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6-1-1908

Rusts of Cereals and Other Plants

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South Dakota
Agricultural Experiment Station

South Dakota State College of Agriculture
and Mechanic Arts
Brookings, S. D.

Rusts of Cereals and Other Plants

Department of Botany

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RUSTS OF CEREALS AND OTHER PLANTS.

E. W. OLIVE.

Rusts are among the most common as well as among the most destructive of fungous diseases. They attack the cereals and grasses of our fields, the fruit trees of our orchards, and even the ornamental plants of our garden, causing in years especially favorable for their growth, enormous financial losses. Rusts are with us every year; we may not notice them so much during certain dry seasons, but not a year passes without the disease being present on grain and other plants to a greater or less extent. Professor Bolley of the North Dakota Station estimates that the average annual loss to the wheat crop alone through rust in the United States approximates about twenty millions of dollars. Galloway judged the loss in wheat for the year 1891 at sixty-seven million dollars. Such great sums recorded each year as the loss to farmers by rust is more often probably underestimated than exaggerated. Various crop experts placed the loss to the wheat crops of the wheat states of the Northwest, for the season of 1905, at thirty million bushels, aside from the loss in grade of the crop harvested. The "rusty year" of 1904, when grain rust was prevalent throughout the whole United States, was even more disastrous. Probably the loss throughout South Dakota during that year approximated as much as fifty per cent of the average annual crop. The disease was epidemic during 1904 on account of the especially favorable weather conditions which prevailed during that season. A wet spring, followed by warm, moist weather, presents just the conditions the rust needs for its rapid growth and spread. The weather known as "muggy", caused by showers with heat between and by heavy dews, results in a heavy, more or less succulent growth of the wheat plant, which thus becomes particularly susceptible to the entrance and rapid growth of the rust parasite. Those people are thus not altogether wrong who think that the rust is caused by warm, wet weather.

Every farmer knows what rust looks like to the naked eye, for it is usually so conspicuous as to attract the attention of every careful observer. The common name, Rust, is applied on account

of the reddish brown, rusty appearance which the diseased spots assume, especially when the summer spores are being produced. Nearly every one whose crops have been devastated by these diseases dreads especially what is commonly called the "stem rust", or "black rust", (*Puccinia graminis*) since this species is the one to which the greater losses seem to be due. But there are two other kinds of rust which attack wheat and other cereals, which can hardly be distinguished from the "black rust" except by very close observation, or else under the microscope. These are known as the "orange leaf-rust" (*Puccinia rubigo-vera*) and "crown-rust" (generally on oats) known technically as *Puccinia coronata*. Before describing these three kinds of rusts in some detail, it may be well to explain first the main points in the life history of the common stem rust of wheat, since this is the most important one from the farmer's point of view. It will be seen from the following account that the rust problem is not a simple one. The disease cannot be prevented as easily as can smut in oats, for instance, by means of seed treatment with formaldehyde. The problem in the prevention of rusts is such a difficult one, in fact, that many points still remain to be solved.

The main thing which can be done at present, therefore, is simply to record the present status of our knowledge as to the nature of these complicated organisms and to awaken interest in a knowledge of their habits. As is now generally well known, the rusts are minute, parasitic plants known as fungi. Fungi are sometimes conspicuous plants, like the toadstools and mushrooms; still others are parasites inside other plants, and so small as to escape the naked eye altogether. All consist essentially of a mass of microscopic tubes or cells arranged end to end in the form of threads; and all of them reproduce their kind by means of minute cut-off cells or pieces, called spores. If we start with the stem rust of wheat (*Puccinia graminis*) in the early summer stage, it will be noticed that the spots are at this time generally confined to the stem or the leaf sheath; and are seldom found on the blade of the leaf. The spots are long and narrow and at this early season are reddish brown in color. The rusty spots are of course caused by the masses of minute spores, which are cut off from the tip of

the fungus threads, and which break through the epidermis of the wheat plant. These spores fall off when ripe and are blown about as minute, invisible specks over the fields, perhaps even miles from where they were produced. If a spore alights on a wheat plant, it proceeds to germinate in the dew or film of moisture deposited on the plant and grows down into the living tissues of the host. The thread thus produced pushes its way between the cells of the host plant, branching often, and here and there sending small branches into the cells of the wheat, thus robbing the latter of some of its nourishment. After developing thus inside the wheat plant for about ten days or two weeks, another crop of reddish spores bursts forth, which may then scatter the disease to still other plants. Starting with one spore the disease may thus, in this short time, multiply itself a thousand fold and more. It is easy to see how damp, muggy weather, assisted by a few windy days, is responsible for such a devastating rust epidemic as swept over the country in 1904. The production of reddish summer spores in immense numbers may thus be repeated from very early in the season until late. This is the stage in the fungus which apparently does the greatest amount of damage, since the spores produced during the summer scatter the disease so rapidly, thus levying the tax of nutrition and energy upon the wheat crop for miles and miles around. Whole crops may even be completely ruined. More often, however, the farmer does not lose all but gets simply a short crop; and the grains resulting from the rusted wheat are seen to be small and immature, sometimes only one-half the weight of that from the rust-free wheat. In some parts of the country, wheat growing has been utterly abandoned, in fact, on account of wheat rust.

On account of the conspicuous nature of the summer spores as well as their color, this stage of the disease is often called the "red rust"; but it must be remembered that all three species of the rusts on wheat mentioned above have reddish summer spores in one stage of their development. The summer spores are known technically as *UREDOSPORES*, from a Latin word meaning "to burn."

Late in the season when the wheat has become well advanced towards maturity, it will be noticed that the successive crops o

the reddish spores diminish in numbers and there now appears, generally on the stem or leaf-sheath of the wheat, and sometimes even in the same spots with the reddish spores, long, black lines or spots, made up of the dark-brown or black, so-called winter spores. (See Fig. 4). This stage in the development of the stem rust is often popularly called the "black rust". These black spores which have the shape of minute Indian clubs, are the TELEUTOSPORES, or "last formed" spores, as the name indicates. They have thick, resistant cell walls and the spores are capable of living for a long time. In fact, in all the rusts of wheat, it has been fairly definitely proven that the TELEUTOSPORES cannot be made to germinate at all until after they have rested through the winter or at least a part of it. They remain then as black spots on the stubble or straw over winter and the spring warmth and moisture causes them again to revive and to germinate to form a short thread. This short thread cuts off a number of minute spores called sporidia, generally four of them, which are thrown off to sail about as invisible specks in the spring winds.

We have traced so far through two stages of the stem rust of wheat (*PUCCINIA GRAMINIS*), and have noticed that both kinds of spores are borne on the wheat plant. Now happens a peculiar thing. The minute spores just mentioned, produced in the spring, will not affect the wheat plant at all, even under the most favorable circumstances. Numerous experimenters have failed time and again to make these sporidia attack the wheat plant, either by way of root, seed, leaf or stem. The only plants which they are known to attack are the barberries, shrubby plants with prickly leaves, now common in South Dakota in ornamental hedges, one species of which grows wild in the Black Hills. (See Fig. 1). DeBary, a noted German botanist, proved definitely, as early as 1864, that the barberry is the plant which was attacked by the spring stage of the common wheat rust. For a long time, many practical farmers had suspected that the barberry bushes were their enemy, in that they appeared to have something to do with the spread of the wheat rust; and even a century and a half ago, in 1760, the state of Massachusetts passed a law compelling the people to cut down the barberry. Apparently the law was soon allowed to lapse, how-



Fig. 1. Branches of the Barberry bush, bearing cluster cups, or the aecidium stage, of the black or stem, rust of wheat (*PUCCINIA GRAMINIS*).

ever, for New England roadsides and fields are lined with an abundance of the shrubs to this day

Such a rust as that on wheat, which passes part of its existence on a secondary host, is called a HETEROECIOUS rust. Such conditions are common among rusts; in fact, all the common cereal rusts pass their spring stage on a secondary host plant. Such diseases are thus comparable to malaria, which passes one stage of its existence in a certain kind of mosquito; and to that caused by the trichina parasite, which lives part of its life history in the pig. The other kind of rusts, known as AUTOECIOUS rusts, which live all their lives on one host, are also common; the rose rust, flax rust and asparagus rust are examples.

When the wheat rust sporidia are blown on the barberry leaves early in the spring, their germ tubes grow down into the tissues and make a yellowish, diseased, often swollen spot. In about fifteen to twenty days a new set of spores breaks through the epidermis of the leaf over the infected spot. The spores are formed in countless numbers in chains, which arise at the bottom of little cup-shaped depressions, large enough to be seen readily with the naked eye. Many little cups arise from one infected spot; hence the name "cluster cup stage" is often given to the barberry stage of the disease. "Aecidium-cup" is also applied to this phase; and "aecidiospores" to these special spores produced in chains in the barberry cupules.

Now comes the jump back to the wheat again. The minute aecidiospores are so light and easily detached that they are readily distributed by the winds. If they lodge on a wheat plant, they germinate at once in the film of dew present at times on the surface, and each produces one or more long, slender germ-tubes. These grow down through the breathing-pores of the host-plant and produce an infection which, if the weather be moist and otherwise favorable, may ultimately spread the disease over the whole wheat field or over great areas for miles around. This brings us back, then, to the summer spores of the wheat, the uredo-spores; we have thus completed the full life cycle of the fungus. (See Fig. 2).

The early spring growth of the wheat rust thus goes over for a short time to the barberry shrubs; while the destructive summer

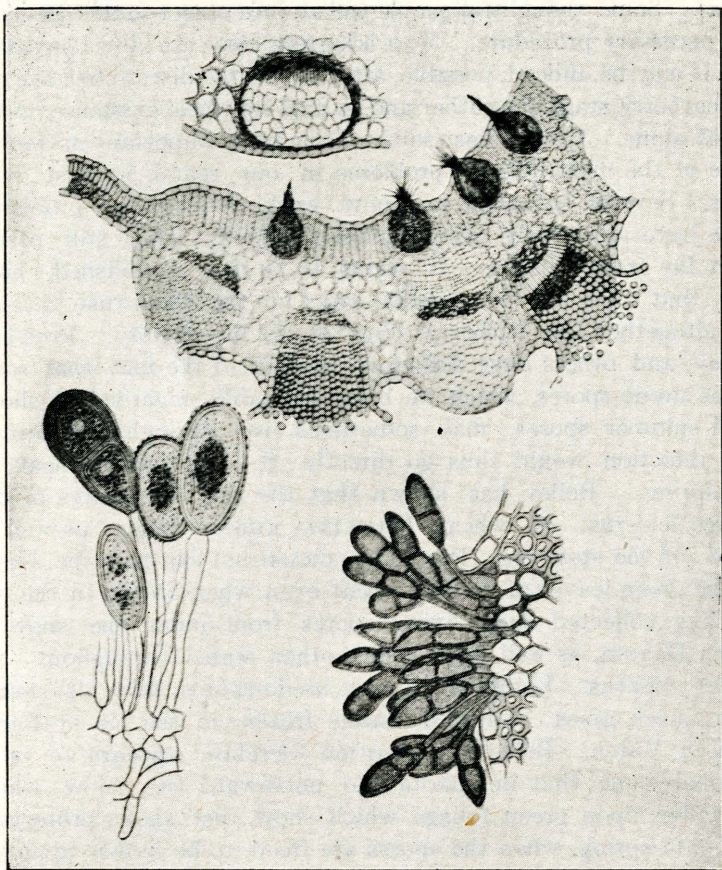


Fig. 2. Stages in the life history of the stem rust of wheat (*PUCCINIA GRAMINIS*). Above, a cross section of a barberry leaf showing young and old aecidia, or cluster-cups. Below, at the left, three summer spores (uredospores) and one teleutospore; at the right, a group of ripe, thick walled, winter spores, or teleutospores, bursting out of the leaf. (After DeBary, from Sach's Lehrbuch).

stage and the resting winter condition come back again to the wheat. Some thoughtful people will at once object to this life-cycle as a necessary procedure. Most scientists also are now convinced that it may be, indeed, possible, after all, for the disease to leave out the barberry stage altogether and to pass its whole existence on the wheat alone. Herein lies some of our most important as well as some of the most difficult problems in our search for rust remedies. Several botanists are now working on these problems; some have apparently been partially solved, while still others seem far from solution. It seems to be now established, however, that there are two possible ways for the wheat rust to leave out altogether the barberry stage of its life history. Professor Bolley and others have definitely established the fact that some of the uredo-spores, which we have ordinarily regarded as short-lived summer spores, may sometimes live through the winter. The infection would thus go directly to the young wheat in the spring. Bolley has shown that the red rust spores of the orange leaf-rust of wheat (*PUCCINIA RUBIGO-VERA*) as well as these of the stem rust (*PUC-CINIA GRAMINIS*) can pass the winter on the green leaves of winter wheat even when frozen in the ice. He has collected such living spores from under the snow in North Dakota, as well as in many other states throughout the winter months. Living stem rust uredo-spores were also taken from quack grass and wild barley frozen in the ice at Fargo even in March. Bolley's contention therefore appears to be a reasonable one; that in Dakota and northward the snow which has fallen upon green foliage which show rust spots, protects it until late spring, when the spores are freed, to be blown about to infect again young foliage of wheat and other grain.

Mr. Christman, of Wisconsin, thinks, however, that, although it is true that these uredo-spores may remain dormant for long periods during the winter without losing their vitality, it is unlikely that these spores play the main part in starting the disease in wheat in the spring. He points out that as long as the wheat and oats and barley plants can survive the winter, the internal rust filaments, or mycelium, which have come from last fall's infection, can also live over with the host plant. Christman showed that the pale

spots often seen during the winter and early spring months on the leaves of badly rusted grain develop further during the warm days of March and produce, even as late as April 3rd, open pustules of red rust spores. His idea is then that the disease survives the winter mainly in the form of a mycelium which lies more or less dormant in the old winter leaves of the host plant. The uredospores then produced in the early spring from the wintered-over mycelium scatters the disease broadcast over the growing crops. But we see no rust to speak of for another month or so, because, according to Christman, during the cooler weather of early spring the time from the earliest infection of the rust to the first crop of summer spores, called the "incubation period", is lengthened beyond the usual time, to between three or four weeks. The severity of the winter, so Christman thinks, may thus be one of the chief factors in determining the violence of yearly outbreaks of rust, since a milder winter or a season with much protecting snows, may enable more healthy host tissue and hence more internal fungus mycelium to survive. The number of uredospores at hand in the spring would consequently be much increased after such a favorable winter.

We see, then, how it is possible for the stem rust of wheat to omit the barberry stage altogether from its life-cycle either, first, by means of uredospores which have survived the winter on winter wheat or on other grains, or on volunteer growths of wheat or rye or oats, etc.; or, second, by means of the fungus threads (mycelium) living over winter within the tissues of the host plant and producing a fresh crop of uredospores early in the spring. Most botanists think it quite likely too that many wild grasses, such as quack grass, the native wheat grasses, red top, wild barley, or squirrel tail grass, etc., may carry the rust over winter either as spores or living mycelium and transmit it to the wheat next season.

The problem in the case of the orange leaf rust (*PUCCINIA RUBIGO-VERA*) is in quite a similar state of uncertainty with regard to certain points. This rust is very abundant on wheat and other grain throughout the country, and it also does much damage by robbing the growing crop. This leaf rust may be distinguished from the stem rust, or "black rust", by the different position of

the smaller, orange-colored spots of summer spores, since in the leaf rust they occur in chief abundance on the lower surface of the leaf blade. We are not at all sure whether this rust has any cluster cup stage in this country comparable to the barberry stage; but in Europe it passes this part of the life-cycle on certain members of the Borage family. We, in fact, have long felt certain that the orange leaf-rust could dispense altogether in this country with the cluster-cup stage, and could hibernate in some wild grasses or in winter wheat.

The third kind of rust mentioned above as occurring particularly on oats—crown rust, (*PUCCINIA CORONATA*), has its spring stage on the buckthorn. Buckthorn is a well known plant, as it is very commonly used for ornamental hedges throughout South Dakota; being even much more employed for this purpose than barberry. (See Figure 3.) During this past spring, hedges of this plant in this vicinity have been everywhere viciously attacked by the yellow cluster-cup stage; stunting the leaves and deforming and twisting the young stems. We should consequently expect the rust on oats to be especially virulent during this wet season, since the spores from the disease on the buckthorn are now being scattered broadcast. All that is now necessary to make the season any more favorable for the rust is to have a series of warm, muggy days.

The three kinds of rust described above are the most important ones from an economic standpoint. Rust on corn is familiar to many, however, although it is generally thought not to cause any serious loss. Professor Arthur, of Indiana, has only very recently discovered that the cluster-cup stage of the corn rust is found on a common species of *Oxalis*, or wood-sorrel.

Many inquiries have recently been received at this station regarding the rust on ash trees. The cluster-cup stage apparently inflicts some damage on the leaves, young stems and fruits of the ash; the grass stage of the disease is passed on a common (*SPARTINA*) wild marsh grass.

In the southern part of this state apple leaf-rust (*GYMNO-SPORANGIUM*) does considerable damage, particularly to such susceptible varieties as the Wealthy. The stage of the rust on apple

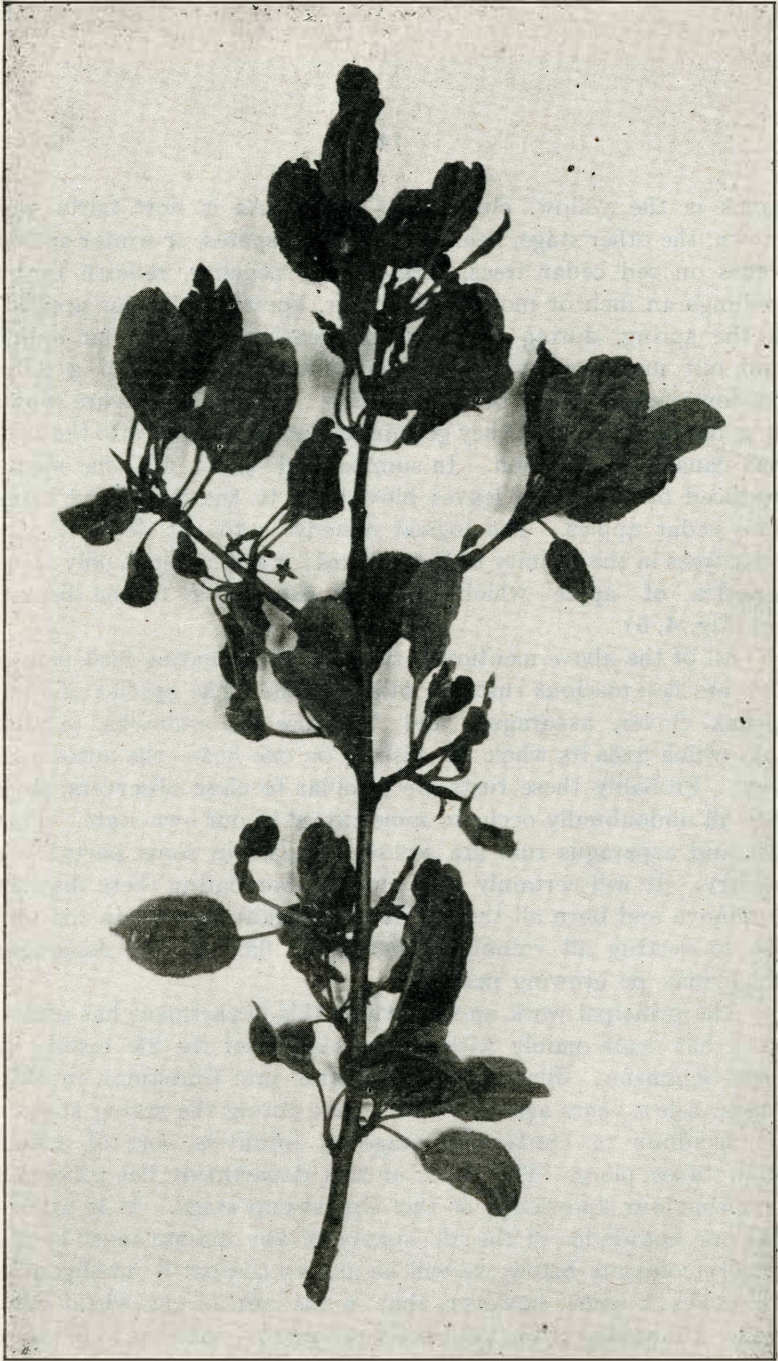
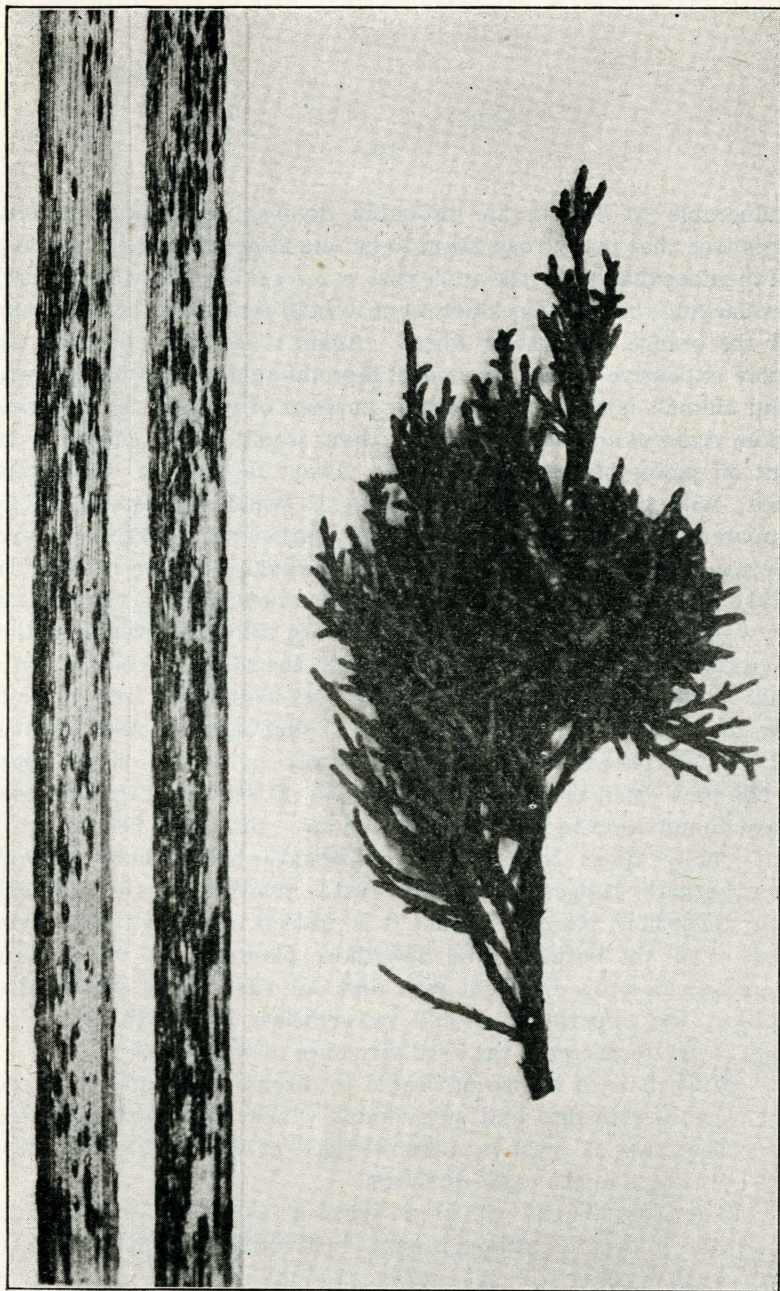


Fig. 3. Branch of Buckthorn (*RHAMNUS CATHARTICA*), bearing the cluster-cups of the crown rust (*PUCCINIA CORONATA*).

leaves is the yellow. cluster-cup stage. As is now fairly well known, the other stage, bearing the teleutospores, or winter spores, occurs on red cedar trees, forming the peculiar, reddish brown swellings an inch or more in diameter, known as "cedar apples". In the spring, during damp, rainy weather, these cedar apples send out numerous, yellowish, spike-like projections, of a jelly-like consistency, which bear the spores. If these spores are blown on a damp apple leaf, they germinate and grow down into the leaf, thus causing an infection. In summer and early fall, the spores produced on the apple leaves blow back to the cedar and cause more cedar apples. The logical remedy is to cut down all the cedar trees in the vicinity of the orchard; or else to plant only those varieties of apple which are least susceptible to the disease. (See Fig. 4, b).

All of the above mentioned rusts have alternating host plants; they are heteroecious rusts, in other words. The species of rusts on flax, clover, asparagus, and the rose are examples of that class which lives its whole life history on one host—the autoecious rusts. Probably these rusts are familiar to close observers, since they all undoubtedly occur to some extent in our own state. Flax rust and asparagus rust are serious diseases in some parts of the country. It will certainly help much in combating these diseases to remove and burn all the old, infected plant remains in the fall; also to destroy all volunteer growths of flax or wild asparagus which may be growing near.

The principal work on rust which this department has undertaken has dealt mainly with certain details of the life history of these organisms. Blackman in England, and Christman in Wisconsin, a few years ago discovered that during the spring stage—the aecidium or cluster-cup stage—a primitive sort of sexual union takes place. The work of this department has extended somewhat our knowledge of this cluster-cup stage. It is argued that our knowledge of the life history of any disease must be absolutely complete before we will be able to combat it intelligently. The hopes of some, however, that in the case of the wheat rust, a fuller knowledge of the vital processes might enable us to discover some weak point in the life history which might prove to be more



A

B

Fig. 4. a. Stems of wheat showing black clusters of winter spores, or teleutospores, of "stem" rust, or "black" rust (*PUCCINIA GRAMINIS*). (After Freeman.)

b Cedar apple (*GYMNOSPORANGIUM MACROPUS*) on red cedar, showing the gelatinous spike-like masses of winter spores.

vulnerable to attack. are probably doomed to disappointment. It is true that many rusts seem to be unable to exist in the absence of their aecidial hosts; the apple rust, e. g., is not found where cedars are lacking; but this does not seem to hold for either the stem rust or the orange leaf-rust of wheat. Again it is reasoned, since the more expensive sexual method of reproduction among both plants and animals is apparently for the purpose of making the offspring more vigorous and more variable than would result simply from cut off pieces of the parent, doing away in case of the grain rust, with their aecidial host plants in which the sexual unions apparently take place (i. e., the barberries, buckthorns, and Borage plants) might cause the rust gradually to lose its vitality and finally to die out altogether. But we must remember that so far as we know, the orange leaf-rust does not utilize anywhere in this country an aecidial host plant, in which the sexual processes could take place. This fungus apparently gets along very well without the sexual process. It is well known that potatoes and bananas have been grown for generations simply by means of cuttings; seeds have been used but little if at all in their propagation, and they do not seem to have deteriorated any. But it has been pointed out many times that the rust of wheat is always more virulent near barberry hedges and that oat rust is invariably more prevalent near buckthorn plants. While it is indeed impossible to expect that if all the barberry and buckthorn plants in the whole state were once destroyed, wheat rust and oat rust would wholly disappear, the experiment would nevertheless be worth trying, if only to try to decrease the local virulence of the disease.

While it is of course advisable to discuss to a limited extent the various remedies and suggestions which have been proposed for wheat rust, it must be acknowledged at the outset that these are only steps in the right direction.

It is plain that it will do no harm at all to use grain from a rusted crop for seed, although many instinctively believe that seed from rusted fields will necessarily produce a rusted crop. It is true that rusted grain is light weight and shriveled, but if the seed is properly graded to plump, hard grains of about normal weight, a normal stand may be expected. Neither the grain from

a rusted crop nor badly rusted straw need be discarded, for it has been conclusively shown by work done both at the Minnesota station and at the Canadian Experimental Farms that both the grain and straw have a proportionately higher nutritive value and may be profitably used for feeding. As Mr. Shutt, the Canadian chemist, says: "The growth of the rust arrests development and indicates premature ripeness, which, as we have seen, means a straw in which still remains the elaborated food, and a grain small, immature, rich in protein and deficient in starch." (See Figure),

Proper drainage will help much to keep down grain rust. As long as the surface keeps fairly dry, no rust spores can adhere and infect the wheat plants. In well-drained, sandy soil, such as is found about Aberdeen, for instance, rust has a poorer chance than in the bottom lands of the Sioux Valley. As Prof. Bolley points out, co-operative efforts to secure proper general drainage of all the great cereal producing areas in the whole United States, will greatly lessen the liability of rust epidemics.

Prof. Bolley further contends, and wisely, it seems to me, that it is a bad thing for our spring wheat belt to push winter wheat any farther north. It is easy to see how harm may result to spring wheat in two ways from this association: first, winter wheat may carry the rust over to transmit it in the spring to spring wheat; second, the rust gets a good start, at least two weeks or more earlier in the season, on winter wheat, so that when it is transferred to the tender spring wheat, it is especially virulent. Spring wheat can no longer be grown profitably in Iowa, Michigan or New York state. With the general introduction of winter wheat into South Dakota, it is quite probable that a few years would see spring wheat in this region ceasing to give proper yields.

It will further help in keeping down wheat rust to some extent to cut down and to burn roadside weeds and grasses—especially the extremely common wild barley, or squirrel-tail grass, quack and wheat grasses. Barberry bushes and buckthorn bushes also ought to be destroyed. This should be a general practice, since it will do but little good to cut the bushes down in any one locality.

One of the most promising means of combating the rust of



Fig. 5. Shriveled grain resulting from rusted wheat, contrasted with well filled kernels.

wheat seems to be the breeding of immune varieties. The Government and many experiment stations have long been experimenting along this line of work, especially with durum wheats, but the advance has been slow. The North Dakota Station is trying by careful selection and grading of seed from rusted crops to find a race of wheat which can successfully resist the disease. Such resistance may result from a certain special fitness to survive—something inherited, which somehow imparts partial or complete immunity; or, the resistance may be only apparent, since the plant may not have been moist enough for infection, or the wind-blown spores may not have reached it. Mr. Biffen, in England, has gone at the matter from a somewhat different point of view and his results bid fair to give us a wheat with desirable milling qualities and at the same time with considerable resistance to rust. He has found that when a rust-resistant variety is crossed with a variety especially prone to rust, the hybrids which result follow certain definite laws formulated by Mendel. A certain percentage of the hybrid plants are seen to be immune to rust, immunity in this case being what we call a recessive quality, so that a pure race of wheat may be thus established which should always remain rust-resistant.

The following books and articles on rusts have been in the main utilized in the preparation of this bulletin.

H. L. Bolley. Rust problems. Bul. 68, N. Dak., 1906.

A. H. Christman. Observations on the wintering of the grain rusts. Trans. Wisconsin Acad. Sci. Vol. 15, 1905.

F. M. Freeman. Minnesota Plant Diseases. 1905.

D. McAlpine. The Rusts of Australia. 1906.

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83. Millet for Fattening Swine.
84. Report of Investigations at the Highmore Station for 1903.
89. Preliminary Experiments With Vapor Treatments for the Prevention of the Stinking Smut in Wheat.
90. Tankage and Other By-Products for Pigs; Shrunken Wheat for Swine.
91. Co-operative Vegetable Tests in 1904. Peas, Beans, Sweet Corn, Cabbage.
92. The Milling Qualities of Macaroni Wheat.
93. Plums in South Dakota.
94. Alfalfa and Red Clover.
95. The Treatment of Nail Pricks of the Horse's Foot
96. Forage Plants and Cereals. At Highmore Sub-Station.
97. Speltz and Millet for the Production of Baby Beef.
98. Crop Rotation.
99. Macaroni or Durum Wheats. A Continuation of Bulletin 92.
100. The Value of Speltz for the Production of Beef and Pork.
101. Forage Plants at the Highmore Sub-Station. 1906.
102. Evergreens for South Dakota.
103. Breeding Hardy Strawberries.
104. Breeding Hardy Raspberries.
105. Stock Food for Pigs.
106. Sugar Beets in South Dakota.
107. Sheep Scab.
108. New Hybrid Fruits.
109. Rusts of Cereals and Other Plants.