THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Frances Jean MacInnes final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

May 28 1919

E. C. Stakman
Chairman

L. I. Knight

E. J. Durand

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Frances Jean Mac Innes for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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May 22 1919

WHEAT SCAB

A thesis presented to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the Degree of Master of Science

By

Jean Mac Innes

June, 1919

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WHEAT SCAB

The Fungi Imperfecti as a group have only recently been considered important in relation to cereal diseases although many of them have been recognized as pathogens for some time. Bolley (8-12) in North Dakota in about 1909 advanced the idea that members of this group were very important factors in reducing wheat yields. Some work has been done on those forms of Fungi Imperfecti which attack the roots of cereal plants in the soil and also those causing diseases of the parts of the plants above ground and several of them have been found to produce definite diseases. The wheat scab organism is one of the Fungi Imperfecti which is parasitic on both the seedling and the mature plants. Furthermore, the relation has been shown of this organism to diseases of hosts other than wheat. This makes a more thorough knowledge of the organism of very great importance.

PLANTS ATTACKED

Scab is considered primarily as a disease of wheat. It is reported as occurring on: *Triticum aestivum* L. (61 and others), *T. durum* Desf. (69,4), *T. monococcum* L. (59), and *T. dicoccum* Shrank (59). Authentic specimens have been examined by the writer on the following species of Triticum: *T. polonicum* L., *T. turgidum* L., *T. sativum compactum* Hack., *T. durum* Desf., *T. monococcum* L., *T. spelta* L., and *T. aestivum* L. Marquis (82,83) of the spring wheats, and the Durums (4), as a class are reported as being particularly susceptible but none of the varieties commonly grown seem to be entirely immune.

Barley (61, 37, 59), rye (37, 59), oats (59), and several wild grasses are known to be attacked by scab. Among the grasses are *Lolium perenne* L. (61, 69), *Molinia coerulea* (L.) Moench (37), *Holcus lanatus* L. (69), *Spartinia stricta* Roth. (50), *Glyceria fluitans* R. Br. (50), *Agrostis pulchella* Roth. (50), *Panicum sp.* (37), and *Paspalum sp.* (37).

Root rots and ear rots of *Zea mays* L. are reported by a number of workers (32, 31, 69, 42, 29) as being caused by the same organism as that causing wheat scab. The perithecial stage is particularly associated with these diseases.

An organism considered to be identical with the one causing scab has been isolated from clover (59), legumes (1), potatoes (2, 60) and sweet potatoes (22).

SYMPTOMOLOGY

Wheat scab occurs on the kernels, the base or margins of the glumes, the rhacis, the culms, and the nodes. The roots and young seedlings may be attacked by the same organism and characteristic leaf spots have been produced artificially.

The disease usually appears on the heads very soon after they have emerged from the sheath. One or more spikelets on any part of the head or the whole head may be attacked. The infected portion is white to yellow and appears prematurely ripe. This is in sharp contrast with the green glumes or heads of the healthy plants. The parts of the diseased spikelets become glued together by a gelatinous layer of the fungus (Plate 1). This incrustation is at first white to cream in color but later changes to pink, yellow, or orange. The kernels from diseased spikelets are either not developed at all or are small, shrunken , and covered with a considerable amount of white or very slightly pink mycelium (Plate II Fig. 1).

Associated with the pink or orange spore masses, a little later in the season, are small, black, more or less sphaerical bodies which are covered with a characteristic blue grey bloom. These are the perithecia of the perfect stage of the organism (Plates IV & V).

The shrivelled kernels of scabby wheat (Plate VI), are usually distinguishable from those shrivelled from other causes, even after threshing, by the pink or white color on the outside. The pink color may fade during the winter, especially if the kernels are exposed to light. Scabby kernels break open easily and the interior is somewhat soft. Kernels shrivelled by rust or on account of immaturity usually retain more of the normal color.

Seedling blight caused by this organism cannot be distinguished very readily from seedling blights due to other Fungi Imperfecti. In general, however, the plants are stunted when attacked in the seedling stage and the root system is much reduced. Individual rootlets may be browned and may eventually break off. Seedlings attacked at the ground line may fall over and die.

GEOGRAPHICAL DISTRIBUTION AND ECONOMIC IMPORTANCE.

Scab on cereals was first described in England (61) and since then a number of writers in that country (15,21,37) have emphasized the importance of the disease. Massee (37-P.493) stated that it "is not a rare pest attacking the grain of wheat, rye, barley, and various grasses---". Investigators in France (17,18), Italy (38,20,64), and Germany (69, 70,77) have described diseases similar to scab but the economic importance was not emphasized. Scab is in all probability not as important in Europe as the somewhat similar disease which causes "Schneeschimmel" of rye and other cereals, a disease so far not reported in America (71,68,62).

The earliest mention of scab of wheat in North America was found by Thorne (66) in the report of the Athens County Agricultural Society to the Ohio State Board of Agriculture for 1865. According to this report, "wet weather, rust, and scab" had reduced the yield of wheat. It is not known whether or not wheat scab as now understood is referred to. The first authentic report found was that of Chester (14) in 1890 in Delaware. Weed (74) in the same year stated that the yield of one field of wheat in Madison County , Ohio, had been reduced from about 40 bushels to 8 bushels per acre. He wrote (p.48), "Two other fields -- were shrunken in yield from the same cause at least one third".

The general distribution[1] of the disease in North America

[1] Compiled from a special report from the Plant Disease Survey kindly furnished by Dr. Haskell of the United States Department of Agriculture and also from W.P. Fraser of the Dominion Experimental Farms of the Dominion of Canada.

is shown in Fig. 1. Scab is present in all of the wheat growing regions east of the Mississippi and also in North Dakota, South Dakota and Nebraska. Utah, where the disease occurs infrequently, and Oregon are the only western states from which it has been reported. In Canada the disease is reported to be prevalent only in the maritime provinces - Nova Scotia, Quebec, New Brunswick, and Prince Edward Island. It occurs in Ontario to a limited extent in wet seasons, No record of the presence of the disease in the western provinces has been received, although extensive surveys were made in the summers of 1917 and 1918[1].

The damage done by the wheat scab organism is quite variable from year to year in the different sections of the country. In 1905 and 1907 the grain in the spring wheat belt was severely attacked and the losses of from 5 to 10 percent of the crop were reported. Serious damage was done again in 1915 and 1916 in the same area, while in 1917 and 1918 the losses were not so great.

In certain parts of the winter wheat area of Illinois, Ohio, and Indiana, the disease is present to a greater or lesser extent every year. The losses were large in 1915 and 1916 and even greater in 1917 and 1918. In 1918 wheat in Tennessee and Kentucky was even more severely attacked than in Ohio and Indiana. The production of winter wheat in Illinois in the same year was reduced five percent while in Iowa the disease was more common on spring than on winter wheat.

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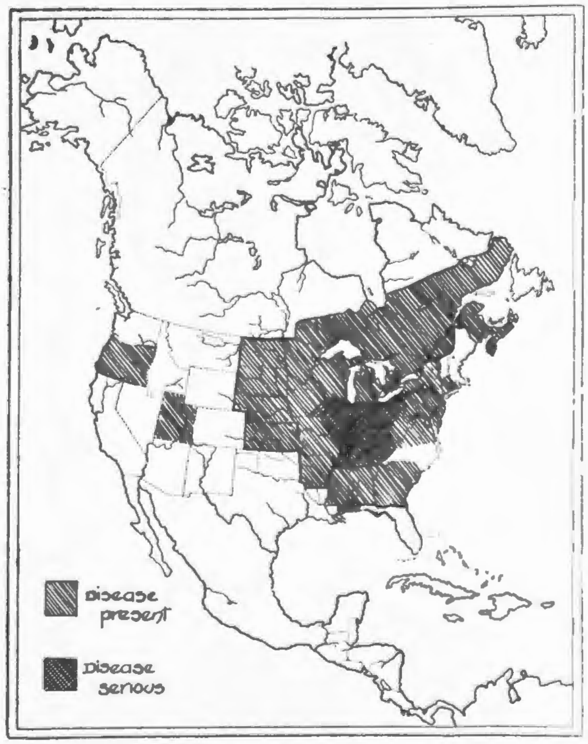
[1]Information kindly furnished by Dr. W.P.Fraser, Botanist at the Dominion Experimental Farms of the Department of Agriculture of the Dominion of Canada.



Geographical Distribution of Wheat Scab

Figure 1.

In Kentucky scab is said to have been second to leaf rust in amount of infection in 1918, and caused greater losses than any other cereal disease. The percentage of infection on the heads varied from ten to one hundred[1].

In Minnesota the disease has been reported in practically all of the counties in the southern half of the state. It has been found as far north as Norman County in the western part of the state. The losses in Minnesota are generally not as great as they are in the winter wheat regions of Indiana and Illinois, but the annual loss of wheat from scab varies from one to five percent. The reduction in the yield of wheat was estimated at five percent for the state in 1915, and it was only slightly less in 1916. In 1918 the disease was quite generally present in the southern counties of the state but the damage was practically negligible.

PREVIOUS INVESTIGATIONS

Smith (61) in England in 1884 first described scab on wheat, barley, and *Lolium perenne*.. He also described the three Fusaria associated with these diseases. He said (p.209) that the fungus attacked, "chiefly --- those plants which have been more or less invaded by corn mildew or other cereal fungi".

MacAlpine (36) in 1896 mentioned a disease on wheat near Melbourne, New South Wales, Australia and described the

[1]Report on wheat scab from the United States Department of Agriculture Plant Disease Survey.

organism associated with it. He found salmon colored patches on the stem, especially at the nodes and on the ears. Rusted wheat was particularly susceptible.

Chester (14) reported and described the disease on wheat in Delaware in 1890.

Griffiths (21) in England suggested, as means of preventing the disease, sowing only new and sound grain of wheat and barley, and also advocated steeping the grain in a solution of iron sulphate (1 to 2% solution) for from two to three hours before sowing. Arthur (3) noticed a disease of cereals which he thought was the same as the one described by Smith. He considered that the weakened condition of the plants favored the attack of scab. Late sown and poorly grown wheat suffered most. A difference in the time of flowering was thought to influence the prevalence of the disease. His conclusions were that, "vigorous growth and early blossoming are the chief safe guards against the disease".

Hickman (23) attributed the greater amount of disease in 1892 to (a) lack of proper preparation of the seed bed, (b) lack of vigor of the seed, (c) later ripening of such wheat, and (d) defective drainage.

Pammel (41) reported some varietal differences in susceptibility of wheats to the disease. "Wheat Blight", "Blighted Heads", and "Wheat Scab" were common names used for the disease at that time (1890). Buckhout (13), Bessey (6, 7), Kirchner (35), Sorauer (64), and Detmers (19) all described the disease briefly and the organisms associated with it.

Selby (56-58) and Selby and Manns (59) in Ohio gave considerable attention to wheat scab. Perithecia, which proved to be those of <u>Gibberella Saubinetii</u> (Mont.) Sacc., were found associated with the disease and <u>Fusarium roseum</u> Link was therefore considered as the conidial stage of the organism. The fungus was present on the glumes and straw of wheat and on stalks and stubble of corn. Asci disappeared in winter leaving spores free in the perithecia. The fungus was found to be carried over from year to year in the seed and both those kernels capable of germination and those which were dead were found to contain the fungus. Successful infection was obtained by inoculations on rye, oats, barley and speltz with the fungus taken from wheat. They concluded, therefore, that all the species described by other writers on different cereals were probably identical. An aggressive parasite on clover, indistinguishable from the one on wheat, was found to cause seedling blight of wheat, oats, clover, and alfalfa but no mention was made of inoculations on heads.

Hoffer, Johnson, and Atanasoff (31) produced typical scab from Gibberella obtained from corn roots and stalks. Hoffer, and Holbert (30,29) and Holbert, Trost, and Hoffer (32) found a relation between the amount of scab on wheat and the presence or absence of corn in the preceding rotations.

Johnson (34) isolated <u>Fusarium culmorum</u> (W.G.Sm.) Sacc. in pure culture from wilted oat seedlings. The percentage of germination was much lower in the pots of sterile seedlings than that of the controls. Field experiments gave much the same results.

Berthault (5) found Fusarium rubiginosum Ap & Wr.[1] so constantly present in foot rot of cereals that he considered it to be one of the causes.

Rostrup (45-48), Ritzema Bos (44), Westerdijk (76), Mortensen (39), Volkart (72), and others demonstrated that Fusaria could be carried in the seed but they dealt mainly with the organism causing "Schneeschimmel".

Stakman (65) described the effect of the organism isolated from scabby seed on the roots of wheat seedlings grown in Sach's modified agar media. Inoculated plants were generally found to be stunted and produced very short roots. The innermost part of the cortex and the vascular tissue of the roots was found to be most heavily infected, and disorganization proceeded out toward the epidermis. In the central cylinder of the root, "the hyphae seemed to be mainly intracellular while in the cortex they were primarily intercellular and pushed the cells apart".

A disease somewhat similar to wheat scab attacks rye and other cereals in Europe and is known as "Schneeschimmel". It is described as beginning under the snow, and, when the snow melts in the spring, whole patches of the young seedlings will be found lying blackened and dead on the ground with a white or reddish grey mycelium covering them. This disappears very rapidly after the snow is gone. A secondary

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[1] Sherbakoff (60) gave F. rubiginosum Ap & Wr as a synonym of F. culmorum (W.G.Sm.) Sacc.

infection on the heads often takes place (55) just before or during harvest. Bread made from the diseased grain (68) causes dizziness, headaches, and a tendency to vomit. The organisms associated with the disease (54,79,43), the life history of the organisms (62,63,55,43), and the control of the disease (55,40,24-27,28,75,68) are discussed by a number of workers. This disease is not present in America as far as is known.

The experimental work in the present paper was undertaken to determine more definitely (1) the organism, or organism, associated with the disease, (2) the life history of the organism, (3) contributing factors influencing the presence or absence of the disease, (4) the varietal resistance or susceptibility of wheat, and the host range of the organism, and (5) the possible means of control.

ETIOLOGY

DESCRIPTION OF THE CAUSAL ORGANISM OF WHEAT SCAB

Cultural Characters

Considerable variation in the color of the spore masses was observed on the heads of scabby cereals in the field. Cultures of Fusaria more or less similar to those from wheat scab were obtained from nodes, roots, and blighted seedlings[1], as well as from decayed potatoes[2]. Further-

[1]Isolated by Louise J. Stakman of this laboratory.

[2]Isolated by G.R. Bisby of this laboratory.

more, cultural characters of the wheat scab organism itself were often variable. It was, therefore, important to determine whether more than one type of Fusarium was associated with scab, and whether the organisms from other parts of the plants were identical with the scab fungus.

For that reason cultures of Fusaria from various parts of plants of cereals, from different localities, were compared on a number of media. The following kinds were used: potato plugs; sterilized wheat, oats, barley, and rye; tubes of potato dextrose agar, beerwort agar, rice; plates of 5 percent potato dextrose agar, beerwort agar, and oat agar. The tubes were kept at room temperature, transfers being made from each strain[1] to the same medium on the same day in order that the cultures might be comparable. Petri dishes were kept in the thermostat at 25 degrees C. These were inoculated from tube cultures which were only two or three days old, as considerable difference in the rate of growth was noticed when transfers were made from tubes of different ages. As near as possible the same amount of inoculum was transferred. Only mycelium was used as spores required more time to start growth. Tubes from which the plates were poured were filled to the same level and petri dishes of equal diameter were used to insure the same thickness of medium.

Single spore cultures[2] were obtained wherever a sufficient number of spores were available. Cultures from

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[1]A "strain" as used in this paper is an isolation from any individual plant or part of plant.

[2]A slight modification of the method of obtaining single spore cultures as used by Sherbakoff (60-p.104) was found

scabby material often never sporulated but no consistent difference between the single spore cultures and those of the original isolations were noticed.

The fungus isolated from scabby kernels or spikelets were found to have the following characteristics when grown on 5% potato dextrose agar:

> The aerial mycelium after the first twenty four hours growth was light, flocculent, and hyaline or very slightly pink in the center of the colony. When the colony was 2 to 3 days old, pink , red and orange pigment was characteristically present in a large proportion of the aerial mycelium, the remaining being hyaline. The mycelium in the substratum was, normally, colored more deeply than that above and varied in color from a brilliant brick red to a light red. No orange color was observed in the substratum.

Cultural characteristics on beerwort agar were very similar to those on 5 percent potato dextrose agar. Colonies on oat agar, however, were small and the mycelium hyaline even after two weeks growth. A slight amount of aerial mycelium was observed on the colonies from scabby material while cultures from the diseased roots, nodes, or blighted seedlings in general grew only in the substratum.

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to save considerable time. Several drops of sterile distilled water, about 0.5cc each, were put in a sterile petri dish. Spores were transferred to one of these drops and carefully mixed thru the liquid. A loopfull was then transferred to a slide and examined under the microscope. If there were more than 20-30 spores on the slide a similar loopfull was transferred to a second drop in the petri dish. Usually sufficient dilution was obtained in this manner. A tube of agar which had been cooled to 40-45°C. was then inoculated with a loopfull containing the proper number of spores. One dilution transfer was then made and both tubes poured. Fusarium spores were found to germinate in agar at 25°C. in 10-12 hours. If it were necessary to keep them longer they were kept in the ice box. The spores were found easily with the low power of the microscope and their position located with a drop of ink.

Cultures of Fusaria obtained from diseased roots were, as a rule, easily distinguishable from the scab organism (Plate VII Figs 1 & 3). The colonies on 5 percent potato dextrose agar were much more compact in growth and generally either pure white or very pale pink in color. The growth

TABLE I

HOST, LOCALITY, AND PART OF HOST FROM WHICH TYPICAL WHEAT SCAB ORGANISM WAS ISOLATED.

Host	Place of collection	Part of plant from which isolated.
Wheat (Marquis)	Albert Lea, Minn.	Seeds
Wheat (?)	St. Paul, Minn.	Nodes or roots
"	Indiana	Scabby heads
" (Minn.470)	St. Paul, Minn.	" "
Timothy*	"	Leaf spot
Alopecurus pratensis*	"	" "
Barley	Lindstrom, Minn.	Scabby heads
Rye	?	" "
Wheat	Zumbrota, Minn.	" "
"	Farmington, Minn.	" "
"	Brooten, Minn.	" "
Rye	St. Paul, Minn.	" "
Wheat (Fulcaster)	Jackson, Tenn.	" "
"	Kentucky	" "
Barley	Wabasha, Minn.	" "
Wheat (Club)	St. Paul, Minn.	" "
" (Durum)	Brookings, S.D.	" "
"	Bloomington, Ill.	Scabby seeds
Corn (Sweet)	St. Paul, Minn.	Ear
" (Field)	Deer Creek, Minn.	"
"	Bloomington, S.D.	"
Elymus canadensis	North Dakota	Node
Wheat	" "	Seeds

* Artificial inoculations.

also was much less rapid in most cases (Fig.4). The colonies of the scab organism averaged from 8 to 9 cm. in diameter after three days growth, while the average size for the node or root organism was from 4-6 cm. In only two cases was a culture obtained from nodes or roots which was typical of the wheat scab fungus (Table 1) and atypical cultures were never isolated from scabby material. The cultural characteristics of the Fusaria isolated from rotting potatoes were in no case identical with those of the wheat scab organism.

One culture isolated from a head of wheat heavily infected with Gibberella Saubinetii (Mont.) Sacc., which at first was identical culturally with the wheat scab fungus, eventually lost all the color, produced much less vegetative mycelium, and many bright yellow masses of spores. As far as could be determined these spores were typical of the wheat scab organism.

The results obtained indicate that, culturally, there is one type of organism which is associated with scab of cereals. Considerable variation was observed within this group, however, and inoculation experiments may bring out different infection capabilities for some of the different strains.

Conidia

Macrospores were examined from scabby heads of several varieties of wheat and of rye. Considerable difference was observed between the spores from the various hosts. Therefore, one hundred spores from a number of varieties were measured. Only material collected in the fall of 1918 was used, because non-vialbe spores were found to be considerably shrunken in size.

A distinct tendency toward morphologic differences is noticable between spores produced on the various hosts (Fig. 2, Plate VIII, Table II). The spores taken from Velvet Don Wheat, for instance, are shown to be predominately short and narrow (Plate VIII, Fig. 1) while those produced on Minnesota 163 (Fig. 2) are long and broad. Spores from Minnesota 470 (Fig. 3), on the other hand, are wide but a much larger proportion are shorter than those from Minnesota 163 (Fig. 2). Spores produced on rye (Fig. 4) are as wide as those taken from Minnesota 470 but the mode is much shorter.

However, measurements of spores from two different heads of wheat (Figs. 6a and 6b) varied considerably in width. A large number of measurements of spores from different heads will have to be made and inoculation experiments carried out before any definite conclusions can be drawn.

The spores from scabby heads ranged in size from 29-72 x 2.9-5.8μ (Table II). The average was 52.6 x 4.5μ. The number of septations varied from 1 to 9, the average being 5. No measurements of the microspores nor the chlamydospores were made.

Ascospores and Asci

Only a small number of measurements were made of the perithecial stage of the organism, as very little material was available. Ten mature asci (Plate IX, Fig. 7) were measured and they range in size from 58-78 x 8-14μ. Eight spores were in each ascus. The spores (Fig. 8) measured 20-27 x 3.5-5.8μ.

TABLE II

RESULTS OF MEASUREMENTS OF SPORES DEVELOPED ON SCABBY HEADS OF VARIETIES OF WHEAT AND OF RYE.

Host	Spores Measured	Average		Mode		Extremes	
		Size	Septations	Size	Septations	Size	Septations
Rye	100	44.6x4.6	4.1	43.5x4.3	5	31.9-58.0x2.9-5.8	3-6
Wheat (Marquis)	100	52.6x4.7	4.6	58.0x5.8	5	29.0-66.6x2.9-5.8	1-7
Wheat (Minn. 470)	100	52.4x5.0	4.6	55.1x5.0	5	29.0-72.5x2.9-5.8	2-7
Wheat (Minn. 163)	100	53.5x5.0	4.8	58.0x5.0	5	37.7-72.5x3.6-5.8	1-6
Wheat (Minn.1594)	100	56.9x5.0	5.0	55.1x5.0	5	34.8-66.6x3.6-5.8	3-9
Wheat (Velvet Don)	100	49.3x3.8	4.3	49.3x3.6	5	34.8-63.8x2.9-5.0	1-6
Wheat (Preston)	100	49.1x4.8	4.1	52.3x5.0	5	31.9-60.9x2.9-5.8	1-7

Figure 2

Comparative Spore Sizes of the Scab Fungus from Rye and several varieties of Wheat

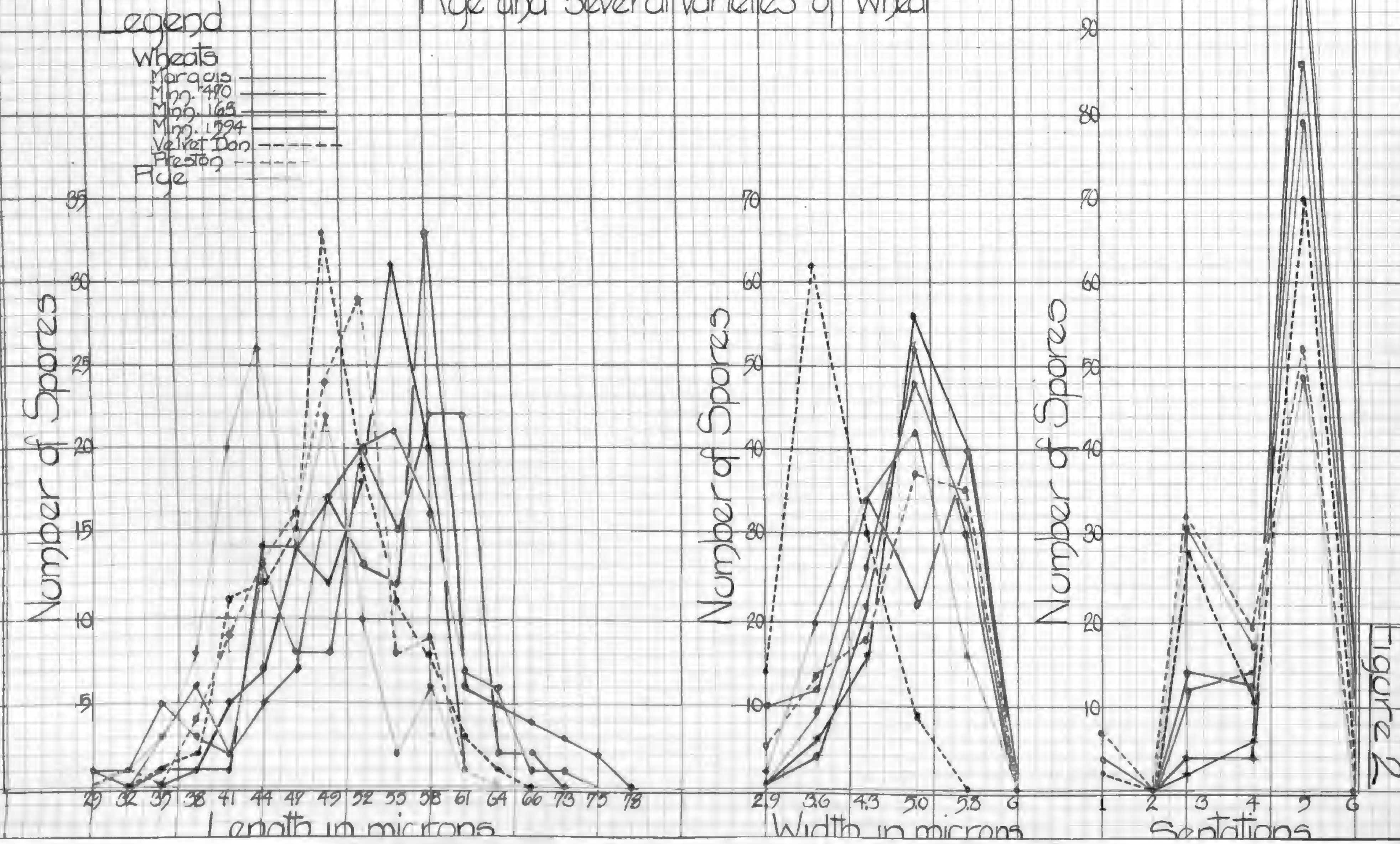

Figure 2

Taxonomy

No satisfactory description of the wheat scab organism has been found. A summary is given in Table III of the different species of Fusarium described on cereals and grasses in America and elsewhere. The spore measurements of Fusarium roseum Link as given in Saccardo (50) on species of Gramineum in Europe agree more closely with the measurements taken by the writer than do any of those given for F. culmorum (several authorities - 53,31,60,36,78 and others). The number of septations, however, are not the same. F. roseum Link is also given in Saccardo (49) as the conidial stage of Gibberella Saubinetii (Mont.) Sacc. on Triticum, Zea, and a number of other hosts. The spore measurements are shprter and wider than those of spores found in the vacinity of St. Paul but the number of septations is the same.

Gibberella Saubinetii (Mont.) Sacc. is apparently quite consistently associated with wheat scab in America. Selby (56) in 1898 first noticed this ascigerous stage in connection with the Fusarium disease. He, therefore, identified the conidial stage as Fusarium roseum Link. Most other writers (6 and others), however, have accepted the name given by Smith (61) - Fusarium [Fusisporium] culmorum (W.G.Sm.)Sacc. * and this is the mame generally used in the United States at the present time.

Wollenweber (78) described four strains of Fusarium on sweet potatoes, one of which produced perithecia consistently and was identified as Gibberella Saubinetii (Mont.) Sacc.

TABLE III

SPECIES OF FUSARIUM DESCRIBED ON CEREALS AND GRASSES

Organism	Authority	Host	Locality	Septations	Spore Measurements
F. andropogonis Cooke	Saccardo(51)	Andropogon virgineae	America	3-5	33-40x3
F. culmorum (W.Sm.)Sacc.	" (52)	Triticum sativum	England	3-5	28-32x6-8
F. culmorum (citation ?)	Ferraris(21)	Cereals	Italy	---	30-40x8-11
F. culmorum (W.Sm.)Sacc.	Sherbakoff(60)	Potatoes & cereals	-----	5	37-40x5-6
F. culmorum M'Alp.	MacAlpine(36)	Wheat	N.S.Wales	5	30-40x4-5
F. culmorum (W.Sm.)Sacc.	Wollenweber(78)	Species of gramineum	Eu & Am.	5	30-45x5-7
Fusisporium culmorum W.Sm(b)	Smith(61)	Wheat	England	3-4	32-50x5-7[a]
F. gramineum Corda	Saccardo(50)	Zea mays	Eu & Am.	---	----------
F. heterosporium Nees.	" (50)	Species of gramineum	Eu & Am.	3-5	30-35x-
Fusisporium hordei W.Sm.	Smith(61)	Hordeum vulgare	England	2-3	27-37x5[a]
F. Hordei (W.Sm.)Sacc.	Saccardo(50)	" "	Denmark	3	30-32x5
F. insidiosum (Berk.) Sacc.	" (50)	Agrostis pulchella	England	1-5	50x----
F. lolii (W.Sm.)Sacc.	" (52)	Lolium perennis	England	3	28-30x5
Fusisporium lolii W.Sm.	Smith(61)	" "	England	2-3	20-30x2-4[a]
F. maydis Kalchbr.	Saccardo(50)	Zea mays	Europe	---	----------
F. miniatulum Sacc.	" (51)	Secale cereale	France	3	19-22x4-5
F. minimum Fuck.	" (50)	Dying gramineum	Europe	3	14x3
F. nivale Ces.	" (51)	Cereals	Italy	1-5	14-20x---
F. nivale (Fries)Sorauer	Ferraris(20)	Grain	------	---	30-36x4
F. roseum Lk.	Saccardo(49)	Triticum,Zea, etc.	Eu & Am.	5	24-40x5
F. roseum Lk.	" (50)	Gramineum	Europe	3	33-60x4
F. roseum Lk.	" (53)	Visci albi(dead)	Europe	3	42-45x4-5
F. roseum Lk.	" (53)	Lonicerae tataricae	Europe	1-3	30-40x3-4
F. roseum Lk.	Ferraris(20)	Wheat	Europe	---	---------
F. rubiginosum Ap. & W.[b]	Appel & Wollenweber(2)	Potatoes	------	5	32-44x6-7
F. schribauxii Delacr.[b]	Saccardo(51)	Triticum sativum	France	4	35-40x6-7
F. tritici Erikss.	Saccardo(51)	Triticum durum	Sweden	1-2	12-20x1-2

(a) Approximated from the drawings

(b) Given by Sherbakoff (91) as synonymous with F. culmorum (W.Sm.) Sacc.

Another strain never produced perithecia and was considered to be Fusarium culmorum (W. Sm.) Sacc. These and the other two mentioned had been included under Fusarium roseum Link. He gave considerable evidence to support his reasons for separating the above forms. He stated that the three other forms are (p. 353) "often confused with that of Gibberella owing to the frequent association of the so called F. roseum Link with the Gibberella on grains of cereals, while the true Fusarium of Gibberella is comparatively rare in nature because of its ready metamorphosis into a stroma". He added (p. 356), "According to Saccardo (1873, p. 513) the 5-septate conidia measure 24-40 x 5-6 μ while in our Gibberella from wheat grains they average 45-60 x 5.0-5.5 μ and have an absolute fluctuation from 35-73 x 5-6 μ".

Ferraris (20 - p. 339) considered the fungus Gibberella Saubinetii (Mont.) Sacc. as the cause of wheat scab ("golpe blanca") with Fusarium roseum Link as the conidial stage. "Fusarium culmorum W.Sm.", on the other hand, "is probably identical with the form conidia of Sphaeroderma damnosum Sacc. et Berl. which produces the so called Sardinian grain disease --" (pp. 340,899). No spore measurements are given for F. roseum but the spores of F. culmorum are 30-40 x 8-11 μ.

Sherbakoff (60) isolated Fusarium culmorum (W. Sm.) Sacc. from potatoes and gave the following synonyms:

Fusisporium culmorum W.G.Sm.
Fusarium Schribauxi Delacr,
Fusarium corallinum Mattirolo (not Sacc.)
Fusarium rubiginosum Ap et Wr.

The spores of this species measure 38.5 x 5.85 μ (37-40 x 5.3-6.2) and were mostly 5-septate.

It seems probable, as is suggested by Wollenweber (78), that there are several forms of Fusaria which may cause scab. Inoculation experiments and more extensive spore measurements will have to be made with the various organisms before this can be proven.

LIFE HISTORY OF THE CAUSAL ORGANISM

Infection and Subsequent Development

The complete life history of the wheat scab organism has never been very satisfactorily worked out. Infection of the heads, which is in all probability brought about by wind borne spores, takes place any time after the heads emerge from the sheath. The exact time of infection is apparently dependent upon the moisture and temperature conditions at ripening time. When infection takes place while the grain is still in flower, the ovary ceases to grow (Plate II, Fig. 1, Plate XIV, Fig. 1). If, however, infection occurs later, the kernels may develop somewhat but are filled with the fungus and, when the wheat is mature, are shrivelled(Plate VI, Fig. 1). Such kernels are covered with loose white mycelium which later becomes pink.

The mycelium also grows in the glumes and rhacis of the host. It may be quite abundant between the glumes and lemma and palea, often filling the space with a loose weft of the fungus. The outer surface of the glumes bears the sporodochia on which the conidiophores and conidia are formed. The masses of these conidia form the pink or orange covering over the surface of the glume or rhacis (Plate I).

The perithecia are produced from the same mycelium as that on which the conidia are formed. The perithecial stage has not been observed without the presence of Fusarium spores, although after wintering out of doors the latter may become very rare. No mature asci developed in the perithecia collected in the fall of 1918 on the plots at University Farm, St. Paul, even in the specimens put under special conditions for wintering over. Perithecia on wheat heads, however, obtained last fall from Indiana contained fully matured ascospores at that time.

Overwintering

The conditions under which spores and mycelium of the wheat scab fungus may live over winter are not definitely known. Heads of scabby wheat, scabby kernels, and cultures of the organism were, therefore, placed under a number of different conditions in the winters of 1917-18 and 1918-19.

Mycelium

Cultures were made in the spring of 1918 from the material kept over winter in 1917-18 (Table IV). The organism was obtained from the kernels in practically every case. Much of this material was in the laboratory until the spring of 1919 and the fungus was found to be alive when cultures were made at that time.

TABLE IV

RESULTS OF OVERWINTERING STUDIES OF SCABBY MATERIAL - 1917-18

Location of the Material		Ice box 10°C.		Thermostat 25°C.		Cold store room				Outside on ground			
						Light		Dark		Light		Dark	
Kind of Material	How kept	A	B	A	B	A	B	A	B	A	B	A	B
Healthy seed	Cloth bags	–	---	–	---	–	---	–	---	–	---	–	---
Scabby seed	Do.	+	–	+	–	+	–	+	–	+	–	–	–
Scabby seed		+	---	+	---	+	---	+	---	---	---	+	---
Scabby seed	Petri dish	+	---	+	---	+	---	+	---	+	---	+	---
Inoculated seed	Do	?	+	+	+	+	–	+	---	+	---	?	+
Inoculated seed	Test tubes	+	+	+	---	+	–	+	–	+	---	+	–
Inoculated seed	Do	+	---	+	---	+	---	+	---	+–	---	+	---

A - Cultured April 1918

B - Cultured April 1919

The conditions of the experiment and results of the cultures made from the material put under special conditions in 1918-19 are given in Table V. The three conditions were intended to simulate a store house for grain, wild grasses left standing in the field, and stubble or the soil. In each set part of the material was kept in the light and part in the dark. Unfortunately the third set was destroyed accidental-

TABLE V

RESULTS OF OVERWINTERING STUDIES OF SCABBY MATERIAL
1918 - 19

Material	Outside		Inside		Outside
	Light	Dark	Light	Dark	In snow
Scabby kernels	6/14 *	10/11	8/9	4/10	Destroyed
Kernels from scabby heads	6/9	2/2	5/10	2/2	"
Perithecia	0	0	0	0	"

* Denominator the number of seeds cultured, numerator the number containing the organism

ly before any data were taken. Just as in 1918, the mycelium in the kernels survived under all the conditions of the experiment.

Spores

Hanging drop cultures were made of spores from the same material which was overwintered in 1918-19 (Table VI). Very slight germination was obtained where the material was exposed to the light, whether inside or out of doors. One hundred percent germination of the spores in one sample was obtained but it seemed possible that the spores of the latter were not typical of the wheat scab organism. They were shorter, more plump , and only 3 to 4 septate. A large percentage of the spores were viable when kept in the dark either inside or outside. The average percentage of germination of those kept in the dark outside was nearly twice as great as that of those kept in the dark inside.

TABLE VI

RESULTS OF GERMINATION TESTS WITH SPORES KEPT DURING WINTER OF 1918-19

Test no.	Inside		Outside	
	Light	Dark	Light	Dark
	Percentage of germination			
1	0	50	0(b)	100
2	100(a)	50	0(b)	100
3	1	75	0(b)	100
4	0	25	0(b)	0
5	.5	.5	0(b)	90
6	0	0	0	50
7	0	85	---	100
8	10	.5	---	50(c)
9	0	25	---	50
10	0(b)	100	---	---
Avg.%	1.1	43	0	71

(a) Spores not typical of the wheat scab organism.
(b) Very few spores found.
(c) Moisture lost in hanging drop.

Spores which were viable were easily distinguishable, after four hours in sugar solution, from those which were dead. Viable spores were swollen, the contents granular, and in a few cases germ tubes had developed. Non-viable spores were shrunken and less granular.

Ward (73) in most cases obtained a higher percentage of germination with spores of Puccinia dispersa (Erikss.) which were kept in the light than those were kept in the dark but his results were not consistent.

The urediniospores of Puccinia graminis tritici, P. graminis avenae, and P. graminis secalis were found by Thiel[1] to be viable for from ten days to two weeks longer when kept in the dark than when kept in the light.

CONTRIBUTING FACTORS

Very few data are available regarding the conditions which are the most favorable for the development of scab. The temperature relations of the organism causing the disease have not been worked out. The disease is known to be most prevalent in moist, hot seasons, but no controlled experiments have been made which correlate the moisture and temperature conditions with the amount of scab. Selby and Manns (59) observed that infection took place just before, during, or immediately after the flowering time of the host. However, the effect of the age of the host, and the temperature and moisture conditions on the percentage of scab was not recorded.

Temperature Relations of the Organism

Several series of cultures of the organism were grown at different temperatures on potato dextrose agar. The average diameter of the colonies under the various conditions are

[1] Unpublished results obtained by the Minnesota Agricultural

given in Table VII. The temperature in the ice box varied from 9 to 12°C. but the average was about 10°C. The other temperatures were fairly constant.

The minimum temperature is approximately 5°C. and the maximum between 30 and 35°C. (Plates X and XI, Figs.1-6). The optimum is near 25°C. A number of attempts were made to determine the exact optimum and maximum but the results were very conflicting. More variation was observed between

TABLE VII

RATE OF GROWTH OF THE WHEAT SCAB ORGANISM
AT DIFFERENT TEMPERATURES

Temperature in degrees C.	Number of days after inoculation								
	1	2	3	4	5	6	7	8	9
	Diameter of colonies in cm.								
5				.4	1.5				2.1
10		.6	1.6	1.8	2.7			6.3	7.5
15	1.0	1.5	2.5	3.7	4.6				
20	1.0	2.3	3.7	6.3	7.8				
25	1.2	3.2	5.5	8.5	9.9				
30	.7	2.0	3.5	4.5	6.0	7.0			
35	0	0	0	0	0	0	0	0	0

cultures on petri dishes containing unequal amounts of culture medium than between cultures kept at temperatures differing

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Experiment Station in cooperation with the office of Cereal Investigations of the United States Department of Agriculture.

by only one or two degrees. However, indications are that the fungus grows more slowly at temperatures above 25°C. The character of the mycelium produced at 30°C. differed from that growing at lower temperatures (Plate XI, Fig.6). The growth was not so flocculent, indicating that the conditions were unfavorable for the growth of the organism.

Tisdale (67) found the optimum temperature for growth for Fusarium lini Bolley to be about 26 to 28°C., and the maximum to be between 34 and 37°C. The minimum was between 10 and 11°C. Pot experiments showed that more flax wilt developed at temperatures near the optimum than at lower temperatures.

Harter, Weimer, and Adams (22) inoculated sweet potatoes with "Fusarium culmorum Wollenweber" and kept them at the following temperatures: 10.6, 13.5, 16.9, 20.5, 21.2, and 23°C. Decay was only obtained in the potatoes held at 10.6, 13.5, and 16.9°C. Those kept at the other temperatures and the checks remained sound. They concluded, therefore, that the organism had a relatively low optimum.

Germinating spores of the wheat scab organism were apparently not killed by freezing. Several petri dishes of potato dextrose agar containing germinating spores, were exposed to a temperature of -8°C. for periods ranging from ten minutes to one hour and a half. The agar did not solidify again after freezing, but the organism developed normally when transferred to fresh media.

Fluctuating temperature had an effect upon the color produced by one strain of the fungus. At 25°C. the culture was white. After being in the ice box at about 10°C. for a few days, the new growth became bright red. The culture was then kept at a temperature of 25°C. and, although the line separating the two colors was not as distinct as previously, the new growth was white. Several unsuccessful attempts were made to duplicate these results.

A culture grown at normal temperature for two days was marked and exposed to freezing temperature for an hour. A light red ring was produced immediately under the mark after a few days at normal temperature. The great variation in color of scabby material in the field may possibly be explained by temperature changes.

Effect of Time of Planting on Seedling blight and on the Percentage of Scab

Four sets each of scabby and healthy seed were planted at intervals of from three to five days to determine the relation of maturity of the plant to the resulting amount of scab.

The weather was very dry up to the time of the third planting after which considerable rain fell. Little difference in rate of development was observable between the plants in the two plots planted during the dry period. The plants in the plots planted after the rain developed together also but somewhat more slowly than those planted earlier.

The plots planted with healthy seed (Table VIII) were for some reason somewhat slower in development that the others

TABLE VIII

RESULTS OF PLANTING HEALTHY AND SCABBY SEED

Section	Time of planting	Kind of seed	Character of stand		Time of heading				No. rows counted	Total no. heads counted	Avg. no. heads per row	Total no. scabby heads	Avg. no. scabby heads	per cent scab
			5/16	6/4	7/2	7/5	7/9	7/18						
11	5/4	Scabby	Just showing	Excelent	Many heads out of sheath	All heads out of sheath	Full head	Full head	4	1724	431	4	1	.3
12	5/7	Do.	Do.	Do.	Do.	Do.	Do.	Do.	4	2172	543	0	0	0
13	5/11	Do.	None up	Very poor	None out of sheath	A few heads showing in boot	All heads out of boot	Do.	4	1567	391	12	3	.9
14	5/16	Do.	Do.	Do.	Do.	Do.	Do.	Do.	4	1793	448	9	2.2	.6
21	5/4	Healthy	Good rows showing	Excelent	Few heads out not as advanced as 11.	Many out of boot	Many in full head	Do	4	3023	755	11	2.7	2.9
22	5/7	Do.	Do.	Do.	Do.	Do.	Do.	Do.	4	3288	822	12	3.0	.37
23	5/11	Do.	None up	Moderate stand not as good as 21.	No heads out	No heads out	Just out of boot	Do.	4	2658	664	69	17.2	2.7
24	5/16	Do.	Do.	Good stand	Do.	Do.	Still in boot	Do.	4	3166	791	112	28.0	3.5

and the percentage of scab was considerably higher in these plots. The late development, especially in sections 23 and 24, brought the heads out of the sheath just before a rise in temperature and humidity (Fig. 3).

Out of about 7,000 heads in the plots planted with scabby seed less than one percent of scabby heads were found, while the plots planted with healthy seed contained as high as 3.5% of scabby heads out of 12,000 heads counted.

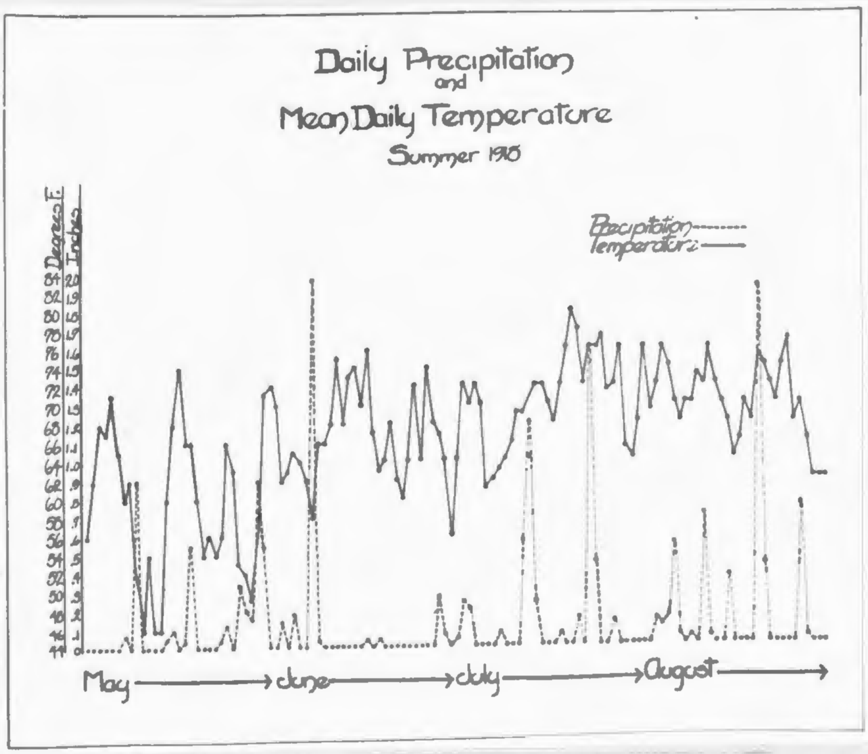

Figure 3

Only two thirds as many heads developed in a row in the plots planted with scabby seed as in the plots planted with healthy seed. Absence of the organism does not account for all the difference, however, as it was necessary to shorten the plot planted with scabby wheat by one fourth. If, however, the whole plot had been planted, about 9,600 heads would have developed as compared to the 12,000 heads found in the plot planted with healthy seed. The difference is probably due, in part at least, to lower germination and seedling blight. Furthermore, sections 11 and 12, which were planted with scabby seed early and in more or less dry soil, had a much better stand than sections 13 and 14 planted later and after a storm. The heavier stand in the healthy plot may explain the larger percentage of scab.

There seems to be but little relation between the planting of scabby seed and the subsequent amount of scab on the heads, A greenhouse experiment (Table XV), in which healthy seed and treated and untreated scabby seed were planted, gave similar results. If the plants survived the seedling stage, they grew to maturity.

Effect of Moisture and Temperature on the Percentage of Scab in the Field.

Plots of wheat were covered for different lengths of time with large cloth cages in an attempt to determine the exact time of infection. The humidity and temperature under the cages were apparently conducive to the production of scab because more scab appeared on the plants under the cages than on the checks. However, there was considerable variation in the amount of scab in the different plots, giving some indication of the time of infection in relation to moisture and temperature conditions.

Four plots, each one rod square, were planted with healthy Marquis wheat. The develpoment of the plants in the four plots was uniform. The cages for covering the plots were 12x8x4 feet. They were covered with heavy muslin, single thickness.

The first cover was put on before any of the heads were out of the sheath, the second when about 75% of the plants were in bloom, the third when the plants were in full head, and the fourth when the grain was in the milk stage. The last cover, which was to have been put on when the plants were nearly mature, was not made because scab had appeared on all the plots before that time.

The highest percentage of scab (Table IX) developed on the plants in the plot covered when the plants were in full head (Plot 4). The plants in plot 2 were covered two days earlier when about 75% of the heads were in bloom. About one third as much scab developed on these plants as on those in plot 4. One and twenty two hundredths inches of rain fell and the maximum temperature (74-80°F.) for the summer (Fig. 3) was reached in the few days immediatly after these cages were put on. The temperature was approximately that which was found to be optimum for the fungus (Table VII).

The weather was dry and comparatively cool immediately after the plants in plot 1 were covered. The percentage of scab was somewhat less in this plot than in the plot covered when 75% of the heads were in full bloom (plot 2), and was much lower than in the plot covered when the plants were

TABLE IX

THE EFFECT ON THE AMOUNT OF SCAB OF COVERING PLANTS AT DIFFERENT STAGES OF DEVELOPMENT

No. of Plot	Stage of development	Date covered	No. plants counted	No. rows counted	Average per row	No scab by plants	Aver. per row	Per-cent scab
1	In sheath	6/25[a]	1546	3	515	108	36	7.1
2	75% in bloom	7/6	974	3	325	95	31	10.1
3	Check	---	1627	4	407	30	7.5	1.8
4	In full head	7/8	800	2	400	171	85	35.3
5	Check	---	675	3	225	17	5.7	2.5
6	In milk stage	7/24	1081	3	360	13	4	1.3
7	Check	---	865	3	288	13	4	1.3
8	Mature	---[b]	---	---	---	---	---	---
9	Check	----[b]	----	---	----	---	---	---

[a] Covered first with low cages, later with high.

[b] No counts made as scab had appeared on checks.

in full head (Plot 4).

There was another heavy rain on July 23, the day before the third cage was placed over the plants, at the time when the plants were in the milk stage. The temperature dropped somewhat after this time. The percentage of scab in this plot was no greater than in the check plots.

The plants are evidently most susceptible to infection before the kernels in the heads have reached the milk stage providing the humidity and temperature are high. The fungus developed best on the plants under the cages because those plants did not dry out as rapidly after a rain as those in the open. The actual moisture and temperature conditions under the cages were not recorded.

TABLE X

EFFECT OF COVERING INDIVIDUAL HEADS OF WHEAT WITH WAX PAPER BAGS ON THE PERCENT OF SCAB.

Stage of development	Number covered	Number collected	Number scabby	Percent scabby
Still in sheath	12	3	0	0
Just out of sheath	12	7	3	5
Fully out of sheath	12	8	1*	0

* Very slight infection.

A few individual heads of wheat at different stages of development were covered at the same time with wax paper bags (Plate XII). More scab developed (Table X) on those heads which were covered when they were just coming out of the sheath (Plate XII, Fig.2) than on the heads which were covered while still in the sheath (Fig.1) or on those which had completely emerged from the sheath (Fig 3). Lack of material prevented testing this further. Infection, however, is probably wind borne, and young heads are evidently more susceptible than more mature ones. Artificial inoculations (Table XII) were not successful after the heads were far out of the sheath.

VARIETAL RESISTANCE AND HOST RANGE

Wheat scab is known to attack many varieties of wheat. The Durums, as a class, and the variety Marquis are particularly susceptible. Some non-cereal plants are also considered as hosts of the scab fungus and several species of Fusarium are described as parasites on a number of the wild grasses. However, the comparative susceptibility of different varieties of wheat to the fungus has not been determined and the parasitism of the wheat scab fungus on wild grasses has not been shown.

In the summer of 1918 several varieties of wheat commonly grown in Minnesota were planted under similar conditions in the field and were sprayed with spores and mycelium of the fungus. Artificial inoculations were also made on individual heads of the different varieties of wheat and a number of the wild grasses.

The Percentage of Scab on Varieties of Wheat Inoculated by Spraying

Four rod rows of each variety of wheat were planted. Spores and mycelium of the fungus isolated from scabby wheat were sprayed on the plants when they were in full head and again three days later.

The rate of develpoment of the different varieties was not uniform (Table XI). Minnesota 470, for instance, required two weeks to reach the stage of full head from the time the heads first appeared in the sheath. The heads of the variety Preston, on the other hand, appeared in the sheath and were in full head in a week. The other varieties required about ten days. The percentage of scab on Minnesota 470 was 16.2 while that on Preston was only 2.6. There was approximately the same amount of scab as on Preston on Minnesota 163, Marquis, and Velvet Don. Minnesota 1594 was least susceptible. Minnesota 169 and Kubanka 990 plots were not pure so no counts were made.

Percentage of Scab Praduced by Inoculating Individual Heads of Cereals and Grasses

Artificial inoculations on individual heads of different varieties of wheat and the wild grasses (Table XII) were made in the following manner:

> The wheat scab fungus, usually with a small amount of the medium upon which it was grown, was pushed inside the sheath of heads which had not completely emerged, care being taken not to injure either the sheath or the head. The inoculations were made, wherever possible, on rainy or cloudy days or in the evening. Moist cotton was wrapped around the sheath after inoculation and the head and sheath covered with a wax paper bag. The string of

TABLE XI

VARIETAL SUSCEPTIBILITY OF WHEAT TO SCAB -- SUMMER 1918

VARIETY	Days required for heading.[1]	No. row	No. heads per row	Avg. no. heads per row	No. scabby heads per row	Avg. no. scabby heads per row	Per-cent scabby heads per row	Avg. percent scabby heads per row
Minn. 163	10	2 3	458 465	461	11 16	13	2.6 3.4	3.0
Minn. 1594	10	2 3	431 452	441	4 4	4	.9 .9	.9
Marquis	10	2 3	532 535	536	8 16	12	1.5 2.9	2.2.
Minn. 470	14	2 3	365 375	365	58 59	58	16.1 16.4	16.2
Preston	7	2 3	508 365	436	12 10	11	2.3 2.9	2.6
Velvet Don	10	2 3	383 431	407	5 13	9	1.3 3.0	2.1
Minn. 169	10	2 3	---	---	---	---	---	---
Kubanka 990	12	2 3	---	---	---	---	---	---

[1] Estimated from the time the heads first appeared in the sheath to time of full head.

TABLE XII

RESULTS OF INOCULATING CEREALS & GRASSES WITH THE WHEAT SCAB FUNGUS

Plant inoculated	Date in-inoculated	No plants inoc.	No. plants collected	No plants scabby
Agropyron caninum	6/25	12	7	1
Agropyron cristatum	6/19	?	3	0
Agropyron repens	6/10	?	2	1
Agropyron smithii	6/10	?	2	0
Agropyron tenerum	6/10	?	6	0
Bromus inermis	6/10	?	2	0
Elymus canadensis	7/10	12	12	11
Elymus robustus	7/10	12	12	11
Elymus virginicus	7/10	12	9	8
Lolium temulentum	7/10	12	12	0(?)
Cereals				
Barley	7/5	12	9	7
Barley (Hooded)	6/25	12	11	5(a)
Oats	6/28	12	12	9(b)
Rye	6/26	12	8	6
Wheat (Velvet Don)	7/5	12	11	8
Wheat (Preston)	7/5	12	12	11
Wheat (Minn. 470)	7/5	12	7	6
Wheat (Kubanka 990)	7/5	12	12	12(c)
Wheat (Marquis)	7/5	12	8	8
Wheat (Minn. 1594)	7/5	12	8	8
Wheat (Minn. 169)	7/5	12	12	11(d)
Wheat (Minn. 163)	7/5	12	11	9

(a) 7 heads had lost their spikelets but 3 of the 7 had definite spots on the sheath and 5 had spores on the stem.
(b) Definite spots on the sheaths of 10 infected plants.
(c) Bags left on until collected. Very heavy infection
(d) Both mycelium and spores developed from the inoculum but the infection on the plants was very weak.

the label held the bag in place (Plate XIII). The covers were left on from three days to a week.

Inoculations were not successful when made after the heads had emerged from the sheath and the glumes had begun to harden.

Only a few inoculations were made on some of the grasses because the best method for infection was not worked out until after they were in full bloom. Successful infection resulted on the three species of Elymus (Plate XIV, Fig.2) which were inoculated. Typical scab developed on Agropyron repens and A. caninum. The negative results on the other grasses inoculated are possibly due in some cases to the fact that the heads were too old at the time of inoculation.

Typical scab developed on all the varieties of wheat and other cereals inoculated, but some of the varieties of wheat were more heavily infected than others. Minnesota 470 became most heavily infected. This was true also when the plants of Minnesota 470 were sprayed with the fungus (Table XI). The infections obtained on Minnesota 169 were weak, although the inoculum had developed normally. The heavy infection on Kubanka 990 was probably due to failure to remove the covers.

Cultures were made from a number of the leaf spots resulting from artificial inoculations and invariably the organism was reisolated. Pure cultures of the organism were also obtained from browned pedicles of the artificially inoculated heads of Bromus inermis.

Symptoms typical of scab resulted from all the artificial inoculations. A pink incrustation developed on the glumes, and the kernels either did not form or were small, shrivelled, and covered with a mass of pinkish white mycelium.

Results of Inoculating Seedlings of Cereals

Inoculations were made in the greenhouse[1] to determine the effect of the wheat scab organism on seedlings of wheat, rye, barley and oats. The uninjured base of each plant was inoculated with the fungus at the surface of the soil when the plants were ten days old. The pots containing the plants were then put in pans of water under bell jars. After three days the bell jars were removed but the pots were left in the pans of water. On the third day after inoculation tufts of mycelium had formed where the inoculations were made.

Durum wheat (Table XIII) was most severely attacked - three out of the seven plants inoculated being killed. A few of the wheat, barley and rye plants were distinctly browned at the base but none of them were killed. One of the oat plants became infected but the fungus did not develop further. All the other plants developed normally.

CONTROL

No satisfactory methods of control of wheat scab are known. Selby (56,58) suggested the burning of stubble,

[1] Unpublished data taken by E.C. Stakman in the winter of 1917 at the University Farm, St. Paul, Minnesota.

cleaning of seed, and rotation of crops as preventive measures. Holbert, Trost, and Hoffer (32) found that systems of rotation had a definite relation to the amount of scab on wheat. More scab was always present on the wheat following two years of corn than on wheat following wheat. Cook and Helyer (16) suggested that seed from a diseased plot should not be planted.

Much work has been done on the control of the disease known as "Schneeschimmel" in Europe. Hiltner (24,27) gave

TABLE XIII

RESULTS OF INOCULATING CEREALS IN THE SEEDLING STAGE WITH THE WHEAT SCAB FUNGUS

Plant inoculated	Result	Character of Infection	
		Date Observed	
		2/3/17	2/6/17
Rye	1/2*	Quite distinctly browned at the base; plants stunted	No change
Oats	1/9	Possibly slightly affected; infection taken place but development of the fungus little.	Do.
Durum	4/7	Distinctly affected; 2 nearly dead, bases of plants browned and softened, 1 breaking over, 1 dead - rotted near base.	3/7 dead; 1 large, 2 small, all but one of others affected.
Wheat	2/7	Distinctly browned at the base	No change
Barley	5/9	Distinctly browned at the base, none dying.	No change

*Denominator the number of plants observed; numerator the number of plants affected.

treatment with corrosive sublimate or formaldehyde as being effective in decreasing the damage done by the fungus causing the disease. Weidner (75) described two preparations which were found useful in control. Naumov (40) suggested the use of healthy seed, crop rotation, and immediate threshing after harvest.

Some of these methods have been tried on a small scale in attempting to reduce the damage done by the wheat scab organism in this country. Field experiments were conducted in the summers of 1917 and 1918 to test further the effect of seed treatment. Controlled experiments in the greenhouse were also carried out.

Results of Treatment with Formaldehyde on Scab in the Field

In 1917 the shrivelled kernels from scabby seed were separated from the plump kernels by fanning, and part of each grade was treated with formaldehyde. One square rod each of the treated and untreated lots were planted.

The average number of plants per row (Table XIV), when the seedlings were counted, was least on the plot planted with shrivelled untreated seed. The plot planted with plump untreated seed developed a larger number of seedlings than the plot planted with plump treated seed. The percentage of scab, on the other hand, averaged considerably higher on the treated plots. The plot planted with plump treated seed produced a smaller yield than the plot planted with shrivelled treated seed or than either of the untreated plots. In 1918 a similar experiment was conducted. The percentage of scab was again considerably higher on the treated than on the untreated plots.

TABLE XIV

RESULTS OF TREATING SCABBY SEED WITH FORMALDEHYDE

Grade of Seed	Treatment	Germination of seed per row	No. heads counted	No. scabby heads	Percent. of scabby heads	Yield in lbs.
1917						
Date observed		5/15	8/17	8/17	8/17	8/18
Plump	Formaldehyde 1:320	145	2105	35	1.66	9.6
Shrivelled	Do.	175	2938	33	1.12	11.9
Plump	None.	196	3764	13	.35	11.7
Shrivelled	Do.	111	2507	21	.87	11.7
1918						
Plump	Formaldehyde (1:320)	---	875	7	.79	---
Shrivelled	Do.	---	870	10	1.14	---
Original	Do.	---	976	8	.84	---
Plump	None.	---	1003	6	.59	---
Shrivelled	Do.	---	939	2	.21	---
Original	Do.	---	932	1	.10	---

These results indicate that infection of the heads is local and has no immediate relation to the planting of scabby seed. The higher percentage of scab on the plots planted with treated seed is possibly due to the somewhat heavier stand.

Results of Treatment with Formaldehyde on Scab in the Greenhouse

Three series of pots were planted in the greenhouse, one series with healthy seed, one with treated scabby seed, and one with untreated scabby seed[1]. Twenty five pots were used in each series and ten seeds were planted in each pot. Only 21.2% of the untreated, scabby seed produced mature plants (Table XV). Over eighty percent of the treated scabby seed, on the other hand, grew to maturity as compared to about ninety percent of the healthy seed (Plate XVIII).

TABLE XV

RESULTS OF TREATMENT ON THE NUMBER AND SIZE OF PLANTS AND ON THE PERCENTAGE OF SCAB. GREENHOUSE 1917

Kind of seed	Treatment	No. pots	No. seeds per pot	No. plants growing 3/6	% plants growing 3/6	Avg. growth per plant 4/7	% scab at maturity 7/19
Healthy	None	25	10	224	89.6	8.38 in.	0
Scabby	Formaldehyde 1:320	25	10	204	81.6	7.96 in.	0
Scabby	None	25	10	53	21.2	7.41 in.	0

The plants were measured when they were about two months old. The average height of the plants grown from

[1] Unpublished data taken in the greenhouse in the winter of 1917 under the direction of E.C.Stakman.

healthy seed was slightly greater than that of those grown from scabby seed. Very slight difference resulted in the average height of the plants grown from treated and untreated seed. The plants were allowed to grow to maturity but no scab developed on any of the heads produced.

Planting scabby seed lowers the average germination of the seed and healthy seedlings may be attacked by the organism and be killed. The plants which survive the seedling stage, however, apparently may grow to maturity and produce healthy seed unless subsequently infected. In other words, infection is local and not systemic.

CONCLUSIONS

In this work an organism having characteristic cultural characters was isolated from scabby cereals. However, there was some variation within the group and inoculation experiments may bring out different infection capabilities for some of the different strains. The Fusaria isolated from roots or nodes of cereals or from potatoes were not identical culturally with the wheat scab fungus but their pathogenicity to heads of cereals has not been determined. The fungus causing scab, however, is known to rot potatoes and also to attack roots of seedlings. The interrelation of the Fusaria from cereals, grasses, and potatoes and other root crops should be definitely determined.

The spores from scabby heads of different varieties of wheat were found to differ somewhat morphologically. This suggests the possibility that the morphology of the organism is easily changed by the host upon which it is grown, or that there are several distinct strains of Fusarium which may cause scab of cereals. Careful physiological and morphological studies of the organisms causing scab and seedling blights should be made.

The optimum temperature for the production of scab of cereals in the field was found to be approximately that of the optimum for the fungus. A temperature of 76° F. or above and high humidity while the heads are forming are apparently necessary for the development of an epidemic of scab. This would probably explain the occurrence of serious epidemics of scab at irregular intervals.

Apparently the use of scabby seed does not directly affect the amount of scab on the heads. The persistent use of scabby seed, however, would undoubtedly increase the number of spores in the soil and consequently the possibility for infection on the heads.

All of the cereals and a number of the wild grasses are hosts of the organism which causes wheat scab. The disease is fairly common on the hosts other than wheat but apparently little damage is done. However, these hosts may increase the amount of scab present and be a source of infection for wheat. Careful observations should be made to ascertain the relative prevalence of the disease on all the cereals and wild grasses.

The organism lives over winter in the seed of cereals, on corn roots and stubble, and also may attack the roots and heads of the cereals and a number of the wild grasses. It also may cause a rot of potatoes and other root crops, and is considered to be an active parasite on legumes. In view of these facts, the usual recommendations that the seed be fanned, graded, and treated before planting are not sufficient to control the disease. Fanning of the seed no doubt removes a large proportion of the scabby kernels but in heavily infected seed many kernels containing the organism are not removed. Furthermore, treatment of scabby seed with formaldehyde reduces the seedling blight but the head infection is not controlled. General soil sanitation, including the rotation of crops, or the use of seed which is known to be free from the disease, or careful fanning, grading, and treating of the seed will decrease the damage done to seedlings, and reduce the amount of soil contamination and consequently the infection of the heads.

SUMMARY

1. An organism with characteristic cultural characters was isolated from scabby cereals.

2. Morphologically the spores from scabby heads of cereals in the vicinity of St. Paul were found to agree more closely with spore measurements given for *Fusarium roseum* Link than for *Fusarium culmorum* (W. G. Sm.) Sacc. *Gibberella Saubinetii* (Mont.) Sacc. was also found associated with the disease.

3. The mycelium in the kernels of scabby wheat was not killed after several months exposure to winter weather. However, spores kept in the light, either inside or outside, were killed, while spores under similar conditions but in the dark retained their viability.

4. The minimum temperature for growth of the wheat scab organism on artificial media is approximately 5° C., the optimum 25° C., and the maximum between 30° and 35° C.

5. The stand in plots planted with scabby seed was reduced by one third as compared with that in plots planted with healthy seed. Furthermore, scabby seed planted late and following a storm produced a poorer stand than scabby seed planted early and in dry soil.

6. Infection of the heads takes place best before the heads reach the milk stage provided the humidity and temperature are high.

7. The highest percentage of infection on the varieties of wheat used was obtained on Minnesota 470. All of the cereals and a number of the wild grasses were successfully infected with the fungus isolated from scabby wheat.

8. Treatment of scabby seed with formaldehyde reduced the seedling blight but the head infection was not controlled.

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EXPLANATION OF PLATES

PLATE I - Scab on the heads of Marquis wheat.

PLATE II - Fig. 1 - Diseased spikelet of wheat dissected, showing shrivelled kernels which are covered with mycelium.

Fig. 2 - Healthy spikelet.

PLATE III - Enlarged spikelets showing scab on the glumes.

PLATE IV - Head of wheat (Minn. 470) showing Gibberella Saubinetii (Mont.) Sacc. on a single spikelet.

PLATE V - Fig. 1 - Enlarged head of a hybrid wheat (Imuillo X Marquis, F_3) heavily infected with Gibberella.
Fig. 2 - Gibberella on glumes of wheat and diseased kernels.

PLATE VI - Fig. 1 - Seed from a scabby crop.
Fig. 1_o- Light shrivelled kernels removed by thorough fanning.
Fig. 2 - Heavy, plump, healthy seed left after thorough fanning.
Fig. 3 - Moderately scabby seed obtained by medium blowing.

PLATE VII - Cultural characteristics of Fusaria isolated from different parts of cereal plants:
Fig. 1 - From scabby head of wheat (Minn.470) Color dark.
Fig. 2 - From scabby head of rye.
Fig. 3 - From browned glumes of wheat. Fungus pure white.
Fig. 4 - From diseases roots of wheat. Fungus white and growth slow.

PLATE VIII - Spores from scabby heads of cereals collected in the fall of 1918 at University Farm, St. Paul. (X 760)
Fig. 1 - Velvet Don Wheat.
Fig. 2 - Wheat (Minn.163)
Fig. 3 - (a) From one head of Minn. 470.
(b) From another head of Minn. 470.
Fig. 4 - Rye
Fig. 5 - Wheat (Minn. 1594).
Fig. 6 - (a) From one head of Marquis wheat
(b) From another head of Marquis wheat.
Fig. 7 - Wheat (Minn. 169).
(a) Natural Infection.
(b) Artificial Inoculation.

Fig. 8 - Barley (From Wabasha, Minn.)
Fig. 9 - Club Wheat.
Fig. 10 - Wheat (Preston).

PLATE IX - Fig. 1 - Conidiophores of the wheat scab organism from scabby heads of cereals (X 760)
Fig. 2 - Germinating spores of the wheat scab organism after 12 hours in sugar solution. (X 1100).
Fig. 3 - Mycelium of the wheat scab organism from beerwort agar. (X 1100).
Fig. 4 - Perithecium of Gibberella Saubinetii (Mont.) Sacc. from head of wheat. (X 160).
Fig. 5 - Detail of the perithecial wall. (X 1100).
Fig. 6 - Immature asci from perithecium. (X 760)
Fig. 7 - Mature ascus. (X 760).
Fig. 8 - Ascospores. (X 760).

PLATES X and XI - Temperature relations of the organism

Fig. 1 - 5°C. Fig. 4 - 20°C.
Fig. 2 - 10°C. Fig. 5 - 25°C.
Fig. 3 - 15°C. Fig. 6 - 30°C.

PLATE XII - Stages of development of the heads when covers were put on:
Fig. 1 - Head not out of sheath.
Fig. 2 - Head just emerging from sheath.
Fig. 3 - Head completely emerged from sheath.

PLATE XIII - Method of covering heads after artificial inoculations were made.

PLATE XIV - Fig. 1 - Wheat (Minn. 163) artificially inoculated.
Fig. 2 - Elymus virginicus artificially inoculated.

PLATE XV - Fig. 1 - Leaf spot on sheath of rye produced by artificial inoculation with the wheat scab organism.
Fig. 2 - Same on sheath of oat plant.

PLATE XVI - Artificially inoculated head of oats.

PLATE XVII - Fig. 1a - Seed of Hystrix patula shrivelled from artificial inoculation with the wheat scab organism.
Fig. 1b - Same uninoculated.
Fig. 2a - Healthy seed and spikelet of oats.
Fig. 2b - Stamens of oats which ceased to develop due to artificial inoculation with the wheat scab fungus. Also a diseased spikelet. Both from the same head as Fig. 2a.

PLATE XVIII - Pots planted with healthy seed and treated and untreated scabby seed:
Fig. 1 - Healthy seed
Fig. 2 - Scabby seed treated.
Fig. 3 - Scabby seed untreated.

Plate I

Plate II

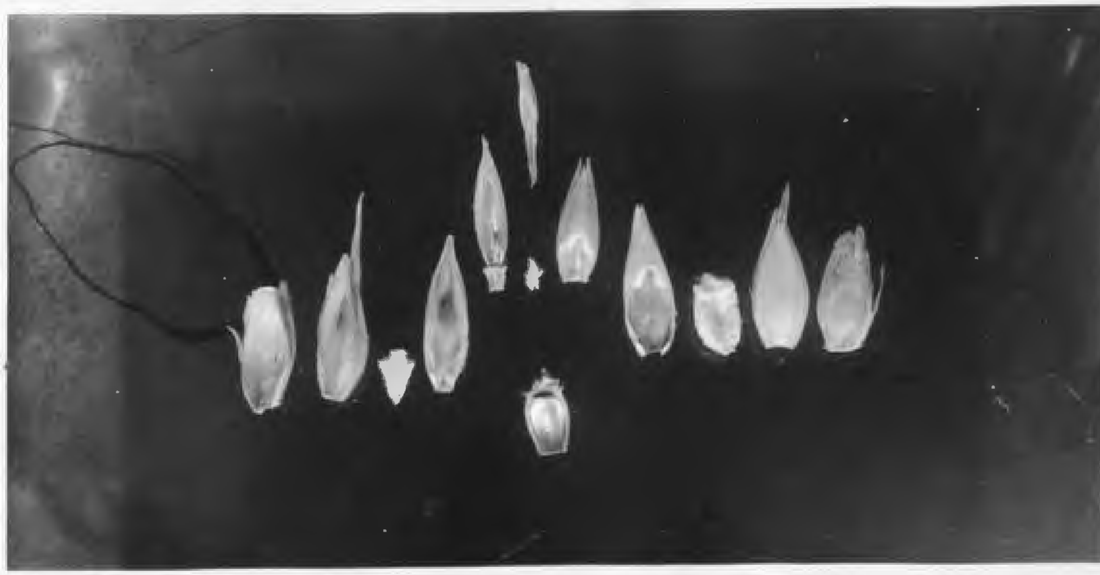


Figure 1

Figure 2

Plate III

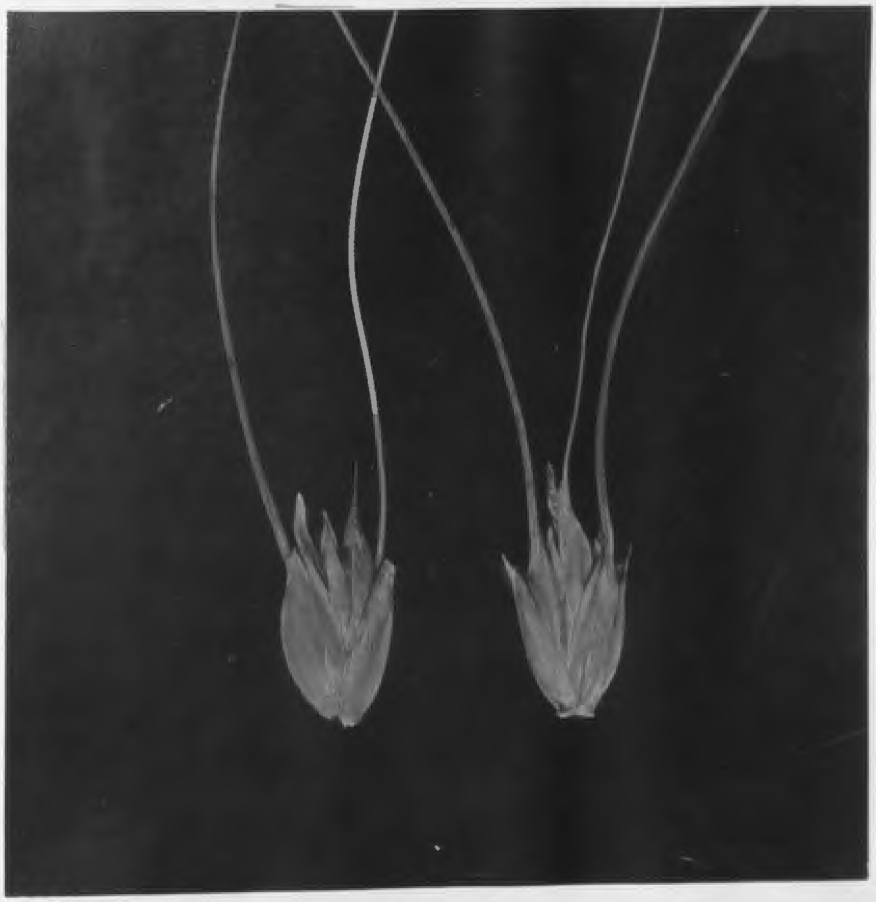


Plate IV

Plate V

Figure 1

Figure 2

Plate VI

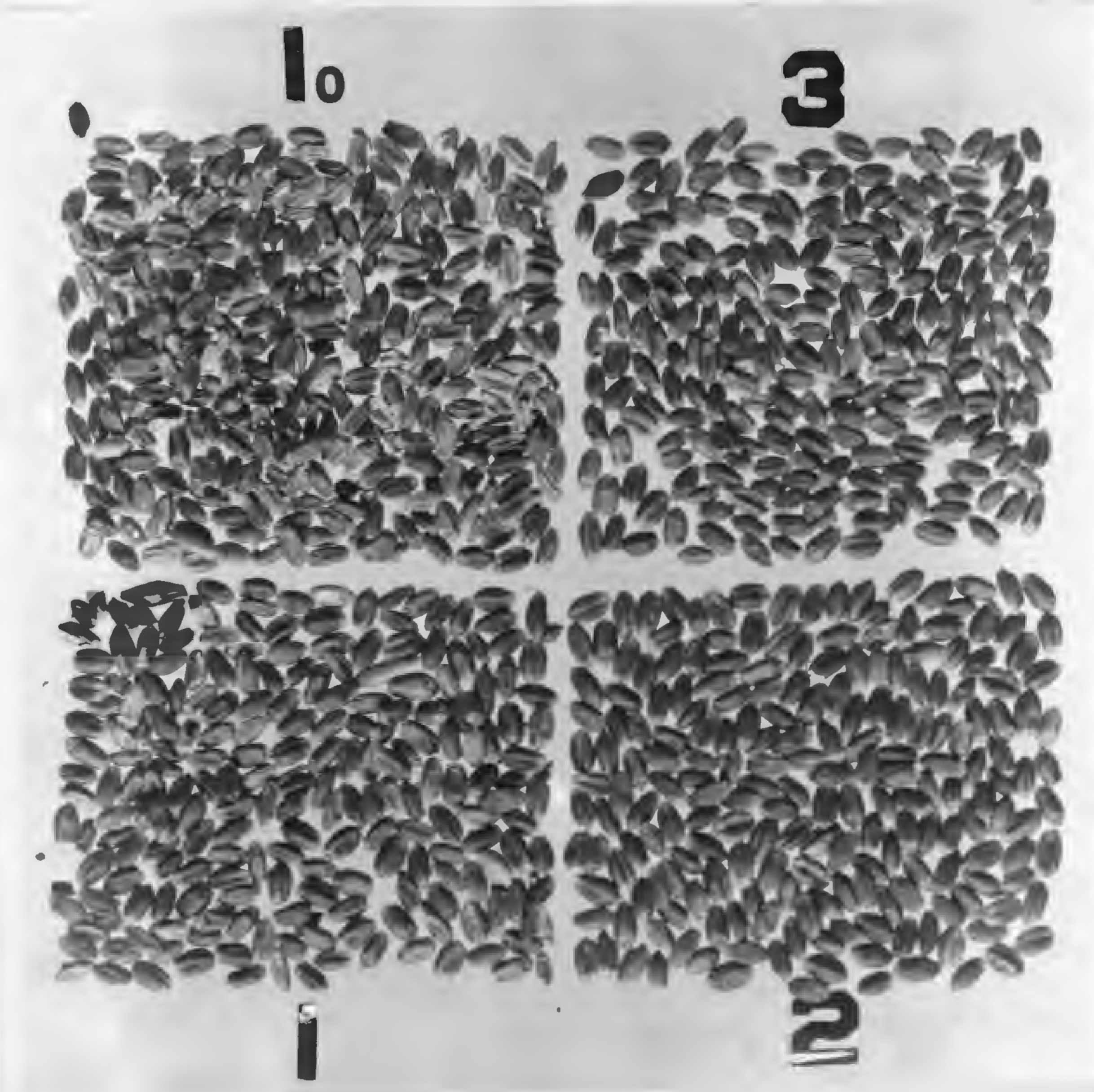


Fig. 1
Fig. 2

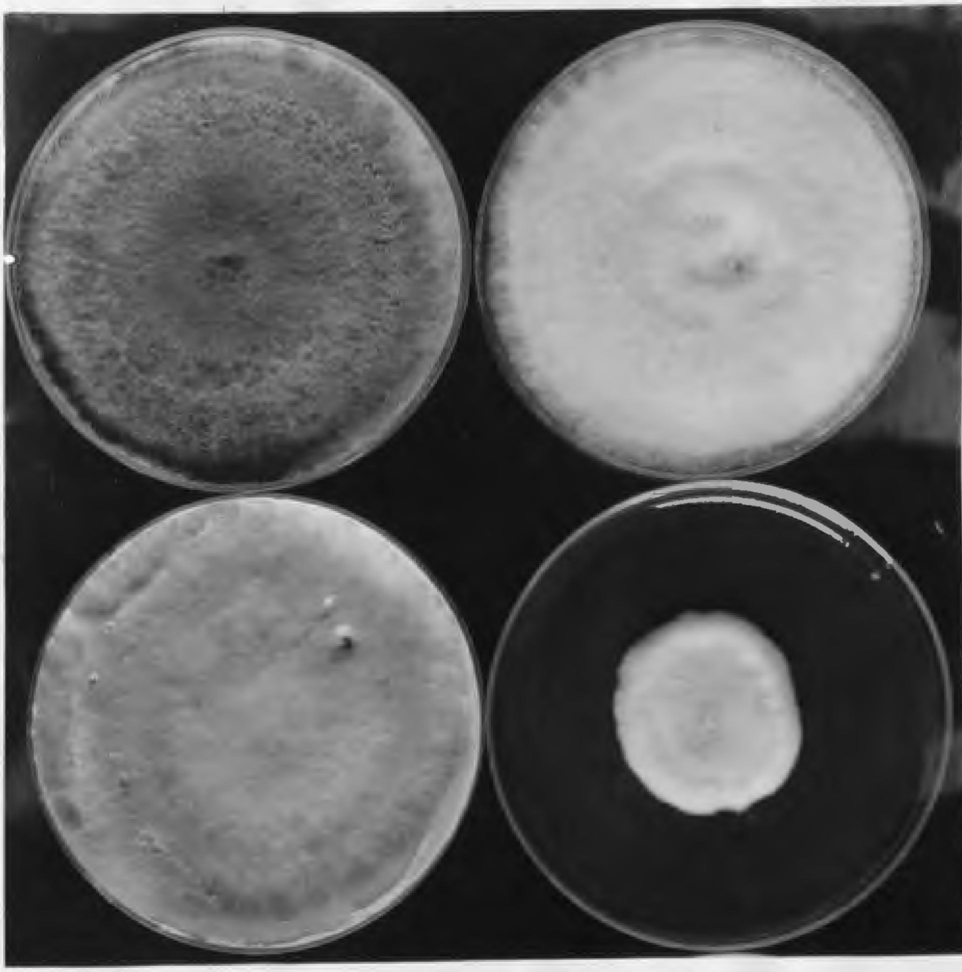


Fig. 3
Fig. 4

Plate VIII

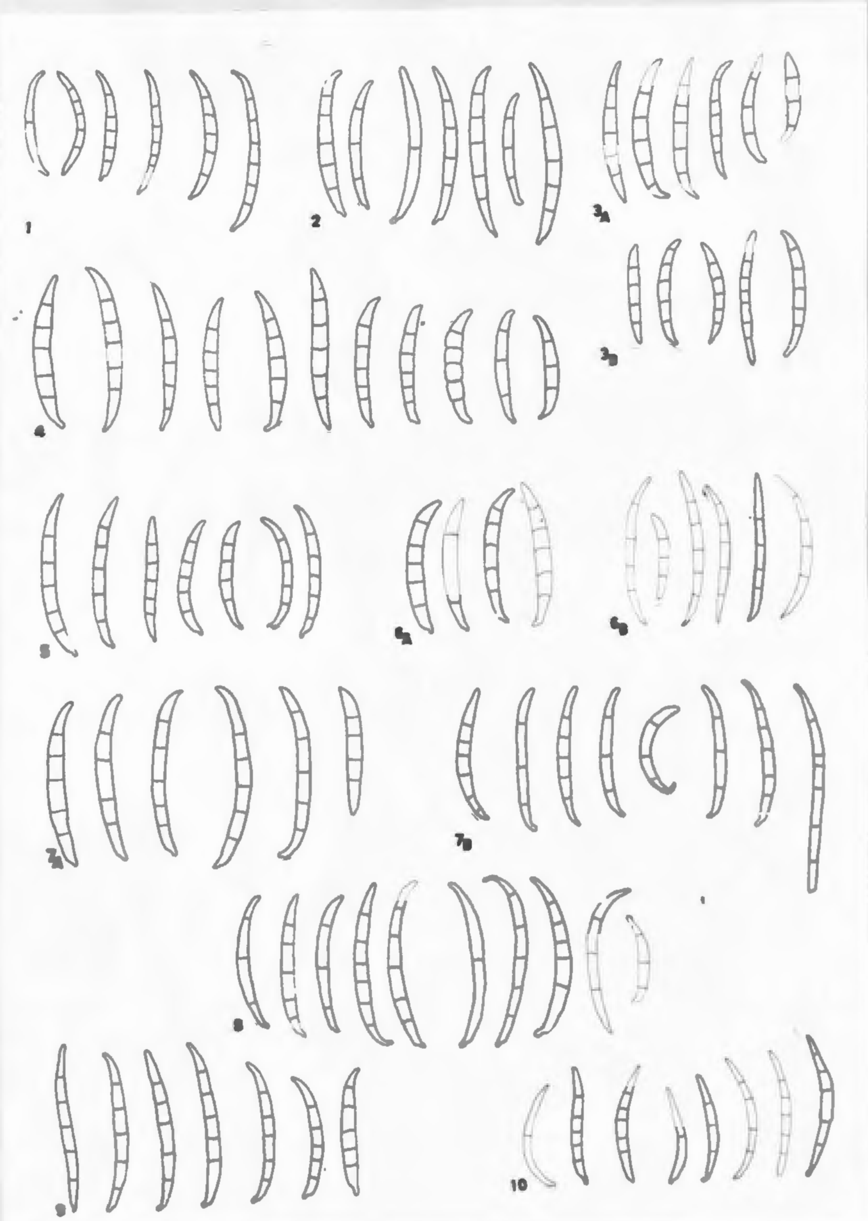
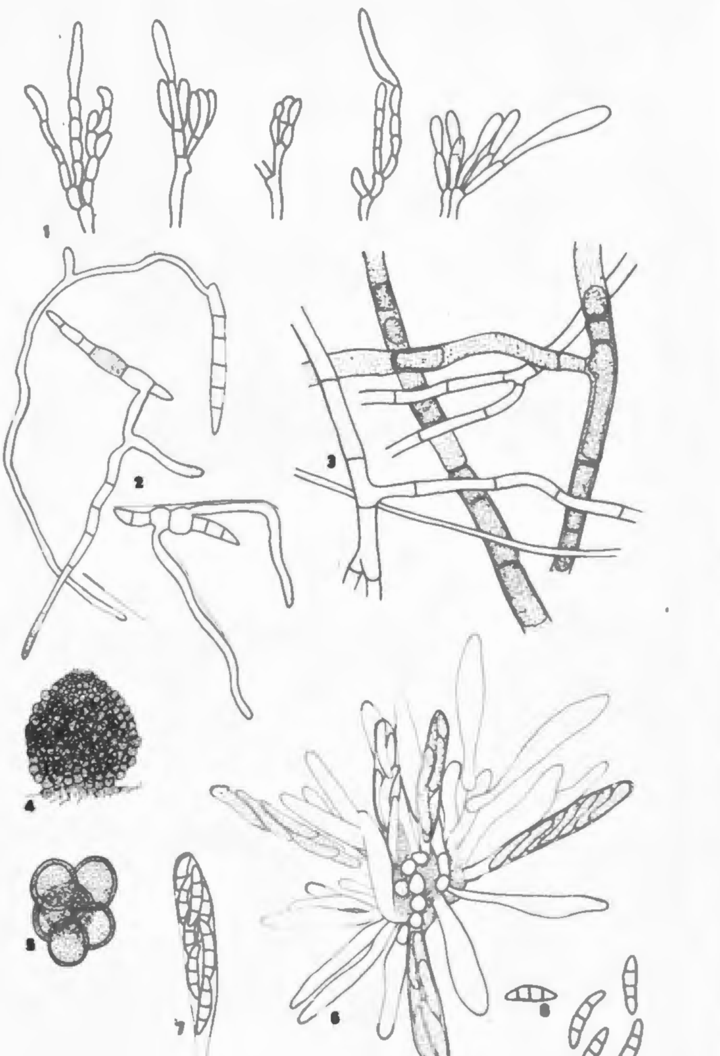


Plate IX



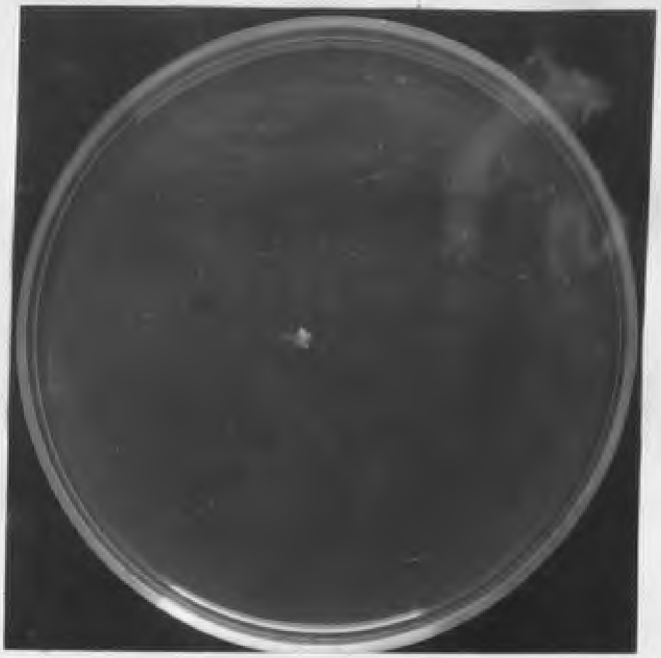


Figure 1

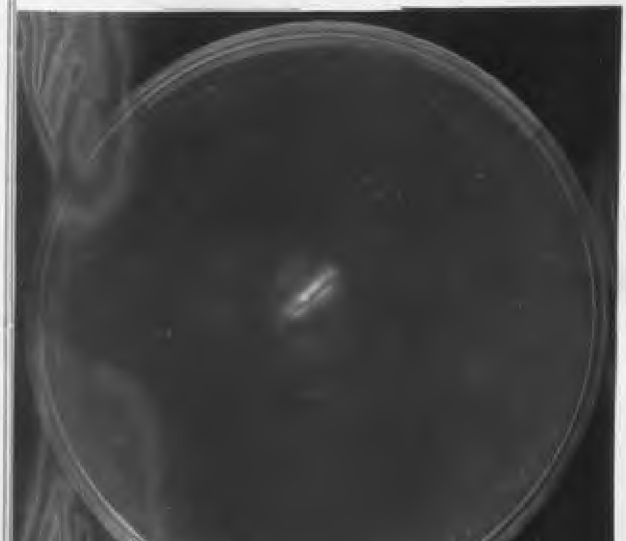


Figure 2

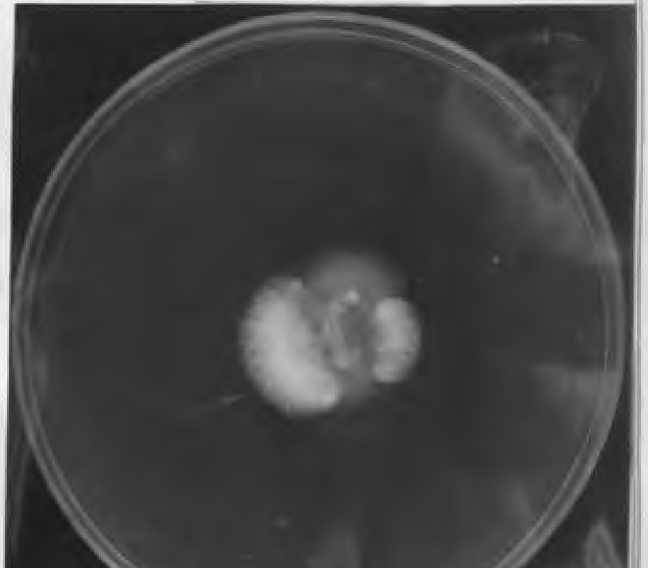


Figure 3

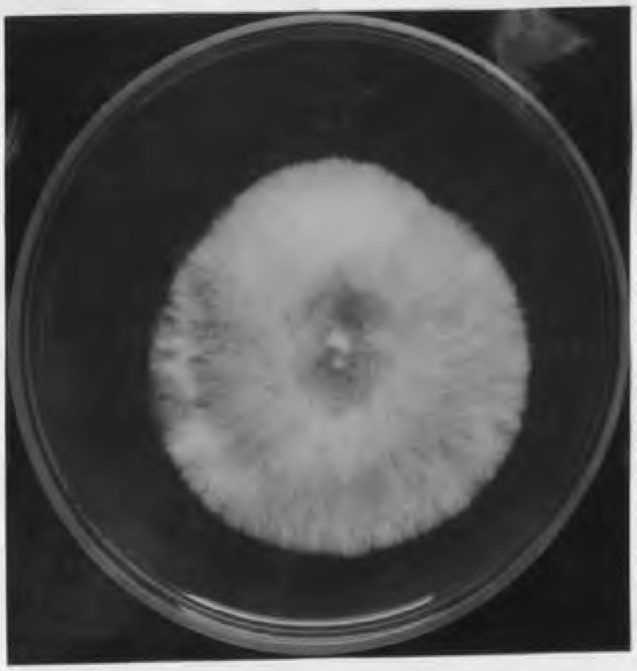


Figure 4

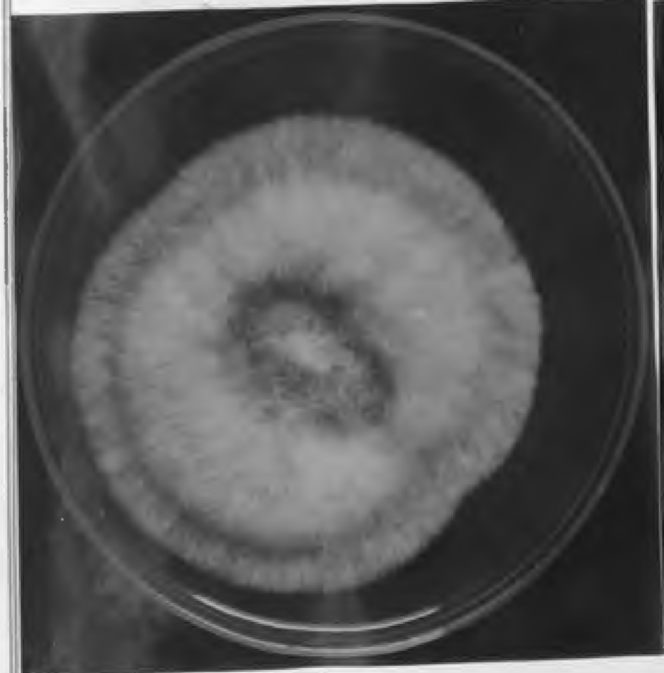


Figure 5

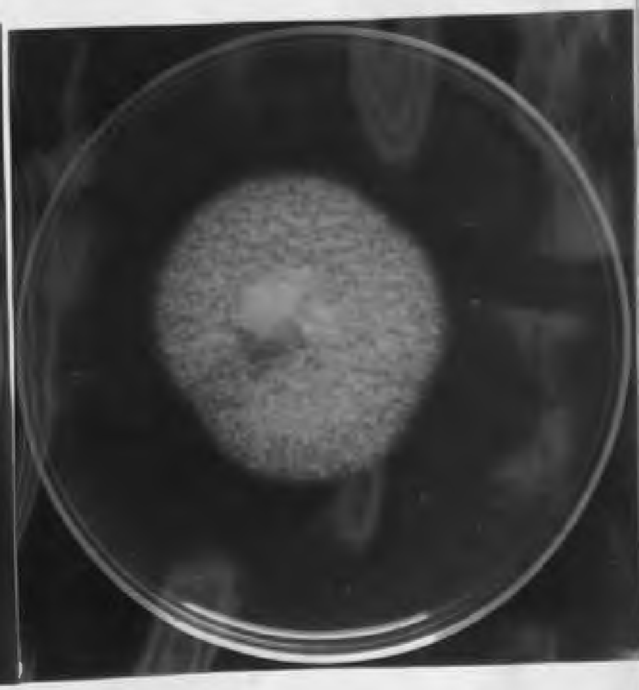


Figure 6

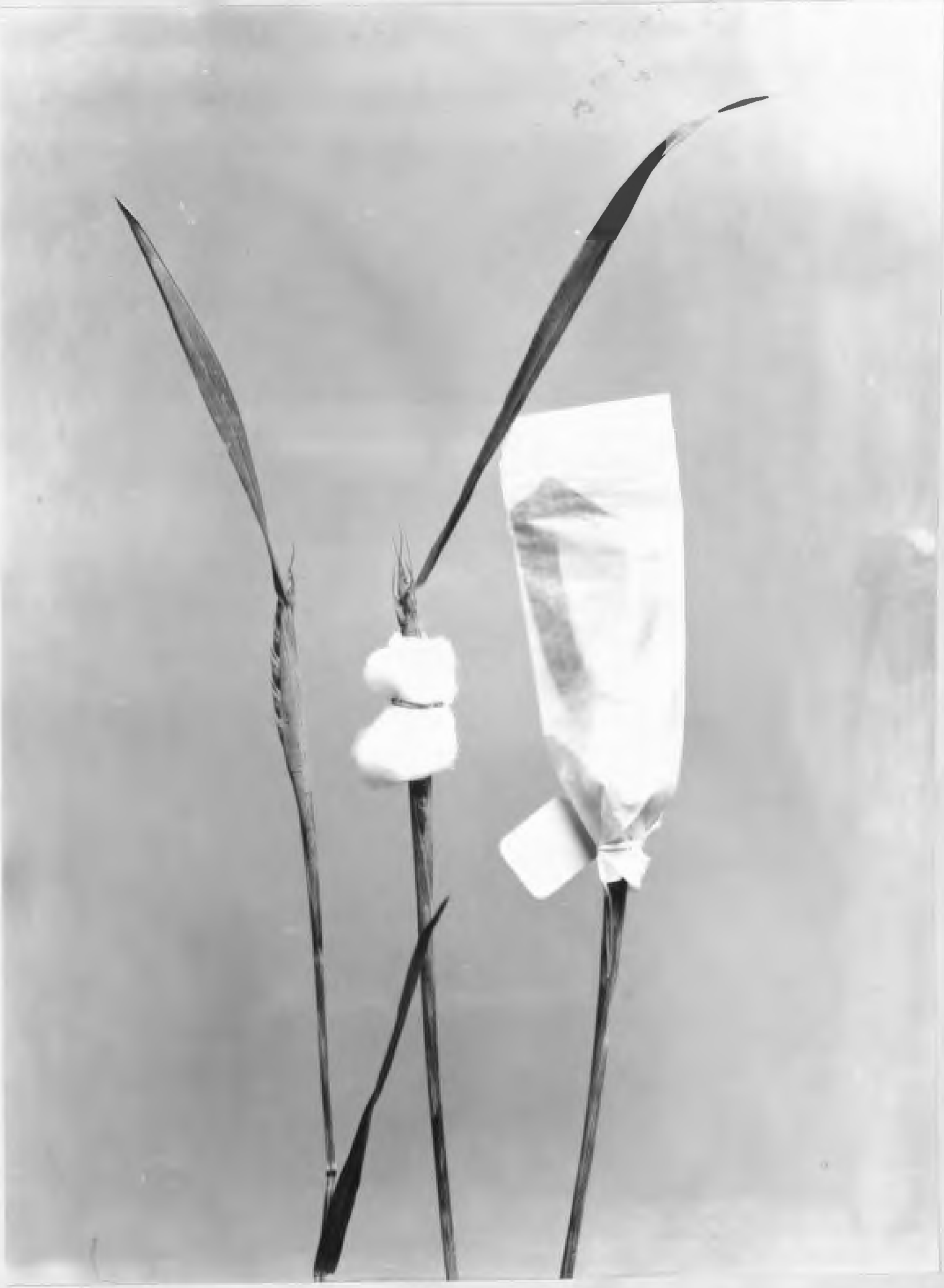


Plate XII

Figure 1

Figure 2

Plate XV

Figure 1

Figure 2

Plate XVI

Plate XVII

Fig. 1a   Fig. 1b

Fig. 2a   Fig. 2b

Plate XVIII