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FUSARIUM BLIGHT OF THE CEREAL CROPS

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INTRODUCTION.

That the cereal crops are subject to attacks by various Fusarium species, which in some years and localities may decrease materially their yields, has been known almost for a century, but it was not until the appearance of SCHAFFNIT's work on the so-called „Snow mold" in Germany, NAUMOFF's work on „Intoxicating bread" in Russia, and ATANASOFF's work on the Fusarium-blight of cereals in the United States that the first light was thrown on this so complicated and economically so important problem.

At the same time these works not only placed the study of this problem on a purely scientific basis, but also formed a sound foundation for the further investigations of this disease.

The data included in this paper are the result of writer's studies and observations on this problem during the last six years. These studies have been conducted at the Department of Plant Pathology of the University of Wisconsin, United States and were continued at the Central Institute for Agricultural Research at Sofia, Bulgaria; the Biologische Reichsanstalt für Land- und Forstwirtschaft at Berlin-Dahlem, Germany, and the Instituut voor Phytopathologie at Wageningen, Holland.

Part of these results have been already published in form of a preliminary report three years ago (13) [1]. However, writer's subsequent studies and observations on this subject made at various places in Europe, have added valuable contributions towards the better understanding of the Fusarium disease of the cereal crops, so that a second publication in a somewhat monographic form seems desirable. This is further justified by the fact that in Europe, inclusive Holland, the Fusarium blight

[1]) Reference is made by number to "Literature cited," p. 102.

of cereals though economically a very important disease, is generally overlooked or ignored as a whole.

The European literature and especially the rich German literature on this subject has made valuable contributions towards the understanding of: the effect of this disease on the germinating power of the grains, the seedling blight, the snow mold and the poor overwintering of fields planted with infected seed, the foot rot phase and the seed disinfection as control measure against this disease. Yet the most important phase of the disease, namely the blighting of the heads, which is by far its most destructive form, and which gives rise to the other phases of the disease, has been generally overlooked. It is indeed difficult to understand how it could be possible for all of the European students of this problem, who have studied the effect of the fusarial infection on the seed and who often speak of 50 or 70 % infected seed, that they should not have seen the blighting of the heads of the crops during the period of filling out and ripening, since before we can have 50 or 70 % infection in the newly harvested grain we should have had no less than 50 or more per cent decrease in yields. But of such decrease in the yields there has never been question in the European literature; this is true of Holland also.

The further aim of this monograph is to emphasize for the second time the intimate relation which exists between — or the identity of — the various injuries of the cereal crops caused by Fusarium spp, which injuries represent only links in a closed ring.

Whether the cereal crops are attacked in one or several ways by *Calonectria graminicola* [*Fusarium minimum* (*nivale*)] common in Germany and the Scandinavian countries; by *Gibberella saubenetti* common throughout the wheat growing section of the United States, Holland, Bulgaria, and Southern Russia; bij *Fusarium avenaceum* common in Northern Russia, or by *Fusarium culmorum*, common in Holland, Germany, Sweden, France and Oregon U. S. A., or by the numerous other Fusarium spp., the symptoms and pathologic effects are identical in all cases, under all conditions and in all countries.

Separating this disease into seedling blight, snow mold, foot rot, stalk rot and head blight (wheat scab) as has been done up to now as the result of our limited and fractional knowledge of this problem as a whole, is no more permissible, unless these forms are meant as different stages of the same disease.

The cereal crops, wheat, rye, barley, oats and spelt, as well as some of the grasses, are subject to attacks by a large number of fungi belonging to the genus Fusarium. In a considerable number of cases, the same Fusarium species will attack each of the above crops in at least two different ways, producing two distinct pathologic conditions. The first is an attack on the underground portion of the young („seedling blight") and later on on the full-grown plants („foot rot"), producing rotting of the roots and bases, weakening of the plants and possibly partial or entire wilting and death of some of them. The second condition is an attack on the fully grown plants above the ground. This may be a spotting of the leaves; rotting of the nodes, found on rye, wheat and barley; or blighting of the heads of wheat, rye, barley, spelt and, in some cases, of oats and the various grasses. *In all cases the various attacks on the same host are entirely independent of each other.* A wheat plant may be attacked under the ground, or on the head only, or both on the roots and the head, and in some cases even on the nodes, *but in all cases these infections are entirely independent one of the other and may be caused by the same or different Fusarium species.* An infection of the roots does not presuppose an infection of the head or nodes, or vice versa, though in very rare cases the infection of the roots may reach the first or second node, or the infection on the head proceed down to the first or second upper node. An infection of the middle nodes may cause the wilting of the part above the point of infection, but it never reaches the head nor will it extend down to the roots.

Though independent from each other, the various forms of the disease in most cases may stand in direct relation to each other: The head infection gives us infected seed, which upon planting give rise to seedling blight. The plants that have survived the seedling blight when growing under unfavorable conditions during the winter and early spring may again succumb to the disease, in this stage to root rot; same plants may show later on, when fully grown, the foot-or stalk-rot form of the disease; the conidia formed on the plants attacked by footrot or stalk rot may cause blighting of the heads, thus completing the cycle and giving us again infected seed. Fig. 1.

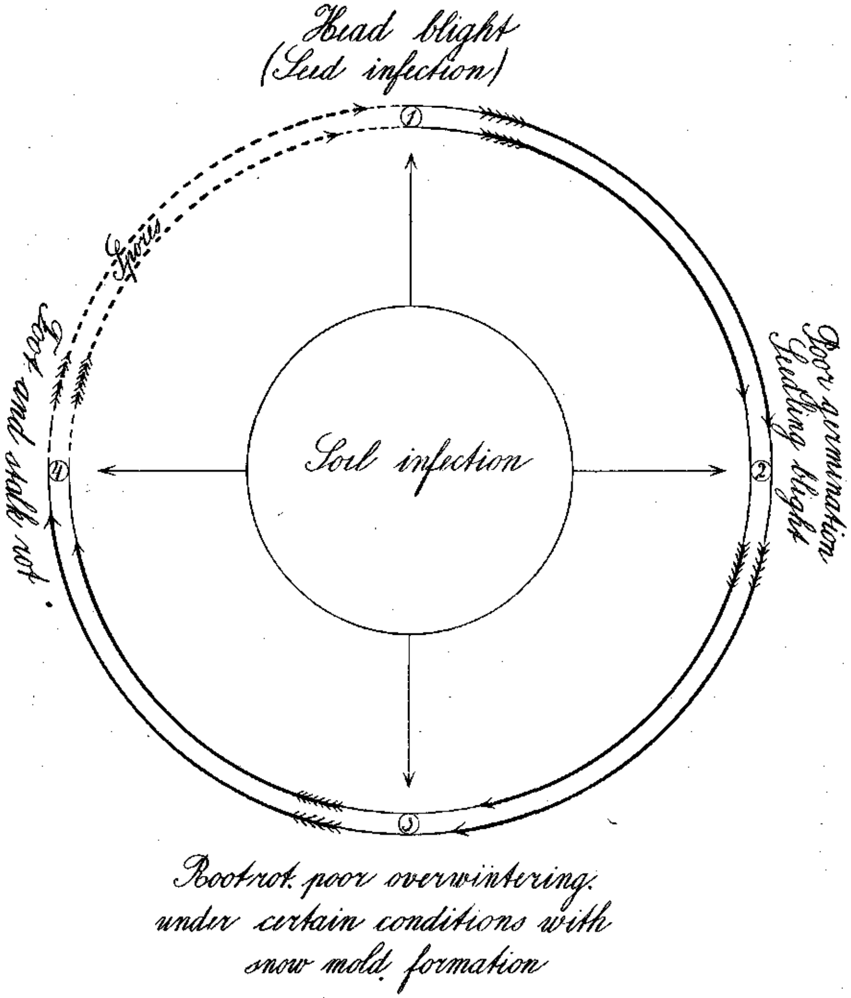

Fig. 1. Diagramatic presentation of the various stages of the Fusarium-blight of cereals and the interrelation of the various forms of this disease, — also of the relation of soil infection to the various forms of the disease.

Up to the present time these forms of Fusarium attack have received but slight attention and whenever any attention was given to them they have been generally considered as different diseases, caused by one or more different or usually unknown species of Fusarium. The results of our work prove, however, very conclusively, as has already been shown, partially at least.

by other workers, that these different pathologic conditions are nothing but different phases of the same problem.

Though a comparatively large number of Fusarium species have been found by the writer associated with both root, base, and head attacks of the cereal crops, it is his belief that a more thorough and more extensive study of the Fusarium species associated with the disease, a study covering all regions of the world, as this paper does not pretend to do, will increase the number of species concerned. Especially will it point out their relative distribution and importance throughout the different regions.

THE DISEASE.

GEOGRAPHIC DISTRIBUTION

In the United States the Fusarium-blight of the cereals is more or less common throughout the cereal growing sections of the country. It has been reported by the Plant Disease Survey for 1917, 1918 and 1919 from the following states: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Pennsylvania, New Jersey, Delaware, Maryland, West Virginia, Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, Kentucky, Ohio, Indiana, Michigan, Illinois, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Montana, Oregon, and Oklahoma. It was looked for, but was not found in the following states: Washington, California, Wyoming, Texas, Arkansas, Kansas, Louisiana, Mississippi, and Rhode Island. It has been reported also from various parts of Canada.

In Europe, the disease has been found in England, Holland, France, Italy, Bulgaria, Austria, Germany, Denmark, Norway, Sweden, and Russia. In Holland this disease is as widely spread as in the United States and in some years causes great losses. While in Russia it is common throughout the wheat and rye growing sections, it is also very common in the Usurian provinces on the Siberian Pacific coast. The disease has also been reported from Australia (151) and South America (79).

Though the geographic distribution of the various Fusarium spp. causing this disease is practically the same as that of the disease itself, it must be pointed out that their quantitative distribution varies greatly in the various regions of the world, i.e. in certain regions certain Fusarium spp. predominate while in other regions other Fusarium spp. are commonly the cause of the disease.

ECONOMIC IMPORTANCE

The Fusarium-blight of cereal crops injures the plants in several ways and is generally considered as one of the important diseases of these crops. It decreases the percentage of germination of the seed and causes dying off and weakening of the young seedlings in fall and spring and also wilting and dying of full grown plants; it partly or wholly blights out the heads, thus preventing them from filling out and greatly lowers the quality of the grain. The severity of the blighting of the head varies from the fraction of one per cent to one hundred per cent, and the loss due to decrease in yield in individual fields and localities may vary from zero to over fifty per cent.

The data concerning the economic importance of the disease are incomplete, inadequate, and for some phases of the disease and for most of the crops and countries they are entirely lacking. What little information we have on this subject is found in the Plant Disease Bulletin issued by the Plant Disease Survey, Bureau of Plant Industry, U. S. D. A. This covers only the losses caused by blighting of the heads of wheat alone and only for a number of the states where the Fusarium disease is known to be present and common in this form. No information is available relative to the loss due to decrease in germination and due to killing of seedlings and grown plants.

Below are presented the data by states as gathered by the Plant Disease Survey and no attempt whatever is being made to draw conclusions or to interpret results.

The reports of the American Plant Diseases Survey are given here in extenso for every state as they make apparent the regional distribution of the disease and express in ciphers the great losses which the agriculturist suffers annually from the Fusarium blight of cereals. The percentages given here indicate the loss from the total production of the respective states.

DELAWARE: 1917. Disease is very common, there being one or more per cent loss.

GEORGIA: 1918. Not especially severe in the state. A trace of the disease has been observed on the experimental plots at Athens.

ILLINOIS: (ANDERSON) 1918. Unusually severe. It is one of the most serious, if not the most serious disease of wheat in Illinois. I judge the loss to be about five percent.

(W. L. BURLISON, G.H. DUNGEN) 1919. Particularly serious in this season: in many fields will cut the yield more than 50 %. The disease has been reported very generally all over the state. Some county agents have estimated that from one-half to three quarters of the crop is infected. It has developed very rapidly during the past week or ten days and the loss wlll be much greater than was anticipated a week ago.'

INDIANA: (M. W. GARDNER) 1919. Wheat scab is the most serious wheat disease in Indiana and has been reported from all parts of the state. Infection varied from 0 to 100 % and the yield was greatly reduced in many cases.

MARYLAND: 1917. It is reported as occuring on wheat to the extent of three to five percent.

MICHIGAN: 1917. The disease has been observed on wheat, barley and rye, causing 10 percent loss in some cases.

MINNESOTA: (BISBY) 1918. Quite widely distributed on spring wheat, but did not cause any serious losses.

(E. C. STAKMAN) 1919. One of the worst diseases of wheat this year was, by all odds, scab. It is infinitely worse than it has been since 1916, and especially in the southern third of the state. It is remarkable, that it becomes less severe in travelling north through the wheat region.

MISSOURI: (READ) 1918. Generally distributed, usually less than one percent infection, but occasionally damage is two to five percent.

MONTANA: (Jennison) 1918. Doing much damage in certain localities. In one district visited the week of August 4—10, 50 percent damage was found in all varieties of spring wheat.

NEW JERSEY: (COOK) 1918. The most prevalent disease is scab, which is very abundant.

NORTH DAKOTA: 1917. Fusarium culmorum and other species of Fusarium are less abundant than last year. Last year it ran epidemic in the Durum and Marquis wheats, almost destroying these crops in some sections before the rust came. This year the disease showed up at seeding time, preventing sprouting of a percentage of seed and prevented proper stool formation throughout the season.

(H. L. BOLLEY) 1919. Scab caused great damage in Marquis, Fife, Blue stem and most species of durum throughout the state. It was destructive at all stages, particularly on old crop lands under constant cultivation and often on new lands where scabby seed was used.

OHIO: (STOVER) 1917. A good many fields have from 10 to 30 percent of the heads affected and some fields show as high as 75 percent. Usually only a few spikelets in the head are diseased, but sometimes the whole head or the whole upper half of the head may be badly injured.

(SELBY) 1918. Percentage of affected heads run from less than 1 to 30 percent. Damage will probably average 3 to 5 percent of the crop.

(SELBY) 1919. Generally severe, especially in western and northern Ohio and where wheat followed corn. Maximum percent of head attack

8 %. Low percentages in southern Ohio. Estimated maximum loss in yield scarcely exceeds 33 %.

IOWA: (A. Z. BAKKE) 1919. Very common throughout the state. Most destructive disease of wheat in state.

OREGON: 1917. Very little scab this season.

PENNSYLVANIA: (ORTON) 1918. On the average the crop may have suffered eight percent at least.

SOUTH CAROLINA: (SEAL) 1918. Reported as causing serious losses in a few cases, but, in general, seems to be of little importance.

SOUTH DAKOTA: 1917. Comperatively little this year. Last year it destroyed one-third of the crop in eastern South Dakota and about one fifth in western South Dakota.

TENNESSEE: 1918. This disease has been by far the most important. Damage as high as 50 percent is claimed for some sections in eastern Tennessee, while in the middle section it is probably 10 to 25 percent.

(S. H. ESSARY) 1919. Heaviest damage known. Serious damage. Loss estimated 10 to 90 %.

VIRGINIA: 1917. A general average for the state would probably be about 1 to 2 percent reduction in yield. In a number of counties reports indicate that the yield will not be more than 50 to 75 percent of a full crop.

WEST VIRGINIA: 1918. Scab is more prevalent than we have ever noted previously, the percentage of diseased heads being in some cases far above 50.

(N. J. GIDDINGS) 1919. This, I believe, is the most serious disease of wheat in West Virginia. Last year it was very prevalent and the wheat was refused at some mills on account of the scab infected grain. This year it is quite generally reported and is likely to be as destructive at it was last year.

It is further stated that: „Numerous cases were observed and many others reported, particularly in Illinois, where scab (blight) was so severe on Marquis wheat that large fields were left unharvested. Others were harvested at least in part, and when threshed yielded as low as five and six bushels to the acre where thirty-five or forty bushels per acre were expected before the disease developed."

The Fusarium seedling blight was reported for the first time in 1919 from Minnesota, Wisconsin, Illinois and Indiana: „The seedling blight was particularly severe in Minnesota where it is reported as follows: „The seedling blight was very prevalent in the Red River Valley and some other parts of the state in the latter part of May and early June, the wheat scab organism was isolated from many of the diseased seedlings, particularly the macaroni wheat, though Helminthosporium was often present also. The disease often appeared in spots causing a complete failure in the diseased area. Many fields were plowed and planted to flax."

According to the estimations of the Plant Disease Survey the total loss due to the blighting of the heads of wheat alone by Fusarium spp. amounted to 10.620.000 bushels in 1917. The writer (13) basing his judgement upon the estimates of the Plant disease survey and his own observations came to the conclusion that „the total loss for the whole country caused by the various phases of the disease is probably close to 20.000.000 bushels."

That even this estimation was a very moderate one is shown by the fact that for the year 1919 the Plant Disease Survey estimated the loss due to this disease only for the middle Western States as being several times higher than the writer's estimation for the year 1918. „Particularly in south eastern South Dakota, Southern Minnesota, Southern Wisconsin, Iowa, Illinois, Indiana, Kentucky and Tennessee wheat scab (blight) was, by all odds, the most important factor in shrinkage of yields and lowering of quality of wheat in 1919. In these States alone there was, according to estimates made by the Bureau of Corp Estimates, a total shrinkage of 88.509.000 bushels of all wheat from the June 1 forecast. While in this group of States stem rust was responsible for considerable of the shrinkage from June 1 forecast in South Dakota, Minnesota, and Wisconsin, scab was the one big factor in the other States named, that is, in Iowa, Illinois, Indiana, Kentucky and Tennessee". The loss due to decreasing the quality of the grain is not known and must certainly run into many millions of dollars.

With the exception of the very fragmentary reports found in the official German „Berichte über Landwirtschaft", there is no definite information concerning the importance of the disease in Europe, especially in Russia where it is known to be one of the most important and destructive cereal diseases. BAUDYS (293) and STRANÁK (295) report that this disease is the most important cereal disease in Szechoslowakia. In 1920 it decreased the yield by 20 %. In some cases the loss was as high as 80 % and even higher while in still other cases it did not pay to harvest the infected fields. For Holland also there are no definite data regarding the importance of this disease. The short reports of RITZEMA BOS (200-203), WESTERDIJK, (284) and DOYER (45) regarding the poor germinating power of the cereal grains in some years as a result of fusarial infection, which represents only a very small fraction of the actual and total loss, show that this disease can become in some years as destructive in Holland as it is in the United States and Russia.

Though it has not been possible for the writer to examine many fields in Holland and Germany, he feels however fully justified, from what he has already seen, to state that the Fusarium-blight of the cereal crops is as important in these countries as it is in the United States, and this in spite of the fact that the most destructive phase of this disease, the blighting of the heads, has been generally overlooked in Europe.

REVIEW OF LITERATURE.

Fragmentary descriptions and brief notes on Fusarium species and fusarial diseases of plants, and, in particular, of the cereal crops, date as early as the first quarter of the last century. In each case, however, either the description of the disease or that of the causative organism is lacking, so that it is not quite certain whether a certain Fusarium species occurring on wheat, for instance, is pathogenic or whether a certain condition or disease of the crops was due to certain Fusarium species.

For the above reasons the early works on this subject, though of some importance, are not reviewed here but are included in the bibliography. As such may be mentioned here the works of Link, Nees, Freis, Thienemann, Drejer and Liebman, Corda, Unger, Fee, Örsted, Pakorney, Fuckel, etc.

In 1883, MATTHEWS (155) reports that during the malting season of 1879-'80 the quality of the majority of samples of English-grown barley was decidedly inferior. His attention was directed to the frequent occurrence of so-called „red corns" among the couches of a small malthouse where various samples of English barley were being worked up. Upon microscopic examination of such red barley kernels, he found that the coloration was due to the presence of a fungus, which, according to Dr. HANSEN of the Carlsberg Laboratory, Copenhagen, was either *Fusarium graminearum* or some closely related species. MATTHEWS observed a similar condition on other cereals in England. Judging from his fine and most carefully executed illustrations of the fungus he had to deal with, there is little doubt but that it was *F. herbarum.*

W. G. SMITH (246), in 1884, gave us the first reliable description of blighting of wheat heads. He attributed the cause to *Fusisporium* (now Fusarium) *culmorum*, which he was the first to describe. *F. culmorum* is now known to be an important parasite of various plants and one of the causes of blighting of the heads of cereal crops. „It attacks the ears (heads), chiefly perhaps of those plants which have been more or less invaded by corn mildew or other cereal fungi." SMITH described also under the name *Fusisporium hordei* the fungus causing the „red corn" of barley, previously studied by MATTHEWS. Though he obtained the material for this description of *F. hordei* from MATTHEWS, he was dealing with a different species from that illustrated and described by MATTHEWS as *Fusarium graminearum*. Here, too, „the fungus is said to chiefly invade barley of poor quality and ill-conditioned crops and ears, seldom or never appearing on good sound barley." „It is clear that no badly affected grains can possibly germinate. In both wheat and barley the fungi when present give the grain a peculiar and disagreeable taste."

E. F. SMITH, in 1899, basing his judgment upon extensive studies, reported that Fusaria live and overwinter in the soil and attack the plants from the earth. A soil once infected with any of these resistant fungi becomes worthless for growing plants subject to attacks by these organisms for many years.

This fact has been confirmed since by numerous workers. For the cereal Fusaria this was done by SORAUER, SCHAFFNIT ATANASOFF and others.

T. D. CHESTER (29), in 1890, gave the first description of blighting of wheat heads in the United States. He reported that the disease had been serious in Delaware for some years past. It frequently occasioned the loss of more than one half of a normal yield. The causative organism he called *Fusarium culmorum*, but his illustrations picture the conidia of *Gibberella saubinetti*. He found the mycelium of the fungus in all parts of the grain, including the embryo.

WEED (279, 280), in 1890 described blighting of wheat, attributing the cause to *Fusarium culmorum*. His fine and detailed illustrations show beyond doubt that he, too, dealt with the conidial form of *Gibberella saubinetti*.

Delacroix (35), in 1890, isolated and described *Fusarium schribauxi* Delac. from germinating seeds of *Triticum sativum*. This species may be the same as *F. culmorum* (W. G. Sm.) Sacc.

Pammel (176, 177), in 1891 and 1892, and Arthur (11), in 1891, described briefly the blighting of wheat heads in Iowa and Indiana, respectively, and both thought that the causative organism might be *F. culmorum*. Arthur observed that the disease was worse on the late maturing than on the early ones and that certain French varieties were particularly susceptible to it.

Woronin (191), in 1890, published two short articles on what is known in Russia as „intoxicating bread". He reported that the grains produced in the south-Usurian provinces, Siberia, show marked toxic properties when used as food by both men and beasts. He was sent to Siberia to study this question and, in 1891, he published the results of his investigations. Upon studying the causes of intoxicating bread, he found a number of fungi on grains possessing such properties, the most common of which was *Fusarium roseum* Lk. with its perfect form *Gibberella saubinetii* Sacc. He considered this fungus as being occasionally responsible for the toxic properties of the cereals, but he believed the extremely moist atmosphere of the country to be more often responsible.

The recent Russian works (63, 163, 165) on this subject have shown that the Fusarium blight of the cereals, due to *Gibberella saubinetii* and *F. avenaceum* is the actual cause of the toxic properties of the grains in Russia and Siberia.

Palchevski (175), in the same year, also attributed the toxic properties of the grain to *Fusarium roseum*.

Sarokin (251) observed, in 1891, that in the Usurian provinces the heads of the cereal grains were often covered by a pinkish fungous growth, which is one of the marked symptoms of wheat blight. This pinkish fungous growth he identified as *Fusarium roseum*. He noted, also, that in many cases perithecia were formed on these pink colored heads, which he identified as *Gibberella saubinetii*, and considered the latter as being the perfect form of *F. roseum*.

Erikson (51), in 1891, described *Fusarium tritici* (Liebm.) now *F. minimum* Fuck, on *Triticum durum* in Sweden.

Prillieux and Delacroix (189), in 1891, studying the intoxicating properties of rye in France, noted that the grain possessing toxic properties usually showed the presence of *Stromatinia temulenta* while some kernels developed rich fusarial growth. This fungus they describe as *F. miniatum*. While concluding that the toxic properties of the grain were due to *S. temulenta,* they were not certain that *F. miniatum* did not also have some relation to it.

Briosi et al (25), in 1892, reported *Gibberella saubinetii* Sacc. as occurring commonly on rice, in Italy, especially when nitrogen fertilizer had been used, but apparently causing no injury.

Detmers (40), in 1892, reported blighting of wheat heads from Ohio.

Frank and Sorauer (57), in 1892, obtained from Kiel heads of rye which were covered with what they described as *Fusarium heterosporum*. In prolonged wet weather one whole field was entirely destroyed by the fungus. This is the first authentic report of the occurrence of Fusarium blight in western Europe.

Hickman (80), observed that defective drainage evidently increased the blight, and that everything which tends to weaken the plant or retard its ripening renders it more subject to attacks.

Buckhout (28), in 1893, reported blighting of the wheat heads as being widespread in Pennsylvania.

Berlese (16), in 1897, and Saccardo and Berlese (216), in 1895, described a new disease attacking the culms of wheat in Italy. The cause of this disease they attributed to *Sphaeroderma damnosum* Sacc. et Berl., with its conidial form *Fusarium culmorum* (?). In spite of most intensive and careful studies of F. culmorum by many investigators in recent years, also by the writer, no one has been able to produce, or has even suspected, the existence of any perfect form of this fungus. It is very probable that Saccardo and Berlese were either working with another Fusarium species or that their cultures were impure.

McAlpine (151), in 1896, described blighting of wheat heads as occurring in Australia and being caused by *F. culmorum* McAlp. He is the first to report that this organism attacks not only the heads, but also forms salmon colored patches on the stems, especially on the nodes of the wheat. McAlpine changed the name of Smith's organism *Fusisporium culmorum* to *Fusarium* *culmorum*. This, however, had been done earlier by SACCARDO.

BESSEY (18), in 1898, reported blighting of wheat heads from Nebraska.

SELBY, in 1898, briefly described blighting of wheat heads in Ohio which he considered to be due to *F. roseum* Lk. with its perfect form *Gibberella saubnietii* Sacc. The latter, in culture, always gave a fusarial growth. His efforts to inoculate plants in the field with this Fusarium were unsuccessful. In the affected fields he found the Gibberella perithecia upon fallen glumes, straw, corn stalks, stubble, etc. He reported, also, that the badly infected kernels of wheat are able to carry the fungus over in the Fusarium stage. It is not clear, he says, "that the infection passes from corn stubble or corn stalks to wheat."

PEGLION (181, 182) in 1900 and 1901, reported, for the first time, the occurrence of blighting of the wheat heads in Italy (Tuscania), which he called „Golpe bianca". He attributed the disease to *F. roseum*.

SORAUER (247, 248), in 1901, gave a detailed description of the snow fungus on rye, barley, and wheat, its cause, and the effect of various weather and cultural conditions upon the degree of infection. SORAUER first described the causal organism as a Fusarium, and changed the name from *Lanosa nivales* Fries to *F. nivale* Sor.

SCALIA (219), in 1902, reported blighting of rye heads from Sicilia, which he attributed to *F. heterosporium*.

FERRARIS (55), in 1902, found *Gibberella saubinetii* on the peduncles of rice in Piemonte, Italy.

HENNINGS, P. (79), in 1902, reported *Gibberella tritici* P. Henn. now *G. saubinetii*, on the glumes and awns of *Triticum spelta* in Sao Paulo, Brazil.

SORAUER (249), in 1903, in an extensive paper on frost injuries on cereals, discusses the kind and effect of frost injury and the diseases which follow as a result of the partial killing or weakening of the plants. In this connection he, also, discusses the snow fungus. The causative organism *F. nivale* Sor., is a saprophyte, according to SORAUER, and becomes parasitic only on such plants whose assimilation activities have been decreased because of one or another condition, snow pressure, for instance, etc.

RITZEMA BOS (200), in 1904, reported the interesting fact that the Fusarium present in the seed obtained during the rainy year of 1903 caused a considerable decrease in the germinative power of the seed and that the young plants were killed either before breaking through the seed coat or before reaching the surface of the soil.

JACHEVSKI (121-122), in 1905-1907, confirmed the earlier observations of some Russian plant pathologists that the intoxicating properties of cereals, especially of rye, are due to *F. roseum* Lk., which attacks rye in damp localities and in wet seasons and is apparently spread by rain, wind, and insects.

BOLLEY (19), in 1904-'05, described an interesting blighting of wheat plants, which he attributed to rotting of the roots. An attempt to isolate a definite organism proved unsuccessful, we shall see later on that this blighting of the wheat plants is known to have been due, at least in part, to Fusarium species.

FREEMAN (59) in 1906, gave a short description of blighting of wheat heads in Minnesota. He was the first to observe that the infection proceeds from the head down, as will be pointed out later on.

RITZEMA BOS (202), in 1906, reported briefly the occurrence of fusarial blighting of wheat heads in Holland, but did not determine the species of Fusarium causing this blighting.

MUTH (162), in 1907, studying the effect of fungous infection of seed on the germinative power of the same, found that *Fusarium roseum* decreases more or less the germinative power of some seeds, particularly of grasses. He made no experiments with cereals.

DUCOMET (48), in 1907, described a disease of barley caused by *F. hordearum* Ducomet. The symptoms of the disease are very much like those of *Helminthosporium teres* Sacc. on the same host.

HILTNER (82), in 1907, basing his judgment upon data obtained through a questionnaire addressed to the farmers in Bavaria and upon his own personal observations, came to the following conclusions concerning the parasitism of the snow mold *F. nivale*. The attack by the snow mold was most common (1) on rye; (2) in localities where there was plenty of snow on unfrozen ground for long periods of time and late in spring; (3) kind of soil seems to have no effect; (4) autumn fertilizing with stable manure favors the snow fungus attack because of the higher temperature on the surface of the soil; (5) time of planting important in rye, especially in *Zeeländer* rye, the late sown suffering severely from the snow mold; (6) the causative organism *F. nivale*, is perhaps introduced into the soil by the seed; (7) foreign varieties suffer more from snow fungus than native varieties.

Beginning in 1908, HILTNER alone and in collaboration with KORFF, IHSSEN, LANG and GENTNER, contributed many short papers on the effect of environmental conditions upon fusarial attacks on cereals and, primarily, upon their control through treating the seed with corrosive sublimate.

As early as 1907, HILTNER suspected and later on claimed that the cereal grains may be infected with Fusarium, and, when such grains are used for seed, some of the young seedlings are killed before making much growth. He found that the Fusarium mycelium is present in the outer layer of some kernels and, in some cases, throughout the endosperm and even in the embryo. But, in spite of the presence of the Fusarium in and on the seed, the seedling will succumb to the attack only when grown under unfavorable conditions. The rye variety Zeeländer, the seed of which was infected with Fusarium, was heavily attacked by the snow fungus early in spring, while other varieties in the same field remained healthy. Even this variety, however, was free from snowmold attack when sown early. It is very probable that infection of the grain takes place during the period of seed formation. Since, according to them, there are during that period no conidia of Fusarium in the air (sic), they believed that infection took place with ascospores of the Fusarium in question, though the presence of such was not known at that time. They reported that not only rye, but wheat, barley, and oats, are also attacked by Fusarium, and that the degree of infection of the seed of the grains may be from 1 to 100 per cent.

To HILTNER is due the credit for emphasizing the fact that Fusarium is present in the cereal grains and that it injures severely their germination. He did not know, and seemingly was not interested in, the nature and life history of the organism or organisms concerned, but his work has stimulated wide interest in this question throughout Europe, attracting the attention of both plant pathologist and practical agriculturalist.

Concerning the control of the seed-borne Fusarium with corrosive sublimate, the first experiment with which was undertaken in 1907, HILTNER claims that it not only controls Fusarium infection of the seed, but it gives a better stand even when healthy seed is thus treated. Furthermore, mice do not then eat the planted grain. HILTNER and GENTNER (99), in 1912, went even further, recommending the treatment of the healthy rye seed before planting with corrosive sublimate (0.01 for 45 minutes) to protect it from fusarial attacks when planted on Fusarium-infected soil. It protects, they claimed, not only the seed, but also the young seedlings.

The use of a combination of corrosive sublimate and formaldehyde (0.01 of each) for the control of Fusarium on cereal grains has also been recommended by HILTNER.

The corrosive sublimate treatment as a control for seed-borne Fusarium diseases of cereals, as worked out by HILTNER and his collaborators, is quite generally accepted and used in Germany and, to some extent, in Holland and other European countries.

HILTNER's treatment against Fusarium has been repeatedly tried by many other workers with widely varying results. Some have found it to be quite effective, others decidedly ineffective. The reason of this lies in the fact, as we shall see later, that HILTNER was fundamentally wrong in interpreting his results and that no known chemical disinfectant is in position to free the internally infected cereal kernels from the fusarial infection. HILTNER's apparently positive results with mercuric chloride are the result of very superficial experimental methods and the error that the better results from the treated grain was due to their being freed from the internal infection and not due to the external disinfection of same, or due to the stimulating or other effects of the treatment. Something which he himself has claimed (99).

APPEL (5-6), in 1907 and 1908, showed experimentally that when rye, wheat, barley, and oat seed, infected with Fusarium, is germinated, part of the young seedlings will be killed, while most of them will continue to grow, their bases only being partly rotted and discolored. Later on they appear exactly like plants attacked by the foot rot disease as described by FRANK. In the light of these results, according to APPEL, it appears questionable whether or not foot rot of cereals is entirely, or at least largely, due to *Ophiobolus herpotrichus* (*Leptosphaeria herpotrichoides*) as claimed by some. The external conditions influence largely the degree and severity of infection in this case.

Krüger (141), in 1908, who succeeded Frank in his work on the so-called foot rot disease of cereals in Europe, published an extensive paper on this subject. He attributed the disease to Leptosphaeria and Ophiobolus spp., but he noticed, in some cases, the association of a Fusarium species on wheat plants that were attacked by foot rot. The inoculation experiments (only two in number) to establish the pathogenicity of this Fusarium species and its relation to the disease gave, however, very uncertain, if not entirely negative, results. More recent workers contradict the results of Krüger and some have even expressed the opinion that Fusariun spp. are one of the important causes of foot rot of cereals. In this paper Krüger gives the bibliography related to the foot rot disease as caused by Leptosphaeria and Ophiobolus spp.

Schander (230), in 1908 reported a severe attack of Fusarium on rye, wheat, and barley, in some cases the germination of the grain from infected plots being 40 to 50 per cent lower than that of the healthy seed.

Schöyen (235), in 1908, described briefly the occurence of the snow mold and Fusarium blighting of the rye heads in Norway.

Lindau (146), in 1908, in Sorauer's Handbuch der Pflanzenkrankheiten, stated that there occur on cereals several Fusarium species, all of which are not to be considered as parasites. They are found most commonly on the ripe heads, especially in moist weather, and may become injurious to the grain. The most common species is *F. heterosporum* Nees, which forms the rose-red crust on the chaff of the cereals and numerous wild grasses. Together with this species are found also *F. miniatum* Sacc., *F. schribauxii* Delacr., and *F. avenaceum* Fries. This opinion expressed at a time when most European workers were considering the numerous Fusarium spp. as innocent saprophytes, which opinion has been later upheld by Schaffnit (221) for a number of the cereal pathogenic Fusarium spp. led the European researches on this disease in a wrong direction and has been the cause of the fact that the most important phase of this disease was overlooked in Europe.

Volkart (277), in 1909, observed that cereal seedlings delayed in their development are often attacked at their bases by Fusarium. He observed this condition on wheat, spelt, barley, and oats and reported it as being widely spread throughout Switzerland.

OORTWIJN BOTJES (170), in 1909, observing that in Groningen the spring wheats usually give a poor stand made some experiments to establish the cause of this fact. Planting 50 kernels in sand he noticed that most of them did not germinate and that even those that did germinate gave only weak and sickly plants. Same experiment was repeated, except that in stead of sand filter paper was used. In this case he observed that a far larger number of the seeds germinated, but that the young plants were soon overgrown by a white fungous growth, becoming in some places brown colored and rotted. This fungus was identified by Prof. QUANJER as Fusarium. OORTWIJN BOTJES then treated some of the seed with warm water, the result being a complete elimination of the fungus growth, high germination and healthy plants; similar results were obtained also with coppersulfate.

WESTERDIJK (284), in 1909, reported that in the winter of 1906-1907 a great portion of the winter wheat in Groningen was destroyed by Fusarium. An examination of several wheat samples showed that they were also infected. Such seed upon planting germinated, but the young seedlings were soon killed by the fungus. She treated some of the seed with 0.1 % formaline solution for 3 hours also with copper sulfate solution but the results were as bad as in the case of the untreated seed.

TUBEUF (265), in 1908, reviewed briefly the literature on Fusarium of various hosts and gave a more detailed description of *F. lolii* W. SMITH.

JACHEVSKI (124), in 1909, reported attacks of *F. roseum* Lk., *F. secalis* Jach., and *F. heterosporum* Nees on rye heads in the province of Kostroma, Moscow.

SELBY and MANNS (239), in 1909, proved that *Gibberella saubinetii* causes dying out of young wheat seedlings. They showed, also, that a Fusarium species isolated from wheat kernels has the same effect. This species they called *F. roseum* Lk. and considered it to be the conidial form of *G. saubinetii*, but they were not able to produce the perfect form from the conidial. There is still great doubt as to whether or not the Fusarium species which they isolated from wheat kernels was really the conidial form of *Gibberella saubinetii*, since recent work has shown that there are more than one Fusarium species found in wheat samples and that macroscopically and physiologically, as well as pathologically, they are very similar and can be distinguished only by their normal conidia, of which SELBY and MANNS do not speak. They noticed, also that in both cases the young seedlings were attacked rapidly by the fungi and some killed up to the 30th day after planting, but that those plants that survived soon overcame the effect of the attack, recovered and reached normal development.

JACHEVSKI (125), in 1910, reported that during the dry summer of 1909 no blighting of the heads was observed anywhere in Russia, not even in the south Usurian provinces, where wheat blight has always been abundant.

MIYAKE (157, 158), in 1909 and 1910, reported *G. saubinetii* on the leaves and heads of rice in Japan, but causing no injury.

STÖRMER (254, 255), in 1910 and 1911, reported that foot-rot of rye, generally attributed to Ophiobolus and Leptosphaeria, during the last years has always been caused by Fusarium. He reported, also, that a certain wheat seed sample showed 60 per cent Fusarium infection.

IHSSEN (120), in 1910, found that the fungus commonly associated with the snow mold was *F. nivale* and that *Nectria graminicola*, which usually occurs on plants that have been attacked by the snow fungus, is the perfect form of *F. nivale*. He was not able, however, to produce the perfect stage in pure culture from *F. nivale*.

BECKWITH (14, 15), in 1910 and 1911, presented the results of his studies on the possible causes of decrease in yield of wheat on the so-called „wheat sick" soils. „Quantitative analyses made from soil solutions, taken from soil samples from old wheat lands and from virgin soil, fail to show sufficient difference in composition to warrant the assumption that deterioration in wheat yields is due entirely to deterioration of plant food in the soil." This being the case, it was suspected that the cause must be in the accumulation of some parasitic fungi in such soils. A study of the fungous flora of such soils showed that a number of fungi are present in same soils and that the following: Fusarium, two species, Colletotrichum, two species, Macrosporium, Alternaria, and Helminthosporium, are recognized pathogenes of wheat and other cereals. Check tests from virgin soil did not show these fungi to be present in any large amount. A study of the fungous flora found in the nodes and internodes of wheat from such lands showed that the above soil fungi are found also in the tissues of the wheat plants. It was also noted that the relative distribution of these fungi on the wheat plant varies considerably from season to season and may be influenced by the various environmental conditions. The same fungi were also isolated from the roots of wheat plants showing root infection but here too, „as in the nodes and internodes, the infection was usually a mixed one," i.e., several of these fungi were isolated from the same plant portion.

Bolley (20-23), in 1910, 1911, and 1913, basing his conclusions upon his personal observations covering a period of many years and upon the results obtained by Beckwith (14, 15) endeavored to explain the complex problem of decrease in yield of wheat in some wheat growing regions, and, in particular, the Red River valley, North Dakota, as being due to the accumulation of certain parasitic fungi in the soil. He has emphasized the importance of soil sanitation, among other things, as a control measure for this condition.

Voges (269), in 1910, reported the occurrence of the blighting of wheat heads in Germany. He isolated the fungus and inoculated healthy and ripe wheat kernels, the result being a rapid invasion by the fungus of the interior of the kernels. Upon microscopic examination he found the mycelium of the fungus throughout the endosperm of the kernels. He did not determine the identity of the causative organism, but thought it resembled *F. culmorum*. Judging from his drawings of the organism, there seems to be no doubt but that he worked with *F. culmorum*.

Mortensen (160), in 1911, contributed an extensive paper on the Fusarium diseases of cereals. In the first part of the paper, which is primarily a compilatory work, he divides the various fusarial attacks on cereals in the following way: (1) injury on the heads and seed; (2) injury on the germinating power of the seed; (3) red kernels in malting; (4) snow fungus;

(5) rodbrand (seedling blight); (6) leaf spots on older plants; (7) foot disease; (8) „Knaekkesyge (Stolk rot); and (9) „Haferhatte".

In the second chapter of the first part, he takes up the relations of weather and soil to these diseases, the susceptibility of various varieties, the infection possibilities, time of infection, control measures for seed and soil infections, and the importance of the Fusarium diseases.

In the second part, he gives the results of his own observations and recommends as control measures the hot water treatment (56-57° C.) (1) and copper sulphate (1½ h. in 0.3 $CuSO_4$).

MORTENSEN did not state, however, which Fusarium species or how many Fusarium species were concerned in each of the above pathological conditions, though he mentions the names of some. He was concerned with the diseases and not with their causes.

JACHEVSKI (126), in 1912, separated *Fusarium roseum*, the common cause of blighting of the heads of cereals in Russia, into *Stromatinia temulenta* Prill. and Delacr. with the conidial form *F. roseum*, and *F. palzewskii* Jach., *F. secalis* Jach., and *Gibberella saubinetii* Sacc, with the conidial form *F. rostratum* Ap. & Wr. However, NAUMOFF (165), in 1916, who worked under Jachevski, stated that there was no sufficient reason to separate *F. roseum* into new species. As to the relation of *S. temulenta* to *F. roseum* or any other Fusarium spp., JACHEVSKI failed to produce experimental evidence that this is actually the case. JACHEVSKI separated, also, *F. heterosporum*, which is also supposed to cause blighting of the heads of cereals in Russia, into *F. heterosporum* and *F. pseudoheterosporum*. The latter is identical with *F. avenaceum* (Fr.) Sacc.

SCHAFFNIT (221), in 1912, published what may be considered the most important papers on the snow mold of cereals, both from the taxonomical and physiological standpoints. In this paper, he showed that what SORAUER described as *Fusarium nivale* Sor. as the cause of the snow fungus was not a single species, but a number of Fusarium species. He not only determined and redescribed the real *Fusarium nivale* (*minimum*) Ces., the

1) The seed is kept at 56—57° C. for 5 minutes perhaps, as is commonly practised in Denmark.

perfect form of which (*Nectria*, later *Calonectria graminicola*) he was the first to produce from pure cultures of *F. nivale*, but he listed its numerous synonyms and showed that with the „snow mold" of cereals were associated more than one Fusarium species, the most important of them being *F. nivale* Ces. (F. *minimum*). As less important, he listed *F. rubiginosum* (*F. culmorum*), *F. metachroum* (*F. herbarum*), *F, didymum*, *F. subulatum* (*F. avenaceum*) and *F. lolii*. Most of these species, however, in inoculation experiments gave positive results only by contact infection. *F. nivale* was found most common on young rye plants, while the other species were isolated more commonly from the grain.

Soils infected with *F. nivale* when planted with cereals will produce the disease under favorable conditions (high humidity of the atmosphere, etc.). He concluded that the soil infection is the more important, or, at least, just as important as seed infection. He showed that *F. nivale* as well as other Fusarium species are seed-borne and that when infected seed is used for planting it will produce the disease. A careful study of the occurrence of the *F. nivale* mycelium within the kernels showed that the fungus is usually present in the outer layers of the kernel and only in rare cases does it occur in the inner parts of the seed. He was not able to confirm the supposition that the mycelium of the fungus develops in and with the embryo of the seed.

Schaffnit showed that *F. nivale* attacks not only the seedlings, in the form of seedling blight and later on as snow mold, but that it causes also foot rot, usually as a result of wounding of the plants by mites, insects, or other agencies. *F. nivale* attacks, also, the heads of the cereals during the period from blossoming to ripening of the crop, this he concludes only from his infection experiments, but he evidently never saw the disease in nature. In this connection he distinguished primary infection, which takes place before the ripening of the plants, from secondary, — during the period of full ripening and harvesting. Here, not only *F. nivale*, but also other less parasitic (?) Fusarium species play an important rôle. The primary infection he considers more fatal to the seed than the secondary infection. Schaffnit states that the plants are susceptible of the various attacks by *F. nivale* only during certain periods in their development and that even then they will succumb to the attack only if they are growing under conditions unfavorable for their own development, but favorable for the development of the fungus.

He did considerable work on treatments for elimination of fusarial infection of the seed and found that not only corrosive sublimate, as recommended by HILTNER, but also chinosol 1 $^0/_{00}$ solution for 30 minutes, is an effective treatment for the control of Fusarium on the seed. However, SCHAFFNIT thought that the treatment of the seed would be effective only where the soil is free from the fungi, which, according to him, are present in some soils where they can overwinter, since the conidia of *F. nivale*, as shown by him, are not killed even at a temperature of —25° C.

RIEHM (196), in 1911, states in a footnote that he isolated from fusarium-blighted wheat heads a Fusarium species which developed the perithecia of *Gibberella saubinetii*. This is, as far as the writer knows, the first case where the perfect form of one of the wheat blight organisms has been produced on artificial media and in pure culture, excluding the work of APPEL and WOLLENWEBER (8) in which they reported the same thing except that they isolated their organism from wheat seeds which failed to germinate.

VOGES (270-272) in 1912 and 1913, pointed out as a result of some inoculation experiments, that fungi are not the primary cause of the stalk and foot rots of cereals, but that the latter become subject to stalk and foot rots when weakened by cold and drought. Resistant seed and proper cultivation are the control measures recommended.

As conidial stage of *Ophiobolus herpotrichus*, one of the supposed causes of the stalkrot, he gave *Fusarium culmorum* (271), but in a later paper (274), admitted his error and gave *Acremonium alternatum* Link as the conidial form. Doubt has been expressed, however, concerning the correctness even of the second name.

TRUSSOWA (263), in 1912, also reported good results with corrosive sublimate seed treatment as a control measure for Fusarium of cereals.

LIND et al (144), in 1913, reported severe cases of foot rot of the cereals, which they attributed to Fusarium species and, apparently, also to *Ophiobolus graminis* or *Leptosphaeria herpotrichoides*.

APPEL and FUCHS (10), in 1913, tried to establish whether and under what conditions ripe cereal seed can be attacked by Fusarium. Ripe rye seed was moistened with water suspension of conidia of *F. subulatum* (*avenaceum*) and *F. rubiginosum* (*culmorum*) so that the moisture of the seed was increased with 10, 15, 20 and 25 %. The various samples of the seed were kept at 10 and 20° C. in moist chambers. A decrease of germinative power resulted in the samples to which had been added 20 or 25 % of water, this was especially so in the cases where *F. culmorun* was used. When the infected seed was kept moist for 4-5 days at 20° C. the two Fusarium spp. decreased the germinative power of the seed far more than at 10° C.

REMY and LÜSTNER (193), also in 1913, showed that *F. metachroum* (*herbarum*) can also infect the cereal seed and decrease its germination.

BERTHAULT (17), in 1914, considered the foot rot of cereals as all French pathologists have done, whose works are not reviewed here, as being due to *Ophiobolus graminis* and *Leptosphaeria herpotrichoides*. He states, however, that on plants affected with foot rot are commonly found numerous Fusarium spp., F. *rubiginosum* for instance, and is inclined to think that the latter may also play some part in causing foot rot of cereals.

MANGIN (153), in 1914, distinguished two kinds of footrot, foot rot proper (black leg), caused primarily by *Leptosphaeria herpotrichoides* de Not. and *Ophiobolus graminis* Sacc. and footrot, caused by Fusarium spp., above all by *F. nivale*.

QUANJER and OORTWIJN BOTJES, (191, 192) in 1914, experimenting with various seed treatments against smut noticed that the warm water treatment apparently did increase the germination of the treated seed. Similar results but in much slighter degree were obtained also with seed treated with copper sulfate. This raised the question whether these treatments do not act as a sort of stimulant. A further study of the question however showed that the treatments eliminate the germ-destroying fungi, thereby increasing the germination of the treated seed, whereas formaline was not only ineffective, but seemed even to favor their development. A study of the germ-destroying parasites showed that besides Fusarium also an Alternaria was the cause of this condition.

Spieckermann (252), in 1914, reported that rye treated with chinosol was as badly infected as the untreated, so that the chinosol treatment may be considered, according to him, as useless, at least as recommended by Schaffnit (221). Here, too, the plot treated with corrosive sublimate gave the highest stand; next highest was that treated with $CuSO_4$ (1%—15 minutes); the plot treated with formaldehyde gave the lowest stand, as the treatment injured the germination of the seed. In several laboratory experiments Spieckermann found that Uspulum gave even better results than corrosive sublimate.

Hiltner (106, 107), in the same year, also reported that chinosol gave negative results. Best results were obtained with corrosive sublimate, while formaldehyde and copper sulphate did not give the results anticipated.

Johnson (123), in 1914, reported that seed of wheat, barley, and oats artificially infected with *F. culmorum* showed a very low per cent of germination.

Lind, Rostrup and Ravn (145), in 1914, reported that oats were commonly infected by a Fusarium disease, causing failure to form and fill out the heads. The plants sent out numerous secondary shoots but did not head out.

Hiltner (112), in 1916, showed that covering of the winter cereals with a thin layer of straw or manure favored the crops planted with Fusarium-free seed and those treated for Fusarium, but this method was found very injurious to crops planted with Fusarium-infected and untreated seed.

Schmitz, in 1911 and 1916, noticed that there is a wide range of difference between wheat varieties as to their ability to withstand the attacks of the fusarial blight of the heads. „In general it may be said that smooth varieties scab worse than bearded ones. In both the bearded and smooth varieties the velvet chaff sorts scab the worst. It is always worse in years when the weather is wet, hot and muggy at the time wheat is bearding or the seed is forming. So striking is this that the writer has often been informed by farmers that they would have had a heavy crop of wheat had it not been for the wet weather and heavy dews at the time wheat was in bloom.... This trouble, while common over the state of Maryland, is usually worse in the coastal plain than in the Piedmont and mountain sections."

Güssow (74), in 1916, reported that *F. roseum* (*Gibberella saubinetii*) or „wheat scab" is widely distributed in Canada, especially in the maritime provinces, but apparently causing only little injury or none.

NAUMOFF (163-165), in 1913 and 1916, made important contributions toward the understanding of blighting of the heads of cereal plants by Fusarium species. His second paper covers many phases of the problem and deals in detail with some of them.

He reported that two Fusarium species are concerned with the blighting of the heads of the cereal crops: *F. roseum* Link with its perfect form *Gibberella saubinetii* Sacc. and *F. subulatum* Ap. and Wr., the first being more common in the southern part of the country and the second in the northern part of the country. He divided *F. reseum* into three varieties, which he named *F. roseum* var. I. *Jachevski*, (2) *F. roseum* var. II, *Woronini*, and a third medium variety which he named *F. roseum* var. III, and considered *Gibberella saubinetii* as the perfect form of all of these three varieties.

Studying the pathogenicity of these organisms, NAUMOFF found that: (1) Infection of the soil will result in blighting of the heads of wheat and barley. How the organisms introduced into the soil under sterile conditions reach the heads of the plants, where they cause blighting of same, is not quite clear. Throughout the paper NAUMOFF states that the mycelium of these Fusarium species is found in all parts of the plants, but it is not very clear whether they infect the roots and the lower parts of the plant, whence the infection proceeds up the stem and becomes systemic, or whether the various parts are infected separately by external infections. Though not directly and plainly stated, in many cases the reader may be led to believe that NAUMOFF considers the infection as systemic and that it proceeds from the roots up to the heads, since he frequently speaks in his paper of finding the mycelium of the organisms concerned in all parts of the plants: roots, stems, heads, leaves, and sheaths, also in all tissues of the various plant parts, but nowhere causing any anatomical changes of same.

2. Spores or conidia of the causative organisms when on the

seed or naturally infected seed can cause blighting of the seedlings upon planting such seed.

3. Conidia, spores, and mycelium when placed on normal young plants or by wounding of same also cause infection.

4. Spraying the heads of wheat, rye, and oats with water suspension of conidia of these organisms produced, in all cases, typical blighting of the infected heads as observed in nature.

5. The same results as in No. 4 were also obtained with ascospores of *G. saubinetii*.

6. These organisms can invade the tissues of the seed, straw, and heads of the cereal plants after ripening and harvesting of same if conditions are favorable.

Working on possible control measures for eliminating the infection on the seed, NAUMOFF tried all known seed treatments, but, in all cases, the results were negative. He then tried dry heat as a control measure and claimed that heating of seed with dry heat at 60° C. for wheat, oats, and barley, and 66° C. for rye, for 24 hours (and up to 3 days) kills the Fusarium organisms present in the seed ([1]).

NAUMOFF's work has no doubt added much toward the understanding of the Fusarium disease of cereal crops, but in many cases, the results obtained by him must be repeated and confirmed before being accepted. His inoculation work, using a very limited number of plants, covers a very small number of inoculation experiments, never more than one or two in number. His dividing the conidial stage of *Gibberella saubinetii* into three varieties shows that he must have worked with impure cultures and that in Russia, as in the rest of the world, more than two Fusarium spp. are causing wheat blight.

SCHMIDT (233), in 1917, made an up-to-date review of the German literature on the Fusarium disease of the cereal crops and came to the following conclusion: „Wenn die Uebersicht der bisherigen Arbeiten über die Fusarienerkrankungen der Halmfrüchte zeigt, dass die Ansichten noch wesentlich auseinandergehen, so liegt das einmal in der zum Teil wenig beachteten systematischen Zugehörigkeit der gefundenen Pilze, besonders aber an der grossen Abhängigkeit des Krankheitsverlaufes von äusseren Faktoren, worauf fast alle Autoren mehr oder weniger

1) The writer (12) trying to verify these results came to somewhat different conclusions.

hinweisen. Es erscheint daher fraglich, ob ein näheres Studium der einzelnen Arten hinsichtlich ihrer Pathologie praktisch wertvolle Resultate zeitigen wird.."

Not only the writer cannot agree with SCHMIDT, but on the contrary he is of the opinion that only a careful study of the various Fusarium spp. connected with this problem; — of their life history and pathogenicity can yield practical results and it is unquestionably the neglecting of this fact that has led to the so widely different and fundamentally contradicting results of the German investigations on this problem.

Discussing further the importance of the Fusarium infection in relation to the seed certifying SCHMIDT writes that while field inspection will eliminate the fields showing foot rot, etc., the infection of the seed can be established only experimentally. This shows once more that in spite of the fact that head blight is as common in West Europe as in the United States or Russia, and though it has been observed by some workers in single cases, it is generally overlooked. If a person only were familiar with this disease he would be able to establish the amount of injury long before the harvesting of the crops and even long before their ripening.

FOËX (56), in 1919, reported the occurrence of the Fusarium foot rot on barley and oats in several places in France. The Fusarium sp. constantly associated with the disease he did not determine definitely, but thought that it resembles closely *F. rubiginosum* (*culmorum*). From his description of the fungus it seems quite certain that he actually had to deal with *F. culmorum*.

HOLBERT, TROST and HOFFER (116), in 1919, attempted to show that there is a certain intimate relationship between the occurrence of blighting of the heads of wheat and the system of cropping, blight being most abundant when wheat follows corn in the rotation, which opinion has been quite generally accepted in the United States. The authors do not state how the preceding corn crop affects the occurrence of blight and it is not plain whether they mean that the organism or organisms causing the disease on wheat, attack also, in some form, the corn plants and that in this way the inoculum of the same in these fields has increased, or that the preceding corn crop, by being cultivated more intensely, leaves the soil in such a condition as will delay or lengthen the growing period of the following wheat crop and thus make it susceptible of, or expose it for a longer period of time to the attack of the blight causing organisms.

If the first supposition is what they meant, then it becomes questionable why wheat planted after wheat which had 40 per cent of scab in 1917 should have only 3 per cent of scab in 1918. Should the second supposition be what they considered the cause of abundant scab in fields following corn in the rotation, then how can one explain the comparatively low per cent of blight (5 per cent) in the first part of field 2 (table 2) which had been in corn for three years and the very high per cent of infection (14 per cent) in the first part of field 1 (table 2) which had been in corn only one year. A careful analysis of this short paper leads one to the conclusion that there is yet much to be learned concerning the life history of the blight-causing organisms and the complex external conditions which affect the amount and severity of blight infection and that the explanation given by HOLBERT, TROST and ROFFER falls short of explaining this. Furthermore, their survey fails to give us any information relative to the effect on the disease of the time of planting, blossoming, and ripening of each field and the kind of weather during each of these periods and for each field. These are important factors which we cannot neglect in trying to explain the degree of blight infection.

LINDFORS (148), in 1920, distinguished two Fusarium diseases of the cereal crops: „Snow mold'', primarily due to *F. nivale* and „Foot rot'' chiefly due to *F. culmorum*. His results on the snow mold agree fundamentally with those of SCHAFFNIT (221) on same subject.

Of the foot-rot he writes that it appears usually on the lowest node, which becomes dark-brown or red, and is usually overgrown by the mycelium of the fungus. Infected plants, as a rule die prematurely. The disease in some cases may appear also on the middle nodes. In some cases, especially in oats, the infected plants remain stunted, their bases are irregularly thickened and the plants fail to head out.

Out of 398 diseased plants in 1917 he found that 88.2 % of all diseased plants were infected by *F. culmorum*; 0.7 % by *F. minimum*; 6.2 % by *F. rostratum (G. saubinetii)*; 3.3 %

by *F. metachroum* (*herbarum*); 0.9 % by *F. subulatum* (*avenaceum*) and 0.7 % by other Fusarium spp. In 1918 *F. culmorum* was the cause of the disease in 96 % of all cases. In 1919 he observed many cases of foot-rot infections caused by *F. minimum*, but in this case the symptoms and effects of the disease were much more severe and the plants died earlier in most cases. This form of the disease he calls „acute" while the foot-rot caused by *F. culmorum* he considers as „chronic."

LINDFORS also emphasizes the importance of the environmental conditions for the successful infections and development of the disease. He infected rye heads at various times after the blossoming with conidial suspension of *F. culmorum*. The first infections gave a larger number of infected kernels than the later infections, while SCHAFFNIT (21) had claimed the contrary. It is difficult to understand why LINDFORS, like all the European workers, did not watch his plants more closely and did not establish the percent of infection directly on the heads instead of the seeds, which can give entirely misleading results, as it is possible to have 100 % of head infection with only 5, 10, 20, 30, etc. or up to 100 % infected kernels, just as it is possible to have 20 % of head infections with 20 % of infected kernels. The susceptibility for head infection stands in direct relation to the age of the plant, whereas the severity of seed infection stands in relation only to the weather conditions.

LINDFORS infected also a number of ripe rye heads by spraying them with conidial suspension of *F. culmorum*. These heads he hung out of doors during rainy weather and sprayed them again with conidia. Fourteen days later he examined the heads and found that none of the kernels were infected by the fungus. From this he concluded that the susceptibility for seed infection is highest shortly after the blossoming of the plants, decreasing gradually afterwards.

SCHAFFNIT (229), in 1920, discussing the geographic distribution in Germany of *Calonectria graminicola* (*F. minimum*) the cause of the snow mold and the importance of seed disinfection as control measure against it, repeats again that: „Bei der Infektion des Roggenkornes durch Fusariumarten ist wohl zu scheiden zwischen der Primär-und Sekundärinfektion. Erstere ist die gefährlichere und wird nur durch die Konidienform der parasitären *Calonectria graminicola, Fusarium nivale* hervorgerufen.

Fusarium rubiginosum, Fusarium metachroum, Fusarium metachroum var. *minor* und *Fusarium subulatum* infizieren das Korn erst im Reifestadium und treten sehr häufig vergesellschaftlicht mit *Fusarium nivale* auf, wenn das Getreide wiederholten Durchnässungen während der Ernte ausgesetzt ist und das reife Korn infolge dessen wieder reichlich Wasser aufgenommen hat.

Der Fusariumbefall ist vorwiegend auf den Roggen beschränkt, da das Weizenkorn, wie schon früher dargelegt, bis zur Reife durch die besondere Stellung der Spelzen gegen die Aussenatmosphäre abgeschlossen und daher viel besser gegen Infektion geschützt ist als das Roggenkorn. In erhöhtem Masse gilt dies von Hafer und Gerste".

This passage which contains the essentials of SCHAFFNIT's work on the snow mold is wrong from the beginning to the end. When we exclude NAUMOFF's work on the Fusarium disease of cereals known in Russia under the name „intoxicating bread", which work, because of the fact that it was published in the Russian language, is entirely unknown in Europe, SCHAFFNIT's work on the snow mold is the only really scientific work on the Fusarium blight in Europe. SCHAFFNIT, however, while fully right practically in everything he has said and written regarding the pathogenicity, life cycle, etc. of *Fusarium minimum* (*nivale*), because of his relatively limited experience with the Fusarium disease of the cereal crops as a whole has committed great errors whenever he tried to treat this disease as a whole. It is wrong to speak of primary and secondary head infection, as head infections begin to appear shortly after the blossoming period and continue up to the ripening period, if only conditions be favorable, and should the weather be rainy during long periods of time, „infections" will continue to appear indefinitely even after the full ripening of the plants. Such conditions however, seldom exist during the summer months in any continental country. For this reason SCHAFFNIT's „secondary" form of infection, while possible, is by no means to be compared with the destructiveness of the purely parasitic form of the disease. It is further wrong to believe that *F. minimum (nivale)* is the only organism able to infect the still unripe rye plants in particular or cereal plants in general, since writer's observations and studies on this disease have shown that *G. saubinetii*, SCHAFFNIT's

F. rubiginosum (*F. graminearum*) is the most common cause of the head infections in the United States, where *F. minimum* was found only in a few cases, not worth while even mentioning. The first organism is also as NAUMOFF has shown, the cause of head blighting in Southern Russia. The writer observed it causing blighting of the wheat heads in Bulgaria, Germany and Holland, in the last country causing blighting of 40 % of all blighted heads while F. *minimum* has been seen only a few times. *Fusarium culmorum* causes blighting of more than 50 % of all blighted heads in Holland; it was observed by the writer also in Germany, where VOGES (269) observed same condition. This organism also is in most cases the cause of foot rot of cereals in France and Sweden. *F. anenaceum*, SCHAFFNIT's *F. subulatum*, is further the common cause of head blighting of cereals in northern Russia, while the writer observed it in a considerable number of cases in Germany, Holland and North Wisconsin U. S. A. *F. metachroum* and several other Fusarium spp. also are causing head blighting in Holland and the United States, but are less common than the first named organisms.

SCHAFFNIT's statement that the Fusarium attacks are largely limited to the rye is absolutely wrong. In Russia and the United States this disease is even more common on wheat than it is on rye while in Holland, where the writer saw severe head infection in the wheat fields, the disease was seldom seen in rye fields. The reason for this in writer's judgement lies in the fact that the rye plants will ripen as a rule, earlier than the wheat plants, thus escaping to a large degree the infection while spring wheat which ripens last is most commonly attacked by the disease. SCHAFFNIT's further statement that wheat is not subject to this disease because its kernels are protected by the glumes is very naïve. It hardly needs to be said that in the United States, Russia and Siberia the head blighting of wheat plants under some conditions and in some years decreases the yield practically to zero.

GUYOT (75), in 1921, also observed that *F. culmorum* causes foot-rot in France on barley and oat plants.

OPITZ (172), in 1921, studying the effect of fusarial infection on the germinative power and further development of cereal plants and the effectiveness of Uspulun and Fusariol as a control measure against this infection did not obtain any positive results in either case.

Hopkins (117), in 1921, studying the hydrogen-ion concentration tolerated by *Gibberella saubinetii* found that „the amount of growth increased with decreasing acidity from p H 2.5 to a maximum at p H 4.0-4.5. It then decreased to a minimum at p H 5.0-5.5 and rose again to a second maximum, the highest point of which was not dertermined". Studying the effect of hydrogen-ion concentration of the soil on seedling infection by *G. saubinetti* Hopkins (118) obtained the following results: „At the end of three weeks the greatest amount of infection showed in the most acid (p H = 2.5-3.0) and most alkaline (p H = 3.4-4.0) soils with a minimum in the curve at a p H of about 5.5. This minimum appears to correspond with a minimum in the growth-acidity curve of the wheat scab organism. Two flats of soil of a p H = 6.4, the original soil, uninoclated showed a perfect stand with no diseased seedlings".

MacInnes (150), in 1922, also studied the growth of the wheat blight organism in relation to hydrogen-ion concentration and found that "A certain Fusarium isolated from scabby wheat in Minnesota, has been found to be capable of growing in solutions through an unusually wide range of hydrogen-ion concentration. The organism grew in nutrient media ranging from p H 3.0 to 11.7. Definite results have not yet been obtained for concentrations immediately below p H 3.0 or above 11.7, but indications are that these figures are close to the acid and alkaline limit for growth." Few organisms are known to tolerate as wide a range of hydrogen-ion concentration as MacInnes' Fusarium. This is fully in agreement with what the writer has said of the nature and parasitism of the cereal Fusaria. It is to be regretted only that MacInnes did not identify his organism which makes his work valueless.

DESCRIPTION.

The large number of Fusarium spp. discussed below as cereal pathogenes when attacking these crops in the various stages of their development produce in all cases similar pathologic conditions, so that regardless of which Fusarium spp. may be the cause of the disease in a certain case, the symptoms of the disease are the same in all cases.

BLIGHTED SEED.

Wheat kernels obtained from blighted or partly blighted heads show marked evidence of the effect of the fusarial attack on the heads and can be easily distinguished in a sample of grain, even when only a very small per cent of such kernels are present. While the kernels from blighted heads are easily recognizable as a class, one can never be sure concerning any particular kernel which shows the symptoms of the attack, whether this kernel is Fusarium infected and whether its pathological condition is due to Fusarium, since other fungi, Colletotrichum for instance, may also cause blighting of the heads and bring about the same pathological symptoms in the grain. Wheat grain from Fusarium blighted heads exhibits one of three more or less distinct and in themselves definite pathological symptoms, depending entirely upon the time of head infection.

(1) Kernels from heads infected early in their development, possibly during or shortly after blossoming period, are small in size, sometimes even more than one third shorter, pale greenish gray in color, shrunken, not firm, and very light in weight. Such kernels, as a rule, never germinate. They may be heavily infected and filled out and even covered with the mycelium of the fungus, in case they have been near the point of infection, or they may be perfectly free from any fungus mycelium. Such kernels have usually been formed far above the point of infection, and have remained undeveloped as a result of inadequate food supply and the early drying up of the portion of the head above the point of infection.

(2) Kernels from heads infected two or three weeks after blossoming have the size of the normal kernel except that they are slightly grayish-white or cream-white colored, shrunken, quite soft and starchy, and light in weight, being only half as heavy as the normal kernel. Here, too, they may be internally infected and covered with mycelium which is evident especially in the groove of the kernels, or they may be entirely free from any mycelium, depending, again, on their position on the head in relation to the point of infection. Kernels of this class may germinate, though the percentage of germination is very low.

(3) The third class of kernels are those from heads that have been infected shortly before or during the period of complete

ripening. Such kernels differ very slightly from the normal kernels except that they are partly discolored and lack the healthy appearance of the normal grain, pinkish-red spots being quite common on such kernels. While the pinkish-red coloring of the kernels in all of the three classes of kernels is a good and reliable symptom of fusarial infection, it must be remembered that other fungi, as Macrosporium and Alternaria for instance, may, in some cases, also be the cause of this coloring of the grain. Kernels of this class usually germinate normally, but before the young plant has reached the surface of the soil, or before it attains any size, it will be overcome by the fungus present in the kernel, usually resulting in a complete wilting and rapid dying of the seedling. In some cases the young seedling may survive the attack and reach full development.

The effect of the blighting of the rye heads on the grain is very much like that of wheat. Barley kernels from blighted heads when directly attacked by the fungus become dirty brown in color and, according to the period of infection, remain more or less light in weight. Often there may be found barley kernels with salmon-colored spots on which there sometimes occur masses of Fusarium conidia. Oat kernels are similar to barley kernels, except that they remain lighter in color. Here, too, the same symptoms may be caused by other factors as well and even by mere exposure of the grain or the harvested crop to rain, etc.

SEEDLING BLIGHT.

Seedlings from naturally or artificially infected seed or such from healthy seed planted on infected soil are subject to attacks by Fusarium spp. at a very early stage in their development, and symptoms of the infection may be noticed several days after the germination of the seed. The disease develops quite rapidly and if the weather is warm and moist, it may kill a considerable number of the plants within several days and before the latter reach the surface of the soil. This is especially true of seedlings from naturally infected seed and of weak and shrivelled seed. The first pathologic symptoms appear on the young coleorhiza and coleoptile, consisting of a browning and rotting of these parts. The coleorhiza and coleoptile, which die shortly after the formation of the primary roots and the appearance of the first foliage leaf, seem to offer a good medium for the establishment of the various Fusarium spp. which then penetrate into the living tissues of the primary roots and the first foliage leaf, causing browning and rotting of the invaded portions. If the attack has proceeded successfully, the formation of the two lateral roots (in the case of wheat) is prevented or they are destroyed before attaining any size. The roots at the point of attachment are usually discolored brown to black, sometimes also pinkish-colored, while they continue to remain normal and healthy in their lower parts until the upper parts are completely rotted. Often the grain remains are heavily overgrown with the mycelium of the fungus and in some cases they take a dark carmine red, vinaceous or bluish color, depending on the color of the causal organism. The leaves above the infected portion, which seldom extends above the ground, if still very small, will become yellow and later brown colored, the discoloration beginning at the top. If already over six centimeters in length, they usually take, at first, a light green color, then collapse, and wilt very rapidly, showing a blighting effect; such plants die as a rule. In many cases the infection may be restricted to the primary roots, the coleorhiza and coleoptile and even the first foliage leaf, but before long new roots are formed, the second and third leaves are also out, and the plant may recover entirely from the attack, which, in such cases, remains restricted to the parts originally infected. Such plants if examined three to four weeks later will show no symptoms of the infection and usually continue to develop normally.

SNOW MOLD. POOR OVERWINTERING. ROOT-ROT.

In Germany and the Scandinavian countries the cereal fields, when heavily infected with Fusarium spp., show in rare cases and under certain conditions immediately after the melting of the snow the presence of rich cotton-like development of fungus mycelia on the surface of the soil and around the bases of the plants. This phenomenon is known in these countries under the name „snow mold". Originally it was thought that *F. minimum* was the only cause of this condition. SCHAFFNIT (221) however, has shown, that not one but a number of

Fusarium spp. are connected with the snow mold. Those who have worked with soil infections with the cereal Fusaria have unquestionably often observed the formation of large and visible spots of mycelial cottony growth on the surface of the pots or boxes.

This phenomenon is by no means limited only to the Fusaria and can be brought about by a large number of fungi. High moisture content of the air and the presence of dead organic matter on the surface of the soil are prerequisites for the development of the snow mold in nature or in the laboratory. In both cases the presence of the snow mold is of very short duration and it usually disappears with the coming of the first windy or sunny day. Fields in which the snow mold has been seen should, according to the students of this phenomenon, show poorer stand, i.e. dying out of a small or large portion of the plants. This is known in Germany under the name of winter killing or „Auswintern". Whether the presence of this rich fungus growth means or leads to a dying out of the plants or that the plants have been already killed by the frost or the fungi and that the snow mold appears merely as a result of the above, is something that is not yet fully understood.

Careful examination of the underground portions of Fusarium infected winter crops early in spring and of spring crops somewhat later in the season will, however, show partial rotting of the roots, the base, and in some cases, the interior of the young stem just above the base. Various fungi may be associated with this condition of the cereal crops, among which Fusarium spp. are most common. No attempt has been made to obtain definite data on the relative occurrence of Fusarium spp. on root lesions and discoloration, which, of course, is absolutely necessary before their relative importance as root-rot inducing organisms under field conditions can be established.

The first evidence of the above pathological condition on the roots of the cereal crops, whether the source of fusarial infection be the seed or the soil, is the same and may be the result of a new infection or merely a continuation of the seedling blight stages, the plants succumbing again to the disease as a result of frost injury, lack of air and light or too high moisture content of the soil, etc. First the organisms show their presence on the grain remains and follow some of the primary roots, causing rotting and browning of same. With the formation of the crown and crownroots, the primary stem below the latter, now quite discolored and in some cases beginning to die, is invaded by the organism from the grain remains and the primary roots. Soon it, too, becomes brown and shows evidence of rotting. When the invasion reaches the crown it may stop, depending perhaps on the condition of the plant, or it may continue invading the central woody portion of the primary stem in and above the crown and the secondary stems, causing a browning of their woody portion. Rotting and browning of the scale leaves and sheath may also occur as a result of the invasion. How much of this rotting and discoloration of the underground portion of the cereal crops due to Fusarium spp. is parasitic and how much is saprophytic is not known, as these portions of the plants may be injured also by frost, etc. That there is some parasitizing by the organisms is shown very conclusively by the rotting of the roots next to the grain remains or the crown, while their lower portions continue to be normal. It is shown also by the browning of the interior of the primary stem at and above the crown. The separation of discolorations and rotting of underground portions due to the parasitic and saprophytic action of the organisms concerned is unusually difficult, since a large part of the original underground parts of the plants eventually die even without any fungus invasion, and the presence of parasitic organisms may have nothing to do with it. Such is the case with the sheath and scale leaves, the primary roots and the primary stem below the crown and later on even the crown roots.

The amount of damage, if any, caused by this invasion of the roots and underground portions is even more difficult to determine. As a rule, the plants thus attacked are smaller and stunted, but with the coming of sunny and warmer weather they usually recover and reach normal development, even when very badly injured. With the coming of favorable weather such plants will send out secondary roots or even aerial roots, quite common in oats, and before long the effects of the attack will disappear entirely. Only in rare cases and over small areas does the effect remain permanent, the plants remain stunted, fail to head out and wilt with the coming of the first dry and warm weather.

The condition just described as occurring in the field was produced by the writer under greenhouse conditions and in pure culture inoculation experiments with the following fungi: *Gibberella saubinetii*, *F. culmorum*, *F. culmorum* var. *leteius*, *F. avenaceum*, *Helminthosporium sorokinianum* and two other undetermined Helminthosporium spp. SCHAFFNIT (221) has shown that *F. nivale (minimum)* can produce the same effects.

FOOT- AND STALK-ROT.

In some cases full grown plants may be killed by Fusarium spp. just before or shortly after the time of blossoming. The fungi attack the roots and the stem close to the ground, the first node usually being involved in the infected area. The part in contact with the ground and the roots below are rotted and commonly pink or yellowish-brown in color. This rotting of the base interferes with the water and food supply of the plant and causes its complete wilting. Such plants, because of their weight, are bent or break soon after wilting and are easily recognizable in well-kept fields. In cases where such infections appear in considerable number, the fields look as if sheep have gone over them.

When such plants are pulled out, they break at the base, the roots always remaining in the soil. It must be remembered, however, that the wilting of the whole plant in much the same way is caused by insects and other fungi as well, e.g. Colletotrichum sp., except that, in this case, the base of the dead plant is much more dark brown or black in color.

The attack on the base of grown plants may also be a continuation of the early attack on the young seedlings or the young plants, the plants succumbing to it because of their decline in vigor, unfavorable conditions (hot and dry weather) or it may be the result of a new infection in which the environmental conditions are also important factors.

The nodes of the various cereal crops being more succulent and more easily penetrable by fungi are often attacked by some Fusarium spp. independent of the attack on the base or the head. Here the infection is usually restricted to the node or the area immediately next to the node, never or very seldom extending more than one inch in each direction from the node. In such cases, the portion above the infected node usually wilts and soon dies. Conidia may be formed under certain conditions on the node itself and the infected part of the sheath coming out from it. This condition was first observed by MACALPINE (151) in 1896 and is known in the European literature under the name „Stalk rot", though this name is used also for designating the „foot rot" phase of the disease.

BLIGHTING OF HEADS.

By far the most important phase of the Fusarium blight of the cereals is the blighting of the heads. It stands in no relation to any of the former phases of this disease, except that they may serve as sources of infection and make possible the multiplication of the existing infection material and the abundant production of conidia, which later on reaching the heads in various ways cause blighting of same. Head blight may appear even in the best fields. It is nothing unusual to see that fields which until after their blossoming period did promise an excellent crop have yielded later as a result of blighting of the heads only a fourth or a fifth of the expected yield. The blighting of the heads as a rule is a very rapid process under favorable conditions; only one or two weeks are necessary to completely ruin the crops, so far as their yield in grain is concerned. These are the cases for which the farmers use the expression. „Much straw but little grain".

Wheat. The symptoms and effect of head blighting of the various wheat varieties are, in general, the same. There are, however, slight differences in symptoms among the various varieties, the difference in all cases is a difference of color of the blighted head which usually takes the normal color of the ripe head, of the respective variety or possibly a slightly lighter color. We shall describe the symptoms of blight infection as they appear on some of the beardless wheats, e.g. Marquis wheat.

Blighting of the wheat heads can be detected with absolute certainty at a very early stage and only from three to four days after infection has taken place, provided the weather conditions have been favorable so as to enable the parasite to establish itself on the host and to begin its work of destruction.

The very first signs of blight infection are light brown, water-soaked spots on the glumes from two to three millimeters in length, the veins showing a more intensive water-soaked and a much darker olive green and somewhat more brownish appearance than the area between them. The points where the infected glume or glumes are attached to the rachis, if not already attacked will also soon show the water-soaked appearance. Gradually, or more or less rapidly as the case may be, depending on the weather conditions, the water-soaked area increases, soon covering the whole spikelet, and then spreads to the neighbouring spikelets. If the weather is dry the infection may remain restricted to only one spikelet. Soon the glumes and the spikelets originally infected gradually begin to lose the water-soaked appearance, dry up, and take the color of the ripe head typical of the particular variety. The drying up of the infected spikelets follows closely the advancing point of infection, the latter usually proceeding downward. FREEMAN (59), in 1905, first observed that the infection proceeds downwards. The healthy part of the head above the point of infection, because of the cutting off of the water and food supply by the fungus at the point of infection, usually dries up and dies without passing through the water-soaked stage, i.e. its death is not due to the direct effect of the parasite, but due to lack of water and possibly of food supply. In some cases, however, one or more vascular bundles of the rachis may remain uninjured by the fungus invasion and continue to supply the uninfected portion of the head with water and food, and in rare cases it may remain so until the head normally ripens and has even formed fairly normal kernels. As the infection proceeds down the stem, bringing about the same symptoms as on the head, it may sometimes reach as far as the upper node. Here, too, the whole or only one side of the stem may become affected, while the other side, with one or more vascular bundles still normal, may continue to provide moisture and food for the living portion of the head. Usually, however, especially in dry weather, the infection is restricted to the head only and most commonly only part of the head is destroyed. This may be the upper, middle or lower part, or the whole head, according to the kind and point of infection. A successful infection of the rachis, as is usually the case, will cause blighting or dying of the whole head above the point of infection. In such cases, the dead spikelets shrink and become more closely packed to the rachis, while the uninfected portion of the heads continues its normal development, becomes well filled out, robust and its spikelets wide open, making the difference between infected and uninfected parts still more striking.

The point of infection, even when the infection is in an advanced stage, can easily be located, especially if the weather has been favorable. Under such conditions it is usually covered at first with a short, cottony, slightly pinkish, fungous growth, while the rest of the infected area remains free from such a growth. Later on, if the weather is favorable, this growth extends farther over the infected area and becomes the substratum on which a layer of conidia is formed. This layer of conidia may be smooth (pionnotes) or more or less granular (sporodochia), depending on the causal organism and the age. The older it is, the smoother it becomes. The color of the conidial masses which originally was slightly pinkish now becomes from dark salmon to grenadine in color, depending on the causal organism, being most dense in the case of *F. herbarum* and *F. avenacium*, and less so in the case of *Gibberella saubinetii* and the rest of the Fusarium species. Because of the fact that at the bases of the spikelets moisture from rain or dew is held for a considerable length of time, the conidia are usually formed at the base of the spikelet, extending along the furrow formed at the point where the inner and outer glumes meet. In cases where the infection extends to the upper node, conidia are formed also on the node, but there they never form pionnotes and usually form small sporodochia and are very abnormal in size and shape.

The first infections on the heads become apparent shortly after and even during the latter part of the blossoming period, if this had been protracted because of unfavorable weather conditions and practically continue to appear until the ripening of the heads. The infection of the heads takes place at about the same time as that on the nodes. In both cases, the infection is always independent and has no relation to any of the previous attacks of the disease, except that they may furnish the inoculum for the head and node infection.

Rye. The symptoms of head blighting on rye are very much like those of wheat with the following exceptions. The water-soaked appearance is not so prominent here as it is in wheat. The infection sometimes extends as far down as the second upper node before the plant naturally dries up. Conidia are usually formed only at the bases of the spikelets and in the furrow formed where the inner and outer glumes meet and to some extent under the outer glumes. Under favorable weather conditions, however, conidia are also formed throughout the infected area. Heads infected and killed at an early stage remain straight upward, while the normal heads are slightly bent.

Barley. The symptoms of blight attacks on barley heads are usually different from those on wheat and rye. Only very seldom do they resemble those of the latter. Usually only one kernel is killed, or several kernels in one row. In some cases, the three kernels forming a spikelet are attacked and then the rest of the head, if conditions are favorable. The first sign of infection is a small water-soaked, somewhat brownish, spot at the base or the middle of the kernel, or it may appear first on the rachis. The water-soaking and browning spreads in all directions from the point of infection, soon inclosing the whole kernel, the whole spikelet or several spikelets, but this is in no way as uniform as it is in wheat and rye.

Oats. The symptoms of head blighting of oats resemble those of wheat. Because of the structure of the head of the oat plant the infection is restricted to one spikelet and is, therefore, not as conspicuous as that of wheat or rye.

LIFE HISTORY OF THE CAUSAL ORGANISMS IN RELATION TO PATHOGENESIS.

The complete life history of some of the Fusarium spp. concerned with the several phases of the disease has not as yet been fully worked out and here is presented only the information which the writer has been able to gather during his study of this problem. It is in no way final and it is the writer's belief that further studies in this direction will throw new light on the subject and perhaps modify, to a large extent, our present conception concerning many phases of the life history of the organisms here concerned. The writer here presents the life history of *Gibberella saubinetii,* which is the best understood of all the fungi concerned with the disease, with which the life history of the other Fusarium spp., so far as known, agrees in every respect.

PRODUCTION OF SPORES.

PRODUCTION OF CONIDIA.

Production of conidia is more or less common in all forms of fusarial attacks on cereals. In many cases it may be so abundant that it leaves no doubt as to the real source of inoculum in nature.

On Seedlings. Frequently by pulling out a wilted seedling and examining microscopically portions of its partly decayed kernel or the young stem of the seedling, one will be surprised to see a great number of beautiful and very normally developed conidia. In rare cases masses of conidia are also formed on the rotted stem above the ground. The amount of conidia so formed will be still greater if any particle or organic matter, like straw, old stems, or stubble, happens to be near the wilted or heavily infected plant, since the conidia-forming growth will extend over them. The conidia-forming fungous growth soon disappears, however, leaving no permanent trace.

On Nodes and Bases. Formation of conidia on the infected nodes or bases of mature plants, while common, is never very abundant because of the rapid drying up of these parts and it is well known that moisture is one of the most important factors for the production of conidia.

On Heads. The formation of conidia on the heads of cereal plants, especially of wheat and rye, shortly after infection takes place, is common and so abundant as to give them a very distinct pinkish or salmon coloration. In dry weather the conidia formation is restricted only to the area where the infection originally took place, this being usually the base of the spikelet where the raindrops collect and the moisture is held for a comparatively longer time than on any other part of the plant, except, possibly, the sheaths. The spore formation extends, under such conditions, up the several furrows formed by the joining of inner and outer glumes and to some extent even between the glumes. In moist weather the conidia are formed in great abundance all over the whole area through which the hyphae of the parasite extend. The latter send out conidiophores through the stomatal openings, and even directly through the epidermis forming, originally, small balls of conidiophores and conidia over each stoma. Soon these balls converge into a uniform layer (pionnote) of conidia extending over a large portion of the head.

Preceding June 29, 1918, the weather was dry and there were very few conidia formed on the infected rye heads in the University of Wisconsin rye field at Olin Hill farm. The last two days of the same month were, however, rainy and comparatively cooler, and, subsequently, conidia were formed in such abundance that infected spikelets were practically wholly covered with a layer of conidia which gave them a distinct pink or rose color, making them very easily noticeable, while previous to this it was necessary to look for the labels in order to locate the infected plants under observation.

Dry blighted rye, wheat, or barley heads without any conidia, if put on the ground under a screen and kept moist will also produce abundant conidia.

On Dead Organic Matter. Old straw, pieces of stems and corn stalks in fields where the year before the crop had been heavily infected with the disease were often found to show large pinkish areas bearing numerous conidia, some of which belonged to some of the Fusarium spp. which were found parasitizing on wheat and corn. This was especially common on corn stalks and wheat heads left in the field from the previous year and bearing the perthecia of Gibberella spp. This shows that the fungus hyphae present in the previously infected heads or corn stalks remain viable till spring, when they form new conidia and so help the further propagation of the fungus.

PRODUCTION OF ASCOSPORES.

Whenever the cause of the disease is one of the species having a perfect stage, as *Gibberella saubinetii* or *Calonectria graminicola* the perithecia of these fungi are produced in great numbers on all infected parts on which there has been more or less formation of conidia, since they seem to be formed more commonly on the pseudo-plechtenchimatic structures on which conidia have been formed before.

Perithecia have been observed under greenhouse conditions on seedlings and infected kernels, in the straw and heads of the various cereal crops, and on the stalks, sheaths and ears of corn. The ascospores play an important rôle in the life of these organisms, since they are the most certain and reliable inoculum for the first infection.

DISSEMINATION OF SPORES.

Experimental work on this subject is limited to the study of the agency of wind and to some extent, of rain in the distribution of the conidia. Other factors may also play some rôle in the dissemination of the conidia and ascospores, but time did not permit a study of other factors.

BY WIND.

In a rye field slightly infected with blight numerous spore traps [1]) were placed on stalks in vertical and horizontal positions some on the ground and some at various heights, ranging from 3 to 8 feet high above the ground, and exposed from 12 to 24 hours, then examined under the microscope. The number of *Gibberella saubinetii* and other Fusarium conidia caught was very small as compared with the spores of other fungi, especially rust spores, that were found on each spore trap. *Gibberella saubinetii* conidia [2]) varied from none to eight, being most common on the traps set nearer the ground and, especially, those placed vertically and against the prevailing wind. The largest number of Fusarium conidia were caught by the traps placed on the ground. The fact that the conidia of *Fusarium* spp. are windborne is not new. SAITO (218), studying the atmospheric flora of Tokyo, found that Fusarium conidia are carried by the air, but in small numbers. The same observation has been reported also by a number of other workers.

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1) Ordinary microscope slides were covered with a layer of glycerin or glycerin with some vaseline, and were used as spore traps.

2) These studies were made at Madison, Wis, where G. saubinetii is the most common cause of head blight.

That the ascospores of *G. saubinetii* are also wind-borne is shown by the following field observations. One of the rye fields under observation, consisting of several acres, is located on a hill sloping to the south very abruptly on its west end and gently on the east, and level on the northern side, but protected on this side by a wind-break of high trees. The level part of the hill was sown with winter rye, and the sloping part with second year alfalfa, where barley had been used as a cover crop. On the old barley stems left in the alfalfa field there were a considerable number of *Gibberella saubinetii* perithecia with viable spores. Any wind reaching this field blew from the south. The whole rye field was as uniform, in all respects, as could be expected. The degree of head blight infection, however, was very different through the different parts of the field, although it was only a small and narrow strip of land. Blight was practically absent in its western part, which was surrounded on the northern and western sides by wind breaks. There was considerable blight infection in this part of the field among the plants on the southern side immediately adjacent to the alfalfa field in which, as stated above, the blight inoculum was present and the sloping very rapid. The eastern part of the field, also protected on the northern and eastern sides by wind breaks, had, on the other hand, a large percentage of blight, up to five per cent, not only among the plants next to the clover field, but also throughout its southern half, while its northern half was free from blight. Knowing of no other factors that could account for this difference, the writer is inclined to think that the following is the possible explanation of the question: The west end of the field adjacent to the alfalfa field, where the slope was very rapid, was infected only through the area immediately next to this field because the wind lifting the spores from the alfalfa field could not get them into the upper air currents and so get them over the hill, but deposited them against the slope before they could reach the rye plants on the level ground, and only those rye plants were infected that grew near the alfalfa field. In the eastern part of the field the situation was different. The slope is more gradual and the spores needed to be lifted only a few feet in order to be on a level with the rye field and so could be easily carried to the rye plants even by the slightest air currents. For this reason, perhaps, the infection in this part of the field was quite abundant, but even here, it was restricted to that half of the field which is adjacent to the alfalfa field. This observation illustrates that the source of inoculum was the alfalfa field and that the infection extended only as far as the wind, under the topographical conditions, could carry the spores.

RAIN DISSEMINATION OF CONIDIA.

The conidia produced first are usually very loosely attached to the mycelial growth and are easily detached from it by wind, insects, and other agencies, while the conidia formed later and in pionnotes, as is commonly the case, are glued together. If a drop of water, however, is placed on the pionnote, they are set free with great rapidity and force, as is shown by their moving about rapidly within the drop. It is quite evident that rain helps the liberation of the conidia from the pionnotes and in this way they are carried down to the ground or transmitted from plant to plant in a horizontal way, the latter being brought about by the motion and waving of the plants.

Other factors (insects, mites, etc.) no doubt may also play some rôle in the dissemination of Fusarium conidia, but time did not permit the study of these factors.

PERIOD OF INCUBATION.

ON SEEDLINGS.

The period which elapses between infection and the appearance of the first symptoms of attack on the seedling roots varies so much that no definite incubation period can be given. It varies considerably with the condition of the seed used. When light, shriveled seed is planted on infected soil or is infected by dipping into a suspension of conidia and then planted on sterile soil, the seedlings will succumb to the attack of the parasite much more rapidly than when healthy seed is used. Abundant watering of the plants and a higher soil temperature also affects to some extent, the rapidity of the attack.

In general, the first symptoms of root infection appear under greenhouse conditions after the seventh day after planting. Abundant infection is quite common after the fourteenth day.

Where naturally infected seeds have been used on sterile soil the symptoms of root infection may appear even before the seventh day.

ON HEADS.

In head infection the variation in the incubation period is much smaller. In damp weather the period that elapses between infection and the appearance of the first symptoms (water-soaking) varies from three to six days. In dry weather symptoms of infection may not appear until after the first rain, or if heavy dew falls during the night and lasts for the larger part of the forenoon, symptoms of infection may appear in from five to eight days.

The rapidity with which the blight infection spreads from the point of infection to the rest of the head is never alike in any two cases. It varies considerably with different individuals and depends greatly upon the weather conditions. On healthy, vigorous and more succulent plants, the infection spreads much more rapidly than on plants of average vigor. Moist and cloudy weather followed by warm and clear weather greatly accelerates the rapidity of infection and killing; yet, even under such conditions, on many heads the infection may be restricted to a single spikelet, the rest of the head remaining healthy and developing perfectly normal, healthy, and plump kernels.

For the study of the rapidity of the spread of the disease from the point of infection, the first heads showing primary infection were located daily and marked with tags so that they could be again located. Heads so tagged were examined every two or three days and the changes recorded. In this way the effect of the various factors affecting the rapidity of blight infection and killing were studied. The following are typical records of some infected heads, made in 1918:

N 1009 July 11, 1 spikelet infected. Infection at base of head.
„ 14, 4 spikelets infected.
„ 17, Whole head killed.
N 101 July 11, 5 spikelets infected. Infection at middle.
„ 14, 8 spikelets infected.
„ 17, Whole head killed.

N 1038 July 9, 1 spikelet infected, third from below.
„ 14, 4 spikelets infected.
„ 17, Whole head killed.
N 1039 July 9, 1 spikelet infected. Middle.
„ 14, 4 spikelets infected.
„ 17, 12 spikelets infected.
„ 24, Whole head killed.
N 1156 July 11, 1 spikelet infected, uppermost spikelet infected.
„ 24, 1 spikelet infected. Plant almost ripe. Infected spikelet covered with Fusarium conidia.

TIME OF NATURAL INFECTION.

The first head blight infection in nature takes place during the latter part of the blossoming period. It is, however, not the most severe one, the secondary infections, following shortly after the first, being the ones that are most destructive.

Several wheat, rye, barley, and oat fields, all located within four miles of Madison, were selected for experimental purposes during the spring and summer of 1918 and were being examined every other day, beginning about one week before the blossoming period of rye and two weeks before the blossoming period of wheat, barley and oats.

The following is an abbreviated typical record of the observations on one of the wheat fields:

Station No. 2. Town of Burke, Wis.

Field with Marquis wheat on corn ground. Seed procured from Olds Seed Co., Madison. Field in a level open country. Soil sandy loam. Stand good.

June 22. Plants in blossom. No signs of blight iufection. Throughout the field there are numerous corn stalks with a great number of *Gibberella saubinetii* perithecia with viable spores, some stalks bearing also masses of Fusarium conidia different from the conida of *G. saubinetii* [1]).

June 28. Just passing blossoming stage. No signs of blight infection. Gibberella perithecia oozing their ascospores in masses.

July 7. First signs of blight infection apparent. They consist of a water-soaked spot on single spikelets, usually single glumes.

July 13. All suspected first infections developed into distinct blighting of the heads.

Following the first infection we may have as many successive infections of weather conditions permit.

Similar observations with similar results were made at the

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1) Later determined as *F. herbarum*.

plant breeding plots of Prof. MAYER at Groenewoud near Wageningen.

These observations agree also with the results obtained with artificial inoculations. Inoculation of plants before blossoming and after the latter part of the dough stage gave negative results. While the organism will attack and penetrate the heads and kernels in them during the latter part of the dough stage also during complete maturity, as demonstated first by SCHAFFNIT (221) and later on by NAUMOFF (165), providing that the weather conditions be favorable (abundant moisture and warm weather), this can hardly be spoken of as infection in the true sense of the word and does not play as a rule, too important a rôle in increasing the injury and losses due to these fungi. That in Europe so many workers have attributed great importance to this form of infection is entirely due to the fact that they were ignorant of the so common and purely parasitic blighting of the heads.

Under exactly the same conditions a large number of wheat plants just heading out, others just past blossom, and a third lot in the latter part of the dough stage were inoculated on the same day with the same spore suspension and gave the following results: The first and third lot remained healthy during the first week, while the second lot showed 100 per cent of severe infection. The third lot remained free from the disease till full maturity. Some of the plants in the first lot showed slight infection after the first seven days from the time of inoculation, during which time they were in blossom. These results show that the spores remain on the infected heads till the heads reach a susceptible stage, before infection takes place.

MODE OF INFECTION.

The lower a certain plant-pathogene stands in the scale of parasitism the more simple and primitive is its mode of infection. As has been already stated in a former chapter the Fusarium spp. attacking the cereal crops belong, from stand-point of parasitism, to the lowest group of plant-pathogenes. There is absolutely nothing in their life-cycle or physiology which indicates the existence of a certain specialisation or adaptation of these organisms to a certain host or group of hosts.

ECKERSON and DICKSON (50) studying the influence of soil temperature and moisture on the chemical composition of wheat and corn seedlings and the relation of the latter to their predisposition to seedling blight, caused by *G. saubinetii*, found that when seedlings have grown at low soil temperatures they are high in available carbohydrates and low in available nitrogen. The cell-walls, even in early seedling stage, are cellulose, soon impregnated with lignin. Wheat seedlings grown at high soil temperatures have little or no available carbohydrates and are high in available nitrogen. The cell-walls are composed of pectic materials, cellulose being absent until after photocynthesis begins. They found that: „In the invasion of coleoptile and coleorhiza of seedlings, the parasite penetrates the walls of pectic materials apparently with little resistance and is both inter-and intracellular, whereas, it penetrates the cellulose walls, digesting the middle lamella and thus remaining intercellular. All gradations between these two types of penetration occur in the intermediate soil temperatures."

When the conditions are favorable for the aerial infection by these organisms, i.e. moist weather and a not too low temperature the conidia or ascospores of same organisms germinate on the host plant; this usually takes place on such points of the plant where moisture is abundant, as between or at the base of the glumes or sheath, and where conidia or spores are easily brought by the downward sliding rain and dew drops. In such places, which represent a sort of moist chambers, the Fusarium conidia germinate and continue to develop in the (by means of asmosis enriched) drop of water until they come in contact with the host tissues, where they attach themselves and continue growing, and penetrate directly into the underlying host cells; once in the host cells they continue growing intra-and intercellulary in all directions.

From the glumes the mycelia pass directly into the young kernel and invade more or less all portions of same.

Adams (4) studying the mode of infection and penetration of *G. saubinetii* considers it as probable "that infection becomes established first within the developing embryo, since this is so favorable for the fungus development and then spreads to the storage or endosperm tissue". That this organism and related ones develop in many cases a richer growth within the embryonic tissues has been often observed by the writer, especially in the young kernels; still this does not justify the supposition that these fungi enter the kernels in all cases through the embryonic tissues. They can and do actually enter into the kernels through any point which may first be reached by the advancing mycelium. The infection is therefore a „contact" infection. There where the first contact between host and pathogene is established, is also the point of entrance for the fungus. This has been repeatedly observed on barley kernels on which the point of infection, a brown spot, is always visible.

DICKSON (42) on the other hand claims that „Initial infection usually occurs through the extended anthers".[1]) It is a fact that some of the anthers of the infected heads especially the anthers of the artificially infected heads which are being literally covered with conidia, are heavily overgrown by the mycelia of these fungi but it would hardly justify the supposition that the anthers play any special rôle in the infection of the heads since infection can take place just as easily even after the disappearance of the anthers, as has often been demonstrated by the writer.

SCHAFFNIT's (221) supposition that the „cytolitic enzyme" necessary for the penetrating of the fungus into the plant is produced only after a considerable development of the mycelium and not immediately after the germination of the Fusarium conidia, is even less acceptable. He came to this conclusion because in his infection-experiments in most cases he obtained better results where mycelium was used as inoculum. In connection with this it will only be necessary to state that the writer used throughout his extensive inoculation experiments only conidia for inoculating and obtained in all cases a high percentage of infection, most of which were visible even as early as the 3d day after infection, whereas everyone knows that if we place a single conidium on some suitable agar, it will make in three days just enough growth to become visible to the unaided eye.

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1) In a resent publication, Wisconsin Agr. Stat. Bull. 339. 1922, Dickson writes that there exists a correlation between severity of head blight and the number of anthers remaining enclosed in the glumes. He selected individual plants with open anthers and found that the resultnng plants showed only 2 or 3 percent of blight as against 30 to 40 percent in the control plants.

SOURCE OF NATURAL INFECTION.

An important source of infection is the seed used for sowing. Cereal seeds carry, externally, numerous viable Fusarium conidia and many of the kernels are internally infected with various Fusarium species, as has been shown by SELBY (238), SELBY and MANNS (239), SCHAFFNIT (221), BOLLEY, (23), WOLLENWEBER (287), NAUMOFF (165) and many others. The writer isolated from what seemed fairly normal wheat, barley, oat, and rye kernels several of the fungi that were isolated from blighted heads of these crops. If we take 100 gr. of cereal grains and shake them vigorously in a glass cylinder with 100 cc. of water, then decant and centrifuge the water and examine the sediment we shall see that it contains a considerable number of conidia of pathogenic Fusarium spp., which when kept moist will germinate. Such seeds carry the various Fusarium spp. to the soil where they attack the young seedlings, if conditions are favorable, and pass the winter in the soil, preferably on the dead seedlings or other organic matter. In spring they resume their growth, produce new spores which, when carried later on to other plants, cause head or node infection. This condition was observed in the case of *G. saubinetii*, *F. herbarum*, *F. culmorum*, *F. arcuosporum* and *F. avenaceum*. Whether this is true also of the other Fusarium species described here, has not yet been established. Further studies may establish this condition for those species as well.

The perfect stage of *G. saubinetii*, which is formed in abundance on infected heads, straw, or corn stalks, is a very good source of natural infection. The conidia of all species studied are produced in abundance on the infected heads and stems and are the most important, if not the only, source of later infections.

Whether the Fusaria here concerned are present in the soil at all times and for long periods of time, always ready to attack the susceptible host plants on such soils, is an important phase of this problem to which the writer has given no attention. That these organisms are present in the fields on dead plants, on the straw, stubble and dead organic matter on which they can even overwinter has been repeatedly observed by the writer, but whether they can remain in the soil proper for a considerable length of time is not known.

OVERWINTERING OF THE FUNGI.

For the greater number of the fungi studied here, there is no experimental evidence to show how they overwinter. All of these fungi possess a remarkable resistance against desication and low temperature and it is supposed therefore that the species introduced with the winter crops overwinter in the soil in the form of mycelium, conidia, and clamidospores, where such are formed, on the dead seedlings and other organic substance, and also on and in the seed, straw, heads, and corn stalks that had been infected with these fungi the summer before. This the writer established only for *Gibberella saubinetii*, *F. herbarum*, *F. avenaceum*, *F. culmorum*, and *F. arcuosporum*. The first and second were found during the whole winter on corn stalks in an old corn field near Madison, Wisconsin. The interior of the stalks was well preserved but rose colored; on their surfaces there was a crust-like layer of mycelium on which the conidia were formed. Masses of viable conidia of *F. avenaceum* were found on the 2d of March, 1918, on a standing stem of *Echinochloa crusgalli* in the fields of the Wisconsin Agricultural Experiment Station. *F. arcuosporum* was found sporulating on old oat straw the same date and in the same locality and was also isolated from wheat seedlings collected in the field on the 3d of March, 1919. Conidia of this species formed in thick layers on the cut surfaces of corn stalks late in the fall, were taken in from under the snow on the 25th of February, 1919, and, upon plating, were found viable. The occurence of these fungi on dead stems so early in spring shows either that they passed the winter in the same and, with the coming of warmer weather, formed conidia, or that, in some cases, the conidia were formed during the previous fall. Some of the Fusaria found on cereal crops were isolated several times during the winter of 1918 from corn stalks fed to the cattle on the University farm, and also from corn stalks that had been taken out into the fields with the manure or used for feeding the cattle there. *F. culmorum*, which forms numerous clamidospores overwinters also in the infected stubble of the former crop. The perithecia of *G. saubinetii*, which are so often found in the fall on the straw of cereal crops and on many grasses, and are usually not yet fully developed at that time, constitute the form in which one of the most important parasites of this group overwinters. In spring these perithecia mature, and form numerous ascospores, which are later on liberated from the perithecia and carried to the various susceptible hosts.

These fungi when present in the seed preserve their viability for over two years. Mycelium of Fusarium species present in infected wheat, rye, and barley heads and straw, when stored in the laboratory at room temperature and moisture, was found viable after 12 months. Similar results were obtained also at Wageningen during the years 1922-1923.

THE CAUSAL ORGANISMS.

SOURCE AND METHODS OF ISOLATION.

All species of Fusarium treated here were isolated originally by poured plate dilution of conidia from distinctly blighted wheat heads. During the course of the work, however, some of these species were also often isolated from blighted rye, barley, and oat heads, or stems, and from sheath, shankrot and node rot of corn, or, in a few cases, from other hosts, as indicated in the host list of each described Fusarium species. The organisms attacking the cereal crops above the ground, produce numerous conidia over the infected area. The conidia thus produced are very normal, of uniform size and shape, and the experienced student will not only have no difficulty in separating the various species before he has grown them under artificial conditions, but will also be able to determine, in a general way, the various species, or at least the various sections to which the species belong.

In order to prove that the Fusarium conidia produced on blighted wheat-heads are the conidia of the causal organism and not of a secondary organism which has followed the first, parts of a large number of blighted wheat-heads were washed in water to moisten them, and then disinfected by dipping them into 1 to 1000 mercuric chlorid solution ($MgCl_2$) for two minutes; after this they were rinsed in distilled water and then transferred with a sterile needle to cool poured plates of a suitable medium. In all cases, without exception, only one organism was isolated from each blighted head, rotted stem or nod and it was in all cases the same as the one obtained from the conidia of the same head. This is so true of the Fusarium organisms causing head blight, and aerial infections of the stems, that when one has a clean undiscolored Fusarium blighted head or stem, one may be almost sure, without any microscopical examination, that the causal organism is in pure form. In rare cases the blighted heads or stems may also be smutted, rusted, or brown spotted, and discolored; in such cases, of course, more than one organism may be found on a head. Such heads and stems were discarded and never used for study or isolation of the blight causing Fusarium species.

Plain water agar [1]) was used for diluting, the conidia and for pouring plates. After 12 to 24 hours the plates were examined microscopically and single germinating conidia were marked on the plate; then with a sterile needle made specially for the purpose they were transferred to test tubes containing suitable medium, usually hard oat meal agar. In all cases five single, germinating conidia were transferred to five test tubes. This was done to make sure that there were not more than one species of Fusarium present. Except in rare cases when some of the test tubes were contaminated during the manipulation with foreign organisms such as Penicillium, Alternaria or bacteria, all five test tubes yielded the same species. The cultures thus obtained were pure and generally free from bacteria. To make sure however that the cultures were free from bacteria they were transferred to plates with acid agar and second transfers made from the margins of the plate colonies. The pure cultures thus obtained were used as stock cultures and for further study.

CULTURE MEDIA

Those who have worked with Fusaria have all come to the conclusion that a great variety of media are not necessary for the successful study of this group and that two or three media, each one answering certain purposes, are sufficient. After limited trials of different media the following were found as most adapted for the study of this group of fungi: Hard oat meal agar, hard potato agar with 5 per cent dextrose, medium corn meal agar,

1) One liter of distilled water and 15 grams of bacto agar.

boiled rice, and stems, preferably *Melilotus alba* stems, bean pods, etc.

Hard oat meal agar was found to be by far the most favorable medium for producing abundant and normal conidia of most of the Fusarium spp. studied.

Hard potato agar with 5 per cent dextrose stimulates aerial growth and produces rich pigments, but the pigment produced is dense and changes very rapidly from the lighter shades to the most dark shades, often becoming black.

Medium corn meal agar practically eliminates the aerial growth in many fungi and the color produced remains the same for a much longer time than that of hard potato agar.

Boiled rice is especially useful for the separation of Fusarium species belonging to the Elegans group, which form, on this medium, a pink or rose color, the other species producing a yellow or yellowish brown pigment when the medium is neutral.

Melilotus alba stems and green bean pods favor sporulation and when not too moist will produce normal spores, next in normality to those produced on the above agar media. They are also the best media for perfect stage development.

The method of preparing the media was as follows:

Oat meal and corn meal agars. To 1000 cc. of distilled water is added 100 grams of ground, rolled white oats, used for breakfast food, or 80 grams of corn meal and kept at 60° C., in an incubator for an hour. The liquid was separated by straining through cheese cloth and the volume was restored to the original 1000 cc. To the decoction of oats are added 30 grams of bacto-agar and to that of cornal meal, 15 grams of bacto-agar, and then boiled in a steamer until all the agar is melted. The medium thus prepared is tubed in tubes of the same size, plugged, and sterilized for 30 minutes on two or three successive days.

Potato agar. Two hundred grams of peeled potato tubers were cut into fine slices and added to 1000 cc. of distilled water, then cooked for 40 minutes in a steamer. The liquid was separated by straining through cheese-cloth and the volume restored. To this were added 30 grams of bacto-agar and 50 grams of dextrose and the material was cooked till the agar was entirely melted, then tubed, plugged, and sterilized.

Boiled rice is prepared by placing a small number of rice kernels in a test tube to which is added several times as much water, then plugged and sterilized.

Melilotus stems are cut into short pieces of about 10 c.m., placed single or in twos in each test tube, 8-10 cc. of water added, then plugged and sterilized.

All these media, after sterilization, have a neutral or only a very slight acid reaction.

METHOD OF PERFECT STAGE DEVELOPMENT.

IN NATURE.

A limited study of the field conditions under which the perfect stages of some Fusarium species, which parasitize on the cereal crops and on numerous grasses, are formed, showed that those conditions are as follows:

Successful parasitism of the fungus on some host. The perithecia are usually and preferably formed on such dead parts of the host as have been parasitized.

Successful conidia production. Conidia production on the infected substratum, roots, stems or heads, always precedes the formation of perithecia, since the latter are formed more readily on the crust or plechtenchimatic layer formed by the conidia bearing hyphae and the germinated masses of conidia themselves.

Moisture is a limiting factor in perithecia formation under all conditions. No perithecia are ever formed in the absence of sufficient moisture.

Temperature also must play some role in the formation of the perithecia. All observations on this subject were made during the summer (July and August) when the temperature seemed to be right. Efforts to develop the perithecia from infected material during October and November gave negative results.

Having established the above conditions as factors in the formation of perithecia, the following method for their production was worked out, which, in all cases, gave very good results. The infected parts of the various cereal crops and corn, such as stems, nodes, sheaths, and heads, were gathered from the field and laid on the ground, covered with a screen wire, moistened thoroughly, and then covered with some dry grass and leaves to protect them from drying out. During the first and second weeks, masses of conidia are formed over the entire infected area of the various parts. Soon they extend even over the uninfected area. Before long all conidia will germinate and no others are formed thereafter. During the third week, the perithecia begin to form. In three or four more weeks numerous perithecia are formed and most of them have ripe ascospores.

Following is a record of one of the experiments on perfect stage development:

June 28, 1918. Rye heads infected with *Gibberella saubinetti* were placed under screens so as to be exposed to the action of the weather, sprayed thoroughly with water and covered with dry grass to protect them from drying out.

July 16, 1918. First perithecia beginning to appear.

August 2, 1918. Numerous perithecia formed, but asci not fully developed.

August 21, 1918. All perithecia have ripe ascospores. Heads taken to the laboratory for study.

IN LABORATORY.

In Pure Culture. The development in the laboratory of the perfect stages of such Fusarium species as have perfect stages was done in the way already described by APPEL and WOLLENWEBER and afterwards extended by the second author. It need only be emphasized that perithecia of these fungi will be formed only when transfers are made from what the above authors call "normal culture". Before the culture from which it is planned to develop the perfect stage is brought to this condition, one is bound to fail 95 times out of 100.

When once the culture is in the proper condition the next thing is to transfer it to such media as are known to favor the development of the perithecia. Such are: *Melilotus alba* stems, or any kind of stems, bean pods, etc.

The next thing is to see that the cultures of *Melilotus alba* stems or other stems or media are kept uniformly moist till the perithecia are formed and the ascospores in them are ripe. The presence of certain bacteria in the cultures greatly favors the formation and proper development of the perfect forms of Fusarium spp. A certain bacterium, which was found in a contaminated culture, when added to cultures of Fusarium having perfect forms, favors so much the perithecia formation that practically 100 per cent of the cultures to which this organism was added developed numerous normal perithecia, while even under the best of conditions only a small number of the cultures to which this bacterium was not added, produced perithecia. What this organism is and whether other bacteria can do the same is not known.

The entire work of the production of the perfect stage of any ascomycete in pure cultures has been handicapped up to now, to a certain extent, by the fact that the cultures of such fungi dried out long before the formation and ripening of the perithecia. The addition of water to the cultures exposes the same to outside contaminaton, and, besides, the moisture of the culture will vary considerably from time to time. To avoid all this, the writer was obliged to design and make a special culture tube for this purpose. The new tube consists of a common test tube to the lower end of which is attached a bulb. When the bulb is filled with water, it will drain into the test tube as rapidly as the water from the test tube is vaporized or has been used by the fungus. Such a tube will provide stem or potato plug cultures with a uniform moisture for four or five months, without being refilled, and this is as long as is necessary in any case. When stems are used, they can be placed directly in the test tube so as to reach the bottom, but when potato plugs, bean pods, or other cultural substrata are used, it is better to place some cotton on the bottom of the test tube so that the plugs will be just above the water level of the same. Otherwise, such test tubes are handled in very much the same way as the common test tubes, except that more care should be taken in sterilizing them, since a sudden increase or decrease of the pressure in the sterilizer is likely to force the water out of the bulb into the tube.

From Infected Kernels. Infected wheat kernels when placed in a pot filled with fine sand and only slightly covered with sand, and kept moist at room temperature produced numerous perithecia on their exposed surfaces, which matured before the end of the fourth week from the time of planting. As soon as the ascospores in the perithecia were found to be mature, the kernels were sifted out from the sand and preserved in dry condition for study or inoculation work.

METHOD OF ARTIFICIAL INFECTION.

SEED AND SOIL INOCULATION.

A number of methods are in use for infecting soil with Fusarium spp., most of them consisting in growing the particular Fusarium on various media and then introducing the whole culture into sterilized soil. Such a method is very good, except that it is an artificial one, which resembles in no way the conditions that actually exist in nature. Besides, it introduces into the soil various substances, in some cases toxins perhaps, which may have some effect upon the final results. In order to avoid this and in order to make the conditions in the greenhouse as natural as possible under artificial conditions, only conidia from the various Fusarium spp. were employed for infection of soil used for testing the pathogenicity of these organisms on young seedlings. Practically all Fusarium species, when grown under proper conditions, will produce large masses of conidia. Such conidia may be gathered from the substratum with a flat needle without taking along any conidiophores or mycelial hyphae and suspended in a test tube or flask full of distilled water. Or, if the conidia are not abundant, washing of the culture with distilled water, then straining the latter through sterile cheese-cloth will give a fairly heavy conidial suspension. A suspension of conidia so obtained is used for infecting the seeds, which is done by dipping them into the suspension of conidia for a few minutes, or for infecting soil, by pouring part of the suspension in each of the pots containing sterilized soil to be used for planting healthy seed and then mix up the upper part of the soil. In this case, only a comparatively small number of conidia and only a negligible amount of foreign matter are introduced into the soil.

In all the soil experimental work, the soil used was sterilized in pots in an autoclave for 1 hour at 15 pounds. All the seed used for planting on Fusarium infected soil or for infection of the seeds themselves were sterilized for 30 minutes in 1 : 1000 $MgCl_2$ and then washed with sterile water. Before putting the seed into $MgCl_2$ solution, the seed was placed in a weak alcoholic solution of saponin and shaken well [1]), the object being to

1) 100 cc. of 50 percent alcohol and 1 gram of saponin.

moisten the seed thoroughly and to remove all air bubbles adhering to the seed so as to make the disinfection more perfect. Seeds thus sterilized are perfectly sterile on the outside. However, the fungi present in their internal tissues are not affected by this sterilization. For this reason, only seeds that were comparatively free from such fungi and healthy in appearance were used for sowing purposes.

Throughout the whole work six and twelve inch pots and garden soil were used for planting the seed. In each case, two pots were planted with infected soil or infected seed and one pot as a check. Each experiment was repeated several times. All Fusarium spp. were tried only in pure cultures.

The object of the inoculation work was to establish whether a certain Fusarium sp. causing head blight is also able to attack the roots of the seedlings, and later on cause foot rot of the grown plant. The results, where obtained, are given after the description of each species.

HEAD INOCULATION.

The methods used in testing the pathogenicity of Fusarium species on wheat, rye, barley, oats, spelt, Brome grass, quack grass, and timothy grass are very simple. They consist in producing a heavy suspension of conidia either from heads already infected or from artificial cultures and spraying with it, by means of a small atomizer, a number of heads, usually ten, of the various hosts listed above, when in the proper condition for infection. This method is successful when the weather is moist and cloudy. In dry weather this method will give either no results or only a very small percentage of infection. Certain results can be obtained only when the infected heads are, in some way, kept moist for at least three days after infection, and even this method will not give good results during extremely dry and warm weather.

In our work this was accomplished by placing some moist absorbent cotton around the stems of a bunch of heads just below the infected heads, then covering both heads and bundle of cotton around their stems with a glassine bag, the bag being tightened around the stems on its open end just below the bundle of cotton. A number of heads thus treated are heavy and if not supported will bend over. For this reason a 5 or 6 foot garden stake was driven into the ground next to the plants and the bag covering the heads was bound loosely to it. The moist cotton inside of the bag keeps the air within the same comparatively moist and creates the desirable condition for successful infection. On the other hand, the glassine bags are transparent and the heads are in no way deprived of sunlight. In days when the weather is too dry and warm the bags have to be taken off and the cotton moistened again to saturation with water, then fastened as before, preferably in the evening.

All checks were treated similarly. In cases where the infected plants were left uncovered, the checks were sprayed only with distilled water, while in the experiments where the heads were covered with glassine bags, the checks were sprayed with distilleed water and then bagged, like the infected plants.

The results of the inoculation experiments are presented after the description of each Fusarium sp.

DESCRIPTION OF CAUSAL ORGANISMS.

General remarks. Up to ten years ago the studying and identification of the numerous species of Fusarium was very difficult if not almost impossible, but thanks to APPEL and WOLLENWEBER's work on this genus and especially to that of the second author, the studying and identification of Fusarium species has become considerably easier, yet because of the large number of species belonging to this genus and because of their great similarity and absence of host specialisation, the studying and identification of Fusarium species will never become everybody's job.

In former days, and to some extent even now, most authors while studying some Fusarium species and not being able to tell whether their fungus has been already described or not, did consider it as a new one and described it as such, but always in a way that no one could identify again their organism with their description of same. Others following the old mycological practice did something even worse: When finding some Fusarium sp. on a certain plant, they simply looked up the literature and if perchance there had been already described some Fusarium sp. as parasite of this plant then they simply used the name of this species for their organism. Others again, being ignorant of the nature of the Fusarium spp. used the name „*roseum*'' for any species which caused pink or rose colored discolorations on the attacked hosts and thus placed under one name a large number of widely different Fusarium species. During the last ten years however most students of Fusaria have followed the rules laid down by APPEL and WOLLENWEBER. This led to a simplification of the Fusarium problem, which becomes especially evident from the great number of synonymous names under every retained species.

GIBBERELLA SAUBINETII (MONT.) SACC.

Synonyms.

Gibberella saubinetii (Mont.) Sacc., 1879, *in* Michelia 1 : 5, 513.
Gibberella saubinetii Mont., 1856, Syll. Gen. Spec. Crypt. p. 252.
Botryosphaeria saubinetii (Mont.) Niessl, 1872, *in* Verhandl. Naturf. Ver. Brünn 10 : 195, pl. 4, fig. 29.
Fusarium graminearum Schwabe, 1839, *in* Flora anhalt. 2 : 285, pl. 6, fig. 7; Sacc. Syll. 22 : 1483-1484. 1913.
Gibberella pulicaris (Fr.) f. *zeae maydis*, Rehm. Ascomyceten 381. From New Jersey, 8, 1875. J. B. Ellis.
Fusarium roseum autorum.
Fusarium tropicalis Rehm, 1898 *in* Hedwigia 37 : 194. Is probably a synonym of *G. saubinetii* according to WOLLENWEBER (287).
Gibberella tritici P. Henn., 1902, *in* Hedwigia 41 : 301.
Fusarium rostratum App. et Wr., 1910, *in* Arb. Biol. Anst. f. Land- u. Forstw. 8 : 30.

Diagnosis. Pherithecial stage: The following description of the perfect stage of this organism, given by WOLLENWEBER (287) is adequate: „Perithecia scattered or gregarious, ovoid to subconical, free on the surface of the host as well as embedded in mycelium, or on a tubercular plectenchymatic stroma, which may either push in sphaerostilbe-like bodies through the surface of the host or remain endophytic, 150 to 250 by 100 to 250 μ. Peridium smooth and small-celled at the basal part, but large-celled, verrucose occasionally, with protuberance-like projections of cell groups near the apical end; black to the unaided eye (turning red-brown with acid reaction), dark blue with transmitted light except the almost colorless often rather prominent beak; asci up to over a hundred in each perithecium, intermixed with a few-celled paraphyses; ascospores 8, in one row or irregularly in two rows, subdorsiventral, fusiform slightly curved, tapering at the ends, ochreous in masses; largely 3-septate, 20-30 by 3.75-4.25 μ (up to 5 μ diameter in germination, indicated by a constriction at the septa)".

Conidial Stage. In shape the conidia resemble strongly the conidia of *Fusarium culmorum*. They lack the constriction toward the base so prominent in *Fusarium culmorum*. They differ also in being longer, more slender and having thinner walls and less prominent septa; conidia typically, sometimes up to 100 per cent, 5-septate, 45-65 by 4.2-5.5 μ; 3-septate, 35-45 by 5-5.5 μ; seldom 4 septate; rarely 6-, 7-, or more septate, 60-75 by 4-5 μ; ochreous in mass. Chlamydospores absent. Carmine red pigment on starchy, neutral media.

Habitat. This species is one of the most widely distributed species of Fusarium within the temperate zone. WOLLENWEBER isolated it from berries of *Solanum tuberosum* near Berlin, Germany. C. A. LUDWIG isolated the same from *Ipomea batatis* in storage, La Fayette, Indiana. The writer found the perithecia of the fungus on Bromus, timothy stems, clover and alfalfa and also on *Triticum repens* which had been plowed-under. Mr. TOOLE of Purdue University, La Fayette, Indiana, handed to the writer badly spotted asparagus stems on which the fungus was sporulating and from which it was isolated. According to Saccardo (215) the fungus also occurs on dead stems of Angelica, Asparagus, Beta, Clematis, Conium, Cannabis, Convolvulus, Cucurbita, Gyneria, Phytolacca, Scirpus, and Stipa and on branches of Buxus, Coronilla, Fraxinus, Gleditschia, Juglans, Robinia, Rubus, Rosa, and Ulmus in Europe, Algeria, North America, and Australia. A. D. SELBY (240) adds Emmer, Trifolium and Medicago as new hosts. JOHNSON and DICKSON (132) extended the host list to *Hordeum jubatum*, *Poa pratensis*, *Poa annua*, *Bromus secalinus*, and *Setaria glauca*. It has been found also on *Glyceria aquatica* in Germany, on rice in Japan (157) and Italy (25) and on *Triticum spelta* in S. Paulo, Brazil (79).

Pathogenicity. One of the most destructive species of Fusarium on the cereals, causing head blight and root-rot of wheat, emmer, rye, oats, spelt, barley and corn root and shank-rot in the United States, Holland, Germany, Russia, Bulgaria, Italy, Denmark, Sweden and probably elsewhere.

CALONECTRIA GRAMINICOLA (BERK ET BRM) WR.

Synonyms.

Calonectria graminicola (Berk et Brm) Wr., 1913, *in* Phytopath. 3 : 34. fig. W.; 3 : 231 Tafel 22. Fig. 29—36.

Lanosa nivalis Fries, 1825, *in* Syst. orb. veget. Part I.

Nectria graminicola Berk et Brm., 1859, *in* Ann. Mag. Nat. Hist. 3 Ser. 3 : 376.

Fusarium minimum Fuckel, 1869, *in* Symbol. Mycol. S. 370. Pl. I.; Rabenh. Kryptogamenfl. IX Abt. S. 541.

Fusarium nivale autorum pro parte. Schaffnit — Der Schneeschimmel. Landw. Jahrb. B. 43. 1912.

Fusoma triseptatum Sacc., 1892, *in* Syll. 10 : 566.

Fusoma biseptatum Sacc., 1893, *in* Grevillea 21 : 69, tab. 184, fig. 15; Syll. 11 : 607. 1895.

Fusarium nivale Sor. pro parte. 1901, *in* Zeitschr. f. Pflanzenkr. 11 : 220.

Fusarium hibernans Lindau, Rabenh. Kryptogamenfl. IX Abt. S. 542.

Calonectria nivalis Schaffnit, 1913, *in* Mycol. Centralbl. 2 : 257.

Diagnosis: *Perithecial stage*: Perithecia free or sunken, breaking later on through the substratum, dark brown, round, 160-300 μ, usually gregarious. Asci numerous, spindle-shaped, subdorsiventral, straight, 50-60 μ long paraphyses present, ascospores in two rows, fusoid, one to three septate, 12.5-16 by 2.8-3.5.

Conidial stage: Conidia in mass ochreous to salmon colored, scattered in numerous sporodochia or in pionnotes, mostly 3 septate, averaging 22.5-25.5 by 3.25-4.1 μ; more and up to 6 septate 25-30.5 μ by 2.5-4.3 μ; 1 and 2 septate common, 14-16 by 3.4-3.8 μ Conidia comma or sickle-shaped, pointed toward apex, basal half slightly thicker, ventral line slightly curved, pedicelation absent or slight.

Typical chlamidospores absent, plechtenchymatic stroma thalous or sklerotial, ochreous; aerial mycelium well developed, cottony or thick, in short tuphts, originally white, later pink to rose colored.

Habitat. Occurs in the United States, Holland, Germany, Denmark, and Sweden and may be elsewhere. It has been reported on wheat, rye, oats, *Lolium perenne* and *Hordeum sat.* f. *hibernum* (144), on various grasses and alfalfa.

Pathogenicity. One of the important cereal pathogenes, causing head blight, seedling blight and foot rot in Europe, seldom in the United States, less seldom in Holland.

FUSARIUM CULMORUM (W. G. SM.) SACC.

Synonyms.

Fusisporium culmorum W. G. Sm., 1884, Dis. Field and Garden Crops, pp. 208-210, fig. 92.

Fusarium schribouxi Delacr., 1890, *in* Bul. Soc. Myc. France 6: 99. pl. 15. , fig. 1; Sacc., 1892, Syll. Fung. 19 : 726.

Fusarium mucronatum Fautrey, 1893, Specim. original Museum bot. Upsoliense; Wollenweber, *Fusaria autographice delineata* 1917, pl. 337.

Fusarium culmorum MacAlp., 1896, *in* Agr. Gazette N.S. Wales, p. 305, fig. 39-40.

Fusarium corallinum Mattirolo (non Sacc.) 1897, *in* Mem. R. Accad. Sci. Inst. Bologna S. 5, t. 6, p. 677, fig. 16-17.

Fusarium versicolor Sacc., 1902, *in* Syll. 16: 1099.

Fusarium rubiginosum App. et Wr., 1910, *in* Arb. Biol. Anst. f. Land- u. Forstw. 8 : 108. Pl. 1.

Fusarium (*Fusisporium*) *heidelbergense* Sacc., 1910, *in* Ann. Mycol. 8 : 346; 1913, Syll. 22 : 1483.

Diganosis. Conidia scattered in numerous sporodochia or in pionnotes, in masses cinnamon to cinnamon-brown colored in older cultures, 5-septate, averaging 40-50 by 5.4-6.8 μ, 6-septate, rare, 52-60 by 5-6 μ, seldom 3-4 and 7-septate. Conidia sickle-shaped, gradually pointed toward apex, slightly constricted toward the base, usually prominently pedicellate, having thick walls and very pronounced septa. Clamidospores more or less common, intercalated and in conidia, single, in chains and clusters, 7-14 μ in diameter. Aerial mycelium scant, originally white, later brownish, substrata carmine-red to oxblood-red on hard oat meal agar, and from carmine-red to mummy-brown on hard potato agar with 5 per cent dextrose.

Habitat. Occurs in United States, France, Holland, Germany, Denmark and Sweden. It has been reported on Zea, Avena, Triticum, Secale, Hordeum, Lupinus, Gossypeum, Ipomoea, Beta, Solanum, Cucumis, Cucurbita, *Andropogon Ischaemum*, *Callistephus chinensis*, Cymbidium and *Typha latifolia.*

Pathogenicity: *Fusarium culmorum* attacks the young seedlings of the cereal crops in the same way as *G. saubinetii.* It seldom causes also blighting of the wheat and rye heads in the wheat growing region of the United States, whereas in Holland it is, the common cause of head blight of the cereal crops.

FUSARIUM CULMORUM (W. G. SMITH) SACC. VAR. LETEIUS SHERB.

Fusarium culmorum (W. G. Smith) Sacc. var. *leteius* Sherb., 1915, *in* Cornell Agr. Exp. Station Memoir 6 : 242-244, figs. ID_2 and 43; pl. IV. figs. 1, 2, 10; Pl. V. fig. 9.

Diagnosis. Differs from F. *culmorum* by absence of pionnotes and typical presence of only few, but large, sporadochia from 2 to 6 millimeters in diameter, which are commonly formed in plectenchymatic layers or outgrow this, and by somewhat broader average size of (5.4 to 7.6 μ) and less uniform conidia. Aerial mycelium abundant, cottony, originally white, later carmine-red toward the substratum, but never brown, as in *F. culmorum*: substratum carmine-red on hard oat meal, hard potato and corn meal agars and remains such for considerable length of time, but never dark carmine-red to brown colored.

Pathogenicity: This organism attacks the seedlings of the cereal crops in the same way as described for *G. saubinetii* and in the same degree. It also causes distinct blighting of the heads of wheat and rye. For this it seems to require warmer weather than *G. saubinetii.* The infections were successful only during very warm weather during the latter part of June and the first part of July. This organism causes seedling blight in Oregon U. S. A. and must therefore cause head blight as well, but Rose, who reports the above, does not say anything of this.

FUSARIUM AVENACEUM (FR.) SACC.

Synonyms.

Fusisporium avenaceum Fries, 1823, *in* Systema Mycologicum 2: 238; 3 : 444, 1829.

Fusarium gaudefroyanum Sacc., 1880, *in* Michelia 2 : 132; Sacc. Syll. 4 : 706, 1886.

Fusarium roseum Lk. var. *lupini albi* Sacc., 1881, (cfr. Lindau *in* Rabenh. Krypt. Fl. Abt. IX. p. 52, 1909).

Fusarium avenaceum (Fr) Sacc. Syll. 1886, *in* 4 : 713.

Fusarium diffusum Carm. (cfr Massee Brit. Fung. Fl. 3 : 480, 1893).

Fusarium subulatum App. et Wr., 1910, *in* Arb. K. Biol. Anst. Land- u. Forstw. 8 : 118-132. Tab. 2., Fig. 65-87, WOLLENWEBER, Phytopath. 3 : 32, fig. 1N, 1913.

Fusarium pseudoheterosporum Jacz. *in* Bul. Soc. Myc. France 28 : 340-348.

Fusarium subulatum Ap. et Wr. Sherbakoff, C. D., Cornell Agr. Exp. Sta. Memoir 6 : 147-149, fig. IW, fig. 12 G.-J; pl. II., fig. 11; pl. VII., fig. 4.

Fusarium lucidum Sherb., 1915, *in* Cornell Agr. Exp. Sta. Memoir 6 : 157-161, fig. IV and 15 ; pl. II., fig. 9 and 10; pl. IV., fig. 12; pl. VI., fig. 12. .

Diagnosis. Conidia in pionnotes and sporodochia. Sporodochia on extensive plectenchymatic bases, few in number but large, from 3 to 10 mm. in diameter. On some media small numerous sporodochia are also formed. Apricot-orange to cinnamon-rufaus in mass. Conidia from sporodochia from 37-day-old hard potato agar with 5 per cent dextrose and corn meal agar average as follows: 5-septate predominant, 60-75 by 3.4-4.2 μ (50-85 by 3.0-4.4): 6-septate common, 65-90 by 3.3-4 μ; more than 6-septate rare, 85-95 by 3.4 μ. Conidia slender, very gradually attenuated towards both ends, of nearly same diameter for greater part of their length, elliptical, often the upper end and sometimes both ends more curved, slightly pedicellate. Clamydospores absent. Aerial mycelium usually well developed, white to various hues of red, substratum on potato hard agar with 5 per cent dextrose and on corn meal agar from spinal-red to Bordeaux and carmine-red.

Habitat. On *Avena sativa, Hordeum vulgare, Cecale cereale Triticum vulgare,* Cyperaceae, Salicis spp. *Fagus silvatica, Laburnum vulgaris, Solanum, Zea maydis,* Chenopodiaceae and Leguminosae. It has been reported from France, Germany, Russia and America. In Madison it was found on *Triticum vulgare, Hordeum vulgare, Echinocloa crusgalli, Medicago sativa* and *Zea maydis* and on *Triticum vulgare* in Holland.

Pathogenicity. This organism, though often causing the blighting of heads of wheat and spelt, gave no result in head inoculations under Madison conditions. It is able, however, to cause seedling blight and root rot of grown wheat plants. Its geographic distribution as pathogene is limited to Northern Russia, it has been observed by the writer in number of cases in Holland and North Wisconsin. This fact may be an indication, that it requires a lower temperature for its development as a pathogene.

FUSARIUM HERBARUM (CORDA) FRIES.

Synonyms.

Selenosporium herbarum Corda, 1839, *in* Icon Fung. 3 : 34, pl. VI, fig. 88.

Fusarium herbarum Fries, 1849, *in* Sum. veg. Scand. p. 472.

Fusisporium rimosum Peck, 1878, *in* 30 Rep. New York State Mus. p. 58; Ellis North American Fungi No. 377; Sacc. 4 : 713, sub. *Fusarium rimosum* (Peck) Sacc.

Fusarium amenti Rostr., 1885, *in* Bot. Tidskr. 14 : 230-243; Natur und Mensch. 7 : 290; 8 : 176, 1892.

Fusarium uredinicolum Müll., 1885, *in* Ber. deutsch. bot. Ges. S. 395; Sacc. Syll. 10 : 728.

Fusarium heterosporum Nees f. *Paspali,* 1886, Ellis and Everhart, North American Fungi 2 series, No. 2395.

Fusarium herbarum (Cda.) Fr. var. *conii maculati* Rom., 1889, Romeguère Fungi gall. exs. No. 5358.

Fusarium ustilaginis Rostr. (pr. part), 1890, *in* Festskr. Bot. Foren. Kopenhag. p. 137; Sacc. Syll. 22 : 1485.

Fusarium subviolaceum Roum. et Fautr, 1892, *in* Revue mycol. p. 106; Sacc. Syll. 11 : 651.

Fusarium pirinum (Fries) Rostr. Herbarium E. Rostrup. 1900; Fries, Syst. Myc. 3 : 445, 1832. (Fusisporium); Sacc. f. 4, p. 720, non Sacc. Syll. 22 : 1480.

Fusarium putrefaciens Osterw, 1904, *in* Centralbl. f. Bakt. etc. 2 Abt. 13 : 207, 2 pls; Sorauer Handb. f. Pflanzenkr. 2 : 466, 1908.

Fusoma Feurichii Sydw., H. et Sydw, P., 1905, *in* Ann. mycol. 3 : 186; Sacc. Syll. 18 : 54.

Fusarium sorghi P. Henn., 1907, *in* Flora du Bas et Moy. Congo, Ann. Mus. du Congo 2 : fasc. 2. p. 105; Sacc. Syll. 22 : 1485.

Fusarium speiseri Lindau, 1909, *in* Rabenh. Krypt. Fl. Pilze, 9 : 580; Sacc. Syll. 22 : 1486.

Fusarium metachroum App. and Wr. 1910, *in* Arb. K. Biol. Anst. Land- u. Forstw. 8 : 132-141, Pl. 1, Fig. 111-118; Pl. 3, Fig. 8.

Fusarium lateritum Nees var. *Tulasneanum* Sacc., 1912, Sacc. Syll. 22 : 1479.

Fusarium metachroum App. et Wr. var. *minus* Sherb., 1915, *in* Cornell Agr. Exp. Sta. Memoir 6 : 145-147. Fig. 11.

Diagnosis. Conidia scattered, originally minute, later of considerable size (2-3 mm.) and converging sporadochia, in heavily sporulating subcultures on *Melilotus alba* stems and in presence of abundant moisture pionnotes are also formed. In large sporadochia the conidia are apricot-orange when young to cinnamon-rufous when older. Conidia from 34-day-old culture of hard potato agar with 5 per cent dextrose, and corn meal agar average as follows: 5-septate most common, sometimes up to 100 per cent, 57 by 4 μ (43-74 by 3.4 -44 μ), 3- or 4-septate not common, 6-septate seldom. Conidia ellipsoidal, often with the exception of apex almost straight, gradually pointed at apex, usually not prominently pedicellate. Clamidospores absent. Aerial mycelium abundant on hard and rich media, scant on medium corn meal agar and *Melilotus alba* stems, medium dense, cottony, not tufted, originally white, then pale cinnamon-pink. Substratum from pale acajou red to Vandyke red, in presence of bacteria from pale ochraceous-buff on hard oat meal agar to Brussels-brown and row umber on hard potato agar, particularly at the point of transfer.

Habitat. On *Alnus glutinosa*, Arundinaria, *Asparagus officinalis*, *Brassica oleracea* var. *capitata*, *Conium maculatum*, *Lathyrus silvestris*, *Morus nigra* var. *pendula*, *Paspalum digitatum*, *Pyrus communis*, *P. malus*, *Robinia pseudoacacia*, Rubus, *Solanum tuberosum*, Cicada, *Secale cereale*, *Sorghum vulgare*, *Zea maydis*, *Triticum vulgare*, *T. durum* and *Hordeum vulgare*. Found in North America and Europe.

Pathogenicity: Causing in a small number of cases root rot and head blight, also seedling blight of wheat and rye in Holland and Wisconsin, U. S. A. Remy and Lüstner have also shown that it can infect the cereal grains and cause seedling blight.

FUSARIUM ARCUOSPORUM SHER.

Fusarium arcuosporum Sherb., 1915, *in* Cornell Agr. Exp. Sta. Memoir 6: 186-190, fig. 1B and 23; Pl. 11, fig. 7 and 8; Pl. VI, fig. 10.

Diagnosis. Conidia, scattered single on aerial mycelium, in sporodochia or in pionnotes, sporodochia from small to 2,3 or more millimeters in diameter, salmon-orange in mass. Conidia from 35-day-old hard oat meal agar culture average as follows: 5-septate, 42-58 by 3.4-4.2 μ most common. In some cases conidia from big sporodochia average in length from 50 to 65 μ; 4-septate less common, 37.4-44.2 by 3.4-4.2 μ; 3-septate, 34-41 by 3-4.2 μ Conidia 0-, 1-, 2-, 6-, and 7-septate are rarely found. Conidia very gradually pointed toward apex and commonly prominently pedicellated, typically much arcuate. Clamydospores rare, smooth, round, or lemon-shaped, *intercallary* up to 13 μ in diameter, usually single, also in clusters from two to four cells, but never more. Aerial mycelium on oat meal agar well developed, uniform, cottony, white at first, then rose, Tyrian rose to pomegranate, purple and carmine-red. An ochraceous-tawny to russet color is produced in culutres contaminated with bacteria.

This species upon superficial examination may be mistaken for *F. herbarum* (Cda.) Fr. or *F. avenaceum* (Fr.) Sacc., depending on the condition of the culture. It is, however, very different from either of these species when examined carefully. It differs from *F. herbarum* in that it is much more arcuate and more gradually pointed toward the ends. From *F. avenaceum* it differs in that, (though it may sometimes have its dimensions) it is usually very prominently pedicelated and much more constricted on the ends especially on the basal end, thus making its middle portion much broader than the ends, while in *F. avenaceum* the conidium is more or less uniform in thickness throughout the larger part of its length.

Habitat. Occurs on rotted tubers of *Solanum tuberosum*, Castile, New York, and on wheat and oat plants, Madison, Wisconsin.

This species was isolated in 1919 from weakened wheat plants, which were brought from the field on the 3d of March, 1919. The plants from which it was isolated showed marked discolorations and rotting of the roots and bases, as described elsewhere in this paper.

Pathogenicity. Causes slight seedling blight of the cereal crops.

FUSARIUM SCIRPI LAMB. ET FAUTR.

Synonyms.

Fusarium scirpi Lamb. et Fautr., 1894, *in* Rev. Mycol. p. 111; Sacc. Syll. 11 : 651.

Fusarium roseum Link f. *Solani nigri* Sacc., 1874, Saccardo, Mycotheca Veneta No. 367.

Fusarium gibbosum App. et Wr., *in* 1910. Arb. K. Biol. Anst. f. Land- u. Forstw. 8 : 185-190, fig. 10b and c; Wollenweber, Phytopathol. 3 : fig. lm 1913.; Sherbakoff, Cornell Agr. Expt. Sta. Mem. 6 : 133 fig. 6. 1915.

Diagnosis. Conidia scattered in originally minute sporodochia which later on may obtain considerable size or converge into pionnotes, orange-pink to light salmon-orange in mass when young to cinnamon -brown and Prout's brown when chlamydospores begin to form in them. Conidia from 36-day-old hard oat meal agar culture average as follows: 5-septate, 44-57 by 4-5 μ most common; 0- to 4-septate practically absent in normal cultures; 6-, 7- and more septated rare, 50-60 by 4-5 μ. Conidia sharply bent at the middle almost with hyperbolic dorsal curve, conspicuously broader in the middle, apex long, attenuated to a sharp point, prominently pedicellate. Chlamydospores always present, smooth, abundant, intercalary, single, in chains or clusters, of various shapes and sizes, usually single and round in conidia, 8-9 μ in diameter. Aerial mycelium typically present, loose on agar media, dense cottony on potato plug, honey yellow, substratum from Dresden-brown on corn meal agar and when young, to mummy-brown and even darker.

Habitat. On stems and tubers of *Solanum tuberosum*, *Lupinus luteus*, *Phaseolus vulgaris* and *Triticum vulgare* in Germany, on *Scirpus lacustris* in France and on *Solanum nigrum* in Italy; on *Triticum durum*, *Hordeum vulgare* and *Pisum sativum*, Madison, Wisconsin. It has been reported in the United States also on *Solanum tuberosum*.

Pathogenicity: Causes seedling blight of the cereal crops.

FUSARIUM REDOLENS WR.

Synonyms.

Fusarium vasinfectum Atk. var. *pisi* van Hall, 1903, *in* Ber. d. deutsch. bot. Gesellsch. 21 : 2-5, Taf. 1.

Fusarium redolens Wr., 1913, *in* Phytopathology 3 : 29, Fig. E.

Fusarium redolens Wr. var. *solani* Sherb., 1915, *in* Cornell Agr. Expt. Sta. Memoir 6 : 205-209. Fig. 1P and 31; Pl. II, fig. 3 and 4; Pl. V, fig. 2.

Diagnosis. Conidia, scattered, single on aerial mycelium, in sporodochia or in pionnotes. Sporodochia from very small (less than 1 mm.) to over 5 milimeters in diameter; from light buff to ochraceous-salmon in mass. Conidia from 60-day-old oat meal agar culture and from large sporodochium average as follows: 3-septate, 30-40 by 4.2-5.3 μ most common, in normal sporulating cultures up to 100 per cent. Two-and one-septate conidia not common. Conidia gradually pointed toward apex, often also suddenly constricted. Conidia typically broader toward and more curved near apex, gradually pointed toward the base, pedicellate but never too prominently so. Chlamydospores present, smooth, round, intercalary and terminal; single or in small clusters, formed also in conidia. Aerial mycelium on oat meal agar when present of medium height, uniform, cottony white at first, later on from pale vinaceous-lilac to light vinaceous purple.

Habitat. On Lupinus and *Pisum sativum* in Germany and Holland (St. Johanniskrankheit) on *Solanum tuberosum* tubers, *Triticum vulgare* and *Secale cereale* in the United States, respectively in New York, Wisconsin and Tennessee. Also on rye and wheat in Czechoslowakia and Germany (290).

Pathogenicity. This organism causes in some cases head blight of rye, wheat and barley, also seedling blight of rye, wheat, barley and oats.

FUSARIUM SOLANI (MART. PR. P) AP. ET WR. VAR. CYANUM SHERB.

Fusarium solani (Mart. pr. p.) Ap. et Wr. var. *cyanum* Sherb., 1915, *in* Cornell Agr. Exp. Sta. Memoir 6 : 253, 254, fig. 45 H. to J.

Diagnosis. Conidia scattered single on aerial mycelia in sporodochia or in pionnotes, from pale olive-buff to bluish gray-green and dark bluish gray-green in mass. Conidia from 36-old-day potato plug and *Melilotus alba* stem average as follows: 3-septate most common, not seldom up to 95 per cent, 35-39 by 5-6 μ (30-44 by 4.8-6.2); 2-septate rare, 28-34 by 4.5-5.5 μ; 4-septate very rare, 4-5.8 by 50-60 μ. Conidia short, thick, rarely slightly pedicelate, usually apedicelate, dorsal curve elliptical, ventral almost straight to a slight inwardly bending, apical part slightly thicker, apex rounded or suddenly constricted base more gradually constricted. Chlamydospores always present, numerous, round, single in twos and in clusters, terminal or intercalary, also single in conidia or at the end of germ tubes, 7 to 9 μ in diameter. Aerial mycelium on hard oat meal agar, on hard potato agar and potato plug poorly developed, loose, white to pale olive-buff. Substratum from pale pinkish-buff to buff-brown and blister on hard potato agar with 5 per cent dextrose.

Habitat. On *Solanum tuberosum* in America and Europe and on stems of *Secale cereale,* Madison, Wisconsin.

Pathogenicity: *F. solani* causes seedling blight, foot, and, stalk rot of the cereal crops.

FUSARIUM ARTHROSPORIOIDES SHERB.

Fusarium arthrosporioides Sherb. 1915 *in* Cornell Agr. Exp. Sta Memoir 6 : 175-179. 1915.

Diagnosis. Conidia scattered on aerial mycelium or in sporodochia, sporodochia from small to 2 or 3 mm. in diameter, pale ochraceous-salmon in mass. Conidia from old sporodochia from 60-day-old hard oat meal agar culture; 5-septate, 40-48 by 3.8 μ, most common; 4-septate, 34-44 by 4-4.8 μ; 3 septate, 30-40 by 3.4-4 μ. Conidia elliptical, epically attenuated, prominently narrower toward the base. On aerial mycelia and new sporodochia on various media the predominant types of conidia are: (1) Arthrosporial, 0- to 3-septate, broad, almost straight, spindle-shaped, measuring from 15-35 by 3.4-6 μ; (2) Sporotrichial, 0- to 2-septate, mostly 1-septate, 9-15 by 4-7 μ, pyriform, thick walls; (3) Few normal 3- to 5-septate conidia also present. Chlamydospores common, smooth, round or oblong, intercalary, usually in chains or clusters. Aerial mycelium on hard and rich media well developed, cottony, loose, on poor and softer media and on *Melilotus alba* stems, poor, very loose and interspersed with conidia, from white to light tints of rose and chamois toward substratum. Substratum buckthorn brown to Dresden brown and even darker on hard potato agar with 5 per cent dextrose, usually bright red to oxblood red near the surface.

This fungus forms heavy pseudo-plectenchymatic tissues near the substratum, consisting of closely interwoven chains of swollen cells constricted at the septa, which have a thick membrane and granular contents. Such cells resemble closely the true chlamydospores. For this reason, Sherbakoff in his description of this species stated that true chlamydospores are not present. A careful examination, however, of mycelium produced under different conditions will show the presence of true chlamydospores. These are single, in chains or clusters, having thick walls, and are spherical in shape.

Habitat. Occurs in discolored tissues of tubers of *Solanum tuberosum*, Ireland and on wheat heads in Wisconsin.

Pathogenicity: This organism causes slight seedling blight and in some cases head blight of the cereal crops.

GENERAL DISCUSSION OF PATHOGENICITY.

Practically all of the Fusarium spp. here under consideration are widely spread over the whole world and are primarily saprophytes, capable of living almost indefinitely on dead organic matter and perhaps in the soil, under which conditions they pass in most cases through their whole life-cycle. Under certain conditions however they may attack a large number of cultivated and wild growing plants and may cause a complete failure of many crops, and may even become a prohibiting factor for the further growing of some crops.

Though of great economic importance as plant pathogenes the fungi belonging to the genus Fusarium, represent, with the exception of the comparatively small number of wilt-causing Fusarium spp. the lowest degree of parasitism; they are chiefly rot-producing organisms. In a large number of cases they are primarily wound-parasites or they can attack the plants only when these are growing under unfavorable conditions or only when the plants are passing through some critical period of their development, or only after the plants have reached their full development and are declining in vigor, etc.

With the exception again of the wilt-causing Fusarium spp. or the so called vascular parasites of this genus, which are more or less limited to one host or only closely related host plants, the Fusarium spp., as a rule, attack a very wide range of host plants; this is especially true of the few species treated in this work.

SEED AND SOIL INOCULATIONS.

Seed of wheat, rye, barley and oats naturally or artificially infected with any of the here treated Fusarium spp. or planted on sterile garden-soil artificially infected with these organisms will show a decrease of the germination per cent. In the case of the naturally infected seed, the decrease in the percentage of germination is greater and more variable, depending on the degree and percent of seed infection. It may vary from 2 or 3 to as high as 50 per cent of decrease in germination. Artificially infected seed or seed planted on infected soil will also show a lower percentage of germination than the similarly planted checks. Here, too, it will depend on the kind and condition of the seed and on the environmental conditions. It may vary from 0 to as high as 15 per cent and even more. Good, healthy and plump seed may show no decrease in percentage of germination, while weak and shriveled seed may show considerable decrease in percentage of germination.

TABLE I.

Showing average results of two experiments of each of two wheat samples. The first sample consisted of hand-picked healthy and plump kernels, the second of hand-picked healthy but average kernels. Seed planted on the 23d of May, 1919. Pots kept out of doors. Conidia of *G. saubinetti* used for infecting of the seed.

Kind of Seed	No. of kernels	Germination	No. of healthy plants	No. of plants showing rotting of roots and bases	No. of killed plants
Healthy and plump	Check 100	91	89	2	0
	Inoculated 100	90	75	15	2
Healthy average	Check 100	76	71	5	0
	Inoculated 100	69	42	27	6

Besides preventing some of the seeds from germinating, these organisms will attack a large percentage of the young seedlings, causing rotting and browning of their roots, bases and sheaths. This may vary from 10 to 40 per cent (fig.) A number of the plants thus attacked, usually few in number under normal conditions, will rot and die before reaching the surface of the soil. Others will wilt and die after reaching the surface, while the large majority will recover entirely and attain normal development. Spring wheat plants, over twenty in number, showing marked rotting and browning of the roots, and bases caused by *G. saubinetii*, when grown in pots out of doors, recovered rapidly when transplanted to the pathological garden and reached full development, producing normal heads like the check plants. Only two of the plants thus transplanted wilted shortly after the transplanting, which the writer is inclined to attribute to the transplanting rather than to the parasitism of the organism. This fact shows that though *G. saubinetii* when present on the seed will infect many of the seedlings, it is not able to injure them materially unless the plants are growing under extremely unfavorable conditions.

Similar results have also been obtained with the rest of these organisms. While it was shown by numerous experiments that these organisms are able to decrease the percentage of germination of wheat, rye, barley, and oats and to cause rotting and browning of the roots and bases of some of the seedlings and even to cause wilting and dying of others, it was also noticed that this varied considerably from time to time and that some factors, as light, temperature, moisture and soil conditions, have much to do with the degree and severity of infection.

In order to better understand the relation of the external factors to the degree and severity of parasitism on the seedling by these organisms, this question was made an independent problem, of which Dr. DICKSON of the University of Wisconsin, who succeeded the writer in the studying of this disease, is making a special study.

ROOT ROT.

Winter wheat sterilized as described under methods of seed infection and infected with conidia of *G. saubinetii* were planted on October 20, 1918, in five 12 inch pots with sterile soil (ten kernels being planted in each pot), left in the greenhouse for 15 days, and then taken out of doors. A similar series of spring wheat similarly treated was planted on April 21 in pots of the same size, but left out of doors from the time of planting. In both series, the plants recovered rapidly from the primary attack and grew normally, giving apparently normal plants, except that their bases and roots were slightly rotted and browned. With the coming of dry weather during the second half of June, this rotting and browning of the roots and, especially of the bases, was somewhat intensified and the plants began to wilt quite suddenly, one by one, after June 20. In the field, this usually takes place at the time of blossoming or shortly thereafter. The symptoms accompanying this wilting of the fully developed plants are exactly the same as those described for the footrot of the cereals in Europe and for „Take-all" in Australia. *G. saubinetii* was isolated from the browned and rotted bases of the wilted plants in the above experiments as well as from some of the similarly wilted plants in the field, in which case the rest of the Fusarium spp. here under consideration, were also the cause of this condition in numerous cases. Foot rot was prevalent in Holland during the dry summer of 1921, while head blight was on the contrary very rare in 1921 and quite common in 1922, in which year no foot-rot was observed.

HEAD INOCULATIONS.

In the case of head infection where large quantities of spores are used and as *G. saubinetii*, one of the important head blight causing organisms, usually produces but very few spores in pure cultures it was found that contaminating of the cultures with a pure culture of a certain bacterium favours greatly the sporulation of this organism. In this way large quantities of spores can always be secured for inoculation work. What the organism is and what its effect upon *G. saubinetii* is, was not determined.

The employment of such conidia for inoculation work naturally raises the question whether the bacterium present does not have any effect on the pathogenicity of *G. saubinetii* conidia, for this reason inoculations were made also with suspension of a pure culture of the above bacterium. In all cases the heads inoculated with *G. saubinetii* conidia became blighted, while all heads inoculated with the bacterium suspension remained perfectly free from any blighting or any other injury. This shows that the bacterium favoring the sporulation and perithecia formation of *G. saubinetii*, as mentioned before, is not pathogenic on the wheat heads, and has no effect upon the pathogenicity of *G. saubinetii*. The rest of the Fusarium spp. form abundant conidia on oat meal agar and one can easily secure in this manner any desired quantity of pure conidia.

Wheat, spelt, rye, barley and oat heads, also heads of *Triticum repens*, when inoculated with conidial suspension or ascospore suspension of *G. saubinetii* or conidial suspension of the rest of the head-blight causing organisms will become blighted if only kept moist for several days. The latter proceeds exactly as observed in nature. In over one hundred inoculation experiments in which over three thousand heads of the various cereals, mostly wheat heads, were concerned, infection always resulted. The number of blighted heads in each experiment varies from over 50 per cent to 100 per cent. In the majority of the experiments, all inoculated heads became infected and typically blighted. On many of these heads conidia were formed and on some even the perithecia of *G. saubinetii* developed before the harvesting of the plants.

The inoculation experiments gave positive results from time of blossoming until the middle part of the dough stage. Inoculation made before the first and after the second stage gave either negative or very doubtful results.

IS THE FUSARIUM-BLIGHT OF THE CEREALS A SYSTEMATIC DISEASE?

Those who have even the slightest knowledge of the Fusarium-blight of the cereals will be surprised to see me discussing this question for the second time, but since some workers are claiming anew that this disease is of systemic nature, the writer feels obliged to examine their claims and to add new facts in support of his former work on this question.

In former years, when very little was known regarding the nature of the Fusarium disease of the cereals, many workers were of the opinion that this disease may prove to be a systemic one and that it probably infects the grain of these crops from within as do the smuts. In the United States Bolley has expressed this opinion at various meetings. In Europe Naumoff seems to consider this disease as systemic, though this is by no means certain from his work.

Schaffnit (221) however showed very conclusively that this is not the case, with *Fusarium minimum*, the cause of the snow mold, while the writer came to same conclusions regarding the rest of the Fusarium spp. that attack these plants (13).

Dr. Lucie Doyer (45) however, has questioned the correctness of writer's work in this respect and claims that the Fusarium disease of the cereal crops is a systemic disease, i.e. the fungus penetrates the plant while still young, continuing to grow within the growing plant and when the latter reaches its full development the pathogene infects the newly formed kernels from within, though DOYER does not exclude the possibility that infection from outside may take place as well.

Before discussing DOYER's results it will be necessary to consider her methods of studying this disease; this, however, will be a very easy thing to do as she did not use any methods, made no experiments and had no checks whatever. All she has told us is that in the spring of 1920 she planted several samples of Japhet spring wheat, which were heavily infected with *Gibberella saubinetii*, and that the plants were harvested in the beginning of September. Evidently she had never seen her experimental plots after the planting of the wheat samples, otherwise she would have told us an entirely different story. What she tells us is the following: „Als der Weizen Anfang September geerntet wurde, zeigten sich viele Ähren stark infiziert, da man rosa Sporenmassen oder auch zahlzeiche Perithecien auf den Spelzen antraf. Die Infektion war aber nicht auf die Ähren beschränkt, sondern auch die Basis der Halme war vielfach von Perithecien überdeckt. Bei näherer Orientierung sah man, dass die Internodien der angegriffenen Pflanzen äusserlich meistens nichts von dem Befalle zeigten, dass aber in verschiedenen Fällen die auf ein ander folgenden Knoten wieder von Perithecien und Fusarium-Sporen überwachsen waren". And further that: "In den Fällen aber, welche hier vorlagen, und wo der Weizen hauptsächlich von *Gibberella saubinetii* ergriffen war, weist alles darauf hin, dass eine innere Infektion recht oft vorkommt, obgleich dadurch natürlich eine äusserliche nicht ausgeschlossen wird."

Upon examining the thus obtained wheat plants DOYER was able to demonstrate that the Fusarium mycelia were present throughout the culms of the infected plants and even in their uppermost portion.

This is DOYER's first, last, and only „experimental" evidence that the cereal Fusaria in order to infect the kernels must travel from the root system and base through the whole culm of the plant in order to reach its head, where they infect the newly formed kernels, or in other words these Fusarium pathogenes of the cereal crops are principally the same thing as the smut-producing organisms of same crops.

She writes further: Oft findet man das Mycel in den Parenchymzellen noch ganz oben im Halme und so ist es unter Umständen sehr wohl möglich, dass auch die Ähre von innen aus infiziert wird.... Obgleich also nicht gesagt werden kann, dass die äusserliche Infektion durch Konidienverschleppung ohne Beteutung ist, so glaube ich doch, dass die bisherigen Untersuchungen (which investigations?) genügend gezeigt haben dass eine innerliche Verbreitung der Infektion ebenfalls vorkommen kann".

Planting infected wheat seed (evidently in the hot house) Miss DOYER obtained some seedlings that did show the presence of the disease as described by the writer. Of these plants she writes that: „Solche befallenen Keimpflanzen wurden in einen Topf gepflanzt und in vielen Fällen erholten sie sich augenscheinlich und wachsen weiter. 1) Dergleichen Pflanzen werden sich wohl später als innerlich infiziert erweisen; die diesbezüglichen Versuche sind aber noch im Gange."

Here Miss DOYER admits herself that it must still be established experimentally whether this is really so.

Since Miss DOYER's experiments are „noch im Gange" I will cite for her benefit a passage from my first paper on this subject (13): „Over 20 spring-wheat plants which showed marked rotting and browning of the roots and bases caused by this organism while they were grown on sterilized soil from infected seed in pots out of doors, when transplanted to the pathological garden recovered rapidly and reached full development, producing heads as normal as those on the control plants.... This fact shows that, although G. saubinetii when present on the seed will infect many of the seedlings, it is not able to injure them materially unless the plants are growing under extremely unfavorable conditions...."

Having in mind the undisputable fact that the heads of the unripe cereal crops when successfully infected by any of the numerous Fusarium spp. are always easily recognisable, first by their partial or complete blighting and shrinking and by the rich conidial formation on them after the successful parasitizing

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1) The recovering of the infected seedlings is not only apparent but actual and in most cases absolute if only the conditions are favorable for the noral development of the plants. This fact has been established experimentally by SCHAFFNIT (221), ATANASOFF (13), DICKSON (43), and others.

of the Fusarium pathogenes on same, it should be a very easy matter to establish whether an infection of the heads from within their peduncles is possible as claimed by Miss DOYER or not. In this case we only need take several 10 cm. long portions of their still undiscolored, green and externally still healthy peduncles, to disinfect them externally for 1-2 minutes in 1 to 1000 mercuric chlorid, to rince them in sterile water, and to plate them out in Petri-dishes containing a suitable medium. From a large number of experiments the writer knows that such a sterilisation will never kill the Fusarium mycelia present in any portion of the wheat plants. Should such portions yield Fusarium cultures similar to that obtained from the infected head of same peduncle then this would prove the correctness of Miss DOYER's theory. In this connection must be kept in mind however the fact established by the writer that the infection from the heads in some cases advances down the peduncle; it is however very easy to tell how far from the head down the infection has proceeded, as the peduncle is discolored, watersoaked or brown colored over the area invaded by the fungus. For the above experiment only such portions of the peduncle and the internodes should be taken as are at least 10 cm. below the limit of visible discoloration as result of infection, and it will be much safer to take only the peduncles of such plants for this experiment as show a distinct infection of the head but no discoloration of the peduncles whatever.

It is further absolutely necessary for the successful and final solution of this question to plate the desired portions as soon as the infected plants have been pulled out. Should we allow the plants, needed for this experiment, to stand several days in the laboratory, then we shall very likely find that the mycelium has spread from the infected head through the plant and has gone far beyond the limite of visible discoloration on the stem. That this actually takes place is shown by the following fact: Last summer the writer brought into his laboratory a number of wheat plants with Fusarium-infected heads, some of the plants were immediately plated as pointed out above, and the results were as was to be expected according to the writer's stand-point in this question. Two days after some of the other plants were also plated, but the results were in some cases negative, that is, Fusarium cultures were obtained even from the portions that stood more than 10 cm. below the limit of visible discoloration; this made it necessary to plate out portions of the stem that stood 20 or 30 cm. below the limit of visible discoloration, in which cases no cultures of Fusarium were obtained.

This method will give positive results only in the hands of careful and critical workers and only if a large number of plants are examined in this way.

The mycelium of Fusarium spp. in the infected portions of the plants, whether they are the bases, nodes or heads is to be seen in such abundance and with such an ease that we need not fear that in this case, as in the case of the smuts, the mycelium need not be present throughout the whole length of the stem.

All of the conditions as laid out above for the satisfactory solution of the question whether the Fusarium disease of the cereal crops is a systemic disease as claimed by Miss DOYER or not, have been actually applied by the writer during many years and with a large number of plants, both in the United States and in Holland, but in all cases the results were in full agreement with the writer's standpoint. In connection with this, one thing must be emphasized however and this is that the plants studied in the United States practically never yielded any Fusarium culture from the portion of the stem standing only several centimeters from the limit of visible discoloration as is shown in plate IV, fig. 7, whereas the plants in Holland yielded cultures in some cases even from the portions that were even more than 10 cm. below the limit of visible discoloration, but here too the portions of the stem further below never yielded any culture. This fact however does not change the situation, it merely shows that under the Dutch climatic conditions, excessive soil and athmospheric moisture, etc., and may be the different wheat varieties, the mycelium of these organisms spreads down more rapidly from a point of infection than under American conditions.

Though the above method will give the most reliable results, one can convince oneself whether this disease is systemic or not by mere microscopic examination of the stems of plants showing head blighting. The mycelium of these fungi are easily seen in the host cells, especially if the hand sections have been stained with coton bleu. When present they are quite thick and branched, not seldom even fully developed and normal conidia are to be seen hanging on the mycelia in the host cells. Here only green and living plants with blighted heads should be used for examination, since — if dead or ripe plants are used — one may come again to same conclusions as Miss DOYER did.

A large number of plants have been examined by this method as well, but in no case could there be found any evidence that this disease is systemic. The examination showed in all cases that the various phases of the disease represent strictly local infections from without. At the University of Wisconsin, also where DICKSON and his numerous collaborators, are making extensive studies of the Fusarium disease of the cereals, no one has ever suspected that this disease can be of systemic nature.

To suppose that any of the important Fusarium pathogenes of the cereal crops and especially that *Gibberella saubinetii* could enter a wheat plant through its roots or underground portions, passing through it up to the head, without effecting it in any way and without causing its death, means to place them in the group of vascular Fusaria, it means also complete lack of knowledge of the physiology and habits of one of the most widely spread Fusarium spp.

As is well known, practically all of the wilt-causing Fusarium spp. belong morphologically to the elegance group of this genus. All of these organisms, so far as at present is known, are highly specialized in relation to their host plant and attack as a rule only one plant or only a strictly limited number of plants, belonging as a rule to same family. But even these Fusarium spp. which stand unquestionably much higher in the scale of parasitism than *G. saubinetii* are not in a position to accomplish what Miss DOYER attributes to *Gibberella saubinetii*, as the plants which they attack undergo marked and visible pathologic changes as soon as the parasites attain any degree of development within them and are usually dead before the parasites reach their tops and fruiting bodies, let alone of invading their ripening fruits and seeds as is expected of *G. saubinetii*.

Gibberella saubinetii actually represents the lowest degree of parasitisms. It lacks every specialisation in relation to any host plant, as it attacks an unusually large number of plants belonging to widely different families and orders, it can parasitize only as a wound-parasite or only when the respective plants are growing under decidedly unfavorable conditions, or only when the plants have reached their full development and are naturally declining in vigor. In this respect I may allege as an example the fact that the Fusaria cannot infect the heads of the cereal crops before the plants have passed the blossoming period, i.e. before the ceasing of rapid development and cell-division.

It is evident from the above that not only a systemic invasion of the cereal crops by the various Fusarium spp. does not take place, but that this is also theoretically impossible, as it presupposes a higher degree of parasitism and specialisation which these organisms, as is well known, do not possess.

CLIMATE IN RELATION TO THE DISEASE.

That weather conditions play an important rôle in the development and severity of the various phases of the disease has been long known. ARTHUR (11), in 1891, was the first to emphazise this fact in relation to the head blighting. SORAUER, in 1901 (247) and 1903 (249), studied the effect of frost on the snow mold. He pointed out that the causative organism, *F. nivale* (*minimum*) Sor. is a saprophyte and can attack only such plants whose assimilation-activities have been decreased owing to one or another condition, as snow pressure, etc. RITZEMA BOS (200), in 1904, reported that the seed obtained during the rainy year of 1903 was severely infected by Fusarium which considerably decreased its germination. JACHEVSKI (123) observed in 1907 that the disease is most severe in damp localities and in wet seasons, whereas during the dry summer of 1909 (125) no head blight was observed anywhere in Russia, not even in the south Usurian provinces, where head blight has always been abundant. HILTNER (82), in 1907, writes that the snow mold was most common in localities where there has been plenty of snow on unfrozen ground for long periods of time and late in spring.

APPEL, in 1907 (5) and 1908 (6), emphasized the fact that external conditions influence to a large extent the degree and severity of the Fusarium foot-rot. MORTENSEN (156) reports that the weather conditions, damp air, and abundant moisture unquestionably favor the Fusarium attacks. VOGES, in 1912 (270) and 1913 (273), pointed out that the plants become subject to foot-rot attacks only when weakened by cold and drought. SCHMITZ states that the head blight is always worse in years when the weather is wet, hot and muggy at the time wheat is bearding or the seed is forming. LINDFORS (146) also emphasized the importance of the weather for the development of the Fusarium disease.

Though it is quite certain from the above that the weather plays an important rôle in the development and severity of the disease, much work remains to be done yet, before we can learn the exact effect of the various weather factors upon the different phases of the disease. So far the writer has limited his studies on this subject to the effect of the weather upon head infection.

The weather while being an important factor for the development of the various phases of the disease, is indeed the limiting factor for the occurrence of head blight under certain conditions. Dry weather with slight winds during and after the period of blossoming, extending well toward the dough stage, will practically eliminate blight infection, although all the other necessary conditions might be present. It was observed, in many cases, that in fields where there had been only few blighted heads before the coming of rains and cloudy weather, there was a marked increase in the number of blighted heads only a week after the rain. This was shown very plainly in one of the inoculation experiments, namely Exp. No. 22.

At 7 o'clock in the evening, July 2, 1918, sixty wheat heads were sprayed with a suspension of *Gibberella saubinetii* ascospores and left uncovered.

On July 8, 1918, twelve heads, or 20 per cent, showed signs of first infection. Several days later there came a slight rain and the sky was cloudy for more than a day. By the 20th of this month twenty-eight heads, or 45 per cent, showed symptoms of blighting.

On the other hand, Exp. No. 20, differing from Exp. No. 22 only in the heads being kept moist artificially (See Inoculation experiments.), showed 70 per cent infection on July 8, 1918, and the number of the infected heads did not increase after the rainy and cloudy weather that followed. All checks in both experiments remained healthy. This case, which is one of several, shows that in the absence of proper weather conditions the infection is much smaller than in case the weather is favorable. In Exp. No. 20, where the heads were kept moist, all the heads that were susceptible or properly infected showed infection within six days, and the coming of rain in this case had no effect, as might be expected.

Not only does rainy and cloudy weather favor blight infection, but it also is the most important factor in spore production. This fact has been already discussed elsewhere in this paper.

DICKSON (41) studying the effect of soil temperature on the fusarium seedling blight observed that the seedling blight of winter wheat caused by *G. saubinetii* has been noted most commonly in early-sown fields. The wheat seedlings from naturally infected seed as well as clean seed artificially inoculated did not blight at soil temperatures below 12° C.; severe blighting occurred from 16 to 28° C.; only slight at 32° C., which is about the maximum temperature for the development of the organism, and none at 36° C. While it was shown that healthy wheat seedlings developed the largest root systems and heaviest total dry weight at soil temperatures below 16° C. „Periodic field plantings using scabbed wheat and clean inoculated seed were made from March to June, 1920, at Madison, Wisconsin. In March and April plantings, when the soil was cool, the scabbed and inoculated seed and controls each produced an average of 76 per cent stand. In May plantings, when the soil was warm, the scabbed and inoculated seed produced 32 per cent stand and controls 77 per cent. These field results correlate with greenhouse experiments summarized above."

In his last report on this subject DICKSON (44) came to somewhat different results: „Wheat seedlings blight when grown in a comparatively warm soil, about 12° C.. . . . Wheat and corn seedlings both blight when grown in fairly dry soil regardless of the temperature at which the soil is held. The results, therefore, indicate that in this case at least, disease resistance and predisposition to disease may be largely dependent upon environmental conditions under which the plant is developing. . . . Greenhouse and field experiments conducted during the past three years have demonstrated that wheat and corn seedlings become susceptible to the wheat scab parasite only when grown under unfavorable environmental conditions". The writer (13) came to same conclusion four years ago when he pointed out that „although *G. saubinetii* when present on the seed will infect many of the seedlings, it is not able to injure them materially unless the plants are growing under extremely unfavorable conditions. . . .''

The effect of climate on the occurrence of the various Fusarium spp. as parasites of the cereal crops may prove to be even greater and of a more complicated nature. It is much less understood than the effect on the occurrence of the disease. While it can safely be assumed that the Fusarium-blight of the cereals occurs in all wheat-growing regions of the world, it would be wrong to suppose that all of the Fusarium spp. here under consideration are causing this disease in all regions of the world; yet it must be pointed out that practically all of these organisms are to be found in nearly all wheat-growing regions of the world, i.e. their distribution as pathogenes differs from their geographic distribution. Practically all of the here described species have been found both in Europe and America where they are quite common. Yet in the wheat-growing section of the United States, Southern Russia, and Bulgaria it is *Gibberella saubinetii* that is the cause of the diseases in a large majority of cases whereas in Northern Russia (165) *F. avenaceum* is the most common cereal pathogene. In Oregon *F. culmorum* var *leteius* Sher. is, according to Rose (203), the most common cause of seedling blight, while the writer observed this organism only in a few cases out of a large number of samples from the central states of the Union. In Holland, on the other hand, the writer found that *F. culmorum* is the cause of head blighting in about 50 % of all infected heads, while *G. saubinetii* was found only on 40 % of the infected heads. Lindfors (148) and Foex (56) find also that *F. culmorum* is the cause of the foot-rot infection in Sweden and France respectively in the majority of cases. In Germany on the other hand *F. minimum* is supposed by all to be the most important pathogen of the cereal crops, but whether this is really so must be established yet. Appel and Fuchs (10) studying the Fusaria present on cereal seeds in Germany found that *F. avenaceum* and *F. culmorum* are quite commonly isolated from such seed, while Schaffnit [1]) who has made an extensive study of *F. minimum*, could not

1) According to Schmidt (233) p. 71.

isolate this organism from a sample of grain that was heavily infected by Fusarium. The writer also examined a large number of blighted heads in Germany, but never found *F. minimum*, whereas *F. culmorum* and G. *saubinetii* were commonly seen on these heads.

The very way in which the climate effects the distribution of these fungi as pathogenes and whether it really does so, is not certain. The writer thought at a time that temperature and moisture are the factors which regulate the distribution of these organisms. A study of the optimum and minimum temperatures of each of these organisms and the average temperatures and rain precipitation of the various wheat-growing regions of the world, did not confirm the above supposition. Only a further study of these factors under various climatic conditions can throw light on this subject.

CULTURAL CONDITIONS IN RELATION TO THE DISEASE.

The cultural conditions which determine to a large degree the health and vigor of the plants, affect in various ways the degree and amount of Fusarium injury on the cereal plants. As has been already pointed out the cereal crops, with the exception of head blighting, become susceptible and succumb to the Fusarium attacks only when growing under unfavorable environmental conditions, so that anything that may interfere with the normal physiologic processes and development of the plants and that may weaken their constitution in one or another way, will also increase their susceptibility to such attacks.

Poor drainage (81) and preparation of the soil, too deep planting (290) and application of barn-manure (82, 112) have been observed to favour the development of the seedling blight, snow mold, and foot rot. Though proper cultural conditions can never prevent the blighting of the heads they can under certain conditions materially decrease the amount of loss due to this phase of the disease.

Even though the plants may be well developed and still apparently healthy and normal, when in shady places or overgrown by weeds, they are attacked by head-blight and node-rot to a much greater extent and by a greater number of Fusarium spp. than plants which get a normal amount of sunlight and better aeration. This was especially evident in one of the Wisconsin Experiment Station plots, where a small area sown with barley and wheat was allowed to be overgrown by weeds. The blight infection on this plot was so abundant that in some small areas practically all the plants were infected. In general, the whole field had an average of 10 per cent of infection as compared with 5 per cent in neighboring clean fields. Another interesting fact was that nine different species of Fusarium, two of which have perfect stages, were isolated from blighted heads gathered from this small plot covering not over 200 square meters. *Gibberella saubinetii* was the most common and most destructive species.

Lodging of the fields also gives a marked increase of head blight infection. This became apparent in a wheat field located two miles north-east of Madison. Wis., where the head infection among the standing plants even in the worst-infected portions of the field never exceeded 15 per cent, whereas in the lodged portions of the field the head infection was, in some small areas, as high as 100 per cent. Considering that the field was not over two acres in extent, that the inoculum of *Gibberella saubinetii* which was responsible for over 90 per cent of the infections in this field, was very uniformly distributed throughout the field, and that there were no other explanations for this great difference in degree of infection between the lodged and the standing plants, the effect of lodging on the prevalence of head blight infection becomes more striking.

VARIETIES IN RELATION TO THE DISEASE.

That not all cereal varieties are equally attacked by the Fusarium-blight has long been noticed. ARTHUR (11) was the first to notice that the disease was worse on the late maturing than on the early ones and that certain French varieties were particularly susceptible. SCHMITZ reports that there is a wide range of difference between wheat varieties as to their ability to withstand the attack of the Fusarium blight of the heads. The smooth varieties were blighted worse than the bearded ones. In both the bearded and smooth varieties the velvet chaff sorts blight worst. WOLLENWEBER (290) also states that there exists a difference in the susceptibility of the various varieties.

In discussing the question of varietal susceptibility one must bear in mind that in most cases observed up to now the apparent resistance of some varieties may not mean more than that they are disease-escaping, i.e. early varieties, as ARTHUR (11) writes, as a rule suffer less from head blighting, but should they be delayed in one or another way in their development, they may get as heavily infected as the late varieties.

Having this fact under consideration the writer has been studying this question during the last six years both in the United States and in Europe and feels justified in saying that the various wheat and rye varieties differ materially in their susceptibility to the Fusarium head blight.

During the summer of 1918 more than 30 varieties of wheat, both winter and spring, were grown by the Department of Agronomy, University of Wisconsin, on the University farm, and all were attacked more or less by head-blight. There was marked difference between them in the degree of infection, but no variety was entirely free, as will be seen from the list given in Table II. Among the varieties examined were representatives of types having very fine and succulent chaff to those which have hairy or very hard chaff.

Since the winter varieties examined were badly winter-killed, no significant count could be taken which would indicate their relative susceptibility to headblight. The spring varieties, on the other hand, were in very good condition and uniform throughout the series of plots.

The 15 spring-wheat varieties were sown in small plots of the same size, the plots being in one series which extended across the whole field. The whole series of varieties was repeated so that the variety planted on the first plot was repeated on the sixteenth plot, the variety planted on the second plot was repeated on the seventeenth plot, and so on. The plants in each plot were examined carefully and the blighted heads counted. The number of blighted heads of each variety in the two series was in many cases exactly the same. If there was a difference, it did not amount to more than two or three heads. The results are given in Table II.

TABLE II.

Averages of actual counts of blighted wheat heads in two series of different varieties, arranged according to degree of infection.

VARIETY	Wisconsin Nr.	Number of heads blighted.
Preston × Kubanka cross	101	22
Red Fife	46	20
Red Fife selection E.G.D. 9171	75	20
Marquis	50	15
Marquis selection	48	16
Pedigree Marquis	29	12
Red Fife selection	74	9
Fife, Minn. 163	Pedigree 34	9
Spring Velvet Chaff	60	7
Haynes Bluestem × Kubanka cross.	102	7
Spring-wheat selection	76	3
Bluestem	Pedigree 35	3
Bluestem	Pedigree 36	1
Spring-wheat selection	98	1

These results, while not convincing, are very interesting, especially when we consider that all plots had the same preparation and cultivation, the same preceding crop, were on the same piece of land; that all varieties, though they were not in exactly the same stage of development, yet were in a stage in which they were susceptible to blight, and that the degree of infection of a certain variety was the same in the two series located a considerable distance apart.

One may suspect that the relative amount of infection of the seed used for sowing is the cause both of the difference of infection between different varieties and of the uniformity in degree of infection of the same variety in both series. Though this is possible, it does not seem probable in this case. The plots were small and only 2 feet apart, so that if some plots were more heavily infected because of the more heavily infected seed sown on them, the inoculum from them could easily have served for the plants in the neighboring plots only 2 feet away. The plot with the variety Preston x Kubanka (Wisconsin 101), which had 22 blighted heads, was between plots that had only 1 and 3 blighted heads, respectively. Similar conditions were observed on Prof. MAYER's breeding plots near Wageningen.

The differences between varieties in susceptibility to blight was brought out more plainly in a field where two spring-wheat varieties, Marquis and durum, were sown side by side on the same piece of land, following corn. The infection of the Marquis wheat where the plants were standing was less than 1 per cent and from 10 to 15 per cent among the lodged plants, whereas the infection among the standing durum plants was from 9 to 10 per cent and as high as 100 per cent among the lodged plants.

Throughout the field there were numerous corn stalks with perithecia containing viable spores of *Gibberella saubinetii* and other parasitic species of Gibberella. as well as numerous viable conidia of several blight-causing Fusarium species. While we can doubt the result obtained with various varieties on the University plots, the results obtained on this field indicate clearly the existence of a difference in varietal suspectibility to head-blight. Further observations and experiments in this direction will, no doubt, be of great importance.

CONTROL MEASURES.

From what has been said in the preceding pages regarding the cause and nature of the Fusarium disease of the cereal crops it is evident that the combating of this malady will be difficult and will require much work and intelligence. Contrary to other plant diseases, where a mere disinfection of the seed will insure us against the disease, several methods of combating must be applied simultaneously in the case of the Fusarium disease of cereals, and even then it may take considerable time before the desired results can be attained.

Well prepared land: A proper preparation of the land, that will permit the sowing of the seed at uniform depth and that will ensure a uniform and rapid germination and normal development of the young plants, will decrease the injury of seedling blight and later on of root-and foot rot.

Clean land: While it is not as yet certain whether the fungi which cause this disease can live for a long time in the soil proper, it has been shown conclusively that these organisms are found in abundance on the dead plants, straw, corn stalks and other remains of the preceding crop and that the spores produced on such dead organic matter serve as inoculum for the new crop. An elimination of the plant-remains from the fields will help — if not to eliminate the infectious material — at least to decrease it considerably and it will certainly help to decrease materially the most dangerous part of it. The less inoculum there is in the field, the less will be the number of infected plants. The elimination of the plant-remains from the field can be done by careful and deep plowing-under or removal and burning up wherever this is possible. For the same reason artificial fertilizers should be preferred to stable manure.

Crop rotation.. It has often been observed in the United States that wheat planted after wheat or corn, is more severely attacked by head blight than when planted after other crops. The reason of this lies in the fact that *G. saubinetii*, the common cause of this disease in the United States, attacks also the corn plants in various ways and produces on them numerous conidia and perithecia which later serve as a source of infection for the following crop.

Continuous planting of wheat after wheat or after corn leads to an accumulation of the Fusarium pathogenes in the fields as has been shown by BOLLEY. For this reason it is advisable to avoid planting wheat or rye after wheat or corn.

Good and healthy seed. The use of good seed has been always recommended, but the use of good seed for Fusarium infested fields is imperative. Writer's experiments with soil and seed infections have shown that healthy wheat seed of high germination but of poor quality, when infected or planted on infected soil, will give a much larger per cent of blighted seedlings, than high grade and healthy seed. Even if the soil should be heavily infected, the use of good seed will give under favorable conditions a good stand and a good crop. Only seed of varieties best adapted to the district should be used.

The seed must not only be of good quality but it must be free from Fusarium conidia and Fusarium-blighted kernels. Seed that is internally infected or that carries externally the conidia of these fungi is, as a rule, more severely attacked by seedling blight than when healthy seed is planted on infected soil. For this reason seed from heavily blighted fields should never be used for sowing. Seed from slightly infected fields, if otherwise of good quality, may be used for sowing purposes, provided it has been passed through a fanning-mill with a heavy wind blast to blow out all of the blighted and shriveled grain. This will exclude most of the internally infected kernels which being usually much lighter than the healthy ones are blown out. In order to free the seed also from the numerous viable Fusarium conidia that are commonly found on the grain, it is necessary to disinfect the seed.

No phase of this disease has received as much attention as the seed disinfection as control measure against it; this is especially true for Germany. Yet there exists still a wide difference of opinion regarding the usefulness and efficiency of seed disinfection. The reason of this lies primarily in the generally unknown fact that none of the chemical disinfectants are able to free the internally infected cereal grains from the Fusarium infection; this is especially true of mercuric chlorid or preparations containing mercuric chlorid. To a certain extent this difference of opinion may be accounted for, as RHIEM (197) thinks, by the fact that the various workers have used seed of a different degree of infection.

Those who have used seed with a small percentage of internally infected kernels and considerable external infection did get good results with the various fungicides, whereas those who worked with internally heavily infected seed did get negative results.

Internally infected wheat kernels disinfected with a 2 to 1000 mercuric chlorid solution for half an hour or even for a longer period of time, when plated directly from the mercuric chlorid solution in Petry dishes, containing potato agar or any other agar medium, will develop in all cases a rich fusarial growth. In the course of his study on this disease the writer has done this hundreds of times, but so far he has never succeeded in freeing the internally infected kernels from the infection, without killing also the kernels. That so many workers e.g. HILTNER and SCHAFFNIT, claim the opposite is due to the fact that they evidently never made a laboratory study of this question, but contented themselves only with hot house and field experiments.

While it is evident from the above that mercuric chlorid and other fungicides can never cure the internally infected kernels, it has been also repeatedly shown in the course of writer's studies on this disease that a disinfection of the previously moistened seed in 1 : 1000 mercuric chlorid for half an hour will kill all Fusarium conidia and spores as also all other fungus spores that may be found on the seed.

The only way in which the writer (12) has been so far able to free the internally infected kernels from the infection has been by *drying* the kernels with warm air at 95° to 105° C. for 30 hours. Most wheat, rye, and barley samples, when dry, will not only withstand this treatment uninjured, but will show even a higher germination. The application of this treatment, however cannot be recommended to the practical agriculturists, since it is still in the experimental stage and besides requires the use of special machines.

Resistant varieties: It has been shown in a former chapter that some varieties of wheat are less, others more susceptible to head blighting. It will be therefore highly desirable that wheat breeders in their future breeding-work should consider also the factor „resistance to head blight'', while the practical agriculturist should always give preference to varieties that are known to suffer less from head blight.

The breeding of varieties resistant to seedling blight or foot rot is much less promising, because as has been already pointed out, the plants succumb to these phases of the disease only when grown under unfavorable conditions or when they have been weakened in one or another way. In such cases the biochemical activities and even the morphology of the plants may be changed materially, which in turn may lead to the losing or lowering of their resistance.

Prompt thrashing and storage of harvested grain. The infection from the blighted heads whether they are green or ripe spreads rapidly over the rest of the head and even over the heads standing in contact with them, if only the atmosphere is damp. In order to prevent this spreading of the infection it is necessary to begin thrashing or storing the harvested crop as soon as harvested. Nothing is more detrimental to the market value and germinative power of the grains than leaving the harvested crops to lie for many weeks in the fields, where they are exposed to the influence of weather and biologic factors. That is the condition that makes it possible not only for the Fusaria but even for harmless saprophytes as Penicillium, Alternaria and even mucors to play such an important rôle in decreasing the germinative power of the grains. Such a practice in a country as Holland and portions of Germany where the summer months are usually rainy and damp, is much less tolerable than in countries with a continental climate.

Unquestionably labor conditions on the farm during the summer months may be largely responsible for this, but from a purely financial standpoint the agriculturist will gain much if he should make the extra expenses required for the prompt thrashing or storing of the harvested grains.

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EXPLANATION OF PLATES.

PLATE 1.

Fig. 1. Conidia of the on cereals parasitizing Fusarium spp.
a. Gibberella saubinetti (Mont) Sacc.
b. Fusarium herbarum (Corda) Fries.
c. Fusarium avenaceum (Fries) Sacc.
d. Fusarium arcuosporum Sher.
e. Fusarium scirpi Lamb. et Fautr.
f. Fusarium culmorum (G. W. Sm.) Sacc.
g. Fusarium solani (Mart. pr. p.) Ap. et Wr.
h. Fusarium redolence Wr.
i. Calonectria graminicola (Berk. et Brm.) Wr.
j. Fusarium arthrosporioides Sher.

Fig. 2. Wheat kernels of the variety Kubanka.
a. Kernels from healthy heads.
b. Kernels from blighted heads. They are shriveled and much lighter in color and in weight than the normal kernels shown under *a*.

PLATE 2.

Representative Kubanka wheat seedlings from internally Fusarium infected seed. The six plants at the left show typical seedling blight injury from Fusarium. All 6 of these plants have discolored kernels, rotted bases, and rotted proximal portions of roots. They are much weaker than those from healthy seed. The first 2 plants on the left were killed after they reached the surface of the ground; the third plant was killed before reaching the surface of the ground. Typical Gibberella perithecia developed on this dead plant under the surface of the soil. The 5 plants at the right represent the disease-free condition of treated seed from the same seed lot. This seed had been exposed to dry heat at about 100° C. for 30 hours. The plants are free from any evidence of disease, the bases, kernels, and roots all being clean. Plants from treated seed are also much sturdier than those from untreated seed.

PLATE 3.

Fig. 1. Germination test with naturally infected Mansholt winter and Japhet spring wheat harvested in 1913, on filter paper in moist

atmosphere. On the left are a number of kernels treated with 1‰ mercuric chlorid for 15 minutes. They gave a normal percentage of germination and healthy plants. On the right are an equal number of kernels of same sample but untreated. They gave a smaller percentage of germination, while those that did germinate were overgrown and killed by Fusarium.

Fig. 2 and 3 represent field experiments made at Wageningen in 1914 with same seed used in the experiment shown in fig. 1. The seed planted on the plots to the left has been treated with mercuric chlorid, on the right are the plots planted with untreated seed. The stand in the treated plots much better than in the untreated, with exception of the second (upper) plot of fig. 3 where the untreated seed also gave a good stand. On this plot was planted Mansholts winter wheat, which was less injured by Fusarium than the Japhet spring wheat.

(All of the three photo's given above have been taken by Prof. QUANJER in 1914 during his study on this problem.)

PLATE 4.

Fig. 1. Portions of upper internode of a Fusarium blighted wheat peduncle showing advance of the fungus mycelium down the stem.
a. First section below the head.
b. and *c.* Second and third section below the head respectively.

Fig. 2. Photomicrograph of a wheat seedling from Fusarium internally infected seed which was killed by the fungus before reaching the surface of the soil. On the dead sprout are seen numerous normally developed perithecia of *Gibberella saubinetii*, which in this case was the cause of the disease. Same plant is shown on plate 2, the third plant from the left.

Fig. 3. Footrot of wheat caused by Fusarium. The plants at the left were taken from soil which had been inoculated with *G. saubinetii*. The control plant at the right gives the comperative size of the normal wheat plants.

PLATE 5.

Footrot of wheat caused by Fusarium. Basal portions of the plants shown on plate 4, fig. 3. Note the poor root system and brown and rotted bases of the plants to the left. The control plant at the right gives the comparative size of the normal wheat root system.

PLATE 6.

Blighted wheat heads. Control plant on the right of others, showing gradation of blighting to completely blighted head on the extreme left.

FUSARIUM-ZIEKTE DER GRANEN.

INLEIDING.

De granen worden, evenals sommige grassen, aangetast door een groot aantal schimmels, behoorende tot het geslacht Fusarium. In een aanzienlijk aantal gevallen zal dezelfde Fusarium-soort ieder van de bovenbedoelde gewassen op tenminste twee verschillende wijzen aantasten, daarbij twee verschillende pathologische toestanden teweegbrengend. De eerste is een aantasting van het ondergrondsche gedeelte van de kiemplant (kiemrot) en later van de volwassen plant (voetrot), waarbij verrotting van de wortels en stengelbases, verzwakking van de planten en mogelijk ook gedeeltelijke of geheele verwelking en dood van sommige der aangetaste planten optreden. De tweede toestand bestaat in een aantasting van de volwassen plant boven den grond, die zich voordoet als bladvlekken, als bruinworden van de knopen, of als ziekte der aren. De zieke plekken die men aan een plant waarneemt zijn in den regel niet door eenzelfde inwendig groeiend mycelium met elkaar verbonden. M. a. w.: *de verschillende aantastingen van dezelfde plant zijn onafhankelijk van elkaar en kunnen door dezelfde of door verschillende Fusarium-soorten veroorzaakt worden.*

Hoewel onafhankelijk van elkaar, kunnen de verschillende vormen van de ziekte in de meeste gevallen toch tot elkaar in een zeker verband staan. De aar-aantasting geeft aangetast zaad, dat na zaaiing „kiemrot" doet optreden. De planten, die het „kiemrot" hebben overleefd, kunnen wanneer zij gedurende den winter en het vroege voorjaar onder ongunstige omstandigheden groeien opnieuw door de ziekte worden aangetast, in dit geval door wortel-rot; sommige planten kunnen later in volwassen toestand den voet- of stengelvorm van de ziekte vertoonen; de conidien, die gevormd worden op planten, aangetast door voetrot of stengelrot, kunnen vervolgens aar-aantasting veroorzaken, en opnieuw geinfecteerd zaad teweegbrengen aldus de kring kompleteerende.

Tot op heden is aan deze vormen van Fusarium-aantasting weinig aandacht geschonken en wanneer dit het geval was werden ze meestal beschouwd als verschillende ziekten, veroorzaakt door een of meer gewoonlijk niet gedetermineerde soorten van Fusarium. De resultaten van ons werk bewijzen echter zeer afdoende, zooals ook reeds ten deele althans door andere onderzoekers aangetoond is, dat de verschillende pathologische toestanden niets dan verschillende phasen van dezelfde ziekte vormen.

De gegevens, in dit artikel vervat, zijn de resultaten van schrijver's studies en waarnemingen over dit probleem, gedurende de laatste zes jaren verricht in de Vereenigde Staten, Bulgarije, Duitschland en Nederland. Voor het eerst is hier getracht in de Fusarium-ziekte van granen als een geheel te behandelen, hetgeen niet mogelijk was geweest, wanneer de schrijver niet de gelegenheid had gehad haar in een aantal landstreken en onder verschillende klimatologische en kultureele omstandigheden te bestudeeren.

DE ZIEKTE.

GEOGRAPHISCHE VERSPREIDING.

De Fusarium-ziekte van granen is zeer algemeen verspreid over alle streken van de wereld, waar granen worden verbouwd. Zij is algemeen in de Vereenigde Staten, Canada, Engeland, Nederland, Frankrijk, Italië, Bulgarije, Oostenrijk, Tsjecho-Slowakije, Duitschland, Denemarken, Noorwegen, Zweden en Rusland. De ziekte komt verder voor in Australië en Zuid-Amerika.

EKONOMISCHE BETEEKENIS.

De Fusarium-ziekte der granen wordt algemeen beschouwd als een van de belangrijkste ziekten van deze gewassen. Zij verlaagt aanzienlijk de marktwaarde van het graan en het kiemingspercentage van het zaad; zij veroorzaakt verzwakking en afsterving van de kiemplanten in het najaar en het voorjaar, alsmede verwelken en sterven van volwassen planten; zij vernietigt geheel of gedeeltelijk de aren en verhindert ze dus zaad te vormen.

De gegevens, die betrekking hebben op de economische beteekenis van de ziekte, zijn onvolledig; voor sommige phasen van de ziekte en voor de meeste gewassen en landen, ontbreken ze geheel en al. Met betrekking tot deze ziekte is in Nederland bekend, dat de korrels in 1903 geoogst, hevig door Fusarium waren aangetast en dat de opkomst van het gezaaide graan te wenschen overliet, verder dat in den winter van 1906—1907 (284) een groot deel van de wintertarwe in Groningen er door vernietigd werd. Bij de zomertarwe is de aantasting veel algemeener; zij heeft in Groningen dikwijls een slechten stand tengevolge van Fusarium-aantasting.

Het is verder bekend, dat in de Vereenigde Staten en Rusland deze ziekte onder bepaalde omstandigheden algeheel misgewas kan geven. Talrijke gevallen zijn waargenomen, dat de tarwe-aren zoo hevig aangetast waren, dat het de moeite niet loonde zulke velden te oogsten; in andere gevallen waren de kiemplanten zoo hevig aangetast, dat het noodig was de velden om te ploegen en met andere gewassen te beplanten.

Voor 1917 schatte de Plant Disease Survey, Bureau of Plant Industry, U. S. D. A. het verlies tengevolge van aar-aantasting van tarwe alleen in de Ver. Staten op 10.620.000 bushels. Voor 1919, in welk jaar de ziekte in epidemischen vorm in de Ver. Staten optrad, schatte de Plant Disease Survey het verlies op ruim 80.000.000 bushels.

Ofschoon het den schrijver niet mogelijk was vele velden in Nederland te onderzoeken, voelt hij zich echter ten volle gerechtvaardigd, naar wat hij reeds heeft gezien, te concludeeren, dat de Fusarium-ziekte van de granen even belangrijk is in Nederland als in de Vereenigde Staten.

BESCHRIJVING.

De symptomen van de verschillende vormen van de ziekte zijn in alle gevallen en in alle landen dezelfde, onverschillig welke Fusarium-soorten de oorzaak van de ziekte zijn.

*Zaadaantasting. Tarwe*korrels, afkomstig van geheel of gedeeltelijk aangetaste aren, geven duidelijk blijk van de uitwerking daarvan.

1. Korrels van vroeg, d.w.z. tijdens of kort na den bloei aangetaste aren, zijn klein, bleek, groenachtig grijs van kleur, verschrompeld, zacht en van laag soortelijk gewicht. Zulke korrels kiemen in den regel heelemaal niet.

2. Korrels van aren, twee of drie weken na den bloei aangetast, hebben de grootte van de normale korrels, maar ze zijn grijsachtig wit of roomkleurig, zacht, en, ofschoon reeds vol zetmeel, ongeveer half zoo zwaar als de normale korrels. Zulke korrels kunnen kiemen ofschoon het kiemingspercentage zeer laag is.

3. De derde klasse van aangetaste korrels is afkomstig van aren, kort voor of tijdens de rijping aangetast. Zulke korrels verschillen zeer weinig van de normale, behalve dat ze ten deele verkleurd zijn en het gezonde uiterlijk van de normale korrel missen, terwijl rose-roode plekken zeer algemeen erop voorkomen. Korrels van deze klasse kiemen gewoonlijk normaal.

De korrels van alle drie de klassen kunnen van binnen aangetast zijn en opgevuld en zelfs bedekt met het mycelium van de schimmel, ingeval zij in de nabijheid stonden van de plaats, waar de aar geinfecteerd was. Ze kunnen ook geheel vrij van eenig schimmel-mycelium zijn, wanneer ze ver van de infectie-plaats staan; ze zijn dan onontwikkeld gebleven tengevolge van onvoldoende voedsel-toevoer en vroegtijdige uitdroging van het gedeelte der aar, boven de infectie-plaats.

De aantasting van *rogge*-korrels doet zich op gelijke wijze voor als die van tarwe.

*Gerste*korrels van aangetaste aren worden, wanneer ze direct door de schimmel zijn aangetast, vuil bruin van kleur en het soortelijk gewicht is al naar de periode van aantasting, meer of minder gereduceerd.

*Haver*korrels vertoonen een aantasting, overeenkomende met die van gerstekorrels, behalve dat ze lichter van kleur blijven.

Kiemplant-aantasting.

Kiemplanten van natuurlijk of kunstmatig geinfecteerd zaad of van gezond zaad, dat in besmetten grond wordt gezaaid, worden in een zeer vroeg stadium van hun ontwikkeling door Fusarium-soorten aangetast.

Symptomen van de aantasting kunnen verscheidene dagen na de kieming waargenomen worden of binnen weinig dagen, wanneer het weer maar vochtig en warm is; dan kan een groot gedeelte van de planten tengevolge van de aantasting sterven. De eerste symptomen van aantasting treden op de wortels en scheede van de kiemplant nabij het zaad op; zij bestaan uit bruin-kleuring en verrotting van deze gedeelten. De schimmel dringt verder in het eerste blad binnen en kan de plant dooden. De grootere planten vertoonen bruinkleuring en rotting van hun bases boven den grond, hun bladeren verwelken spoedig, hangen slap neer en drogen op; spoedig verwelkt de heele plant en sterft.

Wortel-rot. De planten,die de eerste aantasting overleefd hebben, kunnen opnieuw onder de ziekte bezwijken, zoodra de omstandigheden voor hen ongunstig worden. Dit komt gewoonlijk voor tijdens den winter, wanneer vorst, te groote bodemvochtigheid of veel bedekking met sneeuw de planten doen verzwakken. Onder bepaalde omstandigheden kan de Fusarium zich onder de sneeuw zoo rijk ontwikkelen, dat de graanvelden geheel bedekt zijn met een katoenachtige schimmel-groei, tentijde dat de sneeuw smelt. Deze vorm der ziekte kent men in sommige streken van Duitschland waar de sneeuw aan de noordhelling van gebergten lang blijft liggen en in de Scandinavische landen, onder den naam van sneeuwschimmel.

Een nauwkeurige beschouwing van de door Fusarium aangetaste wintergewassen, in het vroege voorjaar, en van de voorjaarsgewassen, iets later in het seizoen, zal uitwijzen, dat, afgezien van mogelijke sneeuwschimmelvorming, een meer of minder groot percentage van de planten verdwenen is; soms is de stand dun en zien vele van de nog levende planten er zwak en ziekelijk uit. De boer noemt dit verschijnsel vorstbeschadiging, terwijl het gewoonlijk niets met vorst-beschadiging heeft te maken en veroorzaakt wordt door Fusarium. Wanneer men de wortels en stengelbases van zulke planten beschouwt, zal men zien, dat zij bruin van kleur en verrot zijn. Een gedeelte van de op deze wijze aangetaste planten zal sterven, terwijl de rest door de ziekte heen zal groeien en zich verder ontwikkelen zal. Dit geval kan een voortzetting zijn van de kiemplant-aantasting maar het kan ook het gevolg van een nieuwe infectie zijn.

Voet- en Stengel-rot.

In sommige gevallen kunnen volwassen planten door Fusariumsoorten worden gedood, gedurende of kort na den bloeitijd. De schimmels tasten de wortels en den stengel vlak bij den grond aan, terwijl de eerste knoop meestal in de aantasting betrokken is. Het stengeldeel, dat met den grond in aanraking is en ook de wortels gaan verrotten en worden gewoonlijk rose of geel-bruin van kleur. De rotting van de bases stoort de water- en voedselvoorziening van de plant en veroorzaakt haar geheele verwelking, zoodra het droog weer wordt. Zulke planten buigen of breken door hun gewicht spoedig na de verwelking en zijn in goed onderhouden velden gemakkelijk herkenbaar. In gevallen, waar zulke infecties in groot aantal optreden, zien de velden eruit alsof er een kudde schapen overheen geloopen heeft. Trekt men zulke planten uit, dan breken ze aan de basis af, terwijl de wortels altijd in den grond achterblijven. Er moet echter worden opgemerkt, dat soortgelijke symptomen ook door andere schimmels en door insecten, veroorzaakt kunnen worden.

Het voet-rot kan ook een vervolg zijn op de voorafgaande twee vormen van de ziekte, de plant bezwijkt er dan onder vooral als de weersgesteldheid voor haar ongunstig wordt. Zoowel bij deze nawerking eener vroegere als bij een nieuwe infectie, spelen uitwendige omstandigheden een groote rol.

De knoopen van de verschillende graanplanten worden door hun grooter vochtgehalte en door den geringen weerstand, die zij aan het binnendringen der schimmels bieden, dikwijls door Fusarium-soorten aangetast, onafhankelijk van den aanval op de bases of de aar. Hier is de infectie gewoonlijk beperkt tot den knoop of de omgeving ervan zeer zelden of nooit meer dan 2½ c.M. in beide richtingen zich ervan, verwijderende. In zulke gevallen verwelkt gewoonlijk het gedeelte boven den aangetasten knoop en sterft spoedig.

Aar-aantasting.

Verreweg de belangrijkste vorm van de Fusariumziekte der granen is de aantasting der aren. Zij staat in geen betrekking tot reeds behandelde vormen van deze ziekte, behalve dat conidien daarvan afkomstig kunnen zijn. Wanneer ze later de aren bereiken, bewerkstelligen zij op verschillende manieren aantasting. Aar-aantasting kan zelfs in de beste velden voorkomen. Het is in het geheel geen ongewoon verschijnsel velden te zien, die tot na den bloei een uitmuntenden oogst beloofden en die later tengevolge van aar-aantasting slechts een vierde of vijfde gedeelte van de verwachte opbrengst gaven. Dit zijn de gevallen, die door de boeren aangeduid worden met de uitdrukking: Veel stroo, doch weinig korrel.

Tarwe. Aantasting van tarwe-aren kan met absolute zekerheid in een zeer vroeg stadium worden ontdekt, en wel drie of vier dagen nadat de infectie heeft plaats gehad, wanneer tenminste de weersomstandigheden gunstig zijn geweest voor den parasiet, om na zijn vestiging op de voedsterplant zijn vernielingswerk te beginnen.

De eerste teekenen van aantasting zijn licht-bruine, vetachtige van 2—3 m.M. lange vlekken op de kafjes. Het punt, waar de aangetaste kafjes bevestigd zijn aan de aarspil zal, wanneer het nog niet is aangetast, ook spoedig het vetachtige voorkomen vertoonen. Langzamerhand of vrij snel, al naar de weersgesteldheid neemt de vetachtige plek toe, spoedig het geheele pakje bedekkende, en gaat dan over op de naastbijstaande pakjes. Bij droog weer kan de aantasting zich bepalen tot slechts één pakje. De eerst aangetaste kafjes en pakjes. beginnen langzamerhand hun vetachtig voorkomen te verliezen; zij drogen op en nemen de kleur van de rijpe aar aan, die typisch is voor de varieteit in kwestie. Het opdrogen van de aangetaste pakjes volgt het voortschrijdingspunt der infectie, dat gewoonlijk naar beneden gaat. Het gezonde deel van de aar boven de infectieplaats droogt gewoonlijk tengevolge van afsnijding der water- en voedselvoorziening op en sterft zonder door de schimmel te zijn binnengedrongen.

Gewoonlijk wordt slechts een gedeelte van de aar gedood, wat het bovenste, middelste of onderste deel of in sommige gevallen de geheele aar kan zijn, al naar den aard en de plaats waar de schimmel binnendrong. De plaats van infectie, wordt, bij vochtig weer, spoedig door een katoenachtige, lichtrose schimmelmassa overgroeid, die zich later verder over de aangetaste aar uitbreidt. Hierop vormt zich een laag van conidien, die zalmkleurig zijn, hetgeen de aangetaste aren in de velden gemakkelijk waarneembaar maakt.

De eerste aar-infecties worden kort na het laatste stadium der bloei zichtbaar en zelfs tijdens deze, wanneer hij door ongunstige weersomstandigheden verlengd wordt; ze gaan door tot het rijpen van de aren.

De symptomen van aar-aantasting op *rogge* gelijken zeer veel op die van tarwe.

De symptomen der ziekte op *gerst* zijn gewoonlijk verschillend van die op tarwe en rogge. Meestal wordt slechts een korrel gedood of verschillende korrels op een rij. In sommige gevallen worden de drie korrels, die samen een pakje vormen, aangetast en daarna de rest van de aar.

Het eerste teeken van infectie bestaat in een klein vetachtig, iets bruinachtig vlekje aan de basis of het midden van de korrel, of soms op de aarspil. De bruinkleuring verspreidt zich in alle richtingen vanuit de infectie-plaats, spoedig de geheele korrel, het heele pakje of verschillende pakjes insluitende.

De symptomen der aar-aantasting op *haver* gelijken meer op die van tarwe. Door de struktuur van de haver-aar bepaalt zich de infectie tot een pakje en is dus niet zoo duidelijk zichtbaar als die van tarwe of rogge, maar ook hier kunnen alle deelen van de pluim worden aangetast.

DE ORGANISMEN, DIE DE ZIEKTE VEROORZAKEN.

Een groot aantal zwammen, tot het geslacht Fusarium behoorende, is door den schrijver als oorzaak der hierboven beschreven ziekte der granen gevonden in verschillende landen.

Deze schimmels zijn:

1. Gibberella saubinetti (Mont.) Sacc.
2. Calonectria graminicola (Berk et Brm.) Wr.
3. Fusarium culmorum (G. W. Sm) Sacc.
4. Fusarium culmorum var. leteius Sher.
5. Fusarium avenaceum (Fr.) Sacc.
6. Fusarium herbarum (Corda) Fries.
7. Fusarium arcuosporum Sher.
8. Fusarium scirpi Lamb. et Fautr.
9. Fusarium redolens Wr.
10. Fusarium solani (Mart. pr. p.) Ap et Wr.
11. Fusarium arthrosoprioides Sher.

In Holland zijn de voornaamste van deze F. culmorum (G. W. Sm.) Sacc. en Gibberella Saubinetii (Mont.) Sacc. De eerste veroorzaakte in 1922 $\pm$ 50% van alle aar-aantastingen, de tweede veroorzaakte in hetzelfde jaar $\pm$ 40 % van alle aar-aantastigen, terwijl de overige 10% door sommige van de overige bovengenoemde Fusarium-soorten veroorzaakt werd.

Deze organismen worden in de natuur overal aangetroffen. Gewoonlijk leiden ze een zuiver saprophytisch leven op doode plantendeelen, afkomstig van de vorige oogst of op ander organisch materiaal, waarop ze overwinteren. Ze kunnen de planten alleen aantasten, wanneer deze gewond of beschadigd zijn, wanneer ze onder ongunstige omstandigheden groeien of eerst nadat zij hun volle ontwikkeling bereikt hebben en op natuurlijke wijze in kracht afnemen. Maar niettegenstaande dit feit, kunnen deze zwammen onder bepaalde omstandigheden zoo vernietigend en schadelijk worden, dat zij de oogst geheel en al vernietigen en dus een verlies in opbrengst van 100% veroorzaken.

Bij aanwezigheid op het zaad, verlagen zij de kieming en kunnen een aanzienlijk percentage van de kiemplanten dooden, later kunnen zij de bases van de volwassen plant aantasten en een groot aantal ervan doen afsterven, tenslotte kunnen ze de aren aantasten en doen verdrogen, aldus de normale korrelvorming verhinderende. Alleen deze vorm van de ziekte kan de oogst binnen twee tot drie weken tot vrijwel niets terugbrengen.

HET KLIMAAT MET BETREKKING TOT DE ZIEKTE

Het weer speelt een belangrijke rol bij de ontwikkeling en de vernietigende werking van de verschillende phasen der ziekte. Des te ongunstiger het weer voor de ontwikkeling van de plant is, des te gunstiger is het meestal voor de ziekte.

De aantasting der kiemplanten is het ernstigste in een warmen bodem, boven 12° C. en heeft bij grondtemperaturen onder 12 ° C. niets meer te beteekenen. Geëtioleerde kiemplanten en die, welke gebrek hebben aan zonlicht en lucht zijn er meer aan onderhevig. In vochtige jaren hebben de planten minder te lijden en sterven zelden tengevolge van het voet-rot stadium der ziekte, dan in droge jaren, ook al is de mate van infektie dezelfde.

De weersinvloed op de aar-aantasting door Fusarium is nog grooter. Bij droog weer tijdens de periode na den bloei tot de volledige rijpheid van de aren heeft geen aantasting plaats, zelfs wanneer infectie-materiaal aanwezig is. Vochtig weer tijdens deze periode begunstigt niet alleen de aar-aantasting, maar ook de vorming van conidien en ascosporen.

CULTUUR-OMSTANDIGHEDEN MET BETREKKING TOT DE ZIEKTE.

De cultuur-omstandigheden, werken op verschillende wijzen op den graad en uitbreiding der Fusarium-ziekte in. Zooals reeds is opgemerkt, zijn de planten met uitzondering van de aren alleen vatbaar voor Fusarium-aantasting, wanneer ze onder ongunstige omstandigheden groeien. Alles, waardoor de normale physiologische processen en ontwikkeling van de planten belemmerd wordt, verhoogt dus de vatbaarheid voor de ziekte. Slechte afwatering, te veel stalmest, te diepe ligging van het zaad, slechte grondbewerking etc. bevorderen de aantasting der kiemplanten. Ofschoon goede cultuurvoorwaarden nooit aar-aantasting geheel kunnen voorkomen, kunnen ze onder bepaalde omstandigheden de mate van verlies tengevolge van dezen vorm van aantasting aanzienlijk verlagen. Op beschaduwde plaatsen of onder den invloed van onkruid of legering, worden de knoopen en aren veel heviger aangetast dan bij normale toetreding van licht en lucht.

RASSEN MET BETREKKING TOT DE ZIEKTE.

Vooral bij de aar-aantasting komen groote verschillen in vatbaarheid der rassen voor den dag. Van sommige rassen is de vatbaarheid verscheidene malen grooter dan van andere. De schrijver heeft tot op heden geen rassen gezien, die absoluut onvatbaar voor de ziekte zijn, maar men heeft geen reden te twijfelen aan de mogelijkheid, dat zulke rassen bestaan of voortgebracht kunnen worden. Over de vatbaarheid van Nederlandsche rassen moeten de waarnemingen nog worden voortgezet.

BESTRIJDING.

Na wat in de voorafgaande bladzijden over de oorzaak en den aard der Fusarium-ziekte gezegd is, is het duidelijk, dat de bestrijding van deze ziekte moeilijk zal zijn en veel werk, kennis en volharding zal vereischen. Men kan hier niet als bij de brandziekten met behandeling van het zaad volstaan:

1. *Grondbewerking*. Een nauwkeurige grondbewerking, die zaaien op gelijke diepte mogelijk maakt en die gelijkmatige en snelle kieming en normale ontwikkeling van de zaailingen verzekert, zal de beschadiging der kiemplanten, alsmede wortel- en voet-rot doen afnemen.

2. *Schoon land.* Daar de organismen op de stoppels van den vorigen oogst of op ander organisch materiaal op het veld aanwezig zijn en daarop talrijke conidien en ascosporen vormen, is het noodzakelijk alle plantenresten te verwijderen of ze diep onder te ploegen. Om dezelfde reden is kunstmest te verkiezen boven stalmest, tenminste wanneer verwacht kan worden, dat de behoefte aan stalmest niet groot is.

3. *Vruchtwisseling.* Vaak is opgemerkt, dat tarwe na tarwe of andere granen, heviger aan aar-aantasting lijdt dan wanneer zij na een ander gewas wordt verbouwd. De reden hiervan is gelegen in het feit, dat de ziekteoorzaken op het veld achterblijven op resten van den vorigen graan-oogst, hetgeen leidt tot een ophooping van infectie-materiaal. Hierom is het aan te bevelen een te snelle opeenvolging van granen te vermijden.

4. *Gezond zaad van goede kwaliteit.* Het gebruik van goed zaad is steeds gewenscht, maar voor velden, die met Fusarium besmet zijn, is het een gebiedende eisch. Gezond zaad van goede kwaliteit, op besmetten grond gezaaid, lijdt minder van de kiemplant-ziekte dan gezond zaad van slechte kwaliteit. Het zaad moet niet alleen van goede kwaliteit zijn, maar het moet ook vrij zijn van in- of uitwendige Fusarium-aantasting. Om deze reden moet bij de veldkeuring acht geslagen worden op de aar-aantasting. Zaad van weinig aangetaste velden kan ook wel worden gebruikt, als het voldoende van alle aangetaste en verschrompelde korrels is gezuiverd.

Teneinde het zaad ook te bevrijden van de talrijke Fusarium-conidien, die meestal op de korrels worden gevonden, is het noodig om het te desinfecteeren. De schrijver heeft gevonden, dat 1‰ sublimaat gedurende dertig minuten een zeer goede uitwerking heeft tegen uitwendige Fusarium-aantasting. Tarwe en rogge verdragen deze behandeling goed. Intusschen is het van belang dat nader wordt nagegaan welk van de nieuwe middelen die voor het ontsmetten van zaaizaad worden aanbevolen, de beste resultaten geeft.

5. *Resistente Rassen.* Sinds het bekend is, dat niet alle rassen in gelijke mate voor deze ziekte vatbaar zijn, moet men aan de minder vatbare rassen de voorkeur geven, terwijl de kweekers van tarwe en andere graanrassen ook met resistentie tegen Fusarium-aantasting rekening moeten houden.

6. *Drogen, dorschen en opbergen van het geoogste zaad.* De infectie verspreidt zich snel over de aren, wanneer de lucht vochtig is, hetgeen bij het Hollandsche klimaat meestal wel het geval is. Teneinde dit te vermijden is het noodig om met dorschen of met opbergen van den oogst te beginnen, zoodra het gewas gezicht is, mits droog. Niets is schadelijker voor de marktwaarde en de kiemkracht van het graan dan den oogst gedurende verschillende weken op de velden te laten staan, waar hij blootgesteld is aan den invloed van het weer en aan schimmelaantasting.

Buiten twijfel kunnen arbeids-omstandigheden in het bedrijf de uitvoering hiervan onmogelijk maken, maar de schade door Fusarium teweeggebracht is zoo groot dat extra uitgaven voor een goede winning en berging van het zaad zeker gewettigd zijn.

VERKLARING DER PLATEN.

PLAAT 1.

Fig. 1. Conidien van de op granen parasiteerende Fusarium-soorten.
a. Gibberella saubinetii (Mont) Sacc.
b. Fusarium herbarum (Corda) Fries.
c. Fusarium avenaceum (Fries) Sacc.
d. Fusarium arcuosporum Sher.
e. Fusarium scirpi Lamb. et Fautr.
f. Fusarium culmorum (G. W. Sm.) Sacc.
g. Fusarium solani (Mart. pr. p.) Ap. et Wr.
h. Fusarium redolence Wr.
i. Calonectria graminicola (Berk. et Brm.) Wr.
j. Fusarium arthrosporioides Sher.

Fig. 2. Kubanka tarwekorrels.
a. afkomstig van gezonde aren.
b. afkomstig van door Fusarium aangetaste aren. Zij zijn geschrompeld en veel lichter van kleur en gewicht dan de gezonde korrels onder a.

PLAAT 2.

Links zes typische kiemplanten van inwendig door Fusarium aangetaste Kubanka tarwekorrels. De korrels waren wankleurig, de stengelbasis en de wortelgedeelten vlak bij de korrel waren rot.

De twee planten geheel links zijn gedood toen zij de oppervlakte bereikt hadden, de derde plant was reeds voor dien tijd dood. Op deze planten ontwikkelden zich typische Gibberella perithecien. Rechts planten uit korrels van hetzelfde monster opgegroeid. Dit zaad was gedurende 30 uur aan een droge hitte van 100° C. blootgesteld. Geen ziekte werd in deze planten opgemerkt en zij zijn krachtiger dan die welke uit het onbehandelde zaad opgroeiden.

PLAAT 3.

Fig. 1. Kiemproef met natuurlijk geinfecteerde in 1913 geoogste Mansholt winter en Japhet zomertarwe op vochtig filtreer papier in vochtige atmospheer. Links een even groot aantal korrels als rechts na behandeling met 1 ‰ sublimaat gedurende 15 minuten, waarvan het gevolg is, dat alle korrels normale kiemplanten opleverden. De kiemplanten der niet behandelde horrels links worden overwoekerd en gedood door Fusarium.

Fig. 2 en 3 stellen veldproeven voor in 1914 te Wageningen genomen met dezelfde zaadmonsters van fig. 1. De perceeltjes aan de linkerzijde van als boven met sublimaat behandeld zaad, aan de rechterzijde onbehandeld. Stand links veel beter dan rechts. Alleen bij het achterste (bovenste) veldje van Fig. 2 heeft ook het onbehandelde een goeden stand. Dit is Mansholt wintertarwe, waarin de Fusarium minder schadelijk is dan in de Japhet zomertarwe.

(Alle drie deze photo's zijn genomen door Prof. QUANJER in 1914 toen hij zich met deze proeven bezighield.)

PLAAT 4.

Fig. 1. Stukjes van bovenste internode van en door Fusarium aangetaste halm.
a. Vlak onder de aar.
b. en *c.* Tweede gedeelte daaronder en derde gedeelte verder naar beneden.

Fig. 2. Loupebeeld van tarwezaailing afkomstig van een inwendig geinfecteerde korrel, die door de Fusarium gedood was voor de kiem de oppervlakte van den grond bereikt had. Op de doode spruit ziet men talrijke perithecien van *Gibberella saubinetii*, die in dit geval de oorzaak van de ziekte was. Dezelfde plant ziet men afgebeeld op Plaat 2, de derde plant van links.

Fig. 3. Voet-rot van tarwe veroorzaakt door Fusarium. De planten aan den linkerkant zijn afkomstig van grond, die met *G. saubinetii* geinfecteerd was. De controle plant rechts geeft de grootte van de gezonde tarweplanten aan.

PLAAT 5.

Voet-rot van tarwe door Fusarium veroorzaakt. Basale gedeelten van de planten afgebeeld op plaat 4, fig. 3. De wortels en de halmbasis zijn aangetast. De controle plant rechts heeft normale wortels.

PLAAT 6.

Door Fusarium aangetaste tarwearen. Controle-plant rechts, de andere vertoonen verschillende graden van aantasting.

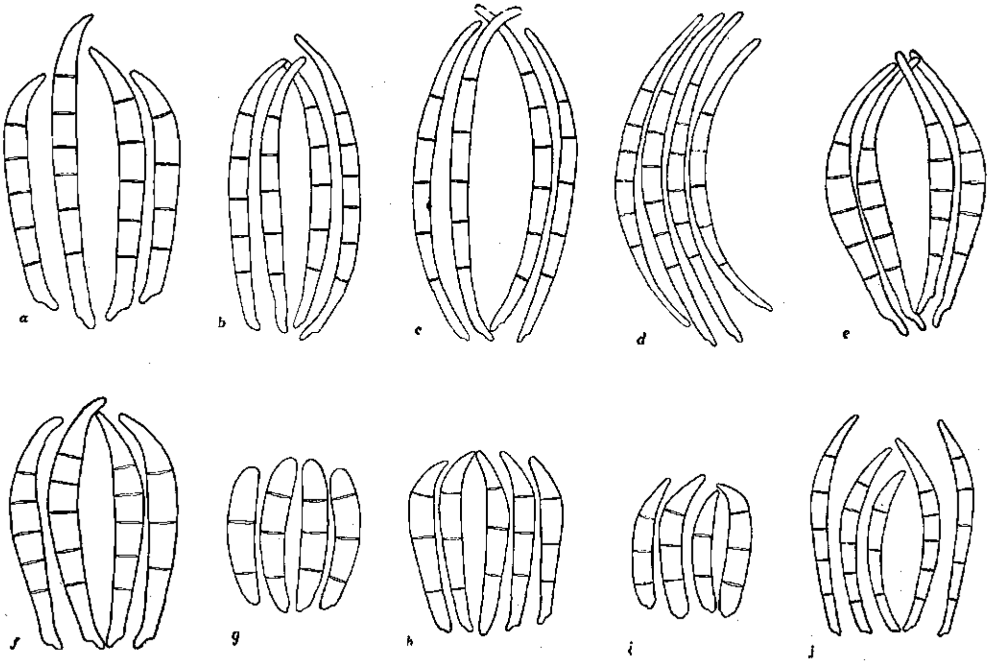


fig. 1.

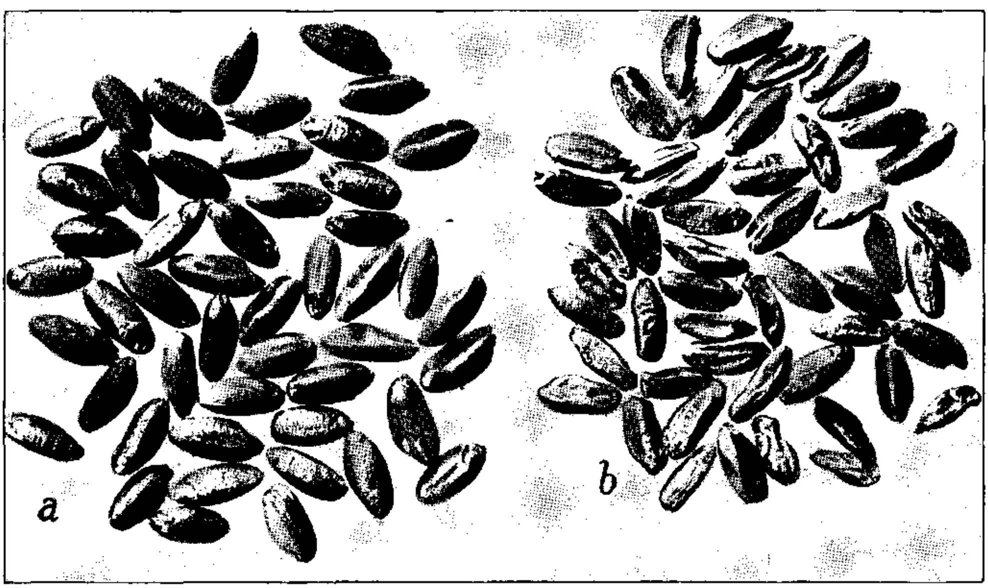


fig. 2.

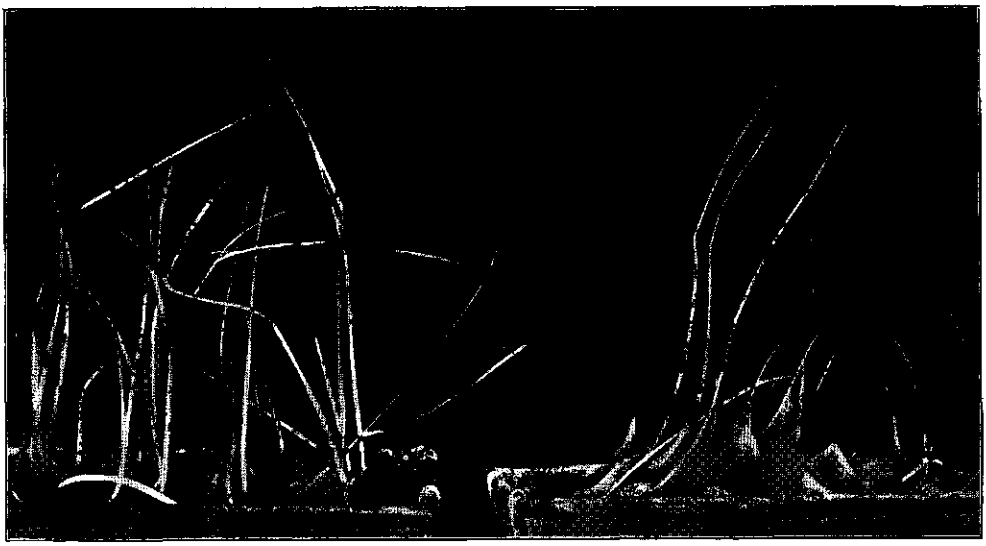


fig. 1.

fig. 2.

fig. 3.

PLATE IV.

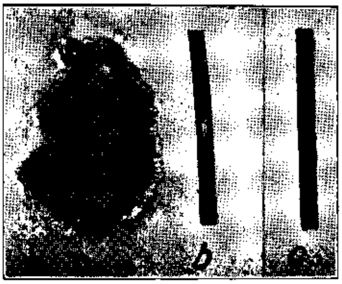


fig. 1.

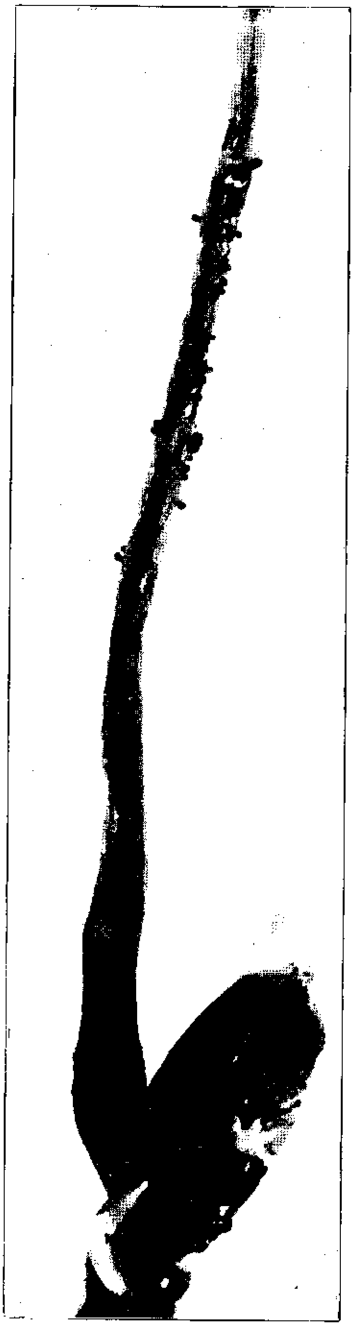


fig. 2.

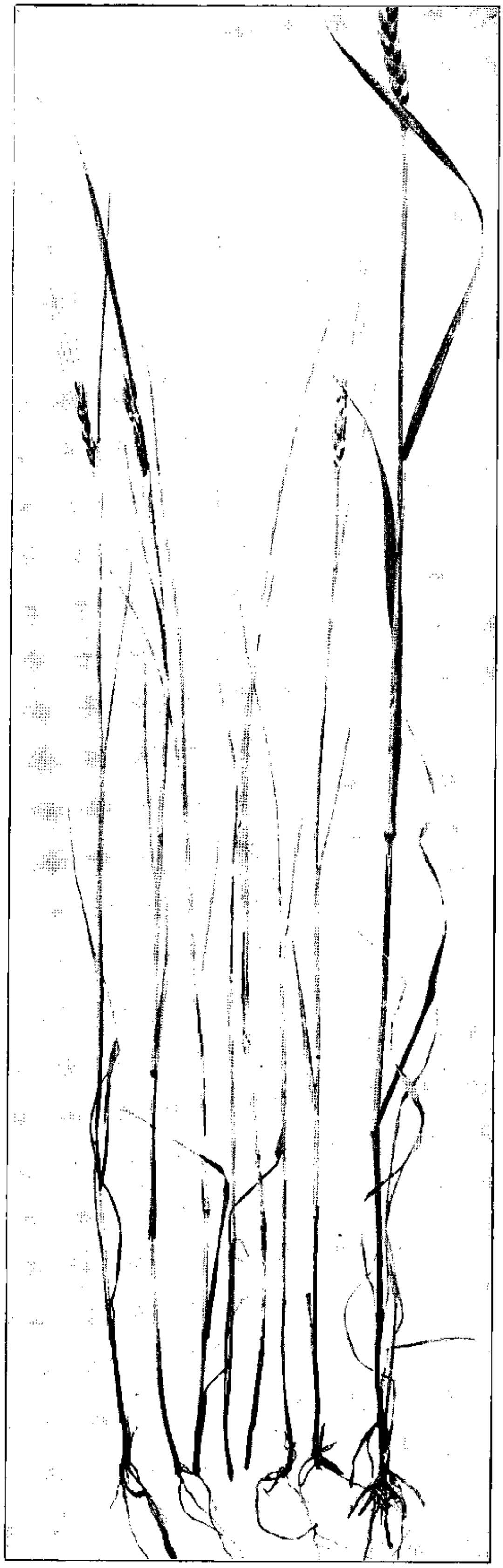
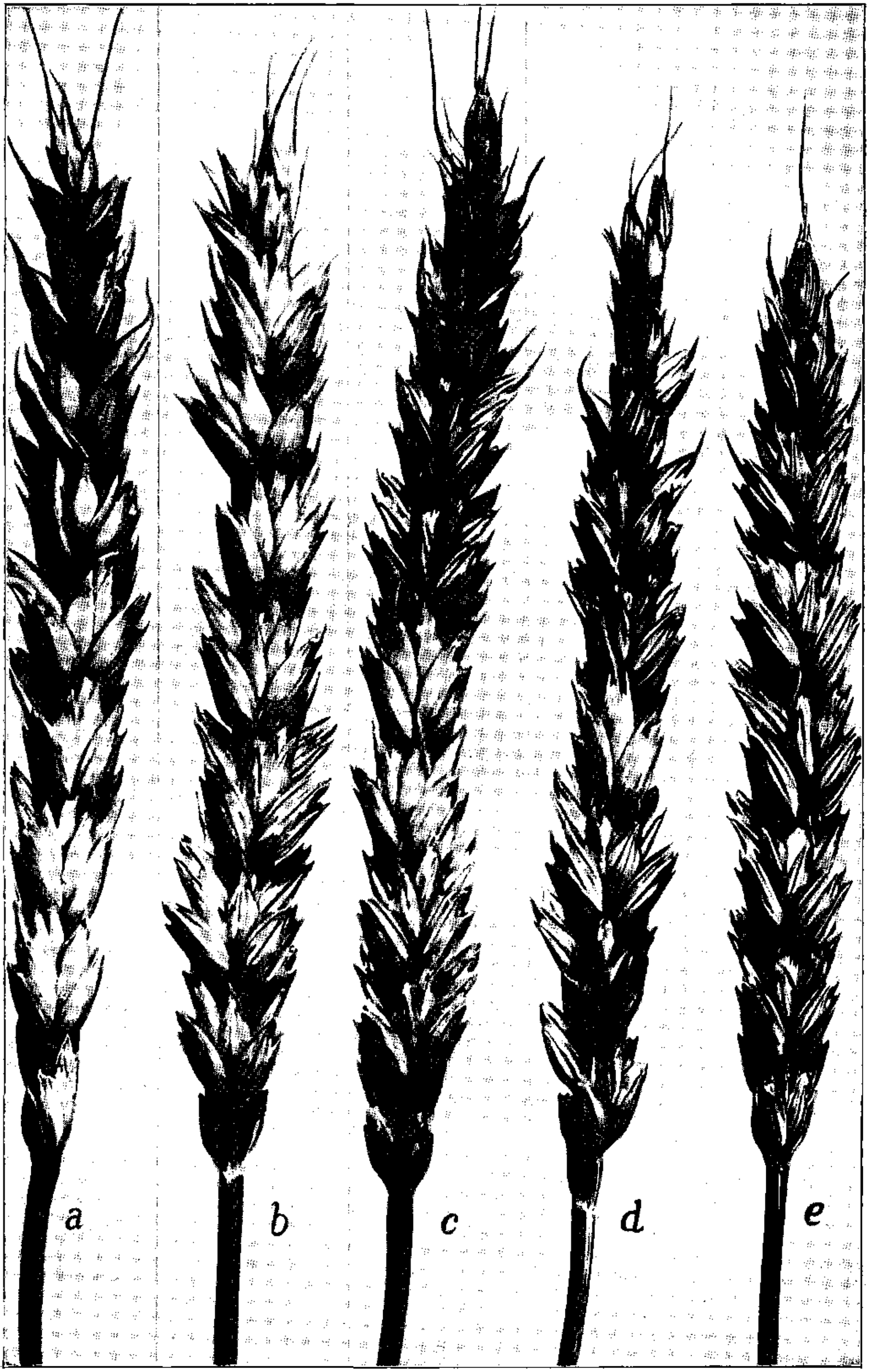


fig. 3.


a
b
c
d
e