem and is a dangerous enemy to trees. The mycelium develops in cracks and under the bark, forming a dense, white felt and causing rapid decay of the wood. The fruiting bodies are white, flat, prostrate forms and do not produce shelves. The pores are small and cover the upper surface of the fruiting body and are very numerous. The mycelial felts and strands are not unlike those of dry rot and the disease is often confused with that of true dry rot. It is frequently found in the timbers of dwellings where it is a dangerous agent of decay very similar in its action to that of the dry rot fungus.

The zoned Polyporus rot [*Polystictus versicolor* (*L.*) *Fr.*]. This is one of our commonest of pore fungi, found chiefly on old stumps and decayed timbers. The shelves are thin and leathery and conspicuously zoned above. The zones are of different colors varying from light tans to very dark brown or black and are frequently velvety in appearance. The pores are on the under surface and are very small. They are white at the surface when fresh. The pore walls often become torn with age. The shelves vary somewhat in size; they are generally from two to three inches across and are aggregated together into very dense clusters in shingle fashion. They appear usually when the logs or branches upon which they form are in advanced stages of decay. The zoned pore fungus is perhaps not of great importance as a timber rot, though it is very frequent on railroad ties.

The pitch-stemmed pore-fungus rot (*Polyporus picipes Fr.*). This form of pore fungus is conspicuous in our woods on account of its large, thin fruiting bodies which are attached by a short black stem. It occurs on broad-leaved trees and is usually found on decaying logs or stumps. It has been reported as occurring on living trees but little is known of its relationship with the latter. Though not uncommon, especially in hard maple and basswood forests, it is not usually very abundant. The fruiting bodies are thin and tough, leathery when moist, becoming brittle when dry. They are usually broad-beaker-shaped to flattened when mature, are dark red-brown above and have a short central black stem. The fruiting bodies are not at all fleshy. The lower surface, which contains the very minute pores, is dirty yellow in color.

The hairy pore-fungus rot (*Polystictus hirsutus Fr.*). This is a very common shelf-pore form which occurs abundantly on dead sticks and limbs of trees. It has been reported also on living trees of hornbeam, alder, birch and oak but exact details of its relationships with these plants are wanting.

Chapter XVII.

Diseases of Timber and Shade Trees, Timber Rots (*Continued*).

The shoe-string fungus rot [*Agaricus* (*Armillaria*) *melleus Bahl.*]. This fungus is also known as the honey-colored mushroom. It is undoubtedly the most common of all of our fall mushrooms. Its edible fruiting bodies may be found at the base of almost any of our indigenous trees. They are very frequent at the base of dead stumps, but may also occur on the ground. They are usually found in dense clusters the lower of which are covered with the fallen spore-powder from the upper fruiting bodies. The whole fruiting body, except the gills, is more or less honey-colored—hence its common name. The stalk is usually swollen toward the base and carries near its summit a membranous remnant, the so-called annulus. The annulus is usually conspicuous especially in the younger stage, but is sometimes only slightly developed and occasionally entirely wanting. The mushroom cap is lined on the under surface with plates or gills which radiate out from the stem and bear the spores. These are white and may often be found as a fine white powder covering sticks and leaves under the fruiting bodies. The honey-colored upper surface of the latter is covered with fine, fibrillar scales of a darker color. These scales may also be found on the young stem. When old the whole fruiting body may become entirely smooth.

At the base of the stipe may usually be found a shoe-string-like strand of the mycelium from which the fruiting body originates. These strands which resemble small, leather shoe-strings in appearance run long distances through the earth and also occur just underneath the bark of trees where they are usually somewhat flattened. The mycelium of the honey mushroom may be parasitic on trees and is one of the most destructive of timber diseases. When the strand of a mycelium

FIG. 128.—Fruiting bodies of the honey-colored mushroom (Armillaria mellea), at the base of a tree. The ring on the fungus stem can be seen in the large one on the left and has just parted from the cap in the one on the extreme right. Original.

comes into contact with the living root of a tree it bores its way through the outer bark into the soft bark and the growing region; here it frays out into a fine felt-like expansion and attacks the living cells. The latter are killed and the fungus proceeds between bark and wood up to the stem and often for some distance up the latter. From the stem the mycelium may make its way down into healthy roots. The attack on the root system results in the death of the tree by cutting off the supply of crude materials. At the base of such a trunk one may later in the autumn find the fruiting bodies. The mycelium in the trunk and roots assumes the form of shoe-string strands and these may grow into a very well developed net-work just under the bark. The mycelium may continue to live on the timber saprophytically after the death of the tree. This fungus has often been reported as a timber-destroying fungus in mines. The honey-colored mushroom attacks the oaks and probably other broad-leaved trees in our state. In Europe it has been reported as particularly destructive to coniferous woods, as well as to broad-leaved trees.

When the disease becomes epidemic, no successful combative measures are known. All diseased trees and fruiting bodies should be burned and young trees should not be planted on infected areas. (See also Figs. 6, 7.)

The fatty Pholiota rot (*Pholiota adiposa Fr.*). On standing trees and particularly on felled timber of oaks and other broad-leaved trees, one often finds in fall clusters of a conspicuous, bright-yellow mushroom, which is responsible for a white rot of timbers. The fruiting bodies may be six inches or more in length; the cap is bright yellow with concentric, blackish spots. The latter are also found on the stem, which is about of equal diameter throughout its length and is tough-fleshy. The cap in moist weather is covered with a slimy gelatinous coat. On the under surface of the fruiting body are gills radiating from the stem as in the honey-colored mushroom. These gills are in this case, however, yellowish to grey in color and throw off ochre-brown spores, which often discolor the stem or other objects upon which they fall. The mycelium attacks the wood and forms bands of white felt which separate the wood up along the lines of the annual rings. Although not infrequently met with, this parasite is probably not very destructive to timbers in this state. It has been observed on living shade trees.

FIG. 129.—Fruiting bodies of the fatty Pholiota (Pholiota adiposa), in a wound of an oak tree trunk. Original.

The scurfy Pholiota rot *(Pholiota squarrosa Müll.)*. This is a close relative of the fatty Pholiota and forms fruiting bodies which resemble those of the latter. They are not so viscid in rainy weather and are persistently scurfy. It occurs on logs,

FIG. 130.—The velvet-stemmed Collybia (Collybia velutipes), on a decaying log. Original.

stumps and cut timber in a manner similar to the preceding species.

The velvet-stemmed Collybia rot (*Collybia velutipes Curt.*). This is an exceedingly abundant fungus especially on cut timber and standing stumps or fallen logs. The fruiting bodies are of the gill-fungus type and usually occur in clusters. The upper surface of the cap is yellowish to tawny and in wet weather is viscid. The gills are light yellow to tawny and produce white spores. The stem is covered with a velvet-like coat of a dark brown to blackish color, especially toward the base of the stem. The fruiting bodies are about one to three inches in length and

FIG. 131.—Fruiting bodies of the sapid Pleurotus (Pleurotus sapidus), on a standing yellow birch trunk. Original.

the cap about one to two inches across. They may be found at almost all seasons from early spring to late fall. This fungus causes one of the rots of timbers and is usually a saprophyte. It has been observed on living elm trees, however, and is possibly a wound-parasite.

The elm Pleurotus rot (*Pleurotus ulmarius Bull.*). This very common gill-fungus is usually found on elms and maple trees, growing from dead trunks or from wounds in the living trees.

A parasitic life has not been demonstrated for it, but its presence in the wood of living trees is known. It is frequently found on shade trees, especially on trunks, which have been pruned and not subsequently protected. The fruiting body is pure white and usually large, often attaining a length of six or seven inches and an equal cap width. It is usually fleshy and the stem is slightly removed from the center of the cap (eccentric). The spores are pure white. The fruiting bodies are frequently clustered. This is a popular edible fungus.

FIG. 132.—Fruiting bodies of the pine Lenzites (Lenzites abietina), common on soft woods. The gills are labyrinth-like, forming long, sinuous pores. This fungus may thus be said to be both a pore and gill fungus. Original.

Several other closely related forms are likewise saprophytes on timbers. Of these the oyster fungus (Pleurotus ostreatus) and the sapid fungus (Pleurotus sapidus) are best known and very common forms. They are all three prized as edible mushrooms. (See also frontispiece and Fig. 20.)

The pine Lenzites [*Lenzites abietina* (*Bull.*) *Fr.*]. This is an exceedingly common timber rot on soft woods. It occurs on railroad ties, fence rails and posts and on soft wood timbers wherever they are placed in conditions favorable to the fungus. The fruiting body is either a flat prostrate one or may become a low shelf. It is seldom large and does not usually exceed a few inches in diameter. The exposed surface is covered with gills which often radiate from the center in the prostrate forms. The fruiting bodies are tough-leathery to woody and dark-yellow- to red-brown in color. The top of the cap is somewhat hairy when young, becoming more or less smooth when old. The gills are rather thick.

The scaly Lentinus rot (*Lentinus lepideus Fr.*). This is a very familiar gill fungus which inhabits almost all kinds of soft needle-leaved tree timbers. It is, as far as is known at present, a saprophyte. It is very frequently met with on fence rails and posts, dead and down tamarack and other kinds of coniferous wood, as well as on wood partially submerged in the soil or water. The fruiting body is a stalked form with a central stem and is very tough-fleshy. The cap is two to three inches or more across and is at first pale yellow. Later, black scales develop on the upper surface. The flesh of the cap is white. The gills are slightly wavy, running down the stem for a short distance and the margins are irregularly toothed,—a character by which this fungus and its close relatives can readily be distinguished from other gill fungi. The gills are white, tinged with yellow. The stem is one inch or more in length and usually tapers toward the base, is hard, pale in color and has scales similar to those of the cap. The fruiting bodies sometimes grow in clusters.

The green cup-fungus rot [*Chlorosplenium aeruginosum (Oeder.) DeN.*]. On various kinds of woods, including balsam fir and birch, grows a fungus with a remarkable habit. The mycelium penetrates deeply, being especially prominent in the spring wood. It colors the wood a very beautiful, deep verdigris green, varying in shade in the different parts. It is more abundant in the summer wood, thus accentuating the grain. The rot works very slowly. Wood, so colored by artificial infection, is used in the arts in the manufacture of Tunbridge ware. It is also used for the extraction of the pigment which resides both in the mycelium and the adjacent walls. The fruiting body is a small stalked cup which at first sight looks much like a smooth-surfaced palisade fungus. The whole fruiting body seldom attains a length of more than three-eighths of an inch and a width of one-fourth inch. The sacs, with eight spores each, line its upper surface. The whole cup is colored similarly to the mycelium. This rot is particularly abundant in the northern part of the state, though on account of its slow growth and its preference for the smaller branches it does comparatively little damage.

Stem canker of balsam fir [*Dasyscypha resinaria* (*Cook and Phil.*) *Rehm.*]. The cause of this disease on the common balsam-fir is a very small cup fungus. It causes canker swellings on the stems and branches. These cankers usually partially and sometimes entirely encircle the stem. In the latter case the tree trunk is killed and the balsam dies. In the canker an abundance of resin is formed. The disease is very similar to the European larch canker, which forms on the common larch of Europe a similar resinous canker. The fungus fruiting cups are produced only on the cankers and are formed within a year of the death of the infected branch or tree. The fruiting bodies are thus produced during the saprophytic life of the fungus. The earlier life of the fungus is probably parasitic, though no infection experiments have been carried out to prove this point.

The fungus cups are very small—about one-fifth of an inch in length and of about the same width. They are provided with a very short stalk and are covered with very fine hairs. The disc or inside of the cup where the spore sacs are formed is orange-colored. The attacked portion of a branch shows a thickened inner bark and the wood rings are also increased in thickness. No remedial measures have been worked out.

Tar spot of maple [*Rhytisma acerinum* (*P.*) *Fr.*]. One frequently meets with black, tar-like spots on leaves of maples in late summer or early fall. These tar spots are caused by a fungus of the cup-fungus group and the spots are in the nature of a storage mass of threads which persist through the winter. In the early summer the spots are yellowish; they then produce small pear-shaped depressions, containing very small spores, which flow out of the depressions onto the surface of the spot. In the fall the spot turns black and then resembles a drop of tar. In this condition it rests over until spring, when the cup fruiting-bodies are produced. Several cups spring from each spot and each cup is lined, on its inner surface, with a palisade of sacs containing eight spores each. Between the sacs

Fig. 133.—Tar spots—on left, willow leaf tar spot (Rhytisma salicinum); on right maple leaf tar spots (Rhytisma acerina). Original.

are numerous sterile fungus threads. Spotted leaves should be collected in the fall and burned to prevent a spread of the disease in the following spring. The formation of the sac spores is thereby effectively prevented.

Tar spot of willow [*Rhytisma salicinum* (*P.*) *Fr.*]. This disease is very similar to that of the tar spot of maples. (See the latter.) The tar spots become black in August and September and may be formed in great numbers. Sometimes leaves are completely covered by the spots and are consequently seriously injured. When the disease threatens to become serious the spotted leaves should be collected and burned in fall.

Ring fungus or ring disease of cone-bearing trees (*Rhizina inflata Quel.*). This fungus is a member of the morel group of sac fungi, but might almost as well be included in the cup fungus group. The fruiting-body is a flattened, crust-like object of very dark brown or blackish color, fleshy in consistency and sticky in moist weather. It may attain a width of several inches and is usually irregular in shape. It is found at the base of trees or on old stumps and is commonly a saprophyte. It is attached to the soil or tree stump by numerous strands of the mycelium which run into the substratum for some distance. The sacs of the fruiting body are long cylinders and contain eight spores each. The mycelium may under favorable conditions become parasitic on the roots of trees. It grows around the root, killing the tissues, and may thus ultimately effect the death of the entire tree. It has not yet been reported from Minnesota but is known in Wisconsin and very probably exists in our state. The fruiting bodies should be destroyed.

The green mold rot of timber (*Species of Penicillium*). There seems to be some evidence that the common green molds, which are so conspicuous as saprophytes on starchy food materials and on cheese, are capable in themselves of causing rot of timbers. Such a mold thrives on the starchy material which is stored up in the medullary rays of woody tissues and from this point invades the woody fibres. The green mold very frequently accompanies other rots and may assist in the disintegration of the wood. It is doubtful, however, that it is ever in itself alone a very serious cause of the decay of timbers. The ordinary mass of green mold is composed of thousands of minute, brush-like clusters of strings of green spores which are exceedingly resistant and can retain their power of germination for a long time. The winter spores are formed in sacs, produced in closed capsules, which open only by irregular splitting or by the decay of the walls. These capsules are not conspicuous and are not met with frequently. For a more complete account of the life history of these fungi the reader is referred to Chapter IX. The growth of this mold is favored by close, moist conditions.

Slime flux of trees. Slimy, mucilaginous material can sometimes be found flowing from wounds in oak, apple, birch, elm, maple and other trees. The wound in itself may not be due to any fungus disease but may be caused by pruning, frost or sunscald, etc. In the slime which proceeds from the wound, however, one usually finds a simple form of the sac fungi (an Endomyces) closely related to the mold of the honey mushroom, and to the yeast fungi. The fungus mycelium is composed of branched threads, on which the simple four-spored sacs are found. There is considerable doubt that the Endomyces is the cause of the slime flux. In the flux one may also find one or more yeasts and other fungi, bacteria and plants belonging to the blue-green algae. Through the agency of the yeasts fermentation often sets in and the flux may then have an odor of beer. Slime-flux wounds often increase in size until large areas of bark die off and the whole tree may subsequently die. Shade and park trees are sometimes killed off in this manner. As the cause of the flux is not definitely known, methods of prevention are not understood. The usual precautions which are recommended for treatment when trees are pruned should be followed.

Witches'-broom of birch (*Species of Exoascus*). Cultivated birches are sometimes attacked by this fungus. The results are seen in the production of witches'-brooms, somewhat similar to those produced in cherries. The fungus is a similar one and produces its sacs on the twigs and leaves. The infected portions should be cut back and burned.

The Nectria of red-knot rot [*Nectria cinnabarina* (*Tode*) *Fr.*]. This fungus is not uncommon in the state. It is a wound parasite, gaining entrance to the inner bark of the tree by such wounds as are produced by hail, birds, squirrels, storms or pruning. Infection takes place from the mycelium which grows into the bark from the wound and establishes itself in the water-conducting tissues of the wood. By continued growth the mycelium permeates the wood and then the growing zone of the tree and the bark are destroyed. The fungus continues to live in the dead wood as a saprophyte and under such conditions produces its fruiting bodies. At first, small clusters of soft, bright red, button-like cushions arise. From the surface of these cushions are produced tiny summer spores, which are successively pinched off from upright threads on the surface of the cushion. These spores are capable of immediate germination and may spread the disease very rapidly. After the formation of these spores has gone on for some time, they decrease in number and finally cease to form. There then appear upon the same cushion small, red, pear-shaped to spherical protuberances, which contain a central cavity and a pore-like opening to the exterior. These are the sac-spore capsules. At the base of the cavity are found long, cylindrical sacs, each of which contains eight spores. The opening of the capsule is lined internally with hairs which clothe the whole canal, leading from the cavity to the exterior. The sac-spores and the sacs are extruded through this opening. The spores will germinate under favorable conditions and will again produce a mycelium in the wood.

The treatment of this disease is similar to that of wound parasites in general, i. e., burning of the infected twigs and wood and clearing up of felled wood to prevent the growth of wild spores.

Leaf blister of oak (*Species of Taphrina*). This fungus is a relative of the fungi of plum pockets and leaf curls and of the witches'-broom fungus of cherry and birch. The spores are produced in sacs which are arranged in a dense palisade on the under surface of the leaf. The leaf is usually distorted in a blister-like fashion, whence the common name of the disease. The red oak has been found in this state attacked by this fungus, though not to any serious extent. The removal and burning of the affected parts would be advisable to prevent a severe recurrence of the disease.

Willow blight or powdery mildew [*Uncinula salicis* (*D. C.*) *Wint.*]. The blight of willows is an exceedingly common disease not only of the willows, but also of the poplars, cottonwoods and birches. The mycelium is usually very abundant and conspicuous in late summer and forms a thick, whitish covering over the leaf. On this arise the spore-sac capsules as tiny, black, pinhead-like bodies, which often occur in great numbers. The mycelium may cover both sides of the leaf and may sometimes be found on almost every leaf of the affected tree, though it is usually most abundant or entirely confined to the leaves of the lower branches. All species of willow are attacked.

FIG. 134.—Powdery mildew of willow leaf (Uncinula salicis). The minute black spots are the spore-sac-capsules and under these can be seen the whitish mycelial coat of threads. Original.

The sac-capsules are large compared with most other Minnesota powdery mildews. They are black in color and have a ring of numerous, colorless, thread-appendages, each of which terminates in a single-pointed hook, in a manner similar to that of the vine powdery mildew. Each capsule contains at least several sacs, in each of which are found eight spores. The summer spores occur in the manner usual for the powdery mildews, producing a powdery, starchy, dust-like coating.

Though a very common fungus, it does not very often occur in sufficient amount or at the proper season to cause very extensive damage and usually no preventive methods are deemed necessary. The ordinary sprays for the fungi with superficial mycelia would probably prove effective against this disease. (See also Fig. 52.)

Powdery mildew of elms (*Uncinula macrospora Peck*). This mildew is not uncommon, though it cannot be said to be abundant throughout the state. It attacks only the young trees or saplings of elms. On an affected tree the fungus is usually exceedingly abundant, covering many or most of the leaves with a very conspicuous mildew. The latter attacks the leaves and occurs on the upper surface. White, circular patches of the superficial mycelium are formed and these may combine with neighboring ones to cover the entire leaf. These patches are conspicuously white and dense and have a somewhat starchy appearance. The winter-spore fruiting bodies are spore-sac-capsules and

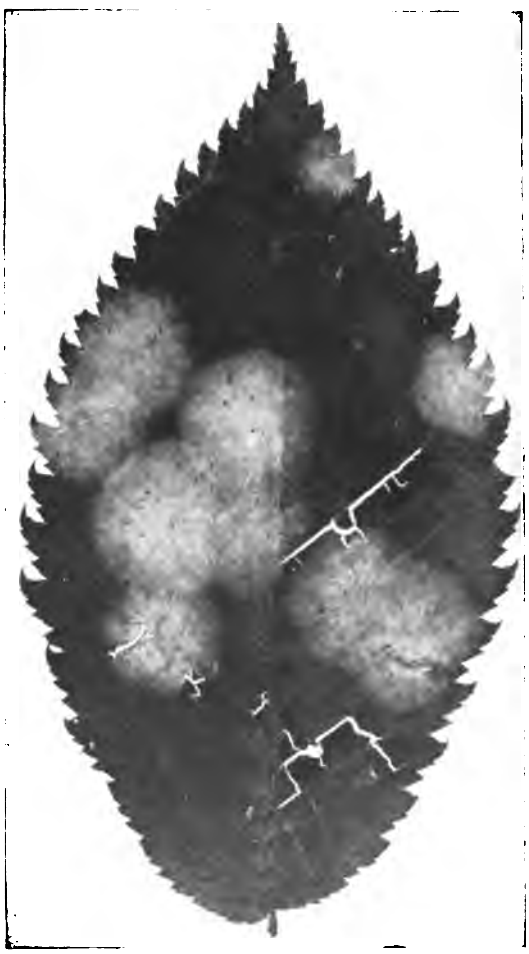


Fig. 135.—Powdery mildew of elms (Uncinula macrospora), on an elm leaf. The exceedingly minute black spots are sac-capsules of the fungus. The fungus mycelial threads form in spots which are very conspicuous. Original.

appear on the mycelium as very minute dots which are at first yellowish and finally become black. Each capsule, when seen under the microscope, is surrounded by a dense circle of thread appendages which are hooked at the end in a manner similar to those of the powdery mildew of willows. Each capsule contains numerous sacs and each sac contains two very large spores. It is very possible that this fungus causes a considerable amount of damage to young elms in forests. The summer spores are formed earlier and cause the starchy appearance of the young mycelium. The fungus does not seem to be widely enough distributed to be a serious menace at present though the vigor with which it attacks is an indication that it may at some future time become a dangerous pest.

Pine stem rust (*Species of Peridermium*). The branches and stems of pine trees are attacked by this fungus. The resulting disease is commonly known as pine knot. The infections are more or less localized and do not extend through the whole plant. The infected portion is stimulated to the production of boil-like swellings which may continue to grow for years. The swelling is often accompanied by an abundant formation of resin and turpentine which sometimes exudes from the canker. The fungus attacks the growing zone in the stem and may finally completely encircle the latter, but this usually happens only after a struggle lasting through several years. The conduction of the water through the stem is seriously interfered with and a drying up of the upper part of the tree may result.

The fungus causing this disease is a rust fungus and is a true parasite. The complete life histories of the American pine-stem rusts have not yet been unraveled; but from a comparison with better known European forms it seems very probable that our species pass a part of their life on another host, beside the pine. On these so-called alternate hosts the winter spores are to be looked for; these spores are therefore at present unknown. The swellings of the pine stem described above always bear the cluster cup spores. The latter are found in cluster cups or over flat areas on the surface of the canker. They are light yellow or yellowish-orange in color. When the cluster cups open in the spring, large areas on the surface of the canker are covered with a bright yellow coat of spores which are later uncovered by the splitting off of scales of the bark. Jack pine in Minnesota is very commonly affected and the white and red pines are also though not so frequently attacked. Scotch pines in nurseries and experimental forests are sometimes very seriously affected.

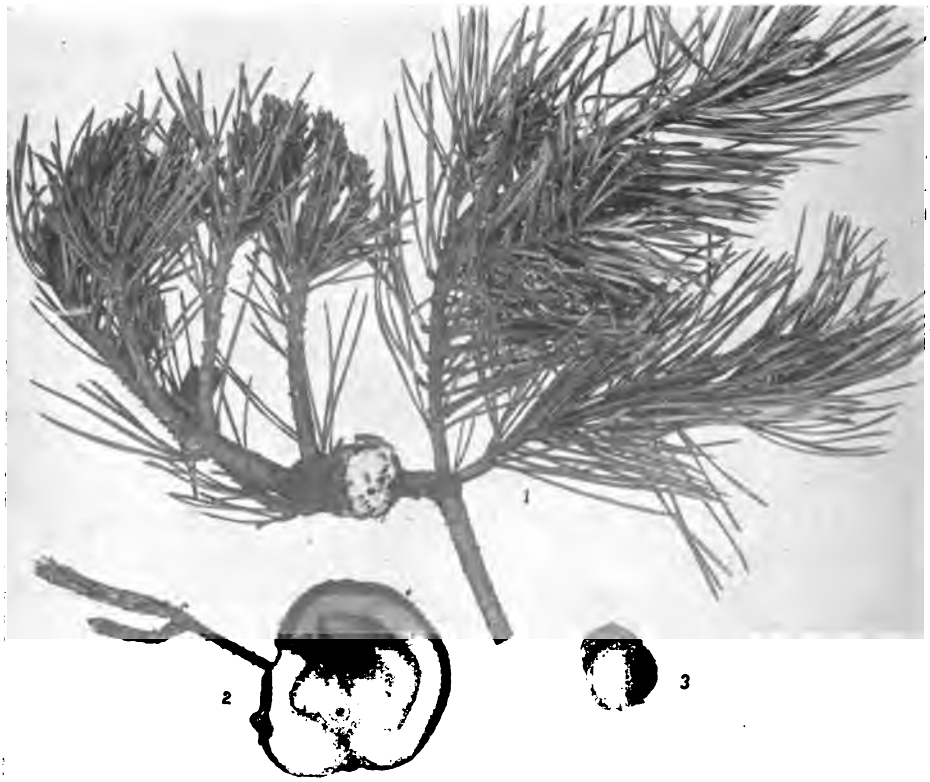


FIG. 136.—Pine knot (a species of Peridermium), on Scotch pine. 1. The branch on the left is seen with a good-sized knot which is covered with the conspicuous clusted-cup spores. The branchlets of this branch are seen to be thicker than the normal branches; the leaves are shorter and not as green and die early. 2. Section through a knot. 3. Section through the same branch as shown in 2, but below the knot, showing that a very great growth has been caused by the parasitic fungus in 2. Original.

In view of our lack of knowledge of the life history of these forms no preventive methods of combating this disease are known. All diseased branches should be cut off and burned as soon as they are discovered.

Leaf rust of pines (*Species of Peridermium*). This is a close relative of the stem rust of pines. It is likewise a rust fungus;

but attacks the leaves instead of the stem. The attacked leaves are often normal in appearance and not at all distorted. The cluster cups are formed on the surface of the leaves in the spring. They are large, swollen, sac-like affairs and contain a powder of light-yellow spores. It is possible that this is the same fungus which forms its summer and winter spores on asters and goldenrods and which is there known as the aster and goldenrod rust.

The leaf rust of pines is seldom present in sufficient quantities to injure the trees seriously.

Ash leaf rust [*Puccinia fraxinata* (*Lk.*) *Arthur.*]. Ash leaves are attacked by a cluster-cup rust which is not at all uncommon in the state, though it does not seem to be abundant. Several species, including the green ash, are the hosts. The cups are formed on large yellow spots on the leaf blade or petiole and the infected portion is often considerably distorted. The dust of spores is a bright orange red. Within recent years this cluster-cup stage has been shown to be connected with winter spores on the common grass plant, Spartina cynosuroides. (See also Fig. 75.)

Witches'-broom of balsam fir (*Aecidium elatinum Alb. et. Schw.*). There are formed on the balsam firs throughout the northern part of Minnesota peculiar bush-like branch-growths known as witches'-brooms. The production of this bush is due to the action of a rust fungus, which lives in the tissues of the branches. The first result of the attack of the parasite is the formation of a spherical swelling on the side branch of the balsam fir tree. From this swelling arise a very large number of branches, which grow very fast and become much longer than the unaffected branches. They often have a somewhat climbing, twining habit and grow upward instead of in a horizontal direction as do the ordinary lateral branches. The diseased branches do not hold their leaves through the whole year but shed them every fall. The fungus forms cluster-cups on the leaves of the broom shoots in great abundance in early summer and when the spores are ripe, a cloud of yellow dust of cluster-cup spores can be shaken from the broom. The broom increases in size from year to year and often several brooms are developed on the same tree. In some cases, almost the entire tree may be broomed. Not only is the symmetry of the growth of the tree interfered with but the tree is usually stunted and may eventually die. The leaves of the diseased shoots contain less leaf-green and are paler in color than the ordinary leaves. The exact method of the infection by spores in this country is not yet known. A similar disease on the silver fir in Europe has recently been thoroughly investigated. It is found that the cluster-cup spores of the silver fir brooms cannot infect the silver fir leaves but can cause infection on certain plants belonging to the pink family, e. g., the common chickweeds. Here the fungus gives rise to the summer- and winter-spore stages. From the winter-spore forms infection of the silver fir takes place. The commencement of the characteristic broom-like growth of the branches takes place in the following year. No experiments have yet been carried on to determine whether or not the American fungus on the balsam fir is or is not identical with the European form on the silver fir.

FIG. 137.—Poplar leaf rust (Melampsora populina). A poplar leaf showing the fine, black spots of the crust-like clusters of winter spores on the under surface. Original.

All brooms should be removed and burned especially before the formation of the cluster-cup spores in the spring. (See Fig. 23.)

The poplar rust [*Melampsora populina* (*Jacq.*) *Wint.*]. The poplar rust is exceedingly abundant in Minnesota and in some cases probably effects considerable damage of young poplars and cottonwoods. Older trees are seldom if ever seriously affected. Only the summer and winter spores occur on the poplar and cottonwood while the cluster cup stage is found on some other plant.

The summer spore groups are small, bright-yellow, resin-like cakes before maturity and when ripe produce a bright-yellow powdery mass of spores. Abundant, sterile, club-shaped cells are found intermixed with the summer spores. The summer spores are very abundant on poplar leaves in August. In early autumn the winter spores commence to form and soon, small, dark-brown, crust-like spore groups are produced, which later become black in color. Fallen poplar and cottonwood leaves, particularly those from the lower parts of the trees, are often entirely blackened and the under surface is almost completely covered with the black crust of winter spores. The winter spores pass the winter on the fallen leaves and in the following spring germinate without separating from the spore group.

In case of a serious epidemic the leaves should be collected and burned in the fall.

The birch leaf rust [*Melampsora betulina* (*Pers.*) *Wint.*]. This rust is closely related to that of poplars and the rotation of spore forms is similar. The appearance of summer- and winter-spore forms also resembles the rust of poplars.

The willow leaf rust [*Melampsora salicis-caprae* (*Pers.*) *Wint.*]. The willow leaf rust is exceedingly abundant on all the species of willow in Minnesota. This rust is also similar in general to that on the poplar leaf and is a closely related form. The leaves of younger shoots are not uncommonly so badly affected that they shrivel up and die. The winter spore groups form similar black crusts to those of poplar rusts and rest over winter; the spores germinate the following spring. This disease occasionally occurs in sufficient amount to threaten seriously the cultivated willows. When occurring in such troublesome quantities the fallen leaves with their winter-spore groups should be burned in late fall.

The cedar apples of red cedar (*Gymnosporangium macropus Link and G. globosum Farl.*). (See Leaf Rust of Apples—Diseases of Orchards.)

Rust of pyrola [*Chrysomyxa pirolae* (*DC.*) *Rostr.*]. The cluster cup stage probably occurs on some conifer. See Diseases of Wild Plants.

Rust of milkweeds [*Cronartium asclepiadeum* (*Willd.*) *Fr.*]. Sometimes found on oak leaves. See Diseases of Wild Flowers. The cluster-cups are probably produced on pine leaves. See Leaf Rust of Pines. Diseases of Timber and Shade Trees.

The mistletoe disease of spruce [*Razoumofskya pusilla* (*Peck*) *Kuntze*]. This parasite is a flowering plant of the mistletoe family, and is the only plant of this family which is native to our state. It produces a very serious disease of the spruce and both white and black spruce are affected. The presence of the parasite in the tree can usually be discovered from a distance by the presence of large "witches'-brooms." The part of the spruce which is attacked multiplies its branches and these are so densely

FIG. 138.—Willow leaf rust (Melampsora salicina). A willow leaf almost covered with the crust-like clusters of winter spores. Original.

clustered that the so-called broom looks like a foreign bush growing on the spruce tree. In badly infected trees the whole plant may consist of bunches of these brooms. By the death of the lower broom-branches, the tree may be left with only a few brooms remaining at the top. The symmetry of the tree is therefore entirely destroyed and the natural growth is very seriously interfered with. Whole forests in Ottertail and Becker counties are badly infested so that in many cases a majority of the trees are diseased. It has also been reported from Itasca county. In view of the decline of the pine forests and the growing importance of the spruce, this disease will later prove of very serious consequence. It is not apparently common on the north shore of Lake Superior but will probably reach all of the spruce-growing regions of the state in the course of time unless measures are taken to prevent it.

The parasitic plant is very small, seldom an inch in length, and its parasitic habit has greatly affected its structure. The leaves are reduced to mere scales and the very short stem is reddish or only slightly greenish. It is rooted in the branches of the spruce tree from which it derives its nutrition. Many plants often arise from the terminal region of a single spruce branch. The flowers are very much reduced in structure and are of two kinds, staminate and pistillate, growing on separate plants. The seeds are produced in berry-like fruits and are provided with sticky envelopes by means of which they cling to the branches of the trees. They are probably distributed by birds.

The only known remedy is the destruction of the infected trees, which will prevent the spread of the disease. This can easily be effected when the trees are badly diseased for the latter can be readily recognized by the brooms and the general irregularity of growth. Care should be taken to find those in the early stages of infection for such trees have not yet developed conspicuous brooms and may still harbor the parasite and thus become the center for new infections to the neighboring trees. (See Figs. 24, 25, 101.)

Downy mildew of seedling trees(*Phytophthora omnivora De Bary*). See Diseases of Greenhouse and Ornamental Plants.

Chapter XVIII.

Diseases of Field and Forage Crops.

The rusts of wheat and other cereals [*Puccinia graminis Pers., P. rubigo-vera (DC.) Wint., and P. coronata Cda.*]. What is commonly known as wheat rust may be due to one or more of a considerable number of rust fungi. These fungi, moreover, may be found on a large number of grasses. The three most important forms of cereal rusts are: the Black or Stem Rust (P. graminis), the Orange Leaf Rust (P. rubigo-vera) and the Crown Rust (P. coronata). In all of these forms, the summer and winter spores are formed on the plants of cultivated cereals or of wild grasses and in the former case (i. e. summer- and winter-spore stages), cause annually an enormous amount of damage. The summer spores first appear in early summer and are formed with great rapidity so that as the grain is growing the disease is also rapidly gaining ground. These spores occur in red lines, crowded between the parallel veins of the leaf. This form is commonly known as red rust and is particularly in evidence after very moist weather conditions, for these are very favorable to the rapid development of the fungus parasite. Toward autumn the production of the summer spores decreases and the formation of winter spores begins. These are produced in long black lines, chiefly on the stalks and form what is commonly known as black rust.

The orange leaf rust makes, as one might say, a specialty of the red rust, or summer spore stage, so that this is the prominent feature of this particular rust. On the other hand the most abundant spore of the black rust is the winter spore, hence its common name. But it must be understood that the orange leaf rust also produces winter spores, and that the stem rust produces summer spores and that both have cluster cups. The crown rust also produces three kinds of spores on its parasitic mycelium. The three rust species can be distinguished first by their life-histories and second under the microscope, chiefly by the shapes of the winter spores and the forms of the spore clusters.

The summer and winter spores may arise from the same mycelium. The winter spores remain unchanged throughout the winter and in the spring under favorable conditions of moisture and heat produce from each cell a short thread or promycelium, which gives rise to four little spores known as sporidia. These sporidia are borne by the wind to other plants, where they germinate and produce a parasitic mycelium, from which arise the cluster cups and pycnidia. In the stem rust this cluster-cup stage is formed on barberry leaves, in the orange leaf rust on certain borages, as hounds-tongue (in Europe), and in the crown rust on the buckthorn (species of Rhamnus).

The last is very abundantly found in Minnesota on the alder-leaved buckthorn (Rhamnus alnifolia). These cluster cups are usually formed on the under leaf-surface of their host and are formed on yellowish spots.

FIG. 139.—Wheat rust (Puccinia graminis). Stems of wheat showing opened and unopened black clusters of winter spores. This is commonly known as "black rust" or "stem rust." Slightly magnified. Original.

The leaf underneath the spots is abnormally increased in size and distorted in shape. The pycnidia usually accompany the cluster cups and come from the same mycelium, but are generally to be found on the upper surface of the leaf. They are probably male-cell receptacles which have lost their fertilizing power and are now functionless. They illustrate a persistence of a habit after its usefulness has passed, a by no means uncommon phenomenon in nature.

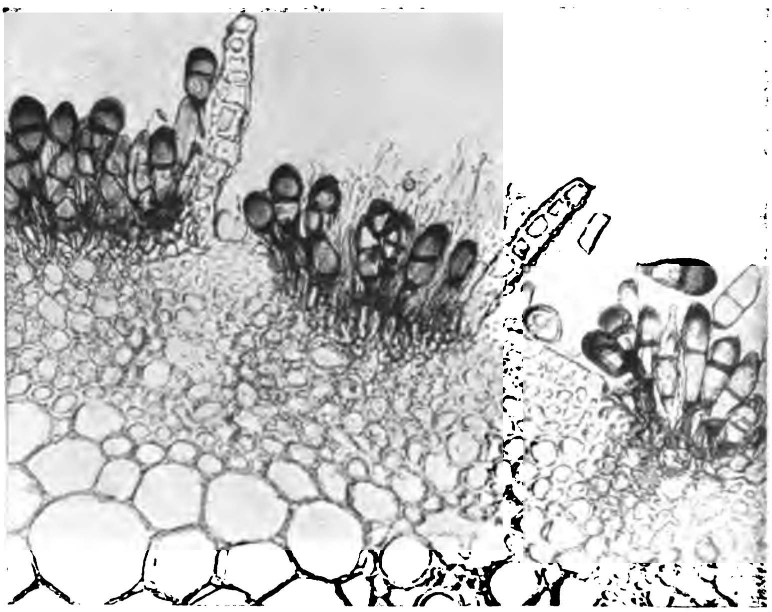


FIG. 140.—Stem rust of wheat (Puccinia graminis). A section of such a stem as is shown in Fig. 139, highly magnified. Clusters of winter spores have broken through the skin cells of the wheat stem. The skin cells of the wheat are seen as erect chains of cells which have been thrown back by the growing out of the winter spores. Such wounds allow the water in the stems to escape since the skin cells of the wheat, which normally prevent the escape of water, are broken. Thus the wheat plants are dried up as well as starved by the drain of the parasite. Each winter spore of the fungus is seen to be two-celled. Highly magnified. Microphotograph by E. W. D. Holway.

The cluster-cup is composed of a thin wall, enclosing an internal mass of orange red spores. The wall splits at the summit and opens out often in star-shaped fashion. The spores are formed in chains from the floor of the cup. The cluster-cup spores are scattered, when mature, by the wind and alight on some grass plant, where they germinate into a tube, which penetrates into the interior of the host through an air-pore, and forms internally a mycelium. The latter, under the most favorable conditions in about eight days, and under less favorable conditions usually within two weeks, again produces the summer spores.

The life-history of a wheat rust can therefore be divided into three parts; first, the stage on the grass or wheat plant, producing the red (summer) and black (winter) spores in succession; second, the germination of the winter spores and the production of sporidia on the ground or in the straw in the springtime; third, the germination of the sporidia on barberry (or borage, buckthorn, according to the particular form of wheat rust), and the subsequent formation from the mycelium so produced, of cluster-cups and pycnidial stages.

Fig. 141.—Oat stems and leaf bases with clusters of summer spores of the oat rust. The spots are large and not sharply defined. Original.

In seasons that are favorable for the development of the rusts whole crops may be completely ruined; but the danger does not end here. Crops are often not so considerably affected and may appear but slightly rusted. The latter cases are often lightly passed over as of no account but such is not the case. If the rust is present in any noticeable amount it is safe to say that the parasitic fungus is levying a tax of nutrition and energy upon the host or crop plant which results in crops correspondingly lighter than should be the case if no rust were present. That is to say, the nutrition which could normally be expended in the formation of more and heavier grains is required to nourish the parasitic rust. The almost fabulous figures recorded each year as the loss to farmers by rust is more often probably underestimated than exaggerated because the smaller losses due to the presence of the rust in very slight and therefore unheeded quantities may never be computed. These are, nevertheless, a certain loss. There is only a difference in degree. The entire elimination of rust would therefore increase the value of crops throughout the country by an enormous per cent.

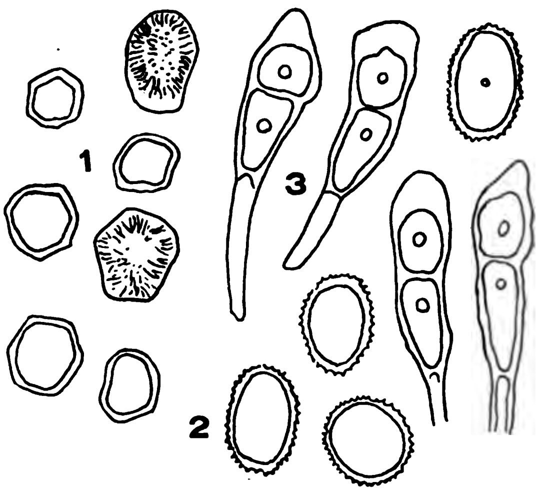


FIG. 142.—Spores of the common "black rust" (Puccinia graminis) of wheat. 1. Cluster-cup spores from the barberry plant. 2. Summer spores from the wheat plant. 3. Winter spores from the wheat plant. Highly magnified. After Arthur and Holway.

At present there is no known method for successfully combating wheat rust. Numerous attempts to fight the disease by spraying with bordeaux and other mixtures have always proved unsuccessful. Where stem rust is the principal form and barberry bushes are common, it has been found that the removal of barberry bushes will diminish the rust considerably. In Minnesota, however, very few barberry bushes are grown, and of these many are often not infected with grass-rust cluster-cups, while the host plants upon which the crown rust and orange leaf rust grow are very common wild plants. The cluster cup of the orange leaf rust forms on plants of the borage family, but no cluster cups have yet been found on these plants in this state, so that either our orange leaf rust differs from the European form or else it can here dispense with the cluster-cup stage altogether. Little can therefore be hoped from the removal of the cluster-cup host plants. There is still another factor which would help to defeat such a method. In at least one of these rusts, the mycelium which produces the summer spores may live through the winter and produce summer spores again in the following summer, thus dispensing with the necessity of the cluster-cup stage. It is also possible that even in some forms, where the mycelium does not hibernate, that the cluster-cups can also be omitted without injury to the rust.

It is an important fact that some of the injurious rusts are found upon wild grass plants and infection from cereals from such sources must not be overlooked. The stem rust in particular is dangerous on this account. It has been shown that the stem rust of wheat is able to infect a half dozen or more com-

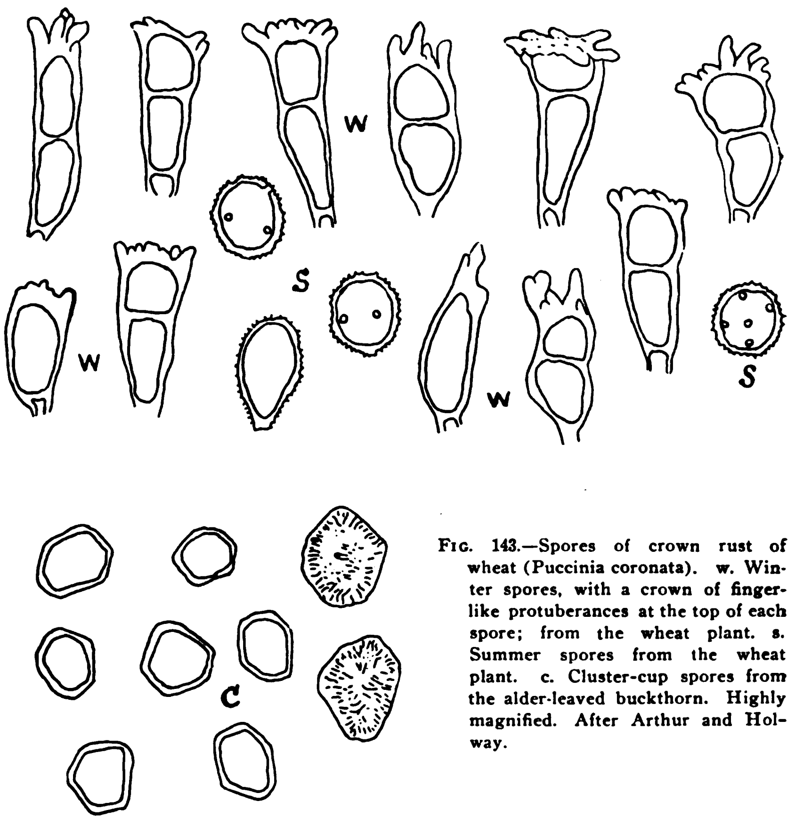


Fig. 143.—Spores of crown rust of wheat (Puccinia coronata). w. Winter spores, with a crown of finger-like protuberances at the top of each spore; from the wheat plant. s. Summer spores from the wheat plant. c. Cluster-cup spores from the alder-leaved buckthorn. Highly magnified. After Arthur and Holway.

mon wild grasses, including squirrel tail grass (Hordeum jubatum), and also that the rust from these can infect wheat plants. This is a very discouraging feature, for it seems almost impossible to eliminate all of these weeds. Unless this is done, however, the spread of stem rust cannot be prevented. The stem rust moreover is the most virulent rust for the spore specialty is the winter spore and this is found chiefly on the stems, hence the common name of stem rust. In this position the mycelium rapidly drains away the nourishment which should go to the heads and allows of an uncontrollable evaporation of water through the broken skins; as a result the berries do not fill but remain shriveled. Such wheat therefore, even if not entirely ruined, suffers a loss of grade.

FIG. 144.—Cluster-cups of the crown rust of wheat (Puccinia coronata), on swollen cushions of the stem of the alder-leaved buckthorn. Photograph by Arthur and Holway.

It is also known that in states south of Minnesota the summer spores of grass rusts live through the winter and cause direct infection of the grass plants in the spring. It is not impossible that these spores from southern states can rapidly work their way north in the early spring and commence the infection each year. The rapidity of formation of successive crops of summer spores would make this manner of spreading easily possible.

Eriksson, an eminent European specialist on rusts, has proposed a theory known as the mycoplasm theory, which supposes that the fungus threads live over in the grain of the wheat as an amorphous substance, totally unlike the ordinary fungus threads. This mycoplasm he supposes to be diffused amongst the protoplasm of the cells of the grain, until the latter commences to germinate, when it again assumes the form of threads and causes an infection of the seedling wheat plant. We cannot here go into the details of the evidence, but in the opinion of a great majority of rust specialists this theory has not sufficient foundation. Infection by the spore methods, described above, is at present the only known method.

Recent work points to more probable success in combating rusts along another line. It has been found that many of the rusts are so closely adapted to the conditions found in the plants, on which they occur, that they have great difficulty or fail entirely in growing upon other varieties. At present there are recognized, by the best authorities on the rusts of cereals, more than a dozen distinct varieties and species. Many of these are indistinguishable from other forms, as far as external characters are concerned, even with the aid of powerful microscopes, but a great difference is soon found when the spores are germinated and infections attempted. It is then seen that some forms are so especially adapted to the species or variety of the host plant, upon which they occur, that they refuse to develop on other varieties or species of the same genus of host. Such rust forms are called "biologic" species. On the other hand it will be seen that some species and varieties of grasses and cereals may thus be immune from some forms of rusts. A "rust-proof" variety would not of course be proof against all forms of rust but *might* be immune from certain forms. Consequently something beneficial may be expected from the efforts of plant breeders in the production of rust-proof cereals. With intelligent care in the selection of cereal varieties and with a broader and better knowledge of the habits and life-history of the parasitic plants causing rusts, it is very probable that the ravages of this disease can be at least considerably checked.

In the production of rust-proof varieties the selection of seed becomes of great importance. Many farmers instinctively believe that seed from rusted fields will necessarily produce a rusted crop. Such is not the case as can easily be seen by a perusal of the above life-history of the rust. The rust does not live over in the seed and seed from rusted fields have no more chance of becoming rusted than that from fields that have had no rust, provided, of course, that it is not shriveled or in other way dam-

FIG. 145.—Cluster-cups of the black or stem rust of wheat (Puccinia graminis), on stems and leaves of Barberry. Photograph by Arthur and Holway.

aged. In fact good seeds from rusted fields should be highly prized for seeding purposes since they indicate that the plants which bore them were probably rust-resistant. It would therefore be advisable to select seed from rusted fields, but such seed must be carefully cleaned and graded so that only strong and healthy berries are used. Of seed from regions free from rust nothing definite can be predicted. The absence may be due to rust-resistance or it may be due to an absence of the fungus in that locality. In the former case the seed would of course be valuable, in the latter it might easily fall a prey to the first attack of rust.

It must further be pointed out that the conditions in a given community must be thoroughly known, i. e. the chief kind of rust and the conditions favoring its spread, as alternate host-plant, etc. The problem, therefore, may divide itself into special sectional problems. Again any new rust-proof varieties may not always remain so, for the rusts can vary and adapt themselves to new hosts and may at some future time find a way to invade the new rust-proof variety. It seems therefore that the problem before us is not one to be dispensed with by one discovery, but that it may involve a long series of breeding experiments—in other words, a continuous fight. It seems furthermore reasonable, when all evidence is weighed, to hope that in such a combat the plant breeder will ultimately emerge victorious. (See also Fig. 11 and Chapter XI.)

In view of the importance of wheat rusts, detailed accounts may be of value, and are given below for the benefit of those who may be especially interested in this subject and who may wish to be able to determine the chief rusts in the field or laboratory. The italicized portions point to distinguishing differences. The crown rust occurs chiefly on oats, more rarely on wheat. In can be recognized microscopically by the crown of prejections at the end of the winter spores. (See Fig. 143.) The two remaining are the important wheat rusts.

The orange leaf rust (commonly called "red rust"). The cluster-cups are unknown in this country (except for a form on Elymus with cluster-cup on Impatiens). The summer-spore-clusters (so-called "red rust"): chiefly on the lower surface of *the leaf blade*, often abundant; occasionally on the leaf sheath; *small, oblong, up to 1 m. m. long*, usually arranged in rows and often running together forming long lines, *orange-colored when fresh*. The summer spores (under the microscope): *globose* or *somewhat globose* or broadly elliptical, finely spiny, *orange-colored*. The winter-spore-clusters: accompany and follow summer spores; *on the leaf blade (seldom on the stem)*; arranged in lines or scattered; *oblong, dark brown or black; remain covered* by the host epidermis *for a long time*. The winter spores: club-shaped, rounded or *truncate* or conic at the apex, slightly constricted near the middle, two-celled, brown, smooth, *have a short stalk or none; accompanied by sterile threads* (paraphyses).

The stem rust (commonly called "black rust"). The *cluster-cup* grows *on barberry*. The summer spore clusters: *chiefly on the leaf sheath*, occasionally *on the stem, seldom on the leaf blade;* scattered or *in rows, elongated or linear*, (2-3 m. m. long), often running together to long lines; bounded by the *fissured epidermis* of host, becoming powdery, *brown when fresh, yellow when dry*. The summer spores: usually *ellipsoidal* or ovate oblong, finely spiny, *yellow brown* (when fresh). The winter spore clusters (so-called "black rust"): *chiefly on the stem* or on *the leaf sheath* (less common on the leaf blade); scattered *or in rows, elongated*, often running together into *long lines*, 1. c. m. or longer; *soon exposed (naked) by the breaking of the host epidermis, black* and *powdery*. The winter spores: oblong or club-shaped, two-celled, smooth, chestnut brown; *apex rounded* or *long-conical* and much thickened; base attenuate; have brown *stalks, often as long as the spore; no sterile threads.*

Rust of corn (*Puccinia sorghi Schw.*). This very common rust occurs on species of sorghum and on corn. The cluster-cup stage has recently been discovered; summer and winter spores are well known. The two latter spores occur in usually small, sometimes considerably elongated, groups or sori of red- or reddish-brown color. The winter spores are two-celled. The cluster-cup is found on a species of Oxalis. This rust is usually not in sufficient abundance to cause any serious loss.

Clover leaf rust [*Uromyces trifolii (Hedw.) Lev.*]. The clover rust occurs on several kinds of clover, notably on red and white. Cluster-cups are formed, but not commonly, in the spring, on the petioles and blades of the leaves, and summer and winter spores are found later appearing as red and brownish powdery spots, usually on the under surface of the leaf. The winter spores are single-celled. The fungus thrives in damp cold summers and is usually not abundant or dangerous in the spring: but it may increase during the summer, especially if conditions are favorable. The early red clover crop is therefore usually unaffected, but later crops may be damaged.

The plowing under of later crops when badly infected has been recommended, as has also the burning over of the fields to prevent a recurrence of the disease in the following season.

Loose smut of oats [*Ustilago avenae* (*Pers.*) *Jens.*]. This exceedingly common and destructive disease is very well known on account of the enormous damage which it yearly causes to oat crops. In the United States alone, losses of many millions of dollars yearly, by oat smut, have been recorded. The application of Jensen's Hot Water Method and the formalin treatments have in recent years greatly decreased the loss by this disease.

FIG. 146.—Loose smut of oats. Original.

When an oat plant is attacked, usually all of the heads, and all of the grains in each head, become smutted. Very few if any grains escape in a smutted plant and those that do are always stunted. The stamens of the flowers as well as the ovaries are attacked by the fungus. The grain is converted into a large sac with a very thin membrane completely filled with the black spores of the fungus. The smut spores are blown about by the wind before harvest time and become attached to healthy grains or fall on the ground. In the following year when the oat grain has commenced to sprout, the fungus spores also germinate. A spore in germination first forms a very short chain of cells, which bud off from their sides little secondary spores. These spores sometimes fuse in twos, thus probably gaining in strength by uniting forces. The spores either with or without fusion may continue to bud off other spores when placed in favorable nutritive conditions such as a culture medium. They are produced in yeast fashion. This is an important feature, for the fungus may thus continue vigorous in such places as manures for an indefinite length of time. Any of these spores, when placed under favorable conditions, can send out a small germ tube which, when it comes into contact with the seedling of an oat plant, will pierce the sheath of the seedling and make its way to the little mound of growing tissue at the tip of the stem. The fungus branches here freely and establishes itself, as a well developed mycelium, between the cells of the host plant. There is no external mark by which such a plant can be distinguished from a healthy one until the formation of the grain. The attacked plant appears perfectly normal. The fungus in the growing point keeps pace with the latter in its growth. The fungus threads disappear in the older tissues so that the mycelium can usually only be found in the region of the growing point. When the oat stem branches the fungus establishes itself in the growing point of the branch as well as in the growing point of the main stem and this accounts for the fact that usually all heads of an attacked plant are smutted. When the head commences to form, the fungus invades every flower and in the organs of the latter it forms its smut spores in great abundance. It is not until this period that the fungus comes into evidence. Every grain is thus attacked and filled with the smut spore powder.

One well known method of prevention of oat smut is the hot water treatment. This has in general been replaced in recent years by the formalin method. Both of these treatments are described under Steeps in Chapter XV. By both of them the smut spores which cling to the grains are killed off, while the grains themselves are not injured. Infection in oats is dependent on the bringing together of germinating smut spores and seedling oat plants, and the destruction of the smut spores attached to the grain very considerably lessens the danger of infection, as it is from these spores that infection generally takes place. The smut spores also germinate most readily at about 50 degrees Fahrenheit or about the out-of-doors spring temperature, and their ability to germinate decreases with the rising temperature. For this reason late sowing is sometimes recommended. This is however entirely unnecessary when the above methods of prevention are used.

Stinking smut of wheat [*Tilletia tritici (Bjerk.) Wint.*]. This is a common smut-fungus of wheats and is well known to be very destructive. The fungus gains entrance to the plant, when the latter is still a seedling, and keeps pace with the growth of its host, until flowering time. The mycelium then invades the ovaries and replaces the contents of the latter with fungus threads. These threads form an oily or greasy mass which is later transformed into the smut powder. The smut spores are blackish in color and have, in bulk, a very disagreeable odor, which gives rise to the common name of the disease. The smutted ovaries do not open until harvested. Smutted heads are usually erect and can be detected in the field at harvest time. The presence on smutted grains in quantity amongst the healthy is a very serious damage as it unfits the crop for use as flour, unless the smut is cleaned out by a special process. When smutted grains are fed to animals the results are sometimes serious. Corn smut and other smuts of grasses are known to have injurious effects upon animals. Horses, cattle, sheep and swine may be affected. Not much is known about the specific results of poisoning from each kind of smut, so that confusion as to symptoms exists. "As a result one generally finds a continuous movement of the jaws, and a flow of saliva, also lameness, staggering and falling." (Tubeuf and Smith, p. 306.)

The stinking smut of wheat differs in its development very radically from the smuts of the group to which the loose smut of oats belongs. When the spore of the latter germinates a fine tube is produced which is divided into a row of cells, each of which buds off tiny, oval or spherical spores from the side of tube. In the stinking smut of wheat, the tube of the germinating smut spore is not divided into cells but forms its spores from the end of the undivided tube. These secondary spores may fuse together in twos and from the fused cell, a third crop of spores may be formed. Any of these secondary or tertiary spores are capable of growing out into a fine tube; when it comes into contact with a wheat seedling this tube penetrates into the tissues of the stem and so begins its parasitic life. The life of such a smut can therefore be divided into two stages; first, the parasitic stage, beginning with penetration of the infection tube and ending with the formation of the smut spore powder; and second, the saprophytic stage, beginning with the germination of the spore and ending with the formation of an infection tube by the secondary and tertiary spores.

The secondary and tertiary spores, produced by the smut spore, are capable of living in a nutrient solution or in fresh manure, where they may form a saprophytic mycelium or may continue to bud off more spores in a yeast-like fashion. They may live thus for years, and when finally brought into contact with the seedling plant, they may still cause infection.

FIG. 147.—Stinking smut of wheat. 1. A head of wheat with smutted grains (smutted grains are colored black). 2. Small portion of a head showing smutted grains which are fissured, and show the black spore mass within. 3. Isolated grains which are smutted and have fissured walls. One grain is sectioned. 4. Smut spores germinated and producing at the end of the germ tube long, needle-like spores, which sometimes fuse together in pairs by cross-threads as shown on the left. 5. The thread spores, shown in 4, in germination sometimes again producing secondary spores. 6. Smut spores germinating to long infection threads without first forming spores. 4-6 highly magnified. After Tubeuf.

The treatments used for loose smut of oats are also effective against this disease. The Jensen hot water method (see chapter on Prevention), has been found useful, but the most effective and easiest method is the formalin treatment, which has practically supplanted the former. This smut can in practice be entirely prevented by this method.

Loose smut of wheat [*Ustilago tritici* (*Pers.*) *Jens.*]. This smut is also known as wheat brand. It is a destructive smut of wheat and differs in many ways from the stinking smut. It can be distinguished, botanically; by the behavior of its spores since they develop at germination a chain of cells similar to the loose smut of oats, instead of an undivided tube, as in stinking smut of wheat. From this chain of cells are budded off the secondary spores, which behave as do those of loose smut of oats. In other characters, which are visible to the naked eye, this smut is well marked off, from the stinking smut of wheat. The smut masses are formed in the place of the grains, and may even supplant the chaffy scales. This smut mass does not remain closed until harvest time, but opens at flowering and the spores are scattered by the wind. At harvest time, therefore, only the bare stalks of the wheat heads, with remnants of scales, remain on the plants. This method of distribution gives rise to the common name of loose smut. The spore mass is a dark, olive-green, dirty mass which differs from the stinking smut in the absence of any fetid odor such as the latter possesses.

No sure method of prevention is known. A modification of the Jensen hot water process for loose smut of oats has given some relief, but seems to injure the seed. The formalin method is also uneffective. The only relief known at present is the selection of clean seed, which can only be done by obtaining the seed from a smut-free district. (See Fig. 72.)

Corn smut [*Ustilago maydis* (*DC.*) *Cda.*]. The smut of corn is a disease familiar to every farmer. It may attack almost any part of the plant, but is particularly abundant upon the cobs, staminate tassels and the leaves. When a cob of corn is attacked a number of the grains become enormously enlarged and are covered with a thin, whitish-grey membrane. The whole cob may thus be enlarged to twice its natural size. The interior of the affected grains is filled with a blackish to dark green powder of smut spores. When a leaf is attacked, tumor-like swellings are produced, which often become as large as an apple and this tumor contains the blackish spore-powder. Upon the staminate tassels, smaller tumors are formed which are of a similar structure to those of the leaf. The smut spores rest through the winter. In the spring they germinate, producing small tubes which bear secondary spores in great abundance; these spores are capable of yeast-like budding when brought under favorable conditions, e. g., in piles of manure; in this manner the infecting ability of the disease is greatly increased. These secondary spores are conveyed by the wind or other agency to other plants and infection follows. Only young parts of the plants can be successfully attacked. The disease is only local in its effects, and in this character it differs very decidedly from such smuts as loose smut of oats and stinking smut of wheat. The part most frequently attacked is the cob and the harvest is often seriously diminished by this disease. Certain varieties of sweet corn are peculiarly susceptible to attack, so that a selection of varieties is often advisable.

FIG. 148.—Smut of corn (Ustilago maydis), on left, on the leaf of the corn; on the right, in the tassels (staminate inflorescence). After Clinton.

Treatment of seed corn with copper sulphate or formalin has absolutely no effect on this smut. If the disease has been bad in the preceding year, fresh manure should be avoided, as the multiplication of the spores is increased by its use. All smut tumors and spore masses must be burned as soon as discovered. Bordeaux spray has been found successful to a certain extent, but usually is unnecessary if the spore masses are carefully removed.

Head smut of sorghum [*Sphacelotheca reiliana (Kuhn.) Clinton*]. This smut attacks the whole head of the sorghum plant and often all of the heads of a plant. The smut mass therefore replaces the entire head and is at first surrounded by a fine white membrane, which later ruptures and exposes the smut powder. Grains, glumes and all parts of the head are destroyed and only the loose strings of the woody tissues of the head branches remain. The head smut can be distinguished from the grain-smut by this habit. The smut mass forms a blackish powder.

No preventives are known for this smut. It is possible that the treatment for grain smut will be effective.

FIG. 149.—Corn smut (Ustilago maydis), on an ear of corn. A few of the kernels near the butt have not been smutted. All of the others have been attacked and have increased enormously in size. The enlarged kernels are filled with the smut powder. Original.

Grain smut of sorghum [*Sphacelotheca sorghi* (*Lk.*) *Clinton*]. This sorghum smut attacks the young grains and forms smut masses in them, but does not destroy the glumes. The smutted grains increase in size, chiefly in length, and have a whitish wall which encloses a mass composed entirely of spores. The spores rest over winter and under proper conditions, in the spring time, form more spores, which can in turn multiply in yeast-like fashion; the resulting spores are capable of causing infection.

Sorghum is also frequently attacked by other smuts and certain varieties of the sorghum are known to be peculiarly susceptible to smut. (See also Head Smut of Sorghum.)

A few experiments on this smut have indicated that hot water treatment may be beneficial. It has proved successful in the treatment of the same smut on broom corn. It is also possible that the formalin method would be effective and useful.

Broom corn smut [*Sphacelotheca sorghi* (*Lk.*) *Clinton*]. This is the same fungus that causes the grain smut of sorghum. When it attacks the broom corn, it seriously affects the formation of the brushes and the smut often discolors them. The young grains and stamens may become smutted and usually all of the grains of a cluster are destroyed. The spore mass is very dark and the spores have an olive-colored tint. The host plant is apparently infected only in the seedling stages and hence care must be taken to avoid the presence of spores in a seed mixture.

Seed broom-corn should be treated in hot water in the usual way at a temperature of 135 degrees Fahrenheit for ten to fifteen minutes. Such treatment of seed will largely if not entirely prevent the smut. It is probable that the formalin method would also be effective.

Naked barley smut [*Ustilago nuda* (*Jens.*) *Kell. and Sw.*]. The naked smut is more common than the covered smut of barley and also more difficult to combat. This smut attacks the grains and forms smutted heads, which do not, however, remain closed as long as do those of the covered smut. The smut masses are at first enclosed in a membrane, but the spores do not adhere so closely and when the membrane of the head breaks the smut spores are quickly dispersed by the wind. The heads of barley have then the appearance of wheat affected by loose smut. The awns of the barley head are either only stunted or may remain intact. The powdery spore mass is dark and black, with a greenish tinge, differing in this respect from the covered smut of barley. The exact method of infection of the host plant is unknown but there seems to be some evidence that it is not in the seedling stage.

"Soak the barley seed four hours in cold water and then let it stand four hours longer in a wet sack. Finally dip and drain as directed in the treatment for oat smut for five minutes in water at a temperature of 126 to 128 degrees Fahrenheit, after which dry and plant as in case of smut of oats." (Kansas Ex. Sta. Rep. for 1889, p. 284.) This treatment is also ample for the covered smut.

Covered smut of barley [*Ustilago hordei* (*Pers.*) *Kell. and Sw.*]. This is one of the two common smuts which attack the barley plant. The smut spores are formed in the very young

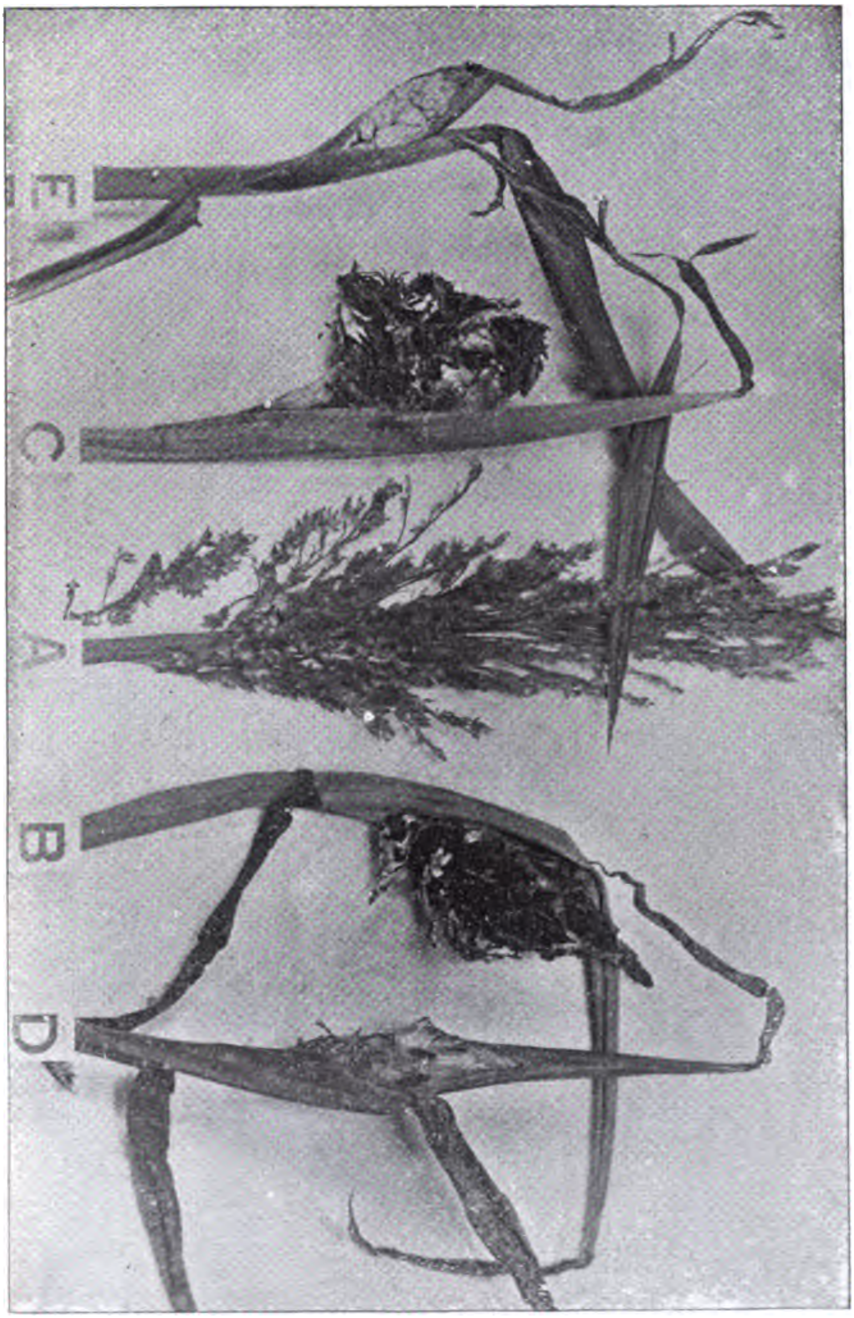


FIG. 150.—Head smut of sorghum. A. Uppermost head or panicle of sorghum, sound. B, C, D, E, lateral heads from same stalk, smutted. After Kellerman.

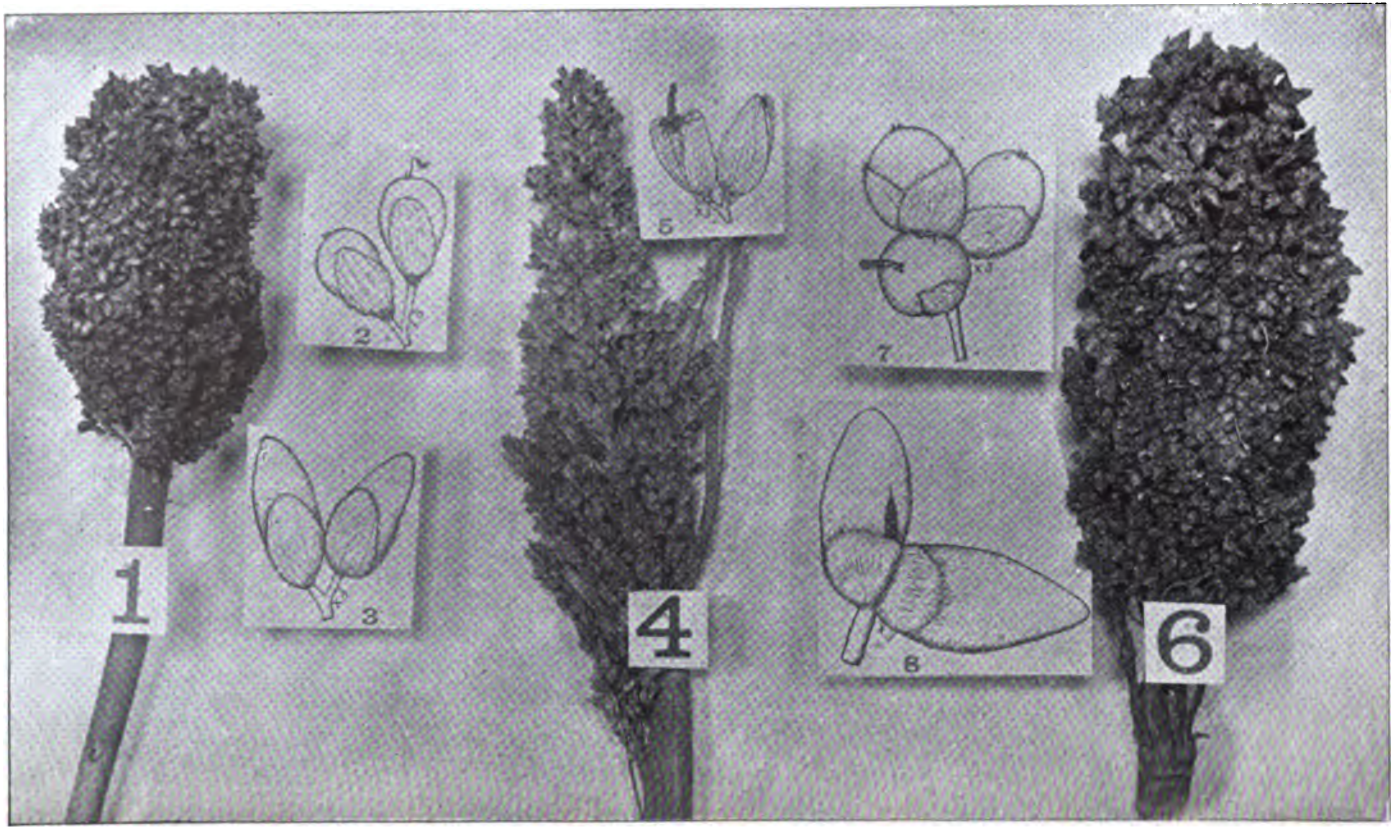


FIG. 151.—Grain smut of sorghum. 1. Smutted head one-half natural size. 2. Sound grains from head 1; magnified three times. 3. Smutted grains from head 1; magnified three times. 4. Smutted head; one-half natural size. 5. Smutted grain from head 4; magnified two diameters. 6. Smutted head; one-half natural size. 7. Sound grains from head 6; magnified two times. 8. Smutted grains from head 6; magnified three times. After Kellerman.

grains, but are not scattered immediately after ripening. They are enclosed in a membrane which includes the scales around the grains. Not all of the interior of the spikelet is converted into spores, but plates and shreds of material remain, which are not smutted. The spores are therefore held firmly together and the smut is thus known as the covered barley smut. The spores are black when seen in mass and have no greenish tinge. On account of the compactness of the smut heads, the disease does not spread with very great rapidity. It is not known whether the spores infect the seedling barley as in oat smut or cause infection later, as in the corn smut.

The hot water method and the copper sulphate steep have both been recommended. The treatment used for the naked barley smut is said to be effective against the covered smut. The formalin method would probably be of use.

Brome smut (*Ustilago bromivora Fisch.*). Brome plants are subject to smut attacks and the spore masses are formed in the young grain. The heads of grains do not show any abnormal growth. The spore mass is usually black.

Millet smut (*Ustilago crameri Körn.*). A smut attacks millet plants and is sometimes abundant. At flowering time, the fungus replaces the ovaries with black masses of the smut spores. All of the heads of the attacked plants are smutted. The spores germinate in the usual way, forming a small tube from which, however, secondary spores are not usually, if ever, produced.

Care should be taken to use clean seed free from smut. The hot water method has been found to be an effective preventive.

Leaf smut of rye [*Urocystis occulta.* (*Wallr.*) *Rab.*]. This fungus attacks several cereals but is most frequent on rye. It has not been reported as very frequent in this country and it is probably not at all abundant in this state. It is unlike most of our common smuts in many of its characters. The spores are formed in elongated lines on the leaves and stem, which are at first greyish but later, after the bursting of the epidermis, exhibit a black powdery smut-mass underneath. The whole plant is deformed and injured. The spores are aggregated together into true spore-balls. About a half-dozen spores cling together into a solid mass, in which a differentiation of labor is evident. The outer spores have lost their power of germinating and act as a protective covering to the central spores, which have retained their germinating power. Thus the functional spores obtain an additional protection by means of the surrounding layer of sterile spores. There are usually two or three functional spores in each spore mass. Upon germination the spores produce a tube from which secondary spores are formed in the manner usual for smuts. Jensen's hot water method has been recommended when the fungus appears in abundance. Formalin would probably prove useful.

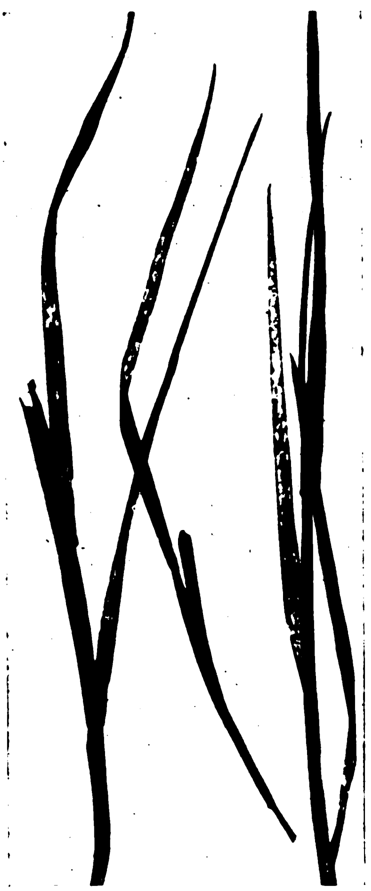


FIG. 152.—Powdery mildew of grasses (Erysiphe graminis), on wild grass-plant leaves. The white coat of the fungus mycelium is very conspicuous. Original.

Powdery mildew of grasses (*Erysiphe graminis DC.*). The cereal grasses are sometimes seriously damaged by the attacks of this disease. A fine whitish mycelium is formed on the leaves in the summer time. The mycelium threads derive their nourishment from the skin cells of the host by short sucker branches sent into these cells. These sucker branches are known as haustoria. Summer spores are produced in large numbers and rapidly carry the disease from leaf to leaf and plant to plant. These spores are spherical or egg-shaped cells microscopically small; they are formed in chains which stand upright, often over the whole upper surface of the leaf. Toward fall the sacs with their spores are formed in sac-capsules. As is usual in powdery mildews, the capsules appear as small black spheres about the size of a pin point. In the earlier stages these capsules are whitish and as they mature, change to yellowish, then brown, and finally to a dark brown or black. The capsule is provided with thread-like appendages, which are dark brown in color and unbranched, and are interwoven with the threads of the mycelium. The mycelium sometimes forms brown spots on the leaves, and if present in quantity, may very seriously interfere with the nutrition of the leaf of the host plant and thereby occasion considerable damage. Each capsule contains a number of egg-shaped sacs, each of which contains about eight spores. The spores are capable of growth, after a rest period, when placed under proper conditions, e. g., out of doors in spring. When germinating, a tube is sent out, which penetrates the epidermis of the host. By a further growth and branching of this tube the mycelium is established.

FIG. 153.—"Black mold" of clover (Phyllachora trifolii), on leaves of white clover. Original.

By the use of flowers of sulphur the spread and growth of the disease can be prevented to some extent. Infected plants should, however, be destroyed every year to get rid of the sac-capsules. The disease is not often abundant enough to be very troublesome.

"Black mold" of clover [*Phyllachora trifolii* (*P.*) *Fckl.*]. This is a very common fungus in Minnesota growing abundantly on white and also on red clover. The summer stage is conspicuous, forming blackish spots on the leaves. The summer spores are borne on the ends of beaded threads and are two-celled. The spore-sac capsules are borne in a blackish cake of mycelium, somewhat similar in appearance to the tar-spot of willows. The fungus is also known on the scarlet clover (Trifolium incarnatum). It is sometimes known as the black mold of clover.

Smothering fungus of grasses [*Epichloe typhina* (*P.*) *Tul.*]. This disease is also known as the Reed Mace Fungus. It is found on grasses and is apparently confined to a few genera. It sometimes causes injury to fodder grasses. The fungus attacks the above-ground portion of the grass and forms white or light tan-colored cushions of mycelium around the leaves and stem of the host. These cushions are so dense that they prevent further growth of the leaves and stem, causing, as it were, strangulation. From this cushion arise first, small colorless spores on short stalks. These are the summer spores, comparable to those of the powdery mildews. Toward fall the sac-spore-capsules are developed. They arise in great numbers, embedded in the outer part of the cushion and are of the same color as the cushion. They are long and pear-shaped, and open to the surface by means of a pore at the end of a slightly protruding neck. In each capsule a large number of sacs are produced in a group, on the floor of the capsule cavity, and each sac contains eight spores. The spores are very long and thread-like and are divided into many cells, arranged in a chain. When ripe, the spores may break up into segments, each of which is capable of germination, producing a mycelium and causing infection. The fungus, when occurring in great abundance on fodder grasses, is said to be injurious to the feeding horses. It seldom becomes a serious pest. (See Figs. 57 and 58.)

The ergot disease of grasses [*Claviceps purpurea* (*Fr.*) *Tul. and other species*]. The ergots of grasses are very closely related to the smothering fungus of the same plants. The ergot fungus attacks the very young and immature grains and the mycelium soon permeates the tissues of the grain. It replaces the latter entirely and forms in its stead a dense mycelium which soon becomes so densely interwoven that it forms a solid body of characteristic form and of doughy consistency. The outer surface of this body is at first thrown into folds and ridges and along these folds one finds the summer spores produced in great numbers. These spores are small, oval, or cylindrical, colorless cells. Their production is accompanied by the secretion of a sugary fluid known as "honey dew," which is attractive to insects. The latter in their search for the "honey dew" distribute the summer spores from plant to plant and rapidly spread the disease. Toward the end of the summer, the formation of summer spores ceases and the underlying fungus mass becomes more compact and hard, and the external threads form several layers of cells which contain a very dark purple coloring matter. This fungus mass is now known as the sclerotium and is the ergot of commerce. The form of the ergot varies in the different grasses. The ergot of rye (commercial ergot) is long and cylindrical and slightly curved. The ergot of wheat is much shorter and thicker, while the ergot of wild rice is still shorter and roughly egg-shaped. The ergot is a storage organ and usually rests through the winter. The storage material is a kind of starch, known as fungus starch, which is stored up in the cells. The fungus threads are so compacted together that they form a mass of cells very similar in appearance to that of the pith of some flowering plants. The ergot rests in or on the ground, where it is often sown with the grain, until early summer. Under the proper conditions of moisture it then develops further. From the surface of the ergot arise several short, violet-colored stalks, which bear at their tips yellowish spherical heads. The latter are the spore-sac-capsule cushions, as may be seen by the small protruding necks of the

FIG. 154.—The ergot fungus (Claviceps purpurea), on rye. The large fungus storage organ (sclerotium or ergot) is seen near the top of the head. After Clinton.

Fig. 155.—Storage organs or ergots of ergot fungi on various grasses. 1. Commercial ergot from rye. 2. On canary grass. 3. On wild rice. 4. On quack grass. 5. On a reed grass (Calamagrostis). The size and shape of the grass grains can be seen in each case, except in the rye. Original.

capsules with their pore-like openings. The arrangement of the capsules is similar to that in the smothering fungus, except that the cushion is spherical in shape. In the capsules are numerous sacs, each containing eight spores. The latter are very long and thread-like and are many times divided by cross walls and each division is capable of the formation of a mycelium. The flowers of the grass plant are again infected by these spore-segments from the sacs.

The storage-body or sclerotium is widely used medicinally and is known as the ergot of rye. In the grains of the latter it is very commonly found. These ergots sometimes attain a length of one and one-half inches. The presence of ergot amongst grains from which flour is made may give rise, among the consumers of the bread, to a disease known as ergotism. Cattle fed with grains containing ergots in considerable amounts may also be severely poisoned. Numerous cases of such poisonings in our northwestern states have been reported. Chronic effects, from long-continued small doses, can be distinguished from acute attacks. The shape of the sclerotium varies with the grain, upon which it is formed. Ergots grow on many of our very common wild grasses and are sometimes here even more conspicuous than on the cereal grasses.

The only preventive means for ergot lie in the destruction of all sclerotia and in the planting of clean seeds, i. e., seeds free from an admixture of ergots.

Leaf spot of alfalfa [*Pseudopeziza medicaginis* (*Lib.*) *Sacc.*]. This small cup fungus causes yellowish spots upon the leaves. In the center of each spot are seen the tiny black fruiting bodies. These are cups of such minute size that they can be clearly seen only with the aid of the hand lens. The disease is sometimes serious, and in Iowa has at times caused a loss of one-half of the crop. Frequent cutting keeps down the disease by preventing the maturing of the fruiting bodies and thus preventing infection. The spores mature in early summer, probably in June. Diseased plants may be cut when the disease first appears.

Cup-fungus leaf-spot of clover (*Pseudopeziza trifolii Fckl.*). This fungus occasions local epidemics among clover and lucerne crops. It is one of the cup fungi but the cup is so minute that, like the cup of the leaf-spot fungus of alfalfa, it can only be seen clearly with the aid of a hand lens. It appears on a leaf in small spots where the mycelium establishes itself. These spots become thickened and from the center of each the cup uncovers by the splitting out of the upper part so that a star-shaped opening is produced and the layer of sacs is exposed. Each sac contains eight spores. The spots may become so numerous that the whole leaf or even the whole plant is destroyed. The fungus may spread with great rapidity. Burning of the fields in fall has been recommended to prevent the reappearance of the fungus in the following year. Frequent cuttings also tend to prevent the spread of the disease.

Wheat scab (*Fusarium culmorum W. G. Sm.*). The fungus of wheat scab is an imperfect fungus. It attacks the grains of the wheat just before ripening and causes the heads to ripen prematurely. The heads may be entirely or only partially destroyed. Affected parts turn whitish or are bleached. The effects often travel from above downward in the head. The mycelium runs over and through the spikelets and glues them together. A gelatinous material is formed by the fungus threads and this causes the glueing together of the spikelets. The heads turn pinkish in color and the grains shrink. The losses from this disease have at times been very serious.

Poor drainage is said to increase the amount of scab. It has also been reported that strong plants will resist the scab more successfully than weak ones. No remedy for scab is at present known.

Flax wilt (*Fusarium lini Bolley*). Flax all over the world is subject to a disease known as wilt. Whenever flax is raised continuously on the same ground for a number of years it sickens, and it soon becomes impossible to raise the plant successfully. This fact has been known for a long time in Europe and rotation of crops has long been practiced there to prevent the disease. The wilting is due to a fungus parasite which attacks the roots and stems of the flax plants in all stages. So virulent does the disease become that after six years of continuous culture of flax on one plat of ground it has been found impossible to raise one plant longer than three weeks. The following account is taken from a bulletin of the North Dakota Ag. Ex. Sta. by H. L. Bolley, who first discovered the true cause of the disease.

"The plants are attacked at all ages and die early or late in the stage of growth according to the time and intensity of the attack. If the soil is much affected, that is to say "flax sick," most of the plants are killed before they get through the surface of the ground. Such areas appear in a field of flax as centers of disease, which enlarge throughout the summer as new plants sicken, wilt, and die down around the margins of the spots, finally giving the whole field a spotted appearance. Young plants two to five inches in height wilt suddenly, dry up, and soon decay if the weather becomes moist. Older plants which are quite woody take on a sickly, weak, yellowish appearance, wilt at the top, slowly die, turn brown, and dry up. Nearly mature plants which are attacked, but not yet dead, are easily pulled up, the roots breaking off easily at about the level of the furrow slice."

FIG. 156.—Flax wilt. Wilted seedlings. After Bolley.

"Upon examination, most of the smaller branch roots are found to be dead, as well as the tap root below the point at which it breaks off. These dead roots and the parts of the tap root already diseased have a very characteristic ashen gray color. Many nearly mature plants, which are attacked late in life, show this dead gray down one side of the tap root only. The leaves, side branches, and a strip of the main stem above this portion are dead, giving a peculiar one-sided blighting, similar to the appearance of a tree struck by lightning."

"If the disease is sowed with the seed upon breaking, but a few of the plants are attacked the first year; and, at flowering time, dead plants will be seen to be quite evenly distributed in the drills. If weather conditions are quite favorable, each new infection increases sufficiently in area to reach over and attack plants in two or three adjacent drills. These infection areas are nearly always circular in outline, and become much enlarged if flax is seeded there the following year. The first year these spots may reach a diameter of one to three or four feet. The second year these same areas are usually much more than doubled, so that it takes but three to five flax crops upon such lands to make the infection general."

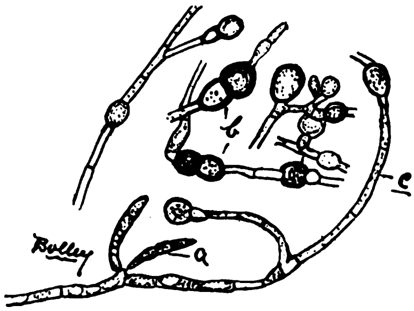


Fig. 157.—Spores of the flax wilt fungus highly magnified. After Bolley.

Diseased fields have not lost their fertility, as was formerly supposed, but can produce good crops of other plants, as corn, wheat, potatoes, etc. The disease seems to thrive on strongly alkaline lands and often under conditions of drouth.

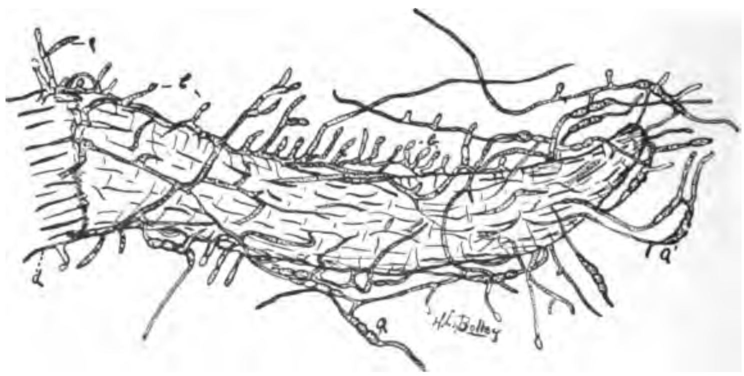


Fig. 158.—Flax wilt. The wilt fungus threads around the root of an attacked flax plant. Highly magnified. After Bolley.

The fungus is an imperfect fungus and lives normally as a saprophyte but becomes on occasion a destructive parasite. The fungus threads live in the tissues of the flax plant root, coming to the surface of the root to produce its spores. The latter are formed in a loose weft arrangement. The ordinary spore is long spindle-shaped, consisting of a string of cells. Thick-walled spores are also produced, consisting of several cells, and are capable of resting over in the soil for some time before germinating. The chief method of distribution of the fungus is by means of the spores which cling to the seeds of the flax.

Flax seed should therefore be treated before seeding to destroy the fungus spores clinging to the coats.

Professor Bolley has recommended the following treatment and preventive measures:

"Use formaldehyde at the rate of one pound of the standard strength to forty or forty-five gallons of water (the same strength used for wheat and oats). Spread the seed upon a tight floor or upon a canvas and sprinkle or spray on a small amount of liquid (a fine spray is best). Shovel, hoe, or rake the grain over rapidly. Repeat this spraying, shoveling, hoeing or raking until the surfaces of all of the seeds are just evenly moist, not wet enough to mat or gum, but evenly damp. (This can be done without matting if the grain is well hoed or shoveled over while the solution is slowly and evenly sprayed upon it.) When the seeds are just evenly moist, cease applying the solution, but continue to shovel the grain over so as to get it dry as soon as possible. Avoid any excess of moisture. If flax seeds are dipped in the solution or are allowed to get enough to soften the seed coats so that they will stick together, they will be considerably injured or even killed.

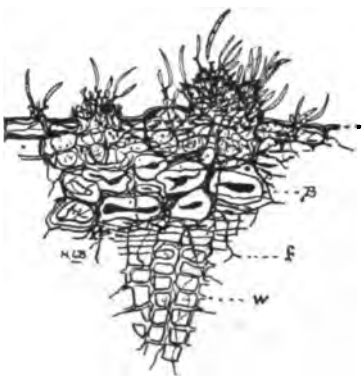


Fig. 159.—Flax wilt. A section of a flax root with fungus threads and spores at the surface. Magnified. After Bolley.

"It takes less than one-half gallon of the solution to properly moisten one bushel of flax seed.

"Caution: One must treat flax with much more care than that usually taken in treating wheat or oats for smut. The solution recommended is strong enough to kill all seeds, if they are made thoroughly wet, or if they are allowed to stay quite damp for some hours.

"The grain must be handled over immediately after treatment until it is found to be dry.

"Note: The seed should be thoroughly cleaned by running through a fanning mill before it is treated because the solution is not strong enough to kill the disease (fungus) which is inside of bits of straw and chaff.

"After treating, it may be well to sow two or three quarts more per acre, as some of the weaker seeds are apt to be killed. Scaly flax seed and seed which has been wet is always very poor for seed. Such seeds harbor the spores of fungi which kill the young plants as soon as the seeds germinate. Cease sowing flax year after year upon the same land. Put at least one cultivated crop and two or more other crops between flax crops. Burn as much of the old straw and stubble which remains upon the ground as possible. Raise your own flax seed, grade it up to the best. Watch for disease areas and notify the station. Thresh your seed, when you can, in your own machine from a patch of strong healthy flax and store it in a clean bin. Keep all the flax straw out of the barnyard, unless it is intended to put all manures through a several years' composting process. I cannot say that this process will be successful in destroying the fungus. It is destructive to most weed seeds and to the spores of many fungi. Avoid the evil effects of deep planting. Much damage is done to the flax crop of the state by too deep planting. The flax wilt disease does more injury to the seedlings when the seed is placed deep in loose soil than when planted shallow. One-half inch to three-fourths inch is the best depth. The seed bed should be of even texture and quite compact."

Downy mildew of clovers (*Peronospora trifoliorum De Bary*). This parasite attacks clovers and its relatives, such as lucerne, etc. The summer spores form on thread branches, similar to those of the downy mildew of mustards and the winter spores are also similar to the latter. Summer spore patches are pinkish grey and are found on the stems, leaves and petioles. Diseased plants should be destroyed to prevent the occurrence of the disease in the following year.

Sorghum blight (*Bacillus sorghi Burr*). This is a bacterial disease of sorghum plants. It appears on the leaves as reddish spots which are usually elongated to narrow lines. Later they increase to large irregular spots and may then entirely destroy the leaves. Both the sheaths and blades of the leaves are affected. The roots are also attacked and it is possible that the bacterium lives over unfavorable seasons in the soil. The bacterium is usually not found in the stems except in the wounded portions. It is probably found in Minnesota though not yet reported.

Land upon which diseased plants have been grown should not be sown to sorghum for a year or two. All diseased plants should be burned.

Chapter XIX.

Diseases of Garden Crops.

Orange- or red-rust of raspberries and blackberries [*Gymnoconia interstitialis* (*Schlect.*) *Lagh.*]. This rust is chiefly known on account of the destruction occasioned by the cluster-cup stages, on the raspberries, blackberries and their allies. The cluster-cup stage differs from that of most of our common rusts by the absence of a cluster-cup wall, so that the chains of spores are spread out on the surface of the leaves. These spores are produced in great numbers in early summer and late spring and form what is commonly known as the orange rust. The rust is produced on the under surface of the leaf, and wild and cultivated raspberries, dewberries and blackberries suffer. The spores fall in a dense orange powder. From golden orange, the lower surface of

FIG. 160.—Orange rust of raspberry and blackberry; to the right on a leaf of wild blackberry; to the left a normal unattacked leaflet. Original.

the leaf gradually becomes lighter yellow. The summer and winter spores are not so conspicuous and occur on the same host. The fungus threads live permanently in the raspberry tissues, so that the destruction of the whole infected plants is necessary.

All diseased plants should be dug out and burned. Spraying with bordeaux has been suggested to hold the spread of the disease in check.

The cluster-cup rust of gooseberry and currant (*Aecidium grossulariae Schum.*). The fungus causing this disease is exceedingly abundant on wild gooseberries and currants throughout the state and is also known on cultivated forms. Serious damage, however, is seldom reported. The fungus is a rust fungus and is known at present only in its cluster-cup stage. This is found on the leaves of the host plant and the cups are always found on bright, orange-yellow, swollen spots of the leaf. The cups stand on the lower surface and when they open, release the golden-orange powder of spores, which may carry the infection to other plants. The cups are accompanied by very minute pear-shaped capsules, containing spores on the upper surface of the yellow leaf-spots. The openings of these can be seen with the naked eye as small black dots on the upper surface of the leaf. These spores do not assist in spreading the disease. It is not known where the summer and winter spores are formed. They probably occur on some species of sedge.

In our lack of knowledge of the complete life history of the disease, the only suggested remedy has been the destruction of diseased parts of the plant.

Mint rust (*Puccinia menthae Pers.*). Mint rust is very abundant on a great many of our wild and cultivated mints. It is said to be very destructive to the latter, where these are cultivated on a large scale. The summer and winter spores are most abundant and form small, dark-brown, powdery patches, chiefly on the leaves. These patches, or sori, often occur in such profusion that they completely cover the under surface of the leaves. The cluster-cups are formed, as usual, in the spring or early summer and are of less frequent occurrence. They occur on the same plants. The mycelium passes the winter in the underground stems of the host. The cluster-cup stage has been reported from a greenhouse in this state where it destroyed almost an entire winter crop of mint.

The complete destruction of all diseased plants and especially all subterranean portions is necessary. (Fig. 209.)

Asparagus rust (*Puccinia asparagi DC.*). Of recent years this rust of asparagus has become of great importance in the eastern states and in California and will undoubtedly soon be of equal importance in this state. In parts of eastern states asparagus culture in whole districts has been ruined by this parasite. The cluster-cup stage is produced on the asparagus plants in the spring but is usually not conspicuously abundant. After the crops have been harvested, the summer spores appear as brownish spots on the stems of the host plant. The winter spores are produced later in long, black streaks upon the stem. The rapid spread of the fungus and the tax of the mycelium on the nutrition of the host, greatly enfeebles the plant and the crop of the following season is seriously affected. If no combative measures are used, the fungus gains strength year by year and soon enforces the abandonment of asparagus culture. The winter spores are two-celled and germinate in the usual way in the following spring. Several fungus parasites on the rust plant are known but they do not apparently exercise sufficient destructive influence to be of assistance to the agriculturalist.

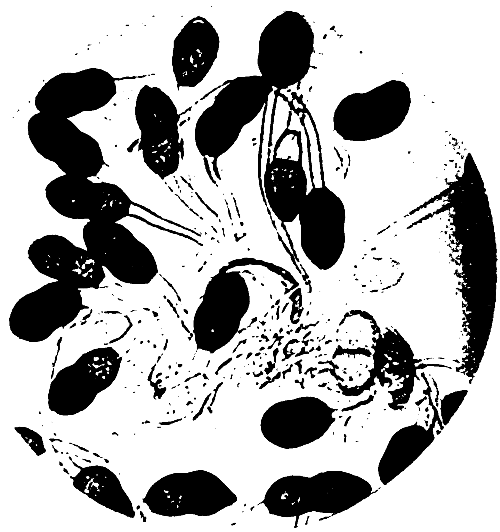


FIG. 161.—Winter spores of the asparagus rust. Highly magnified. Microphotograph by E. W. D. Holway.

This is a very serious disease and difficult to combat. It is first of all necessary to remove all badly diseased plants and to burn all infected plant remains in the fall. In badly diseased districts this method will not alone suffice. Moreover, early cutting and burning, injures the asparagus. Ordinary bordeaux mixtures have been tried but with little success. Resin bordeaux is recommended by the New York Agricultural Experiment Station where the rust has been successfully treated with this mixture. The application with ordinary barrel pumps is too laborious and slow, so that it was found necessary to devise a special sprayer, the plans and description of which are published in the bulletins of that station. (See N. Y. Ex. Sta. Bull. No. 188.) Sulphur has very recently been shown to be quite successful in keeping down the disease in California.

Bean rust [*Uromyces appendiculatus (P.) Link.*]. This is not usually one of the most serious of bean diseases, but may in some localities become a dangerous pest. It attacks chiefly the common garden bean, but has also been reported on other beans. All three spore forms occur on the same host plant. The cluster-cups are yellowish and appear in the late spring. The summer and winter spores appear later in small pustules, about the size of a pinhead. These pustules are light- to dark-red-brown and appear chiefly on the leaf-blades but can also be found on the petioles, stems and even on the pods. The pustules are circular in outline and the spore masses of summer and winter spores are powdery. The winter-spore pustules are dark-brown and may finally become blackish in color. The winter spores are single-celled and germinate in the usual method for rust winter spores.

FIG. 162.—Rust of bean. Winter spore clusters on the lower surface of a bean leaf. After Clinton.

Certain varieties of bean resist the rust and such should be planted. Infected plants should be destroyed by burning. Bordeaux mixture has also been suggested as a means of holding the disease in check, but is not in general use.

Onion smut (*Urocystis cepulae Frost.*). This is a leaf-smut and is due to a fungus somewhat similar to that of the rye smut. The smut masses appear in lines on the foliage leaves and may later appear on the scale leaves of the bulb. The spores are aggregated into true spore-balls, of which the outer spores are sterile and incapable of germination, while the inner are fertile and well protected by the outer ones. The infection of the host plant takes place in the seedling stage.

Diseased plants should be destroyed. Care should be taken not to plant seed in smut-infected soil, since the smut spores retain their power of germination for many years. Care should also be taken to prevent the transference of smutted plants or smut-infected soil from one bed to another. When seeding in infected soil, "apply in the drills per acre one hundred pounds of sulphur thoroughly mixed with fifty pounds of air-slacked lime. Formalin (one pound to thirty gallons water) thoroughly sprinkled over the seed before covered with the soil, or applied by drip attachment to the seeder, is an efficient remedy. Ground lime, drilled in the land with a fertilizer drill, at the rate of 75 to 125 bushels per acre, is helpful in keeping the trouble in check." (Conn. Ag. Ex. Sta. Bull. No. 142—1903.)

The currant pore-fungus rot [*Fomes ribis* (*Schum.*) *Fr.*]. This disease of currant bushes is probably not common but has been observed in this state. The fungus mycelium is parasitic in the root of the currant, producing its fruiting bodies at the surface of the ground, particularly around the base of the stem. The affected portions of the root-tissue turn black and the roots, and subsequently the remainder of the currant bushes, are finally killed. The fruiting bodies are dark-yellow-brown, woody, thin, saucer-shaped shelves and live from year to year. The pores are small and line the under surface of the fruiting body. The latter are sometimes six inches in diameter. It is said also to attack gooseberry bushes.

All fruiting bodies and infected plant-parts should be removed and burned as soon as discovered.

The sclerotium disease of cucumbers and other garden plants (*Sclerotinia libertiana Fckl.*). The fungus cause of this disease is a sac fungus with a peculiar life history. When the sac spores germinate at the surface of the soil they produce a my-

FIG. 163.—Pore-fungus root rot of currant (Fomes ribis), showing shelf-pore fruiting body at the base of the canes of an attacked currant plant. Original.

celium, which feeds in a saprophytic manner upon vegetable debris in the soil. After the mycelium has been strengthened by this saprophytic life it is able to infect living plants. The cucumber seems to suffer considerably but a large assembly of other plants are also subject to the attack of either this or closely allied species of fungi. The mycelium attacks the stem just above the ground and the stem at this point is covered with a fine white mold. The fungus proceeds rapidly up the stem and the latter soon falls and dies. The mycelium now continues to live in the dead tissues and builds up storage organs known as sclerotia. These are small, dark, compact masses of fungus threads in which a great amount of storage material such as fungus starch is deposited. This sclerotium lives through the winter in the dead stem and, in the spring time, produces a cluster of cup-fungus fruiting bodies with long stalks. The inner surface of the cup is lined with a palisade of sacs, each containing eight spores.

The fungus may also attack stored roots and bulbs such as dahlias, turnips and beets and has been known to cause considerable damage. Growing lettuce is also subject to attack and the resulting disease is commonly known as drop from the rapid collapse of the host plant. In this common disease the summer spores of the fungus are produced. All diseased plant parts should be collected and burned. It has been recommended that lime be sprinkled on the soil to kill off the saprophytic mycelium from which the infection takes place. The use of fresh manure should be avoided where the disease has once been found. Sterilizing of the soil has also proven successful in controlling the sclerotium disease of lettuce.

Drop of lettuce (*Sclerotinia libertiana Fckl.*). See Diseases of Greenhouse and Ornamental Plants.

Red knot of currants [*Nectria cinnabarina* (*Tode.*) *Fr.*]. This is not an uncommon disease in Minnesota. It attacks chiefly the currant and often causes the death of the canes. The fruiting bodies appear on the dead canes as small red buttons or cushions which break through the bark of the cane. In an attacked plant the foliage wilts and the fruit colors prematurely. The fruit clusters of the currant are smaller than normal and the berries fall off early. Sometimes only the central canes of the bush are killed off. The fungus fruiting cushions at first bear colorless spores, which are pinched off of threads on the top of the cushion in great numbers. The spore sacs are formed in the fall and arise in pear-shaped capsules. The latter are formed as protuberances from the summit of the button and have an apical opening, through which the spores are forced out. The mycelium is perennial in the cane and can be transferred by cuttings. An infected bush may thus be a constant source of infection. Cuttings from plants should therefore be selected from bushes free from the disease. Infection from spores probably takes place only through wounded canes. Wounding of canes should therefore be avoided as far as possible. Diseased plants should be immediately and completely rooted out and destroyed.

Strawberry leaf-blight [*Sphaerella fragariae (Tul.) Sacc.*]. This disease is a very common one in the state and attacks certain varieties more vigorously than others. It appears on the leaves and the first indication is a spotting of the leaf. The spots are circular and purple in color. As they increase in size the center of each spot becomes whitish and the edge remains purple. On the whitish area appear in early summer minute tufts of fungus threads, which constrict off countless summer spores of exceedingly small size. By means of these the fungus disease may be carried to other plants. The spots are often so numerous that they run together and cover such a considerable portion of the leaf that the latter is rendered useless for starch-making purposes. On the same white spot, later in the season or in the fall after the leaf has fallen, the winter or sac spore is formed. The sacs are produced in very minute, spherical capsules which protrude from the spot as tiny black points. They open to the exterior by means of small apertures through which the spores escape. The release of the spores is delayed until the following spring, so that infection by the sac-spore mycelium does not take place until that time.

To check the spread of the fungus spraying with bordeaux has proved beneficial and several applications should be made. The plants should be sprayed just as the leaves unfold, again after the petals fall, and once or twice after the fruit has been picked. Where the disease is serious, a removal of the plants has been recommended, or the plants may be mowed in the fall, removed and burned. Good results have also been obtained by burning over the bed with the aid of a layer of straw. The selection of varieties will also assist in the combating of the disease, as certain varieties are much more susceptible than others. (Fig. 35.)

Powdery mildew of strawberry (*Sphaerotheca castagnei Lev.*). This disease has not been reported from many localities in the United States but seems to give promise of becoming a destructive disease under favorable conditions. The leaves and fruit are attacked though the former usually suffers most. On the under surface of the leaf the fungus forms the characteristic superficial mildew of this group of fungi and when the summer spores are formed the powdery appearance is noticeable.

The leaves curl up and may finally dry up. The winter spores appear in sacs borne in the receptacles (sac capsules) usual for this group of fungi. The exact identity of the form is not known but it is probably a close relative of the powdery mildew of hops.

Powdered sulphur is usually recommended, or spraying with ammoniacal copper carbonate.

Powdery mildew of cucumbers (*Erysiphe cichoracearum DC.*). This disease has been reported as destructive to cucumbers, especially those grown in greenhouses. It is a typical powdery mildew and appears to be identical with the exceedingly common powdery mildew of composites, which appears so abundantly on a great variety of our wild plants. The mycelium appears on the leaves or stems of the cucumber as small white spots, which soon produce the mealy powder of summer spores. The spread of the infection may be rapid and the infected spots increase in size, becoming yellow and then brown, and may finally destroy the whole leaf or even the entire plant. The winter spores are formed in sacs, found in small black capsules, common in the powdery mildews. A large number of sacs is formed in the capsule and the appendages of the latter are simple and interwoven with the mycelium. When the capsules are formed, the mycelium has become a greyish or dirty white coat on the leaf surface.

Sulphur dusting, spraying with ammoniacal copper carbonate, have all given good results. The ground should not be allowed to become infested with the resting spores (winter spores), hence the diseased plant parts should be burned.

Powdery mildew of gooseberry [*Sphaerotheca mors-uvae* (*Schwein.*) *B. & C.*]. Gooseberries are not infrequently attacked by this destructive disease. The leaves, fruits and shoots are coated with a fine whitish mycelium. Summer and sac spores are produced as is usual in the true powdery mildews, and the sac capsule is in general like that of the rose mildew, though differing, of course, in minor details.

There is another powdery mildew (Microsphaera grossulariae) which is known to occur on the gooseberry though not as commonly as that described above. It can be distinguished by the many-times forked appendages on the sac-capsule and by the large number of sacs in each capsule.

"Spray with potassium sulphide as soon as buds break and repeat about every ten days until end of June." (Conn. Ag. Ex. Sta. Bull. 142—1903.)

Powdery mildew of hops (*Sphaerotheca castagnei Lev.*). This is perhaps identical with the strawberry-leaf powdery mildew, or a biologic form of this species. The mycelium of hop mildew, like that of rose mildew, is superficial and forms a whitish coat on the surface of leaves of hops. It also inhabits members of the rose, composite and other families. The fungus threads send sucker branches into the epidermal cells withdrawing from the latter their nourishment. The sac-capsules are similar also to those of rose mildew. Summer spores are also similarly produced in chains. Where hops is raised in abundance the mildew may cause very serious damage.

Bordeaux or ammoniacal copper carbonate can be used as a spray.

Powdery mildew or blight of roses [*Sphaerotheca pannosa* (*Wallr.*) *Lev.*]. See Diseases of Greenhouse and Ornamental Plants. (See Figs. 203 and 204.)

Powdery mildew of vetch and crowfoot [*Erysiphe communis* (*Wallr.*) *Fr.*]. This is sometimes found on cultivated plants of the pea family. See Diseases of Wild Plants.

Potato scab (*Oospora scabies Thaxt.*). Potato scab is an exceedingly common disease of potatoes. The cause has been the subject of some dispute among botanists but it is now generally accepted that the common form of potato scab in America is due to a parasitic fungus, while the European scab has a very different cause. The American potato-scab fungus belongs to the group of "imperfect" fungi and is found amongst the white, loose-spored forms. Scabby potatoes when freshly removed from the soil show a very delicate moldy coating, in which the loose spore-bearing threads are found. The surface of an attacked potato becomes roughened and scabby, hence the common name of the disease. The fungus can remain in the soil for several years and badly infested fields should not be sown to potatoes. Since the fungus is a lurking parasite and gains entrance through the potato skin, it has been found that a treatment of the "seed" potatoes will kill off the scab fungus. Immersion in a solution of one pound of corrosive sublimate to fifty gallons of water for one and one-half hours will free the potatoes from scab providing other precautionary measures are taken. After treatment, the potatoes must be kept free from the disease. They must not, for example, be brought into contact with other diseased potatoes or must not be planted in soil which is badly infested with the scab. A formalin solution may also be used as a steep. This solution is made up of one pound of formalin to thirty gallons of water, and the "seed" potatoes are immersed for about two hours. The corrosive sublimate solution is very poisonous; potatoes treated by the first method must therefore never be fed to stock.

FIG. 164. Potato scab. After Clinton.

Scab of beet. See Potato Scab.

Anthracnose of currant and gooseberry [*Gloeosporium ribis* (*Lib.*) *Mont. et Desm.*]. This disease is well known in Minnesota. The fungus appears on the upper surface of the leaf in very minute black spots which are cushions of fungus threads. These are formed under the epidermis and then burst through, finally producing spores on the surface of the cushion. The fungus is therefore one of the cushion-forming "imperfect" fungi. The spores cling together in gelatinous masses. When the spots are very abundant the leaf turns pale and falls. The whole bush may thus be deprived of its foliage and in consequence may be seriously injured. The fruit on such bushes is usually inferior and the crop for the following year may also be damaged. Treatment with bordeaux has been recommended, as follows: "First spraying with bordeaux before leaves appear, the second as the leaves are unfolding, and repeat at intervals of ten to fourteen days until the fruit begins to turn." (Conn. Ex. Sta. Bull. 142—1903.)

Bean anthracnose [*Colletotrichum lindemuthianum* (*Sacc. et Magn.*) *Bri. et Cav.*]. Beans are very frequently attacked by anthracnose. The fungus causing this disease is an imperfect fungus belonging to the cushion-forming group. It attacks the pods and also the leaves but is more commonly found on the former. Blackish spots are formed with purplish edges and these spots enlarge, and when abundant may cover a large part of the pod. The tissue under the spot is sunken so that the fungus-thread cushions, which are formed in the center of the spot, are at the bottom of small sunken areas. These cushions bear numerous upright threads, from which spores are pinched off, and between these threads arise sterile, sharp-pointed, dark, spine-like threads, which bristle from the top of the cushion in a formidable manner.

Spraying with bordeaux has been recommended and should commence when the plants are small. They should be made at intervals of a few weeks until the pods are ripening. Damp situations should be avoided and all badly diseased plants should be destroyed. The disease can be carried along with the seed so that it is necessary to avoid seed from infected pods. Care must also be taken to avoid planting beans in badly infected fields.

The leaf blight of celery *(Cercospora apii Fr.)*. The fungus causing this disease is a loose spored, imperfect fungus. It causes the formation of reddish to brownish spots on the leaves, which may spread and increase in size until the leaf is seriously injured. The fungus thrives well on plants in dry situations and is particularly effective against young plants. When badly affected the leaf turns yellow and finally brown. Spots may also appear on the stem. The spores arise from upright fungus-threads in the center of the spot and are arranged in a fine, loose, moldlike growth. Shade and moist situations have been recommended, but are only partially successful. Spraying will also keep the fungus in check. The spraying should commence early and bordeaux may be used at first but the ammoniacal copper carbonate is used in the later sprayings.

FIG. 165.—Anthracnose of bean. After Halsted.

The leaf spot of beets (*Cercospora beticola Sacc.*). This is a common spot disease on the leaves of the beet. The cause of the disease is a loose-spored imperfect fungus. It forms small circular spots on the leaves, often in great abundance. The spots have a purple border and whitish centers, where the loosely arranged threads bearing the spores are found.

Spraying with bordeaux mixture has been recommended. Frequent applications should be made throughout the growing season.

Black rot of tomato (*Macrosporium tomato Cooke*). This fungus attacks chiefly the fruits but is also found on the leaves and stems. It is probably identical with the fungus of early potato blight. It forms on the fruit circular spots, under which the tissues soften and become discolored. The fungus threads form black, velvety masses in the center of the spot and these masses increase rapidly in size until large mold-like patches are produced. The dark spores are pinched off of the threads which are formed in a loose arrangement on the surface of the fruit. This parasite is a sac fungus of the black fungus group but the sac spores are very uncommon.

Bordeaux mixture has proved successful in combating this disease. The first treatment should be given when the flower buds open and should be repeated at intervals of two weeks.

Early blight of potatoes (*Macrosporium solani Ell. et Mart.*). This disease is easily mistaken for the ordinary or "late blight," but has an entirely different cause. It affects early crops and is in general found early in the season. The general symptoms are those of premature ripening of the plants. The leaves turn yellow toward the edge, curl up and finally become dark brown. The entire plant is weakened and may die early, giving the appearance of early ripening. The fungus is similar if not identical with black rot of tomatoes.

Vigorous plants are said to withstand the attack, so that careful cultivation has been recommended. Bordeaux mixture applied early in the season is also an effective preventive.

The sterile-fungus rot of garden plants (*Species of Rhizoctonia*). All kinds of garden plants are affected by a rot which attacks the roots or lower stem and which frequently causes the death of a great many plants. The classification of this fungus cannot at present be determined, since it has never been found to produce spores. It is therefore called a sterile fungus, though it is of course possible that spores are formed under unusual and rare conditions. The fungus produces tufts of threads on the infected parts of the host plant. These thread tufts are usually brown or blackish. The threads are brown and branch irregularly in forking fashion and often break up into lengths which may germinate in the fashion of spores, but these lengths are not considered real spores. The following list will show some though not all of the plants attacked by this fungus in the United States: bean, beet, carrot, celery, cabbage, cauliflower, lettuce, potato, radish, rhubarb, ornamental asparagus, china aster, sweet william, coreopsis, and violet. In many cases this fungus can be shown to be truly parasitic but in others is doubtfully so. It is usually capable of unlimited growth in a saprophytic manner.

The elimination of unfavorable conditions of temperature and moisture are recommended. Freshly decaying vegetable matter should be removed. The soil may be limed as an aid but is not an absolute preventive. A complete sterilization of the soil should entirely prevent the disease.

Grey mold of lettuce. See Diseases of Greenhouse and Ornamental Plants.

White rust of mustards, cabbage, etc. [*Albugo candidus (P.) Ktze.*]. This is one of the most widely distributed fungi known. It occurs on all kinds of plants belonging to the mustard family on both wild and cultivated forms. It is most commonly found on the wayside weed known as shepherd's purse, but is also found on many other wild mustards. Amongst cultivated plants the following are frequently infected: radishes, horseradish, cress, cabbage, turnip, water-cress and wall flower. Plants closely related to the mustard, e. g., caper plants, are also known to become infected.

The fungus attacks the plants in the seedling stage through the seed leaves. The mycelium very frequently causes abnormal and distorted growths in the host plant and in these regions the summer spores are formed. These are produced in extensive patches which at first have a porcelain-like appearance. Later, by the bursting of the superficial tissue of the host plant, the spores are set free as a white powder, hence the name white rust. The spores are formed in chains and the spore powder is blown by the wind to other plants. The spores require moist conditions for germination, and under these conditions break up into tiny swimming spores which scatter the infection by moving about in the drops of water on the leaf. When they come to rest they germinate into a tube which infects the leaf. The winter spores are formed as a result of a breeding act between two swollen organs formed on the fungus threads and are provided with a thick coat. They are produced within the tissues of the host and are set free in the following spring by the decay of the tissues. These winter spores produce swimming spores in a similar manner to the summer spores.

This is not usually of serious importance to crops in this state. Diseased plants should be destroyed.

Downy mildew of mustards, cabbage, etc. [*Peronospora parasitica (P.) DeBy.*]. This disease usually accompanies the white rust of the same plants. It is found in general upon the same plants as white rust and often causes deformations of the host. The summer spores are produced on filmy patches of a downy nature and can thus be distinguished from the white rust. They are not produced in chains but in clusters on much-branched threads, which protrude from the leaf of the host and give the downy appearance to the infected regions. The winter spores, which are similar in appearance to those of white rust, do not, however, produce swimming spores, but germinate into an infection tube.

For preventives see White Rust of Mustards, etc.

The downy mildew of potato. Potato blight [*Phytophthora infestans (Mont.) DeBy.*]. This disease has proved an exceedingly destructive one both in the United States and in Europe. It was first known in the United States between 1840 and 1845 and was introduced into Europe about 1845. It probably came originally from South America, where it grows on many wild plants of the potato family. Shortly after its introduction into Europe, it caused complete failure of the potato crop in many districts. In America it causes most damage in the eastern states and is apparently not so destructive in Minnesota, though by no means unknown in this state. It may sometimes be found growing on close relatives such as tomato and other members of this family. The parasite has the typical habit of the downy mildews and hence grows best in moist seasons or in low-lying, damp situations. The mycelium is destructively parasitic and as soon as it is established in the leaves of the host plant causes a diseased condition. The first indication is the appearance of brownish spots, which rapidly grow darker and finally become blackish. The discoloration is often accompanied by a crumpling of the leaves. The diseased leaves finally suffer complete decay and produce an offensive odor.

The lower surface of the leaf-spots is seen to have a very delicate downy coat, which increases to a white band around the border of the spot. Here are produced the spores, which are formed in a manner peculiar to the potato blight and its close relatives. The method of spore formation serves to distinguish these forms from the downy mildew of vines and other downy mildews. The spore-producing threads pinch off spores from their apices and then the thread grows past the spore, shoving the latter to one side. It grows on for a short distance and then produces another spore apically. The threads show somewhat pointed ends. They are, moreover,

FIG. 166.—Potato blight. Early stages of the blight on the leaves. After Clinton.

usually much branched, so that a miniature bush-like structure is produced and each branch terminates in a spore. These spores, as is true for most of the downy mildews, are in reality spore cases, for when placed in water they later give rise to a large number of swimming spores. When the latter come to rest they germinate into a tube which causes infection of the host plant. As far as is known at present, no winter spores are produced. The mycelium, however, is capable of living in the above ground stems and in the tubers of the potato, and may live in the latter over winter, producing a brown rot of the tubers. In the following spring they can again cause infection by growing up into the stem and leaves. It is there-

Fig. 167.—Potato blight. Later stages on the leaves. After Clinton.

fore unsafe to use for seed potatoes tubers harvested from an infected crop.

"Spray with bordeaux before the trouble appears, about July 7th to 10th, and keep vines well covered, especially from the middle of July to the middle of August. Unless season is very moist three sprayings should suffice. If this treatment is impossible plant early varieties only." (Conn. Ex. Sta. Bull. 142—1903.)

It has been claimed by various authors that the bordeaux spray not only destroys the parasite but improves the foliage of the potato as well. Diseased plants and tubers should be burned. Wet soil should be avoided, if possible, for infection can take place in the tubers in spring as well as in the leaf. Thick-skinned potatoes have been recommended as more resistant to the fungus than thin-skinned ones so that, for storage in particular, these varieties should be selected. (See also Fig. 39.)

Downy mildew of onion (*Peronospora schleideni Ung.*). The mildew of onions has long been known in Europe where it is much feared. It has now become established in many places in the United States and has appeared in abundance in Wisconsin. The fungus, like the other downy mildews, produces summer and winter spores. The former are produced on the leaves upon threads in a manner similar to that in the grape mildew. They give to the leaf a grey to green, moldy appearance and the leaf-gloss appears to be lost. The spores in moist conditions produce swimming spores, but are very sensitive to, and easily destroyed by, drying. The winter spores are provided with a thick protective coat. They are very resistant and in the spring following their formation produce swimming spores in a manner common to the downy mildews. The fungus is very common upon plants raised on previously infected land and in such cases infection is almost certain. The disease spreads rapidly and may cause great damage in a single season.

Infected plants should be destroyed to prevent future infections. When a field is badly infected, as when infected plants are left on the field, the rotation of crops becomes necessary. Spraying with bordeaux has given satisfactory results in combating this disease. In some cases this has proved injurious to the foliage when used in standard strength. There is also difficulty in making the bordeaux adhere to the very glossy surface of the onion leaf. Powdered quicklime (two parts) and sulphur (one part) has been recommended for checking the disease in the early stages. Spraying with potassium sulphide is also effective. Of chief importance are the avoidance of too damp conditions and too much shade, the removal of infected plant parts and the rotation of crops, if necessary.

Downy mildew of cucumber, melon and other gourds [*Plasmopara cubensis (B. & C.) Humpf.*]. This has proven in certain parts of the United States to be an exceedingly virulent disease and has threatened to completely destroy the pickle crops in those districts. It is not as yet known to be common in Minnesota, but it will probably appear here in time and the farmer who is employed in the growing of cucumbers or other gourd fruits will do well to know the disease and to keep a sharp lookout for it. It is known to attack cucumbers, muskmelons, pumpkins, warty and winter squash, watermelons and various other gourd fruits. Unlike the powdery mildew of the cucumber, it is more common in fields and gardens than in greenhouses, but it is not unknown under the latter conditions. It is in many places the chief enemy of cucumber culture. An important feature lies in the fact that it can spread from one host to another.

The disease is best recognized by the action upon the foliage, though it is by no means confined to the leaves, but may occur on the stem as well. Infected leaves turn yellow in spots and these yellow spots are bounded by the veins of the leaves and are therefore usually four-sided and angular. They are up to a quarter of an inch across, but by joining with neighboring spots may become much larger. The spots increase in size and number with great rapidity until the whole leaf finally becomes yellow, then dries up and shrivels. The oldest leaves, i. e., those nearest the hill, are usually first affected and then the disease travels toward the tip of the host plant with great speed. The spread of the disease is particularly favored by hot weather and by a damp atmosphere. The yield of cucumbers is quickly affected, because the whole plant is rapidly weakened or may be entirely destroyed. On the older plants

FIG. 168.—Downy mildew of muskmelon. Blighted vine in the field. After Clinton.

one finds on close examination a fine down, sometimes of a purplish tinge, covering the under side of the leaf. This is caused by the fungus threads, which bear the summer spores. The latter are produced in a similar manner to those of the downy mildew of grapes and are carried by the wind to other leaves and plants. Here they form a large number of swimming spores, which further scatter the infection under proper conditoins of moisture. The swimming spores germinate into infection tubes, and thus establish a mycelium within the leaf. This fungus has not been known to produce winter spores,—probably does, however, under rare conditions. The method of wintering over is therefore at present unknown. It undoubtedly does, nevertheless, pass the winter safely, as has been shown by the experience of cucumber growers in many places.

"Repeated sprayings with bordeaux about every ten days during a season, beginning at least by the middle of July, is useful in keeping this disease in check." The number of sprayings is dependent on the season. In very wet seasons more may be necessary. If the under surfaces of the leaf can be sprayed, the results will be most successful, but great gain is possible by the ordinary method of spraying.

Downy mildew of beans, peas, etc. (*Phytophthora phaseoli Thaxt.*). A downy mildew frequently attacks cultivated beans and closely related plants and may create a very serious amount

FIG. 169.—Downy mildew of muskmelon, showing the under surface of an attacked leaf. After Clinton.

of damage. The summer spores are produced in a similar manner to the blight of potatoes. The young stems, leaves and pods are attacked. The downy patches on the pods are usually dense, woolly growths, whitish in color, while those on the stems and leaves are less dense. As with most downy mildews, moist seasons or moist situations favor the growth of the disease.

Diseased plants should be burned to prevent the recurrence in following seasons. "As the fungus usually appears first and most vigorously in low, moist places, the land used should be high or well-drained. Spraying, beginning with bordeaux and ending with ammoniacal solution of copper carbonate and repeated every ten to fourteen days from the last of June until the first part of September, is helpful in keeping this trouble in check." (Conn. Ex. Sta. Bull. 142—1903.)

This disease is known in eastern states but has not been reported from Minnesota.

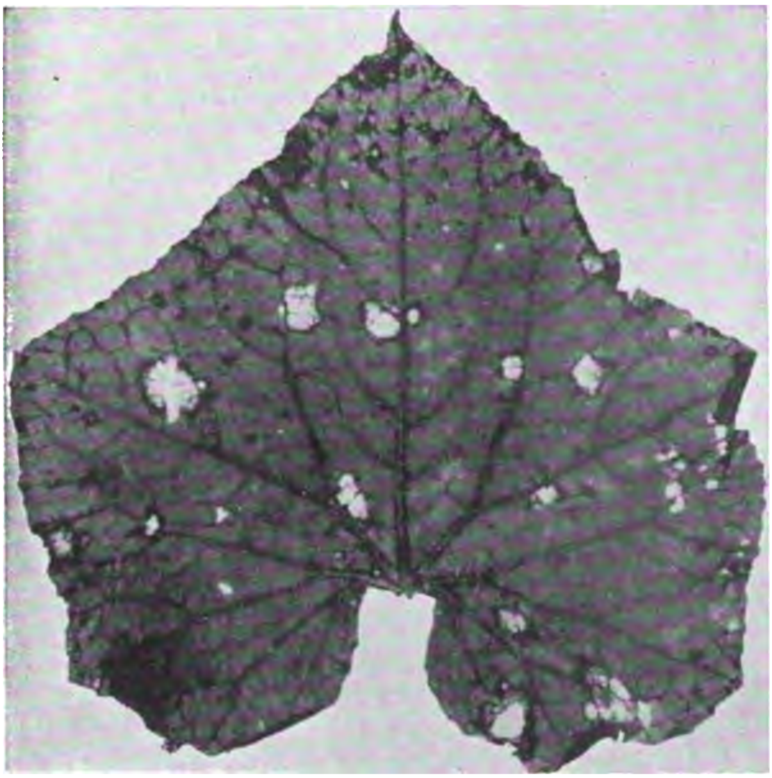


FIG. 170.—Downy mildew of muskmelon. Under surface of an attacked leaf. After F. C. Stewart.

Downy mildew of lettuce (*Bremia lactucae Regel.*). Lettuce in gardens and particularly in greenhouses is attacked by a downy mildew. The spore patches form filmy, grey, mold-like growths on the lower surfaces of the leaves. The spores are borne on much branched threads which terminate in four or five short stalks arising from the rim of a saucer-like expansion. At the ends of these stalks the spores are produced. The fungus

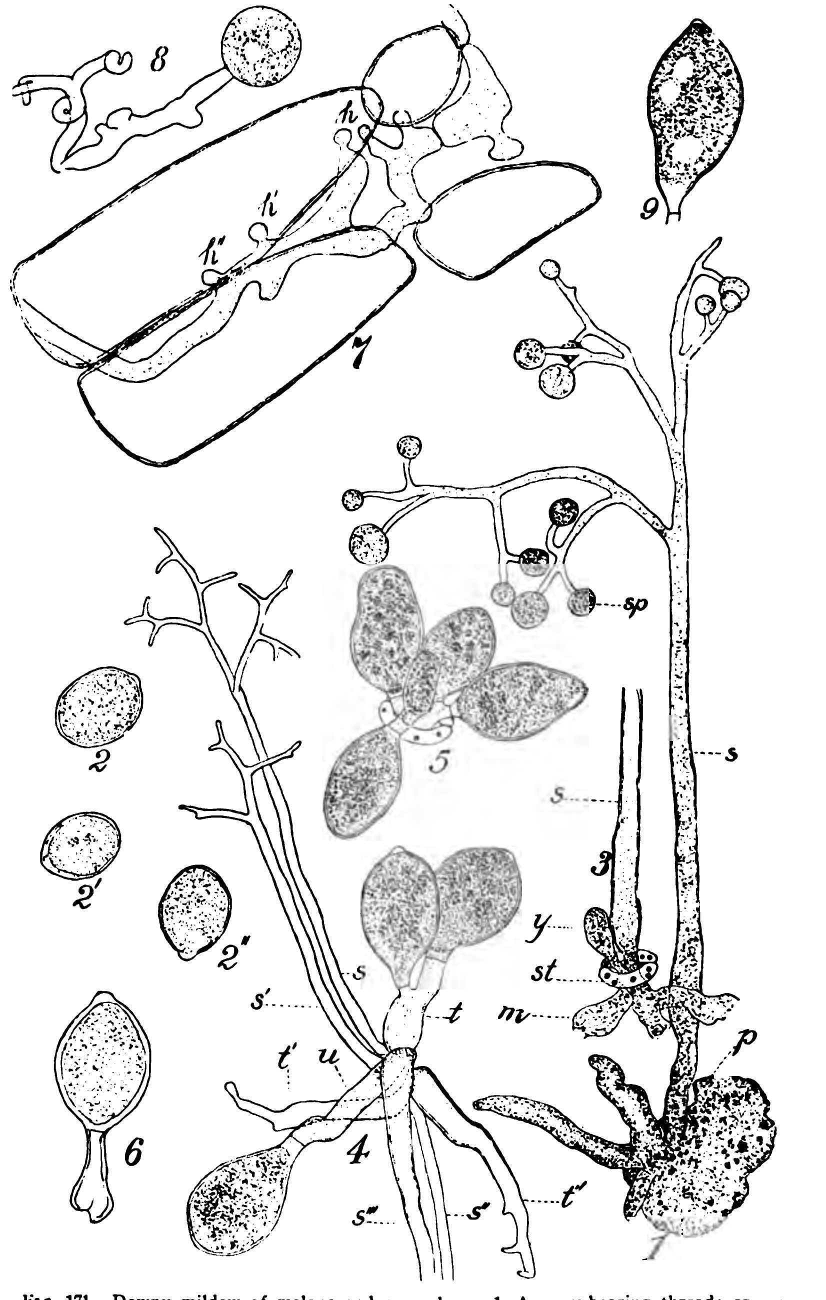


FIG. 171.—Downy mildew of melons and cucumbers. 1. A spore-bearing thread; sp. young spores; 2, 2' and 2'', mature spores of the ordinary form. 3. Spore-bearing thread emerging from an air-pore on a leaf. 4. A cluster of spore-bearing threads taken from a cucumber leaf in dry weather. t, unusual types of spore-bearing threads and spores. 6. A short stalked spore from a muskmelon leaf. 7. Cells of a cucumber leaf with the fungus mycelium between them; sucker threads h, h' and h''. 8. An unusual type of spore from the cucumber. 9. A very large pear-shaped spore of unusual occurrence. Highly magnified. 7. After Humphrey; all of the others after F. C. Stewart.

thrives best in a moist atmosphere and damp situations, hence is often luxuriant in greenhouses. Infected plants are stunted and turn pale yellowish in color.

"This disease is kept in check by subirrigation or care in watering and ventilating to keep plants and atmosphere as free from moisture as is consistent with good growth." (Conn. Ex. Sta. Bull. 142—1903.) It has been recommended that infected frames and houses be abandoned for lettuce culture at least for a time.

The downy mildew of beets (*Peronospora schachtii Fckl.*). This disease may prove a serious pest in the raising of beets. The fungus attacks chiefly the inner leaves and in seedling plants may cause the death of the plant. The spore patches are on the under sides of the inner leaves and are greyish, mold-like patches. The fungus threads are said to be able to live through the winter in the roots.

The infected plants should be burned. Rotation of crops has been recommended in order to give the mycelium in the roots a chance to die out.

The downy mildew of spinach [*Peronospora effusa (Grev.) Rabh.*]. Spinach and the other plants of the goosefoot family are frequently attacked by a downy mildew which may cause serious damage. It is also found on wild plants of the same family. The mold patches of summer spores are found on the lower surface of the leaf and are greyish lilac in color. The winter spores are similar to those of downy mildew of clover.

The diseased plant should be burned to prevent the spread of the disease and its recurrence in the following year.

Downy mildew of clovers. See Diseases of Field and Forage Crops.

Downy mildew of violet (*Peronospora violae DeBy.*). See Diseases of Greenhouse and Ornamental Plants.

Damping-off of seedlings (*Pythium debaryanum Hesse.*). See Diseases of Greenhouse and Ornamental Plants.

The seedling disease of cabbages [*Olpidium brassicae (Wor.) Dang.*]. This disease is probably not serious in Minnesota. It attacks seedling cabbages and causes a dropping of the plant by the death of the stem. The fungus belongs to a very low order of algal fungi and consists of a single cell which invades the host plant, living in one cell of the host. When it forms spores it develops a long tube, which reaches to the surface of the host plant and throws out spores, which are provided with swimming lashes and by means of these swim in raindrops or in the dew. The swimming spores come to rest and invade the same or other plants. A thick-coated, resting winter-spore is produced inside of the host and this may carry the plant over to the following year. Diseased plants should therefore be burned and cabbages should not be planted in beds in which the disease has been serious. As the fungus is a water-loving plant, the seed beds should be well ventilated and kept as dry as possible. Too moist atmospheres should be avoided.

Fig. 172.—Bacterial rot of potato. After Clinton.

Wet rot of potato *(Species of Bacillus).* Wet rot is a well known bacterial disease. The bacteria enter the potato through wounds or through the ventilating holes in the skin (cork), and when once inside, they commence the destruction of the contents of the tuber. Large cavities appear in the tuber containing a fluid mass, with the potato starch grains still intact. The tuber soon becomes soft and the entire center is filled with a putrescent mass, from which the common name of wet rot is derived. This fluid mass is at first acid, on account of the formation of carbonic acid gas, and the acid of rancid butter. When, later, the decomposition has proceeded still further, ammonia gas and other complex organic compounds are formed which give to it an alkaline reaction.

Rotation of crops has been suggested to prevent a recurrence of the disease.

Wilt of cucurbits (*Bacillus tracheiphilus Sm.*). Squash, muskmelons, cucumbers and their relatives are attacked. The existence of this disease has not yet been reported from Minnesota but is well known in eastern states. The disease is caused by bacteria which gain entrance chiefly through wounds in the stem or leaf. These wounds are often caused by insects. The bacteria immediately seek out the water-conducting tissues and settle there in such great numbers that the flow of

FIG. 173.—Bacterial wilt of squash. After Clinton.

water is impeded. The result is a wilting of the plants and death usually follows. This disease is of interest, in that it shows an unhealthy condition in the host plant, induced not by a directly destructive action of the disease-causing organism, but by the interference with the normal life processes of the plant, i. e., the obstruction of the water-conduction current.

The sprays which are used for downy mildew and anthracnose of cucurbits will prevent this disease. Rotation of crops has also been recommended but is an uncertain aid and is doubtfully of use.

Bean leaf blight(*Pseudomonas phaseoli Smith*). This disease is of bacterial origin. It has not been reported from Minnesota but is well known in the eastern United States. It causes a brown tipping of the leaves or dead spots in the leaf. The entire leaf may die. Bean insects, irrigation and mulching are said to have a tendency to increase the disease and certain varieties are more susceptible than others.

Black rot of cabbage(*Pseudomonas campestris Smith*). This is a bacterial disease and causes a rotting of the plant. Cabbage and a large number of related plants are affected. The

FIG. 174.—Black rot of cabbage. A badly infested field. After H. L. Russell.

following list of plants has been reported as sufferers from this rot: cauliflower, kohl rabi, kale, brussel sprouts, broccoli, collards, turnips, rutabagas, winter radish and still others. Rutabagas and their allies are not so commonly nor so severely attacked as the cabbage group.

The effect of the disease is first seen at the edge of the leaf. The lower leaves are most commonly invaded but all of the leaves of a head may be attacked at once. The bacteria work downward along the veins of the leaf to the stem of the plant. The invaded veins turn black. From the stem the bacteria spread outward again with great rapidity. The attacked

FIG. 175. Black rot of cabbage. Artificial infection of cabbage plants. The plants in the center (2), and on the right (1), were inoculated six weeks previously with bacteria. The plant on the left (3) was not inoculated and is therefore unaffected. After H. L. Russell.

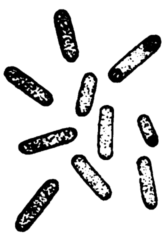


FIG. 176.—Black rot of cabbage. Bacteria highly magnified. After H. L. Russell.

leaves wilt, turn yellow and finally dry up, when they become somewhat papery in appearance. The disease may appear in stored cabbage in which the heads may be entirely destroyed. Other rots assist in transforming the diseased heads into a rotting, bad smelling mass. Cabbage for storage should therefore be carefully inspected and where any blackened veins in the leaves show should be rejected. The bacterium gains entrance either through wounds or through the water-pores at the edge of the leaf. Rainy, moist weather assists in the spread of the disease.

Refuse matter should be removed from the field. Rotation of crops will assist in ridding, in part at least, the soil of the disease. Low, damp soils should be avoided and if irrigation is practiced reduction of moisture will prevent the formation of water drops at the water-pores on the leaves, and thus reduce the number of chances of infection. Diseased plants can readily be detected by breaking off the lower leaves and examining the stalk. If the fibres of the leaf-stalk are blackened, the plant is diseased and should be rooted out and entirely destroyed.

Allowing these plants to remain on the field only increases the danger. It has been found possible and profitable to attempt

Fig. 177.—Black rot of cabbage. Cabbage heads, apparently sound, are attacked by the rot. The progress of the disease is seen in the blackened parts of the stems and leaves. After H. L. Russell.

a control of the disease in its early stages by a close inspection of the young plants and by picking off the infected leaves.

Fig. 178.—Black rot of cabbage. A cabbage leaf showing the manner of infection. Diseased area (B) unshaded except the blackened meshes of veinlets. A. A hole eaten by insects. The disease was introducd at this point and spread backward to the main rib. C. Blackened veinlets affected by the disease. D. Water pores of the cabbage leaf through which the disease germs gain a foothold, producing marginal infection. After H. L. Russell.

Club-root of cabbage, radish, turnip and other cruciferous plants (*Plasmodiophora brassicae Wor.*). This disease is not uncommon in Minnesota but the exact extent of its distribution is not known. The cause of the disease is not a true fungus but is a slime mold or fungus animal. It forms no fungus threads but produces spores somewhat similar to those of the true fungi. The spores gain entrance to the host plant, usually in the root region though the parasite may also exist in the leaf.

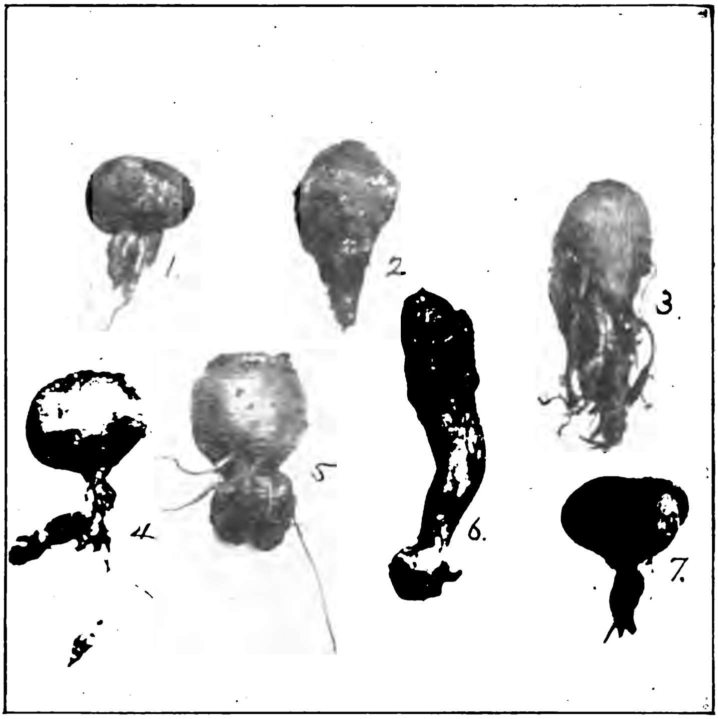


FIG. 179.—Club-root of turnips. 1. Strap-leaf. 2. Aberdeen. 3. Rutabaga. 4. Snowball. 5. Golden Ball. 6. Cowhorn. 7. Kashmyr. After Halsted.

It lives within the host in a truly parasitic manner, destroying the cells in which it dwells. It causes, however, great stimulation of the tissues of the host, so that the latter produces wart-like growths on its roots. The roots, moreover, become much distorted, hence the common name of club root. The host plant is much weakened by the attack and usually fails to head out. The roots soon decay and thus the animal organisms, which have already formed great numbers of spores, return to the soil. Cabbages, radishes, turnips and even common weeds of the mustard family, such as shepherd's purse, when planted in such infected soil, will almost certainly become infected. Even the transferrence of soil from such an infected field to an uninfected one, as by clinging to wagon wheels or farm implements may carry infection with it. Manure from cows fed with clubbed roots will easily infect crops.

No entirely successful treatment of club root is known. A number of varieties of turnips have been tested and the rutabaga was found most susceptible. In general, it seems that those turnips with branching and deeply seated roots are most susceptible, while those that do not penetrate deeply and which are not much branched are least affected. Experiments also seem to indicate that buckwheat grown in turnip land has a favorable effect on the resistance to club root. In general, infected fields should not be used for the same crop—or for any plants of the mustard family—for several years, as the slime mold seems to be able to retain its vitality at least for two or three years. The infection of new fields must be carefully avoided, by preventing the transference of soil or refuse from the infected fields to other plots. The application of a coating of lime to the soil in the proportion of seventy-five bushels to the acre has been tested and has given very satisfactory results. Weeds of the mustard family must be carefully held in check.

FIG. 180.—Club root of cabbage. After Clinton.

Chapter XX.

Diseases of Orchards and Vineyards.

Orchards.

General treatment of apple orchards. The following has been recommended as a general treatment for apple orchards to keep out common fungus and insect pests. (Connecticut Agricultural Experiment Station Bulletin No. 142.)

"1. Spray with copper sulphate solution just before buds start, for Bitter Rot, Black Rot and Scab. This treatment is often omitted.

2. Spray unfolding leaves with Paris Green or Lead Arsenate in Bordeaux for Bud Moth and Apple Scab.

3. Spray with same as soon as blossoms fall for Codling Moth, Curculio, Canker Worm, Tent Caterpillar, Scab and Sooty Blotch.

If badly infected with Sooty Blotch or Scab, spray with Bordeaux mixture ten days later and for Sooty Blotch follow with further spraying.

San José Scale, Bark Lice and Borers need other treatment."

Leaf rust of apples and pears. Cedar apples of red cedar (*Gymnosporangium macropus Link and Gymnosporangium globosum Farl.*). One very commonly finds on the under surface of the leaves of our apple trees large yellow spots, upon which are produced, in spring and early summer, long cluster-cups with beak- or horn-like tops. The leaves are often swollen in the region of these spots and almost no leaf-green is present. The spots frequently occur in sufficient numbers to completely cover many of the leaves and in this case very seriously injure the foliage, and consequently considerably impair the strength of the tree. In the cluster-cups are produced the cluster-cup spores. These spores infect young twigs of the red cedar, which soon swell up, forming a ball-like growth which is known as a "cedar apple."

The fungus passes the winter in this diseased portion of the cedar and in the following year the winter spores are produced in early spring. They are formed in a large number of cone-shaped groups arising from little saucer-like depressions, scattered all over the surface of the cedar apple. Each spore is provided with a long stalk which swells up in rainy weather. Since the winter spores are produced in large numbers there are formed long (G. macropus) or short (G. globosum) beak-like, gelatinous masses with a bright, orange-brown coating of

Fig. 181.—Cedar apples of red cedar. 1. Showing the swollen branches of the cedar with the winter spore gelatine masses removed (Gymnosporangium globosum). 2. Cedar apple of the same fungus with the gelatinous masses of winter spores. 3. Cedar apples caused by another rust fungus (Gymnosporangium macropus), showing masses of winter spores. 4. Same as 3, but larger specimen. Original.

spores. The cedar apples are therefore very conspicuous in wet weather. Some cedar apples (G. globosum) produce winter spores for several seasons in succession while the others (G. macropus) produce spores only one season and then die. The winter spores grow out immediately, while still in the gelatinous mass, and produce a number of tiny spores (sporidia), which are caught up by the wind and carried to an apple tree or thorn tree. Here infection takes place on the leaves of the host, where the cluster-cups are soon again produced.

Fruit tree culture is often seriously damaged by this apple rust, and the disease may become epidemic over considerable areas.

Since cedar trees are a harbor for the fungus, these trees should be carefully watched and removed if necessary. At any rate, branches bearing cedar apples should be promptly removed and burned. It has also been recommended that diseased leaves and badly infected branches of the apple tree be burned, and that the entire tree be destroyed if badly rusted. Spraying has been recommended, but is considered by many to be of doubtful value. Bordeaux is used, and the first spray is given just as the leaves expand and the second a few weeks later. A third is recommended in very rainy seasons. As different apple varieties vary in their power of resistance to this rust, resistant varieties may be selected where damage from this rust is very great.

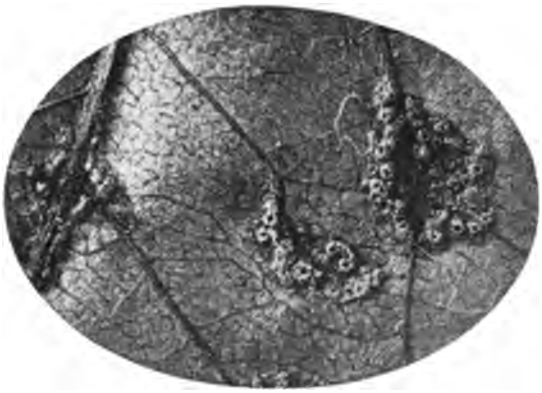


FIG. 182.—Rust of apple leaves. Cluster-cup stage of a cedar apple fungus. After Clinton.

The two following diseases produce leaf rusts of apple very similar to the above.

Club rust of juniper [*Gymnosporangium clavariaeforme (Jcq.) Rees.*]. Another disease, similar in its effects to those of the cedar apple and birds'-nest rust of red cedar, is a rust which attacks our common juniper bushes. An attacked branch swells up into a club-shaped body, often of considerable length. From the surfaces arise, in early spring, small, yellowish, club-shaped or cone-shaped groups of winter spores, which swell up in moist weather. Very small spores (sporidia) are produced in a similar manner to the cedar apple and these infect the leaves of thorns or apples, where the cluster-cups are formed, also in a similar manner to the above-mentioned rusts. The disease may be dangerous to both ornamental junipers and to orchard apple trees.

The preventive measures are similar to those of the leaf-rust of apples produced by the cedar-apples of red cedar.

The birds'-nest rust of red cedar (*Gymnosporangium nidus-avis Thaxt.*). This is a rust disease similar to that of the cedar-apple of red cedar. When this fungus attacks the red cedar an enormous number of short branches are formed. They are densely bunched together and look like a miniature tree perched on the limb of the cedar tree. This bush-like growth is known as a witches'-broom. At a distance it is not unlike a very large birds'-nest in appearance. On examining the branches of the broom, one sees that the leaves are larger and stand out at a greater angle from the branch than do the leaves on the normal branches; they are also very sharp-pointed and the general habit of the branch is more similar to that of the common juniper tree. Near the base of the leaves in the diseased portions of the cedar are found small, brownish, gelatinous cushions of the winter spores. These appear at the end of April. The cushions, just as do the beak-like processes of the cedar apples, swell up in wet weather and shrivel up again when dry. Under moist conditions the winter spores germinate and produce tiny spores (sporidia), which are carried by the wind to june-berry bushes or apple trees. Here the fungus again develops a mycelium and causes a rust disease which is very difficult to distinguish from that caused on the same plant by the cedar-apple rust.

The preventive measures are similar to those recommended for cedar-apples of red cedar and their leaf-rust of apples. (Fig. 26.)

Plum leaf rust (*Puccinia pruni Pers.*). On the leaves of many of our wild cherries and also on those of cultivated plums, cherries, etc., is often produced a rust known as plum-leaf rust. Only summer and winter spores are produced and they occur in groups or sori on the under surface of the leaf. The summer spores are light brown or reddish and the winter spores are darker. The spores arise in small, yellowish spots on the leaf and these spots often occur in sufficient numbers to considerably damage the plant. The winter spores are two-celled.

Spraying with dilute bordeaux has been recommended just as the buds are opening and the leaves are expanding, and at intervals later. The fallen leaves should be burned.

FIG. 183.—Apple scab on the fruit. After Clinton.

Apple scab [*Venturia pomi (Fr.) Wint.*]. Apple scab is by far the most serious disease of apples. The fungus first appears in early summer on the leaves of the apple tree as light, greyish, circular spots which spread rapidly, often combining with neighboring spots to cover large areas of the leaf. The spots later turn olive green and finally black. The surface is covered with upright threads from which the summer spores are thrown off. These spores rapily increase the spread of the fungus from leaf to leaf and tree to tree. The spots are frequently so large and numerous that the leaves become considerably distorted and are often shed. Whole trees may in this way be stripped of their leaves. This sometimes happens un-

FIG. 184.—Apple scab on the fruit. After Longyear.

der conditions favorable to the fungus and such conditions are realized in cold damp summers. The shedding of the leaves, of course, impoverishes the tree not only for one summer, but may weaken it for several successive years. The fungus also attacks the fruit and forms here even more characteristic spots than on the leaf. The fruit spots are dark brown to black, lined with a whitish rim, and are scab-like in appearance. They are usually not over one-half inch in diameter and are more abundant toward the further end of the fruit, though they may occur anywhere on the latter. When abundant the scabs may deform and dwarf the fruit and they always disfigure it, so that its market value is lowered. When the young fruit is seriously attacked the whole fruit may fall. In addition to these injuries, the attacked portions of the fruit become hard and often crack open, allowing the apple to dry out. The cracks also open the way to the soft rots, which soon destroy the apple. The fungus lives through the winter in the sac-spore capsule stage. The sacs each enclose eight spores, and are contained in a pored capsule which is formed in the tissues of the apple plant and bursts out at the surface at maturity, ejecting its spores through a pore opening to the exterior. These sac spores are thrown out in the spring, are carried to the lower branches of adjacent trees and here cause the first infection in the spring.

Fig. 185.—Apple scab on a twig. After Clinton.

In combating this disease a number of recommendations have been made. The disease can be very successfully fought by means of spraying with bordeaux. Several sprayings are usually necessary. A winter spray, with strong copper sulphate, before the buds open should be applied. This should be followed by bordeaux just before blossoming and again just after blossoming, and two or three other sprayings at intervals of two or three weeks. The number of sprayings must be governed by the amount of rainfall and coolness of the season. Good ventilation and spacing of trees and proper pruning will aid in avoiding conditions favorable to the fungus growth. The fallen leaves, where the disease has been prevalent, should be collected and burned, or plowed under, to prevent the formation of spores in the following season. Certain varieties of apples are also known to be more resistant than others toward this disease and a proper selection may aid in combating the fungus.

Soft rots of fruits (*Penecillium, Mucor, etc.*). These rots include some so-called ripe rots and storage rots. The soft rots are due to various fungus growths. They are, in general, molds either of the black or blue mold groups. The habits of these

FIG. 186.—Apple scab on the leaf. After Longyear.

fungi have already been pointed out in previous chapters. They are amateurs in the ways of parasitism, for they need not only assistance in gaining entrance to the host, but they are capable also of successfully attacking only those parts which are in a resting or dormant condition. The protoplasm of such plant parts, as has already been pointed out, approaches the proteid condition of dead plant debris. Ripe fruits of almost all kinds suffer from these rots. The rots are most destructive in moist warm conditions.

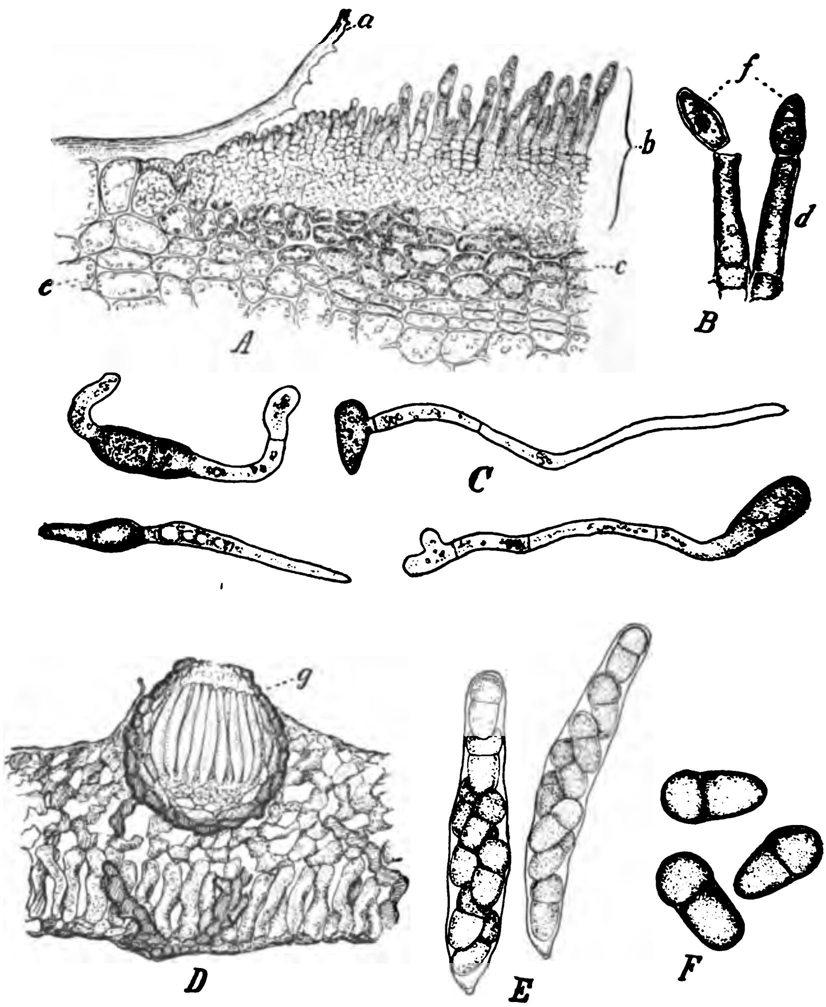


FIG. 187.—Spores of the apple scab fungus. A. Portion of a section through a scab spot on an apple; b, fungus threads spreading under and lifting the cuticle; a and c, partly disorganized cells of the apple; e, healthy cells of the apple. B. Two spore-bearing stalks giving rise to summer spores. C. Spores germinating. D. Portion of a section through an affected leaf of an apple which has lain on the ground over winter and has given rise to the winter spore stage of the disease; g, spore-case containing a bundle of spore-sacs. E. Two spore-sacs, more highly magnified, each containing eight two-celled winter spores, three of which are shown at F. All highly magnified. After Longyear.

Among these molds the blue (or green) mold is perhaps the most common. (See Chapter IX.) So common are the spores of these fungi in the atmosphere that one can find them at all times of the year, often in great abundance, everywhere. Another common soft-rot of fruits is found in certain kinds of black mold. (See Chapter VIII.) The effect of these rots is a rapid softening of the affected parts of the fruit and, as the fungus spreads, the fruit is finally entirely softened and rendered worthless. The fungi gain entrance to the fruit chiefly through wounds in the skin. Cracks in the skin, such as those caused

FIG. 188.—Blue mold soft rot of apple. After L. F. Kinney.

by apple scab, or holes formed by insects, or bruises and cuts obtained in picking, packing and storing, all contribute to the ease of entrance of the fungus.

The prevention of ripe-rots is possible to a certain extent by avoiding those conditions favorable to the entrance and growth of the fungi. Warm moist atmospheres should be avoided, hence cold storage of fruits is desirable. Spraying may reduce other diseases, such as scab, and in this way prevent the ripe rots which usually follow such diseases. The spraying on the tree is not, of course, directly beneficial against the ripe-rot, since the latter are largely store-house diseases. Experiments in formalin treatment and with other chemicals have been unsuccessful. Good ventilation of the stored fruit and a frequent sorting to remove the rotted fruits, thereby diminishing the chances for infection from the spores which are formed on these fruits, are also recommended. Any damage, such as bruising or cracking the fruit skin, is to be avoided in all processes of handling the fruit. (See Fig. 1.)

Bitter rot or ripe rot of apples [*Glomerella rufomaculans (Berk.) Sp. von Schr.*]. This is also known simply as apple rot. It attacks apples before they are ripe, and also apples in storage;

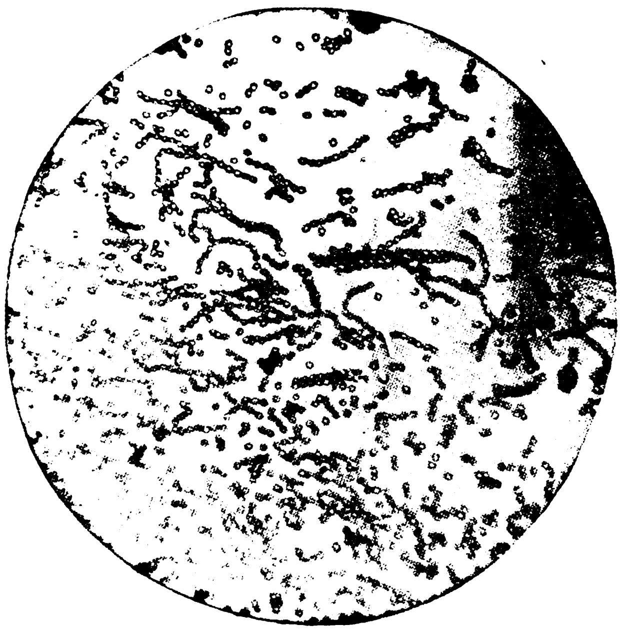


FIG. 189.—Blue mold soft rot of apple. Accessory spores of the fungus. Highly magnified. After L. F. Kinney.

it is a very destructive parasite. The parasite is one of the burnt-wood fungi, and it is the summer-spore stage that is the most conspicuous and the form which causes most damage. Where the fungus attacks the fruit, a small brownish red spot appears and increases in size until a considerable area of the apple is involved. The spot becomes somewhat sunken, is soft, and the apple underneath has a bitter taste. On the surface of the spot arise usually in well-defined circles the summer-spore masses which are small, black cushions formed under the skin of the apple. When the spores are ripe the skin is ruptured, and the spores issue in a long cylindrical gelatinous mass which is somewhat spirally twisted. Rainwater dissolves the spores apart, and the latter are washed to other fruits, again causing infection. The winter or sac spores are formed in small black capsules which are produced in the cankers on the twigs. These cankers are usually found at the bases of infected fruits. The mycelium and winter spores preserve the fungus through the winter. The mycelium, which produces the winter spores, can apparently live saprophytically.

FIG. 190.—Bitter rot of apple. After Clinton.

Decayed fruit, whether in storage or in the orchard, should be destroyed. Diseased twigs should also be pruned back and destroyed. Spraying with bordeaux mixture beginning with a winter spraying, and continued frequently in the growing season, will hold the disease in check. Ammoniacal copper carbonate should be substituted for the bordeaux as the fruit approaches maturity. Potassium sulphide has also been used to advantage.

Brown rot of apples. See Brown Rot of Plums (this chapter).

Brown rot of plum [*Sclerotinia fructigena (P.) Schrt.*]. This is a very common disease of plums and may also attack cherries and apples, though the latter rather rarely. In states where the peach is grown, this fruit suffers most of all from the brown rot. The fungus attacks the fruit at about the beginning of the ripening period, but may also extend to the twigs, leaves and flowers. The attacked portions of the fruit turn brownish, forming brown spots which are soft and rapidly grow in size. On these spots arise the summer spores in small clusters which are arranged in circles in the spot. The spores are formed in chains, like strings of beads. This summer-spore was formerly known as a loose-spored "imperfect" fungus. The winter spores, however, are now known. Sclerotia or storage organs, formed from densely woven fungus threads, are sometimes produced in the fruit. In the following spring, these sclerotia send up a cup fungus fruiting body with a long stalk, and on the inner surface of the cup is formed the layer of spore-sacs. The latter each contain eight spores. These spores probably cause infection in the spring. Attacked fruit falls to the ground or may remain attached to the tree and becomes mummified, producing then an enormous number of spores. These fruit mummies, moreover, may persist through the winter and continue to produce spores in the following spring. It is therefore important that all decaying and rotting fruit, whether on the tree or ground, be gathered and burned. Affected twigs should also be pruned and burned. A winter spray has been suggested and spring and summer sprays with bordeaux have proved beneficial. In addition to the winter spray the following applications have been recommended: with bordeaux (1), just as the leaves begin to unfold; (2), just after the petals fall; (3), after the fruit sets, and with potassium sulphide as the fruit begins to ripen.

Black knot of plum and cherry [*Plowrightia morbosa. (Schw.) Sacc.*]. This is a very common disease of our wild cherries and is also common on wild and cultivated plums. The disease derives its name from the black charcoal-like knots in the branches of the tree. These knots are caused by the threads of the fungus which inhabit the branches at the knotted points. The fungus gains entrance, perhaps, through a crack or wound and immediately causes a stimulation of the tissues, so that a large, soft mass arises, which contains but a small amount of hard woody tissue. This enlarged portion of the branch splits off its outer cork layer and exposes a cushion of densely wefted fungus threads. The cushion is at first yellowish-brown to yellowish-green and turns finally to an olive or dark yellow-brown color. This surface is at first covered with the summer spores which are borne on short upright threads and are capable of causing infection during the same season in which they are formed. Later in the year the knotted portion of the branch turns black and charcoal-like and the surface is then covered with very fine, pimply protuberances, each of which has an opening at its apex. These openings communicate with the pear-shaped cavities of the capsules, which contain the numerous spore-sacs, each bearing eight spores. These are the winter spores and are capable of causing infection during the year following their formation. The fungus

FIG. 191.—Black knot of wild cherry, showing various stages in the development of the knots. Original.

mycelium may also live over the winter in the tissues of the host and grows from year to year. The ultimate effect of the black knot on a branch is to kill off the entire branch above the knot. When a knot works downward to another branch the latter will also soon be killed.

The fungus can be held in check by a persistent pruning off of the knots. Such a pruning prevents the spread of the mycelium in the tissues of the host. The knots should be immediately

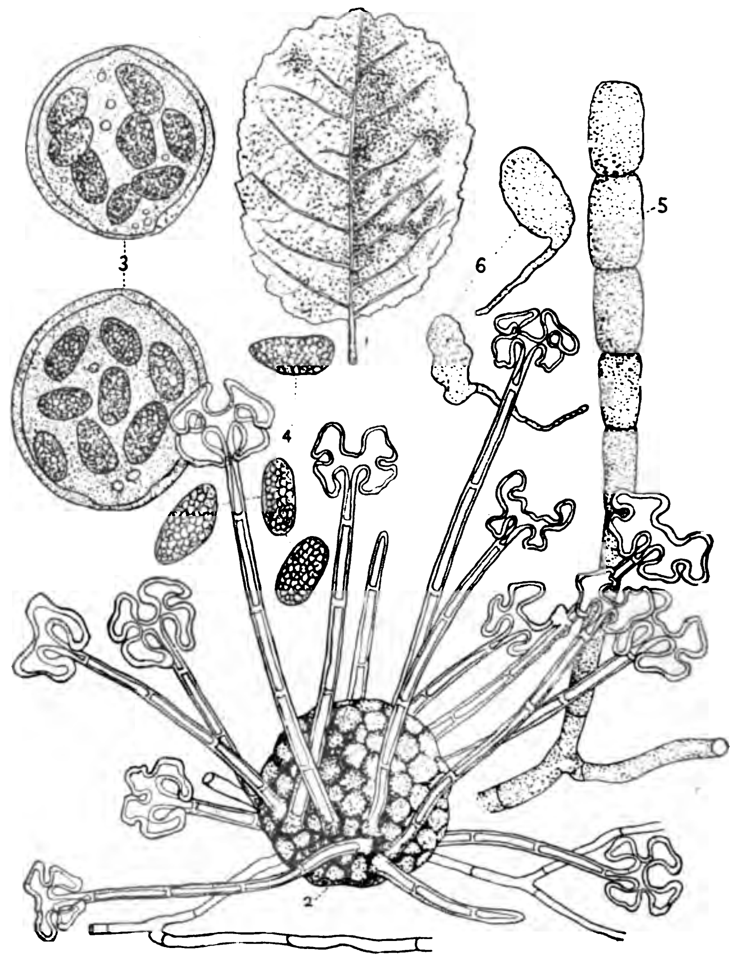


FIG. 192.—Powdery mildew of plums and cherries. 1. Cherry leaf. 2. Spore-sac capsule showing the thread appendages with peculiar forking ends. 3. Spore-sacs, each with eight spores. 4. Very highly magnified spores. 5. A chain of summer spores. 6. Two summer spores germinating. All except 1, highly magnified. After Ellis.

burned. Care should be taken to prevent a prevalence of the knots amongst wild cherries and plums in the neighborhood of the orchard. Spraying with bordeaux would probably assist in preventing a spread of the disease.

Powdery mildew of apple [*Podosphaera leucotricha* (*E. and E.*) *Salmon*]. This mildew attacks apples, pears, thorns and juneberries. It affects chiefly the seedling plants by injuring the leaves. It forms a fine, whitish, powdery mycelium on the surface of the leaves. The small black capsules appear in late summer. Summer spores are produced in the manner usual for the powdery mildews. The small, black sac-capsules are produced in late summer. They are provided with appendages, which form a crown on the summit. The appendages are branched several times in a forking manner. The capsules, when broken open, are seen to contain each a single spherical sac, enclosing about eight spores.

Spray seedlings with bordeaux or ammoniacal solution of copper carbonate shortly after the buds have opened and at intervals of ten to twelve days for two months.

Powdery mildew of plums and cherries [*Podosphaera tridactyla* (*Wall.*) *DeBy.*]. This mildew attacks leaves of plums and cherries. It is found chiefly on young plants. It forms a fine mycelium on the surface of the leaves. The small, black fruiting-bodies appear in the fall. These sac-spore capsules are provided with appendages which resemble those of the powdery mildew of apples. Each capsule contains a single sac with eight spores.

For preventives see Powdery Mildew of Apple.

Plum pockets (*Exoascus pruni Fckl.*). Plum pockets are very familiar objects to all raisers of plum trees. Cherries are also affected by a similar disease. In this disease the fruit is peculiarly enlarged to considerably more than its natural size and is at first yellowish, becoming grey as a coat of spores form on the surface. The diseased fruit has no stone, the entire fruit wall being soft. The mycelium permeates the tissue of the pocket and forms spores in sacs on the surface. The mycelium may live over the winter in the twigs of the plants, so that a plant part once infected may produce pockets yearly. This yearly production of pockets does not always take place, but they may appear only every other year. The disease does not seem to spread with great ease, for it has been observed that trees neighboring on a diseased one may remain free from pockets for a long time. The spores are borne in elongated sacs which are arranged in palisade fashion on the surface of the pocket. Each sac contains about eight spores, which on germination may directly cause infection of a host plant. The fungus of this disease is very closely related to the peach leaf-curl fungus and to others forming witches'-broom on birch, alder and cherry trees. It is a sac-fungus with an arrangement of sacs similar to that in the true cup fungi, but has no true cup, since the sacs occur directly on the tissues of the host.

FIG. 193.—Plum pockets. These plums are devoid of stones and bear the fungus spores on their surfaces. Photograph by H. Cuzner.

The only known effective remedy for plum pockets is the pruning back of the affected parts, so as to remove the fungus mycelium. The pruning must in some cases be quite severe. Of course all pockets must be removed and destroyed, as should all affected parts. It is also advisable not to use the parts of any infected tree for grafting purposes, since the fungus mycelium may be transferred with the graft. It has been suggested that the treatment which is successful in combating the leaf-curl of peach may also prove successful here. This consists in spraying with bordeaux when the buds are swelling and again with bordeaux, just before the petals fall. (See also Fig. 49.)

Witches'-broom of cherries [*Exoascus cerasi* (*Fckl.*) *Sad.*]. One not infrequently meets with wild cherry trees which have the peculiar disease known as witches'-broom. On account of the abnormally large number of branches developed in the affected part of the tree, a bush-like object is produced which looks not unlike some foreign shrub, parasitic on the cherry tree. In this broomed portion the mycelium of the fungus, which is a close relative of the fungi of plum pockets and peach leaf-curl, may be found. This mycelium is perennial. The leaves may be considerably distorted, resembling curl, and over the surface of these leaves the spores are formed in sacs. These sacs are arranged in a palisade on the surface and give to the latter a greyish-white appearance. There are about eight spores in each sac. They germinate directly to an infection tube. The broomed portions should be removed and burned.

Plum scab (*Cladosporium carpophilum Thüm.*). This is an imperfect fungus. Many of the species of the same genus are exceedingly common mold-like saprophytes forming black, moldy growths on dead sticks, stems, seeds, etc. The plum scab is found on plums and cherries. Spots arise on the fruits shortly before ripening. These spots are covered with brown or olive growths of fungus threads from which dark spores are pinched off. The spots may increase in size and number until the whole fruit is covered. The latter then shrivels and is rendered unfit for the market. Many varieties of plums are attacked and the wild American plum seems to suffer as much if not more than any other variety. The fungus is probably one of the black fungus group of the sac fungi but its winter-spore stage has not yet been discovered. It is possible that the fungus lives over the winter in a sterile thread condition on the branches and bark of trees. The fungus has been observed in Minnesota but the extent of its damage is not yet known.

Spraying with bordeaux has been recommended. Several treatments should be given, beginning when the flowers are well set. Diseased plums should be destroyed.

Black rot of apple (*Sphaeropsis malorum Peck.*). The black rot attacks apples usually in the ripening stages or when the fruit is in storage. It also attacks the leaves, forming reddish brown spots, or the twigs, where blackish spots are produced. The fruit, when attacked, turns at first a reddish brown but later becomes black. On attacked portions of the tree the fungus produces its spores. It is an "imperfect" fungus and produces spores in small capsules, which appear on the leaf, twig or fruit spots as tiny black warts. These open to the exterior by minute pores through which the spores, which are cut off of threads lining the interior of the capsule, are thrown out.

Fig. 194.—Black rot of apple. After Clinton.

The treatment which is used against the apple scab is usually recommended in treating black rot. In addition, the dead twigs and limbs should be pruned to prevent the wintering of the fungus in the twig spots. Rotted fruit should be removed and destroyed. Winter spraying has also been recommended.

Apple and pear blight [*Bacillus amylovorus* (*Burr.*) *DeToni.*]. This disease is also known as fire blight. Its cause is a bacterium. The bacteria gain entrance to the twigs of the apple through wounds or through the flowers. They are carried by insects to the stigma of the flower and from this point work their way into the branches. On the branches they form first small, dead spots, which later enlarge to canker-like sores, from which a dark mucilaginous fluid oozes. In this fluid one finds millions of bacteria. In the canker growth butyric acid, carbonic acid gas, and alcohol are formed. The branch above the canker is killed, often suddenly, and the leaves turn brown as though scorched by fire, hence the common name of fire blight. No successful remedy for diseased branches is known. Pruning back is the only successful method of combating the disease.

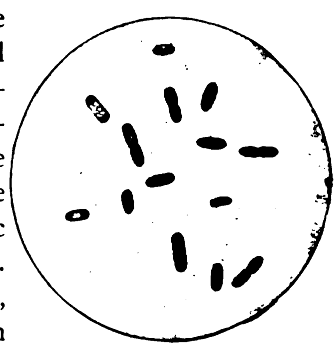


Fig. 195.—Fire blight of apples. Bacteria which cause the disease. Highly magnified. After B. M. Duggar.

The branch should be cut six inches below the canker and care should be taken to keep the knife clean, since it is an easy matter to transfer the bacteria on the knife blade to healthy trees. The blade should therefore be dipped in a corrosive sublimate solution. All diseased twigs should be promptly burned. Since an abundance of moisture in the plant favors the development of the bacteria, an avoidance of a too succulent condition has been recommended, e. g., draining the moisture from around the base of the tree. This procedure has aided in keeping the disease in check.

Downy mildew of seedlings (*Phytophthora omnivora DeBy.*). See Diseases of Greenhouse and Ornamental Plants.

Vineyards.

Black rot of the vine [*Guignardia bidwellii (Ell.) Viala et Rav.*]. This fungus has often proved a very destructive disease and vine growers in the United States have suffered great losses from it. The extent of damage in Minnesota is as yet unknown, though the fungus is probably not uncommon. It has caused considerable trouble in Iowa. The first indication is the production of small reddish or brownish spots on the leaves. On these spots arise minute, black, capsular fruiting-bodies. These capsules do not contain sac-spores, but produce one kind of summer-spore. These spores are formed on threads in the capsule and escape in a sticky mass from the apical opening. They are washed apart by the rain and distributed to other parts of the plant. The berries are also attacked and brownish spots appear on them. Capsular summer spores are formed here similar to those on the leaves and in addition to these two other spore-forms may appear. The berry shrivels and dries up and becomes black, but still clings to the vine. Late in the fall the sac-spore capsules appear on the shriveled grapes. They are small black bodies with an opening, through which the sac spores escape in the following spring. These sac spores probably recommence the infection. All diseased portions should be promptly removed and burned. All infected grapes should be destroyed and in no case should the shriveled grapes be left on the vine until spring. The disease needs prompt and persistent attention and a fight of several years is necessary to hold it down to a minimum of damage. Spraying with bordeaux has been found very beneficial. Spraying should commence early and continue at intervals of about two weeks until a few weeks before the ripening of the fruit. In these later sprayings, ammoniacal copper carbonate should be substituted for the bordeaux.

Powdery mildew of vines [*Uncinula necator* (*Schw.*) *Burr.*]. This is one of the most destructive of the powdery mildews or blights. It attacks grape vines and causes much damage, not only to the leaves but also directly to the fruit. The summer spores are formed in the usual manner for powdery mildews and appear in great numbers spreading the disease very rapidly. The spread is particularly rapid in moist weather. The mycelium first appears in whitish areas, under which the cells of the leaf are killed, leaving brown spots. The leaves usually wither. The grapes dry up in the attacked region and often become split open and subsequently wither or decay. The summer spores are formed throughout the summer; and in the fall the sac spore capsules appear as dark-brown bodies of minute size. The capsule is provided with a crown of numerous thread-like appendages, the tip of each of which is bent back in the form of a stout terminal hook. When broken open each capsule is found to contain four to ten sacs, each of which contains four to eight spores. The disease winters over in the capsular stage and infection is accomplished in the spring from the sac spores, which alight on the leaves. Here they send out a small tube with a flattened disc, which serves to attach the parasitic plant to the leaf. A short sucker branch is then sent out into a cell of the host and the growth of the mycelium proceeds. From this mycelium the summer spores arise.

"Treat as for downy mildew with perhaps a late spraying in the fall after gathering the berries, to destroy the winter spores. Potassium sulphide is also used effectively against this fungus." (Conn. Ag. Ex. Sta. Bull. No. 142—1903.)

"The sprayings with bordeaux mixture, that are generally applied for other diseases, will do much to hold it in check, during the early part of the season; but later on, as the fruit approaches maturity, the weak copper sulphate or the ammoniacal carbonate of copper will be preferable. The application of flowers of sulphur to such varieties as are subject to this disease, at intervals during the season, will also be of value, especially on grapes grown under glass. In dry seasons the frequent stirring of the soil will aid in keeping the vines healthy, but upon the first appearance recourse should be had to one of the above fungicides." (Mich. Ex. Sta. Bull. No. 121.)

The burning of the fallen leaves of infected plants is also to be recommended.

Anthracnose of vines (*Sphaceloma ampelinum DeBary*). This is also known as birds'-eye rot. The cause of the disease is an imperfect fungus and causes great damage in many states of the Union. The extent of its work in Minnesota is not yet known. All parts of the plant are attacked and the disease is a difficult one to combat. The fungus causes small black spots, which later become whitish, though the edge is margined with purple. The spots in the stem sink, leaving depressed regions, while in the leaves dark-brown spots are produced, from which the tissue sometimes falls as in the shot-hole fungus of plums. On the fruit circular spots are produced with a black margin, outside of a red ring, from which the fungus derives its name of birds'-eye rot. The spots may be numerous on a berry and eventually become scabby. An infected cluster of berries bears usually few or no sound ones. The berries die and shrivel but remain attached to the vine. The spores of the fungus are borne in small, black spots, which appear on the leaf and fruit spots. The spore-bearing threads are packed into a cushion which is dark-colored. From the surface of this cushion arise the upright thread branches, bearing colorless spores.

The treatment for black rot of grape is usually recommended for the anthracnose. All diseased portions should be removed. In addition to this, a winter treatment is given in Europe, where the disease was first known and where it has caused a great damage. In the old world this disease has been brought under control by winter and summer spraying and the destruction of infected parts. "In Europe it is the custom to wash the vines and stakes during winter or early spring with sulphuric acid and sulphate of iron solution. The liquid is applied by means of swabs or brushes. It blackens the canes and this is a test of the thoroughness of the work." (See chapter on fungicides. Iron sulphate solution.)

"If after two or three days there remain portions which are unchanged in color the vineyard is treated a second time, particular attention being paid to the parts omitted at the first treatment." Lodeman (The Spraying of Plants, p. 295.)

Downy mildew of vines [*Plasmopara viticola (B. & C.) Berl.*]. This is a very destructive disease of vines originating in the United States, but since about 1878 causing enormous destruc-

FIG. 196.—Downy mildew of grape. Under surface of a leaf, showing down of mildew threads spread over the entire leaf. Original.

tion of vines in Europe. The fungus is a downy mildew and is a destructive parasite. It appears on all above-ground parts of the vines, but most abundantly on the leaves. When the latter are attacked they show, from above, pale green spots which later become light yellow in color. This is the region where the mycelium is at work within the leaf. On the under surface these patches show at first a faint light grey shimmer, which later develops into the grey mold-like growth of the fully developed patches of the summer spores. These patches spread rapidly and the whole leaf, in the course of a few weeks, dies, becomes brittle and useless as a starch-making organ and dangerous as a pro-

FIG. 197.—Downy mildew of grape. On the right is a healthy bunch of grapes; on the left a bunch badly diseased. Original.

ducer of the fungus spores. The so-called spores behave as do those of the downy mildews generally, i. e., when they fall in very moist surroundings they produce six or more swimming spores, which swim about in the water drops and spread the infection on the leaf. When they come to rest they germinate by sending out infection tubes and the latter establish new regions of the mycelium. The leaf patches commence to appear in early summer.

Later in the year the winter spores are formed in the usual way for the downy mildews, i. e., from breeding organs. The winter spore has a thick coat and remains in the leaf after the latter falls. In the spring the decay of the leaf sets the spore free, and in moist conditions it produces numerous swimming spores; the infection of the vines follows in the usual way. The destruction of fallen leaves, to avoid future infection, is therefore seen to be of importance.

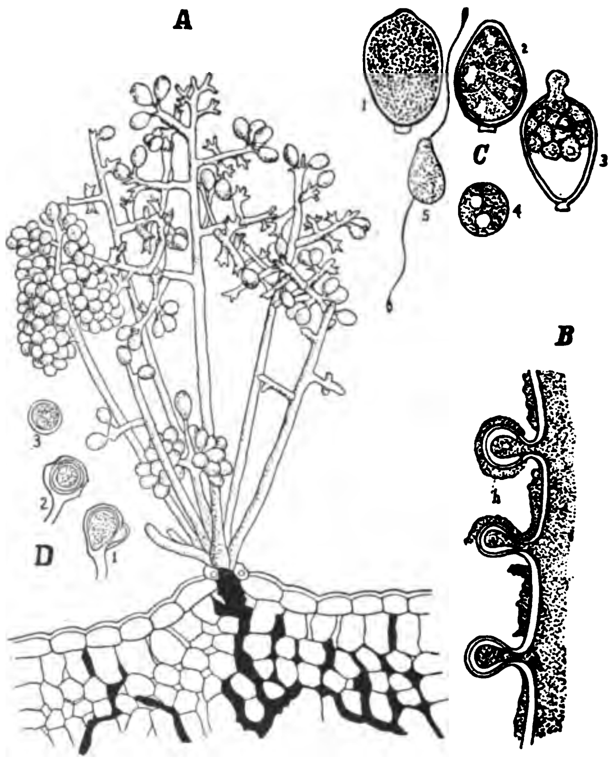


Fig. 198. Downy mildew of grape. A. Section of a leaf with spore-bearing threads emerging from an air-pore. B. Greatly enlarged sucker threads, h. C. Formation of swarm spores in the so-called summer spores; 1, summer spore (is really a spore-case); 2, same with protoplasm divided into regular areas; 3, areas of 2 are seen separated, and the whole mass escaping from the spore-case; 4, an escaped and free area of the protoplasm which becomes the swarm spore, 5. D. Formation of egg-spores by the breeding act. Highly magnified. After Millardet.

The treatment for black rot is usually recommended for this disease. The sprayings may be at longer intervals. (See Black Rot of Grapes.)

Disease-resisting varieties may also be used. It has been recommended that the vine be treated in the fall or early spring, before the buds commence to open, with an iron sulphate solution.

Chapter XXI.

Diseases of Greenhouse and Ornamental Plants.

Carnation smut [*Ustilago violacea* (*P.*) *Fckl.*]. This smut attacks a large number of species of the plants belonging to the pink family, such as common garden-pinks and carnations, and such wild flowers as catch-flies, star-worts, soap-worts and corn cockles. This is a very different disease from the rust of carnations and cannot easily be confused with it. The carnation smut attacks the stamens of the flower and converts the anthers into smut-spore sacs. The smut spores form a violet-colored powder and one can easily mistake this for abnormally colored pollen. When the smut spores escape, many fall upon the petals and sepals discoloring them and rendering them unfit for decorative use. This fungus often exerts a remarkable influence upon those members of the pink family which have pistillate and staminate flowers, e. g., the corn cockles. The pistillate flowers, when attacked, develop stamens which, in an unaffected flower, remain undeveloped. These stamens, as well as those of the staminate flowers, become a prey to the smut fungus. As a general rule no other parts of the flower or plant are enlarged, or in any way distorted. There is no indication of the presence of the fungus, and the latter can only be detected at the ripening of the spores, or by a previous examination of the anthers.

The diseased plants should be promptly destroyed to prevent a spread of the disease.

The violet smut [*Urocystis violae* (*Sow.*) *Fisch.*]. Occasionally on pansies and violets. (See Diseases of Wild Plants.)

The chrysanthemum rust (*Puccinia chrysanthemi Rose.*). This disease has appeared in recent years as an abundant parasite on greenhouse chrysanthemums. It is not, as was formerly supposed, identical with the common wild rust of sunflowers and their allies but it is a distinct importation, probably, from Japan. The summer spores are found in the fall and are produced in very small clusters, which arise in great numbers, chiefly on the under surface, but also on the upper surface of the leaf. These sometimes coalesce to form larger spots. The clusters are at first closed by the epidermis of the leaf but later break out and expose a dark-brown powder of summer spores. The winter spores are two-celled and are produced in black clusters. They are not, however, common in this country. On account of this latter feature the disease should not be very difficult to combat. It is said to tend to disappear of itself after a regular run of a given greenhouse. Great care should be exercised in preventing the introduction of the disease into a greenhouse. This can be done by close examination of all purchased cuttings and plants and by carefully watching them for some time after their introduction. The diseased plant parts should be promptly removed and burned. In case of a persistent attack, "every leaf and stem above ground should be destroyed at the end of the flowering period and the young plants or cuttings, for the next season's supply, be grown in an uncontaminated house, and, if possible, from uncontaminated material." (Ind. Ex. Sta. Bull. 85—1900.) It has been reported that inside cultivation in summer and selection of rust-free stock will be sufficient to keep the disease in check.

Rust of hollyhocks and mallows (*Puccinia malvacearum Mont.*). The mallow rust attacks members of the mallow family, e. g., hollyhocks, marsh-mallows and the small, wild, creeping mallow. It produces only winter-spores which can germinate without a resting period. The spore groups occur in great abundance on the leaf-stalks and leaf-blades and even on the floral parts, causing deformation of these parts. In some cases the plants are killed by the parasite.

The mallow rust has an interesting history. It was introduced from South America into Europe by the Spanish about thirty-two years ago. Before this time it was unknown in Europe or North America. It spread in Europe with remarkable rapidity, growing on cultivated and wild mallows, and is at present an exceedingly abundant and dangerous enemy to mallow growers. It is said to have completely exterminated mallows in many regions. This disease has been introduced from Europe into the United States and is fast gaining ground. It has not yet been reported from Minnesota but will probably reach this state in due time, if not already here.

Spraying with bordeaux mixture or a solution of permanganate of potash has been recommended. Diseased parts should be immediately destroyed.

The violet rust [*Puccinia violæ (Schum.) DC.*]. On all species of our native violet can be found, often in considerable abundance, this rust of violets. It also occurs on the cultivated violets of greenhouses and may cause considerable damage. Cluster-cups are formed on our wild violets, often in great abundance, in the spring. Slight swellings of the leaf and distortion of affected parts are usually caused, and the cluster cups occur on the surface of the malformations. Later, summer and winter-spores are formed, in small round patches, also, usually on the under surface of the leaves. These do not usually show malformations as in the case of the cluster cups.

Infected plants or plant parts should be destroyed.

The carnation rust [*Uromyces caryophyllinus (Schrk.) Schroet.*]. On the leaves or stems of the carnation often appear elongated, brownish patches, breaking through the epidermis and exposing a more or less powdery mass of spores underneath. These proceed from the mycelium, which lives in the stem and leaves. The first spores produced are the summer spores and these are light brown in color. They germinate immediately after formation, and aid in spreading the disease. Later in the season, darker, winter-spores are produced and these pass the winter before germinating. The mycelium, when once established in a plant, remains there and forms pustules of spores in succession. Diseased plants should not, therefore, be used for cuttings, since the latter are sure to be infected. This disease has proved very serious at times to carnation culture.

Diseased plant parts should be cut out and destroyed to prevent the spread. Bordeaux in fine spray at intervals of one to three weeks has proven effective in checking the disease. Potassium sulphide has also been recommended. The cultivation of hardy varieties has been suggested and particular attention should be paid to proper methods of cultivation, ventilation and watering.

The sunflower rust (*Puccinia tanaceti DC.*). This is one of our most common rusts, occurring in great abundance on almost, if not all, species of Helianthus and is particularly abundant upon the common cultivated Helianthus annuus. In addition, it occurs on other more or less closely related plants. The fungus mycelium gains entrance to the plant in the spring and first produces cluster cups. These are followed by the summer spores, throughout the summer months, forming small red-brown patches

FIG. 199.—Leaf rust of roses. The cluster-cup stage on the stems and leaves. On left is a stem distorted by the cluster-cup cushions. Photograph by H. Cuzner

upon large, dark, red-brown spots in great abundance, on the lower surface of the leaves. The summer-spores are followed toward autumn by the winter-spores, which are formed in similar but darker groups. The winter-spores are two-celled. Where

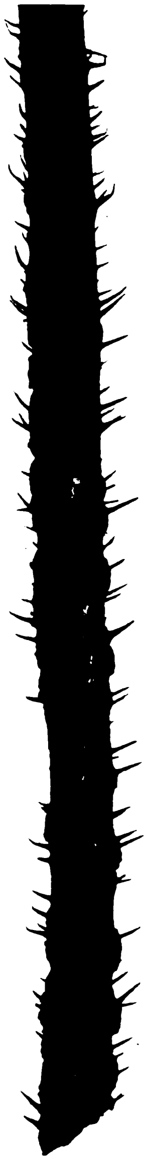


FIG. 200.—Leaf rust of roses. Stem with groups of cluster-cups. Original.

the sunflower has been raised in large quantities, this rust has often proved very injurious.

The leaves and all parts affected by the fungus should be burned in autumn to destroy the winter spores and to prevent the recurrence of the disease in the following spring. (See Fig. 206.)

The rose leaf rust [*Phragmidium subcorticium* (*Schrk.*) *Wint.*]. This is a very common disease of both cultivated and wild roses. All three important spore-forms are formed upon the same host plant. The cluster-cup stage appears in early summer, or late spring, and causes a distortion of the attacked parts. These are usually swollen and badly bent and become bright orange in color. The summer spores appear later and are also brightly colored. The winter spores appear last and are formed in small, round, blackish patches on the under surface of the leaf. These spores form a fine, small, powdery mass. The spores are long and are divided into a number of cells, often about seven or eight, arranged in one row, and have a long club-shaped stalk.

Care should first be taken to prevent the wintering over of the disease. This can be done by destroying the old leaves, particularly those of diseased plants. Late fall or early spring treatment with a strong copper sulphate solution will also aid in destroying the winter spores. The dormant bushes and the ground near them should be drenched. The spread of the cluster-cup and summer-spores can be prevented by spraying after the buds open with bordeaux or ammoniacal copper carbonate.

The rose stem rust (*Phragmidium speciosum Fr.*) This rust is a near relative of the leaf rust of roses but is not identical with it. The attacked stem of the rose becomes swollen and distorted, and soon a large winter spore pustule is formed which looks not unlike a smut mass. The spore mass is black and powdery and the spores are, in general features, similar in appearance to the winter spores of the leaf rust. Infected plant parts should be destroyed before the spores have a chance to disperse.

The Indian turnip leaf rust [*Uromyces caladii (Schw.) Farl.*]. This rust is sometimes found on cultivated Aroids. (See Diseases of Wild Plants.)

Golden-rod and aster leaf rust [*Coleosporium sonchi-arvensis* (*Pers.*) *Lev.*]. The golden-rod rust is an exceedingly abundant disease upon almost if not all of the species of golden-rod, asters and their allies, found in the state. The bright orange-red summer spores appear in great numbers chiefly on the under surface of the leaves, and form a bright-colored powder. Often the entire lower surface of the leaf will be covered with the spore groups. The winter spores arise later in light-colored, crust-like groups. These spores remain attached to the leaf throughout the winter and germinate in the following spring. They do not germinate in exactly the usual way for rust winter-spores for they do not send out a thread in the ordinary manner. Four spores are, however, produced from each winter spore and each is borne on a stalk which comes directly from the spore which has been previously divided up into four cells by cross walls. The cluster-cup spores are probably formed on some coniferous trees.

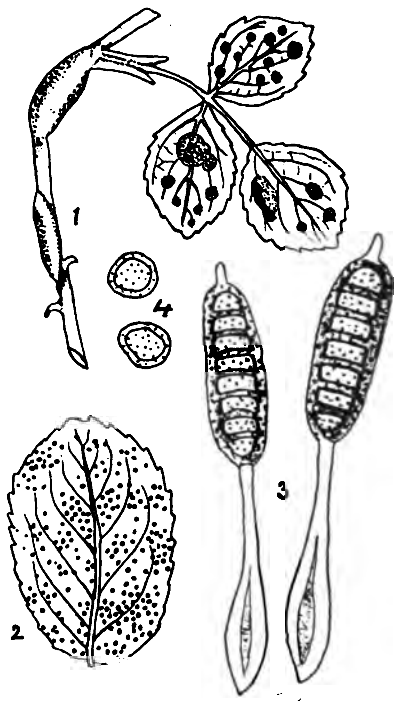


FIG. 201.—Leaf rust of roses. 1. Rose branch and leaves infected with cluster-cup stages of the disease. 2. Leaf with clusters of winter spores. 3. Winter spores. 4. Summer spores. 3 and 4 highly magnified. After Massee.

Cultivated plants may be treated with ammoniacal copper carbonate, early in spring, and the treatment should be continued every two to four weeks. (Fig. 205.)

Cedar apples of red cedar (*Gymnosporangium macropus Link, and G. globosum Fari.*). See Leaf Rust of Apples. Diseases of Orchards and Vineyards.

The powdery mildew of lilac [*Microsphæra alni* (*Wallr.*) *Wint.*]. This is the very common blight of lilacs which, in the fall, covers lilac leaves with a conspicuous white mycelial coating. The same blight is apparently found on many other plants, as alder, birches, high bush cranberry and others. Summer spores are produced in the usual manner for powdery mildews and the

FIG. 202.—Powdery mildew of lilac, showing the white patches of the fungus mycelium. Original.

sac capsules appear in the fall. The latter are furnished with appendages similar in shape to those of the apple powdery mildew. Unlike this blight, however, the sac-capsule of the lilac mildew contains more than one sac. The presence of the blight on the lilac, though it undoubtedly draws some nourishment from its host, does not seem to exert any serious influence upon it.

Burning of the fallen leaves in the autumn has been recommended. Spraying is usually not practiced since the disease ordinarily does no serious injury. Ammoniacal copper carbonate or potassium sulphide would probably prove effective against it.

The powdery mildew or blight of the rose [*Sphaerotheca pannosa* (*Wallr.*) *Lev.*]. An enormous amount of damage is sustained yearly by the ravages of this blight in gardens and greenhouses. The leaves of the attacked rose bushes become covered with a fine white coat of the fungus mycelium and often become distorted or stunted in various ways. The young leaves and buds are especially damaged, and many leaves are killed. The mycelium sends sucker-like branches into the interior of the epidermal cells of the host and from these draws its nourishment. This of course results in a drain upon the host plant. During the summer erect threads are produced on the surface of the leaves and these form chains of spores, which are carried about by the wind and rapidly spread the disease from leaf to leaf and from plant to plant. These summer spores, therefore, act in a manner similar to those of the wheat rust. Toward late summer and fall small black bodies about the size of a pin-point are formed on the mycelium, and these are the closed sac-capsules. They are yellowish-white, when immature, becoming black when mature; they are attached to the mycelium by special brownish appendages. They have a more or less membranous wall, which is divided into polygonal areas. The sac-capsule, when broken, shows a single, spherical, colorless sac, in which are found eight oval spores. The sac-capsule does not open until spring, when the wall decays, setting the spores free. These spores, therefore, function as winter spores. In the spring they germinate, by sending out a fine tube, which again

FIG. 203.—Powdery mildew of roses. A leaf of a rose attacked by the disease. After Clinton.

infects a rose plant. The mycelium, thus produced, soon commences the formation of summer spores. It is the abundance of the latter spores, and the rapid infection by their means, that makes the rose mildew dangerous.

Flowers of sulphur dusted on the leaves of the plant are chiefly employed to prevent the germination of the summer spores. The mycelium is also killed by the sulphur treatment. "For greenhouse treatment paint hot water pipes with mixture of sul-

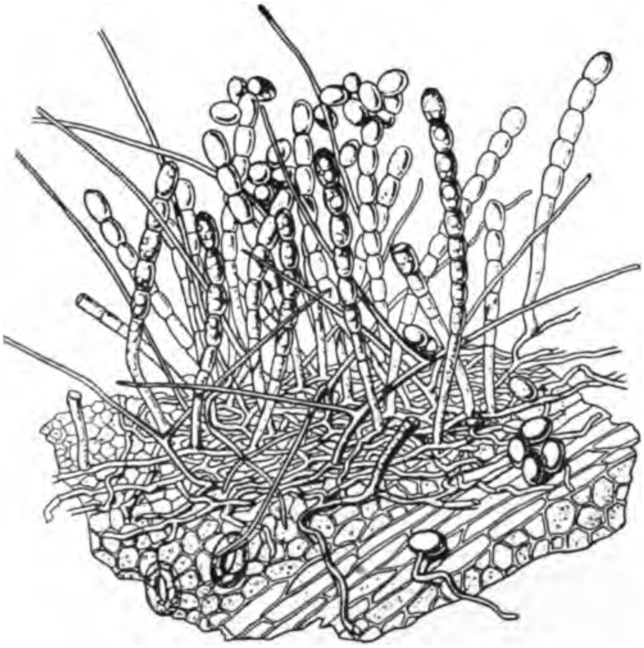


FIG. 204.—Powdery mildew of roses, showing the superficial mycelium and summer spores on the leaves. A germinating spore is seen in the foreground. (On a peach leaf.) After Tulasne.

phur and oil. Potassium sulphide or an ammoniacal solution of copper carbonate can be sprayed on the foliage. Spraying out of doors can be done with bordeaux, if there is no objection to the sediment on the leaves." (Conn. Ag. Ex. Sta. Bull. 142—1903.)

Powdery mildew of chrysanthemums (*Oidium chrysanthemi Rabh.*). The powdery mildew is an occasional destroyer of chrysanthemum plants in homes and greenhouses. As in the other powdery mildews, the mycelium is superficial and forms a cobwebby or mold-like growth on the surfaces of the leaves. From this mycelium arise necklace-like strings of spores in a fashion typical for the summer spores of the powdery mildews. These spores give to the surface of the leaf a powdery appearance. The relationship of this summer spore to its proper winter-spore form has not been determined, but it is probably connected with the very common powdery mildew of wild composite flowers (Erysiphe cichoracearum) or some closely related species. It has never been reported as appearing in dangerously large numbers in any greenhouse in this state. It would probably yield to the common treatments for powdery mildews and other superficial parasites, e. g., ammoniacal copper carbonate or potassium sulphide sprays.

The drop of lettuce (*Sclerotinia libertiana Fckl.*). This fungus has been found very destructive in eastern greenhouses. It attacks many kinds of lettuce and has been found to be the chief enemy of lettuce culture under glass. The fungus is also remarkable in that it is identical with the cause of a rotting-disease of cucumbers. The drop fungus is a cup fungus. The mycelium is parasitic on the lettuce leaves and stem and attacks the plant very vigorously, producing complete collapse and quick rotting. As the rotting of the leaves proceeds, the fungus threads commence to form small storage organs, usually on the lower sides of the fallen leaves. These storage organs or sclerotia are about the size of a large pin head, or slightly larger, and are composed of densely woven masses of fungus threads, stuffed with nutrient material. There are sometimes produced considerably larger sclerotia, and these give rise to the cup form of fruiting body, which bears the sacs on the upper surface. Usually, however, the small sclerotia only are produced in greenhouses and these do not produce the cups. They are, however, very resistant bodies and will survive very unfavorable conditions for a considerable length of time. Thus they carry the disease from one crop to another. Freezing or drying, instead of killing them, accelerates their development when conditions are again favorable. In the latter case the sclerotium fungus threads resume growth and a fine mold-like mass of threads issues from it. These threads are vigorous and can immediately infect the lettuce plants. The fungus thrives best under conditions most favorable to the growth of the lettuce and the greatest amount of damage is done when the lettuce is about mature. Ordinary methods of prevention, such as spraying, are not available for reasons that poisonous substances cannot be used on the lettuce and also that the ordinary sprays do not affect the sclerotia. The most effective remedy is a complete or at least partial sterilization of the soil. A coating of five-eighths or three-fourths inches of sterilized sand or earth will materially reduce the effect of drop, while four inches has in certain experiments completely destroyed all of the disease. The drop can also be greatly reduced by treating the soil with hot water which will raise the temperature of the surface to 176° F. to 186° F. Lime, sulphur and charcoal applications and coatings of saw-dust and coal ashes have been found to be ineffective against drop. Good ventilation and good drainage will help to keep it in check.

The grey mold of lettuce (*Botrytis vulgaris Fr.*). This fungus appears on greenhouse lettuce, causing a leaf rot. The fungus has been described as a saprophyte and it is claimed by recent investigators that it is not at all parasitic. The supposition that it is the summer stage of Sclerotinia libertiana has also been denied. The grey mold of lettuce appears as a fine greyish mold on the rotting leaves. When dry the moldy growth, if shaken, throws off a fine dust of spores which may rapidly spread the disease. The grey mold is probably not responsible for so much damage as is the drop fungus (Sclerotinia libertiana) with which it has been confused. It can be controlled by the same treatment as the drop fungus.

Leaf spots of violets (*Phyllosticta violae Desm. and Cercospora violae Sacc.*). This is a very common and destructive disease of greenhouse violets. There are two kinds of fungi producing two kinds of spots, which are, however, not very easily distinguished from each other. The Cercospora spot is, in general, a cleaner cut spot, while the Phyllosticta may be more diffused. Both are whitish and have dark centers where the spores are formed, in the former case, in a loose weft, in the latter, in dark spherical receptacles or capsules of very minute size. The two diseases may be intimately associated. When the spots are numerous, the leaf may be killed off, and the entire plant sometimes dies. The fungi are both plants of the Imperfect Fungi.

Bordeaux has been found useful in combating the leaf spots, though it does not entirely prevent them. A quarter strength has been recommended for plants under glass—the weak solution will obviate the injurious effects of stronger solutions in retarding flowering. Plants in the open field should be sprayed throughout the summer with one-half strength bordeaux every ten days.

The downy mildew of seedlings (*Phytophthora omnivora DeBy.*). This fungus pest is a parasite on seedling trees of many families of plants. It is especially destructive in nurseries where it may destroy seedlings of conifers and many other plants. It is not dangerous to older plants but confines its attack to young seedlings which have produced only a few leaves. It appears first on the stem, cotyledons, or first leaves, as brown or blackish patches. On these patches develops a very delicate film of spores produced in a manner very similar to those of downy mildew of potato. These spores may germinate directly to an infection tube or they may produce swimming spores, just as do the spores of the potato mildew. The parasite shows little choice of host except in the selection of young plants. It is therefore amateurish in its style of parasitism, but it is nevertheless very destructive. In a few days' time it may destroy whole beds of seedlings. It produces winter spores by a breeding act, as is common among the downy mildews.

When the pest appears in nurseries, if only on a few plants, these can be destroyed. The most effective methods are, however, those of ventilation and drainage. The fungus thrives best in very moist situations and in moisture-laden atmospheres and in shaded positions. By avoiding as far as possible these conditions the fungus may be kept in check. As the winter spores are very resistant, diseased plants should be carefully removed and destroyed and plots which have been infected with the disease should not be used for the same purpose for several years.

The damping-off of seedlings (*Pythium debaryanum Hesse.*). Seedlings of plants of the mustard family are particularly liable to become infected with this disease. Many other palnts, however, as clovers, corn and a great variety of others, have also been known to suffer from it. Potato plants and potato tubers in storage may be attacked, if the moisture is excessive. The disease usually appears where seedlings are too densely crowded together, or in shady places and where there is excessive moisture.

The evidence of the presence of the disease is seen in the falling over of the seedlings and their subsequent death and decay. The fungus requires a great deal of moisture and attacks the stem of the seedling at the surface of the ground. It is very destructive in its attack and kills off the tissues at this point, causing the fall of the seedling. The spores are formed only in the presence of moisture and the plant is able to live in a saprophytic manner. It is a primitive, but directly destructive, parasite. Under favorable conditions the fungus will spread very rapidly and cause great destruction to beds of seedlings. The summer spores are of two kinds. One germinates usually very soon after formation, producing directly an infection tube. The other is somewhat like the so-called summer spores of downy mildew, but undergoes a resting period, after which it breaks up into swimming spores. Each of the latter is provided with two lash-like processes, which aid in its swimming about in the water. When these swimming spores come to rest they germinate into an infection tube which attacks new seedlings or builds up an aquatic mycelium. The winter spore is formed by a breeding act and is provided with a very thick wall so that it can undergo long periods of rest. When it develops further it produces swimming spores, just as do some of the summer spores.

Plenty of sunshine and good drainage will keep the fungus in check. Soil which contains many winter spores, or resting summer spores, should be avoided. (Fig. 34.)

The damping-off of prothallia (*Pythium intermedium DeBy.*). This fungus is a very close relative of the damping-off of seedlings and its behavior is somewhat similar. The host plant is, however, the sexual plant of the ferns, commonly known as the prothallium. The fungus is a common enemy of fern culture in greenhouses, when ferns are raised from spores. The fungus permeates the tissues of the prothallium and the latter wilts, becomes dark in color, dies and decays. The fungus produces summer spores in a manner, in general, similar to that of the damping-off of seedlings. The so-called spores form, under proper conditions of moisture, numerous swimming spores, and these behave in a peculiar manner; for, when they cease to swim, they move in an amoeboid manner until they finally come to rest and germinate.

"If the pots or vessels in which the prothallia are grown are rested on sphagnum, a layer of which can be placed in the bottom of the Wardian case, and after the young prothallia have started, all of the watering be applied through this, the prothallia will do much better than if surface watering is practiced, and far better than where the pots are rested in a vessel partly full of water. The air of the Wardian case or of the house should not be kept too damp." (Cornell Ag. Ex. Sta. Bull. 94—1895.)

The downy mildew of violet (*Peronospora violæ DeBy.*). This disease is well known in Europe, where it attacks cultivated violets and pansies, both in greenhouses and in gardens. It is also known in the United States, though it has not been reported from Minnesota. The summer spores are borne on threads, which come out of the leaf on its lower surface and form there greyish, downy masses of mildew. They are produced on threads in a manner similar to those in the downy mildew of mustards.

Good ventilation and abundant sunlight and the avoidance of damp conditions will keep the fungus in check. It thrives only in moist conditions.

Mildew of mushroom (*Sporodinia grandis Link.*). (See Diseases of Wild Plants.)

Chapter XXII.

Diseases of Wild Plants.

Gall disease of the blueberry, cranberry and other heaths [*Exobasidium vaccinii* (*Fckl.*) *Wor.*]. Plants of the heath family, e. g., cowberries, blueberries and true cranberries, may be attacked by a fungus which produces malformations of branches and leaves. Flowers and flower-stalks are also attacked in some cases, and the formation of fruits prevented. Sometimes the leaf swells up into enormous kidney-shaped, fleshy bodies which are many times thicker than the normal leaves. The hypertrophied portions, where exposed to the light, are colored red. A cut through such a leaf shows it to be composed of a fleshy mass, through which the branching veins can be clearly seen. These veins are much reduced in structure from the normal and contain but a small amount of woody material. The fleshy portions have almost completely lost the power of starch-making, as is shown by the small amount of leaf-green present and by the entire absence of large air-spaces. The fungus threads are very fine and are found only in the attacked regions. They run between the cells of the host, and at the surface of the leaf form a rather dense weft, just underneath the cuticle of the external layer of cells. From this weft numerous spores are produced on basidia, which are arranged in a palisade. The spores can be seen with the naked eye as a fine, white powder on the surface of the leaf. Under the microscope the spores are seen to be produced on small, finely-pointed stalks, four arising from a single cell. When these spores fall on the young leaves or stems of the host-plant they germinate into fine germ-tubes, which penetrate into the leaf through an air pore, or directly through the walls of the outer row of cells, and from this point spread into the mature mycelium. The presence of the mycelium immediately stimulates the leaves to the above-described abnormal growth, which takes place at the expense of the neighboring parts. All diseased plant parts should be burned. (See Fig. 37.)

Rust of Pyrola [*Chrysomyxa pirolae* (*DC.*) *Rostr.*]. On all species of Pyrola found in the northern part of the state occurs a Pyrola rust. It is found chiefly in the spring and often occurs in great abundance. The cluster-cup stage is not yet known, but is probably to be found upon some needle-leaved evergreen tree. The summer spores are by far the most abundant and appear in early summer. Their spore groups often completely cover the lower surface of the leaves with a golden-orange powder-mass. The winter spores form darker, crust-like masses, which are much less abundant. See Leaf Rust of Pines, Chapter XVI.

The rust of milkweeds [*Cronartium asclepiadeum* (*Willd.*) *Fr.*]. This rust is very well known in Europe as a parasite upon many species of the milkweed family. It seems to be very rare, or entirely wanting, on milkweeds in this state, but what is probably the same rust has been found upon the leaves of the oak, not, however, in great abundance. The winter spores, preceded by the summer spores, are formed on the above-named hosts, and the cluster-cups probably on the pines. It is the disease which is produced upon pines that is of chief importance. See Leaf Rust of Pines, Chapter XVI.

Cluster-cup rust of various wildflowers (*Species of Aecidium*). Many of our spring wild flowers, such as buttercups, mayflowers, columbines, squirrel-corn, Dutchman's breeches, Old Man's beard, white cohosh, Solomon's seal, false Solomon's seal, lilies, evening primrose, elder, violet, etc., are attacked by the cluster-cup stages of rusts. In comparatively few cases is the connection between these and the winter-spore stages known. These cluster-cups are found, often in great abundance, from early spring until midsummer and are usually found on yellowish spots, on the under surface of the leaf. On the upper surface of the same spots are formed the little accessory spore-capsules known as pycnidia. These are flask- or pear-shaped bodies, opening in small yellow or black dots, onto the upper surface of the leaf. They often exude a sugary solution. Their behavior is problematical but they are probably vestiges of former functional male, reproductive cells.

A few of these cluster-cup diseases, such as the cluster-cup rust of gooseberries and currants, have been considered in detail Most of them are of minor importance economically, so that preventive means need not be considered.

Cluster-cup of gooseberry and currant (*Aecidium grossulariæ Schum.*). This is very common on wild gooseberries and currants. See Diseases of Garden Crops. See also Rust of Sedges (this chapter).

Cluster-cup rust of composites (*Species of Aecidium*). A number of cluster-cup rusts attack wild and cultivated plants belonging to the composite family, e. g., sunflowers, asters and goldenrods. Very little is known of their relationships with the other spore-forms. They occur in abundance, throughout early summer and midsummer, and are usually found on yellow spots, accompanied by the pycnidia or accessory spore capsules, as in the rusts of wild spring flowers. These cluster-cup rusts must be distinguished from the golden-rod rust, which is caused by a different fungus and is even a different spore-form. A close examination, even with the aid of a hand lens, will serve to distinguish between them. The cluster cups are very easily recognized.

Leaf rust of golden rod and aster. See Diseases of Greenhouse and Ornamental Plants.

Rust of sunflowers (*Puccinia tanaceti DC.*). See Diseases of Greenhouse and Ornamental Plants.

Rusts of ferns [*Hyalopsora polypodii* (*P.*) *Magn.*]. Our common wild ferns are subject to a rust disease, which is not uncommon in this state. The fragile fern is frequently attacked. Summer spores are produced on the under surface of the leaves. The winter spores are scattered through the fern tissues. They are not as conspicuous as the summer spores. The latter occur in dark, rust-like patches, often covering considerable areas.

Stem and leaf rust of cowberry (*Calyptospora goeppertiana Kühn*). An interesting disease of plants of the blueberry family, similar in some of its effects to those of the fungus leaf gall of the same plants, is caused by a rust fungus. This attacks chiefly the cowberry and other related species. The young shoots are attacked and the affected branches become much larger than the healthy and are swollen to several times their normal thickness. This swelling takes place the year following the infection of the plant. The parasite lives in the tissues for several years and the formation of fruits is usually prevented on such affected shoots and the latter are finally killed.

Fig. 205.—Golden-rod rust. Shows black spots, which are clusters of winter spores occurring in crust-like cakes. Original.

The fungus threads, which are found in the swollen parts of the host plant and which cause the stimulation, whereby the increase of growth or swelling of the stem takes place, form their winter rust-spores inside of the cells of the epidermis of

FIG. 206.—Sunflower rust. Winter and summer spore clusters on the leaf of a sunflower. Original.

the host. This epidermis is much altered on account of the action of the fungus. Its cells have thin, instead of thick, outer walls, and are much increased in size. These spores germinate in the spring in the usual way, except that they remain in the cells of the host. The cluster-cups are found on the leaves of some coniferous tree. Spruces in the neighborhood of affected cowberry plants often show an abundance of cluster cups and are usually most seriously attacked in the lower branches. It has not been proven in our American plants that these two stages are connected, but there seems to be considerable probability that such is the case.

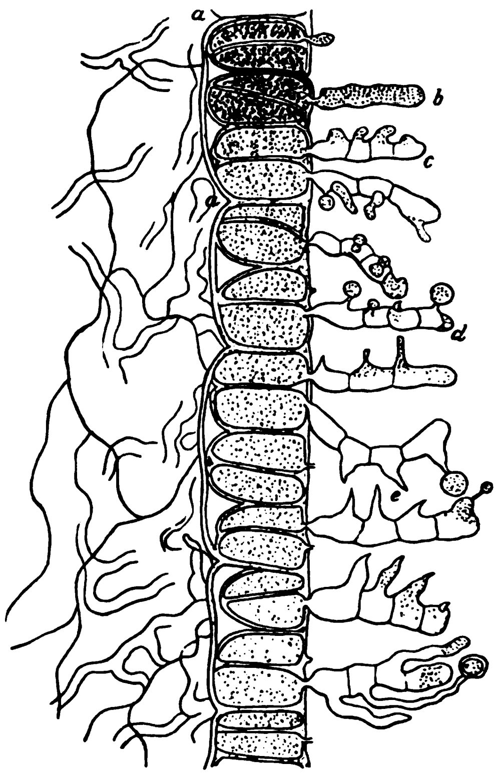


FIG. 207.—The stem rust of cowberry (a plant of the blueberry group). The fungus spores are formed in the skin cells of the host, several in each cell; they have germinated sending out short, divided threads, each division of which produces a short-stalked basidiospore. Highly magnified. After Hartig.

Rust of anemone (*Puccinia fusca Relh.*). Anemone, Thalictrum and allied genera are subject to the attack of anemone rust. In this rust only the winter spores are produced. The affected plants are considerably deformed. The leaf stalks are longer and the leaf blades are thickened. The spore groups are found on the lower surface of the leaves. The winter spores of the anemone rust pass the winter in a resting condition on the dead leaves of the host and germinate in the spring.

Rust of wild sarsaparilla (*Triphragmium clavellosum Berk.*). Although found only rarely in some places, this rust is very common in others. It is particularly abundant in the northern part of the state, but is exceedingly rare or entirely wanting in the middle and southern parts. It forms blackish, winter-spore groups on the under surface of the leaf. These groups are almost smut-like in their appearance. The spores are composed of three cells arranged in clover-leaf fashion. The spore clusters are usually very dense and vary in size from a pinhead's width to three-quarters inch broad. The leaf under the spores colors black, so that the groups can readily be seen from the upper surface of the leaf. Cluster cups and summer spores are not known for this rust.

Rust of sedges [*Puccinia caricis* (*Sçhum.*) *Reb.*]. This is an exceedingly common rust on many Minnesota sedges. The summer and winter spores are produced on the sedge plant and the cluster-cup form is very common on the vacant lot weed, stinging nettle. The attacked nettle-plant parts are usually deformed and swollen, where the mycelium of the rust develops. When the stem is attacked, it is usually much bent and a swollen cushion arises on one side. Similar cushions arise on the leaf stalks and on the leaf blades. On these cushions which are usually orange to yellowish in color are found the cluster cups in great abundance. The winter-spores are found on the sedge leaves in long black rows, similar to the black rust of wheat. Not all of the rusts on sedges are of the same species. Though the winter spores may be so similar in appearance that they can scarcely be distinguished from each other, even with the microscope, they may form their cluster cups on different host plants. The common rust of sedges, however, is that one which forms its cluster cups on the nettle. The white cluster cups of wild black currant are forms of another sedge rust.

FIG. 208. Rust of wild sarsaparilla; shows clusters of the winter spores. Original.

Rust of the dark green rush (*Puccinia angustata Pk.*). One of our commonest broad-leaved marsh rushes is frequently attacked by a rust, which occurs in great abundance on the leaves of the plant. The winter spores are particularly conspicuous, forming long, black lines, in which are found the densely crowded winter-spores. The latter are two-celled.

Rust of Indian turnip [*Uromyces caladii* (*Schw.*) *Farl.*]. This rust is very abundant in Minnesota. It is found in the wild state, chiefly on Indian turnip, but is also known on the dragon root and on other cultivated aroids. All three rust stages grow upon the same host plant. The cluster cups appear in the spring and are evenly distributed over the lower surface of the leaf. In early summer, the summer spores are produced in small, round, yellowish pustules and these are followed by the winter spores. The latter are brownish and single-celled. The mycelium is capable of wintering over in the swollen, underground, bulbous stem, so that a plant, once infected, cannot be rid of the fungus. Infected cultivated plants must therefore be destroyed as soon as the disease appears.

Cedar apple of red cedar (*Gymnosporangium macropus Lk. and Gymnosporangium globosum Farl.*). See Leaf-rust of Apples and Pears. Diseases of Orchards and Vineyards.

Leaf rust of plums (*Puccinia pruni Pers.*). On many wild cherries. See Diseases of Orchard Plants.

Leaf rust of juneberry. See Birds-Nest Rust of Red Cedar. Diseases of Orchards and Vineyards.

Club rust of juniper [*Gymnosporangium clavariaeforme* (*Jcq.*) *Rees.*]. See Diseases of Orchards and Vineyards.

Rust of mints (*Puccinia menthae Pers.*). See Diseases of Garden Plants.

Rust of violets [*Puccinia violae* (*Schum.*) *D. C.*]. See Diseases of Greenhouse Plants.

Rust of rose leaf [*Phragmidium subcorticium* (*Schrk.*) *Wint.*]. See Diseases of Greenhouses and Ornamental Plants.

Smut of anemone [*Urocystis anemones* (*P.*) *Schroet.*]. This is not an uncommon smut upon a great number of our spring wildflowers of the crowfoot family. It is often found upon the liver-leafed anemone or hepatica. The smut forms upon the leaves, stems or petioles and produces large, black, sack-like pustules of spores. The pustule is at first covered with a thin, greyish membrane, which later breaks and releases the spores in a powder. The spores are not formed and liberated singly as in ordinary powdery smuts, but are grouped together into small spore-balls. Each ball consists of a number of spores of two kinds: there are one to several large, central spores surrounded by a protective coat of smaller, lighter spores, which have lost their power of germination. The spore balls escape intact as the smut powder.

Carnation smut [*Ustilago violacea* (*P.*) *Fckl.*]. This smut is often found on wild plants of the pink family; e. g., on chickweeds, starworts, catch-flies, soapworts and corn cockles. See Diseases of Greenhouse and Ornamental Plants.

FIG. 209.—Mint rust. Winter spore clusters on the leaves. Original.

Smut of violet [*Urocystis violae* (*Sow.*) *Fisch.*]. One occasionally meets with this smut on wild violets. It may occur on leaf-blades, petioles, stems or flower stalks. Definite pustules are formed which, when broken, disclose a black, powdery spore-mass. The flowers do not seem to be attacked and the anthers are not smutted, as in the carnation smut. The smut spores are formed in ball-like masses of cells, the outer of which form a protective coat to the inner cells, which are the functional spores.

Diseased plants should be removed and burned.

Smut of pigeon grass (*Ustilago neglecta Niessl.*). There are several smuts which attack the common pigeon grass. Commonly the grains are replaced by the smut-spore-mass, which is at first covered by a thin wall. These closed masses have often a purplish tinge. The spore-mass is black.

Smut of bromes (*Ustilago bromivora Fisch.*). See Diseases of Field Crops.

Root smut of sedge (*Schinzia cypericola Magn.*). This is an uncommon smut and would not be readily recognized as a member of the smut family. Indeed it is very possible that it does not belong to this group. It is moreover of no economic importance but is of interest on account of its root-inhabiting character, a very rare phenomenon in smuts. It attacks sedge roots forming tuber-like swellings which are often branched in finger fashion. The spores are produced internally on the ends of short threads of the mycelium. This smut occurs in Minnesota, though very rarely.

Honey dew fungi (*Apiosporium, Capnodium and other related genera*). These fungi constitute a group of plants with peculiar habits, which have already been partially explained. They belong to the burnt-wood fungi, producing a mycelium of charcoal-like texture and fruiting bodies of the same nature. They are not true parasites, but are saprophytes, which prefer to live on the excreta of various insects. As these excreta are found largely on living leaves the fungus mycelium comes to spread over the surface of the leaf and often to completely enclose it in a dark mycelium. This position may slightly interfere with the light, though the leaf is seldom injured in consequence. These fungi do not effect any important losses to agricultural plants in Minnesota though a number of them are found in the state.

Mold of honey-colored mushroom [*Endomyces decipiens* (*Tul.*) *Reess.*]. One sometimes finds upon the "mushrooms" of the honey agaric (Agaricus melleus), which is so common in Minnesota in late autumn, a mold-like parasite. The mycelium threads of the parasite permeate the tissues of the mushroom.

The spores are formed usually in fours, inside of small sacs, which are formed on the ends of branches of the mycelium. These little sacs or asci are not enclosed in any special covering but are free upon the mycelium.

The red disease of mushrooms [*Hypomyces lactifluorum* (*Schw.*) *Tul.*]. This is a conspicuous though not very abundant disease of wild mushrooms. It is usually found on the milk mushrooms. The disease-fungus is a member of the burnt-wood fungi, though it has not the black color of most of these plants. An attacked milk mushroom becomes greatly modified in structure. It does not form gills as under normal conditions but the entire surface of the mushroom is smooth. It is therefore roughly top-shaped with the peg in the ground. The surface is colored a very brilliant red (scarlet to orange red), which makes the diseased plant a very conspicuous object in the woods. This color is imparted to it by the parasitic fungus. All over the surface one sees the slightly protruding tips of the sac-spore-capsules which are spherical to pear-shaped and are partially embedded in the tissues of the host. Through an apical opening the sac spores escape in enormous numbers so that if the diseased mushroom be placed under a bell jar for several hours, and left undisturbed, a dense white powder of sac spores from the parasite will fall on the underlying glass. These spores are presumably again capable of causing infection.

Powdery mildew of hazel [*Phyllactinia suffulta* (*Reb.*) *Sacc.*]. Hazels are very commonly attacked by a blight, which occurs also on many other trees, such as birch, oak and ash, though not so abundantly on these. A fine, white, cobwebby mycelium is formed on the leaves, upon which the sac-capsules arise in the fall. The sac-capsules are readily recognized among the powdery mildews by the peculiar appendages which are colorless and straight, and when mature have a swollen bulb at the point of attachment to the capsule. The appendages are not very numerous. The capsules contain a number of sacs, each of which encloses eight spores. Although the disease is very common, the damage done is usually slight and does not call for combative measures.

Powdery mildew of vetch and crowfoot [*Erysiphe communis* (*Wall.*) *Fr.*]. This blight is an exceedingly common parasite on many wild plants and is also found on cultivated plants. It is found in great abundance on plants of the crowfoot and pea families. It appears on wild vetches as an extensive, fine, white mycelium, which bears the summer spores as a starchy powder, typical for the powdery mildews. The spore-sac-capsules are formed in the late summer and fall and appear as small black bodies about the size of a very small pin-point. The capsules have unbranched, brown appendages, which are interwoven with the mycelial hyphae. They contain a number of sacs, each enclosing eight spores. This mildew, though common on wild plants, is apparently not very destructive to cultivated plants.

FIG. 210.—Powdery mildew of composites, on the leaf of the great ragweed. The white felt of the superficial mycelium is shown and the numerous black dots are the sac-spore-capsules. Original.

If necessary, treatment as against powdery mildews in general would probably be effective.

Powdery mildew of composites (*Erysiphe cichoracearum DC.*). This is perhaps the most common of all our powdery mildews. It is exceedingly abundant upon a great number of wild plants, belonging chiefly to the composite family. The borage and other families are less frequently attacked. It is found on sunflowers, rag-weeds, verbenas and a host of other plants. It forms a more or less dense and conspicuous, white, cottony coat over the leaf surface. The sac-capsules appear in the fall, but in some cases do not mature until the following spring. They have appendages somewhat similar to those of the powdery mildew of grasses are unbranched, dark in color and interwoven with the mycelial threads. The capsules contain numerous sacs, in each of which are produced eight spores.

See also Powdery Mildew of Cucumbers. Diseases of Garden Crops.

Powdery mildew of mints (*Erysiphe galeopsidis DC.*). This mildew occurs on many wild plants of the mint family. The mycelium appears as a superficial whitish film on the leaves and stems. The fungus is very similar to the powdery mildew of vetches and peas. It differs from this fungus in the form of its sucker threads. The sac-capsules are formed in the fall, but do not mature until the following spring. The fungus is not known extensively on cultivated plants. In case of a serious attack the usual methods against powdery mildews would probably be effective.

Witches'-broom of cherry [*Exoascus cerasi* (*Fckl.*) *Sad.*] See Diseases of Orchards and Vineyards.

Witches'-broom of birch (*Species of Exoascus*). See Diseases of Timbers and Timber Trees.

Plum pockets and cherry pockets (*Species of Exoascus, chiefly Exoascus pruni Fckl.*). See Diseases of Orchards and Vineyards.

Black-knot of plum and cherry [*Plowrightia morbosa* (*Schw.*) *Sacç.*]. See Diseases of Orchards and Vineyards.

Mold of mushrooms (*Sporodinia grandis Link.*). Mushrooms of various kinds, wild as well as cultivated, are attacked by a mold of the bread- or black-mold group. The mold is particularly abundant on mushrooms that have been picked and kept in moist situations for some time. It lives chiefly as a saprophyte and forms on the mushroom a dense, white, moldy felt which is composed of comparatively coarse threads. This white felt later turns brown and then black. When in the brown state one usually finds an abundance of spore-cases, each containing several to many spores. When the felt has become black the sexual reproductive bodies are produced, similar to, but in much greater abundance than in, the ordinary bread mold. Their fusion results in the production of a thick-coated, resting spore. Shortly after the mold has become established decay of the mushrooms sets in and the latter may soon be destroyed. The trouble can usually be obviated by avoiding too moist conditions. There are several other molds of the bread-mold group which attack picked mushrooms.

Gall fungus of the wild peanut (*Synchytrium decipiens Farl.*). This disease has no economical importance in Minnesota. since its host is an unused wild flower, but is of interest on account of the fungus producing it. It is an exceedingly com-

FIG. 211.—Gall fungus on the wild peanut. Minute galls can be seen on the petioles and leaflets. Original.

mon disease and is often found in great abundance. The host plants then appear covered as with a yellow rust, not unlike the cluster-cup stages of a rust fungus. The fungus is a single-celled plant and lives in the cells of the host which it stimulates to an increased growth resembling tiny yellow galls. Swimming spores are produced in a manner similar to those of the seedling disease of cabbages. Winter spores are also formed in a similar manner to those of the cabbage disease. The fungus is abundant in rainy seasons.

Fungus gall of wood anemone [*Synchytrium anemones (DC.) Wor.*]. This fungus is a similar plant to that of the wild peanut. It is single-celled and produces swimming spores in the early summer months. It forms small, dark, reddish galls in the tissues of the host plant, quite like those formed by the gall fungi of dandelion, wild peanut and cranberry, but the galls are colored red as in cranberry. This fungus is very common in Minnesota and is especially conspicuous in late spring and early summer. It can be readily recognized by the dark, reddish color of the host plant leaves and the small wart-like excrescences.

Leaf wart of dandelion (*Synchytrium taraxaci DeBy. et Wor.*). This fungus is closely related to the fungus of the seedling disease of cabbages. It attacks the leaves of the dandelion and stunts and distorts them. The fungus is a single spherical cell and lives in one of the epidermal cells of the host. The latter cell swells to many times its original size and produces the simplest kind of a plant gall. The leaf when badly infected contains many of these galls, so that the surface is more or less roughened by the abundance of warts. Swimming spores are produced in a manner similar to those of the seedling cabbage disease and spread the infection under moist conditions. Thick-coated winter spores are also produced. This disease, though not uncommon, is never serious enough to assist materially in getting rid of the dandelion pest.

Cranberry scald (*Undetermined fungi*). The life stories of the fungi which cause this disease have not yet been worked out. There are probably several kinds producing what is commonly known as scald. Small soft spots arise in the cranberry and these soft spots enlarge rapidly until the whole berry is affected and it now has the appearance of a scalded berry. The skin remains intact but the contents are watery and soft. In the diseased tissues one can find abundant threads of the fungus. The berry in later stages turns dark brown, finally shrivels and becomes black. On the surface are produced minute black spots appearing somewhat like the capsules of certain parasitic burnt-wood fungi. The disease appears in July and August and affects also cranberries in storage. Excessive moisture seems to favor the disease. Sanding of the bogs, an inch in depth, and draining in summer, so that they shall remain fairly dry, have been recommended.

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