THE PASMO DISEASE OF FLAX[1]

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INTRODUCTION

The disease of flax called "pasmo" in South America and the causal organism, *Phlyctaena linicola*, were described by Spegazzini[3] in 1911 from the vicinity of La Plata, Argentina. Girola[4] described the disease more fully, and noted that it caused great injury to flax in Argentina.

In the United States the disease has been noted for several years. In 1916 H. L. Bolley called the attention of C. S. Reddy, at that time in charge of flax-disease investigations, to a disease in his resistant flax which he did not attribute to wilt. In 1917 Reddy isolated the organism and with it performed inoculation experiments in which typical symptoms of the disease were reproduced on flax. In the fall of 1920, on seeing the article by Girola, Reddy was practically certain that this disease was the pasmo disease of flax of South America. Since 1919 the writer[5,6] has noted the disease each season in North Dakota and in certain other States.

The disease appears to have been introduced into the United States with imported flaxseed. Frequently it has been observed at Fargo, N. Dak., that when nonselected flaxseed from Argentina was grown the first year the pasmo disease developed earlier in plats from such seed than in others. It was from such plats that the disease appeared to have originated and spread to other flaxes. Further, many of the selections and hybrids of Argentine flax are very susceptible to the pasmo disease when grown in the United States. For these reasons, and from the fact that many spores of the fungus may be carried on seed coming from infested fields, it appears very probable that the disease was introduced with imported seed.

The present paper summarizes observations on the disease in the United States and gives the results of investigations as far as they have progressed.

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[2] The writer wishes to express his indebtedness to H. L. Bolley, North Dakota Agricultural College, for many helpful suggestions; and to A. G. Johnson, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, for advice, helpful suggestions, and assistance in revising the manuscript; and to A. C. Dillman, Office of Cereal Investigations, for making field observations on the occurrence and severity of the disease at various points, and for critically reading the manuscript.

[3] SPEGAZZINI, C. MYCETES ARGENTINENSES. An. Mus. Nac. Buenos Aires (III) 13: 389-390. 1911.

[4] GIROLA, C. D. CULTIVO DEL LINO EN LA REPUBLICA ARGENTINA. An. Soc. Rural Argentina 54: 105-112, 145-149, 189-197, illus. 1920.

[5] BRENTZEL, W. E. A DISEASE OF FLAX NOT PREVIOUSLY REPORTED IN THE UNITED STATES. (Abstract.) Phytopathology 13: 53-54. 1923.

[6] ——— FURTHER INVESTIGATIONS ON THE PASMO DISEASE OF FLAX. (Abstract.) Phytopathology 14: 48-49. 1924.

DISTRIBUTION AND ECONOMIC IMPORTANCE

During the past three years the disease has been observed on seed flax at various points in North Dakota, especially near Casselton, Fargo, Lisbon, Joliette, Langdon, and Mandan. It has occurred also near Newell, Pierre, Watertown, and Brookings, in South Dakota; and in Hennepin, Ramsey, and Watonwan Counties in Minnesota. In 1922 and 1923 the disease occurred with marked severity near East Lansing, Mich.

The disease occurs on seed flax throughout the most important area of production, and, with temperature and moisture favorable, develops and spreads rapidly, causing more or less blighting and browning of the different parts of the plants. In the advanced stages of infection the leaves, flower buds, and bolls are blighted (pl. 1). The leaves wither and fall or sometimes curl and remain attached. Many bolls fail to fill while others develop shriveled seed. Sometimes the disease develops relatively late in the season and does not reduce the seed yield markedly, although at harvest time the plants may be generally covered by the lesions. With a severe attack the large lesions cause irregular drying and hardening of the stems. Fiber flax, intended for fiber purposes becomes severely damaged by the disease.

SYMPTOMS

The disease spreads readily from infested straw, and may be found on the leaves of seedling plants growing on soil where diseased straw from a previous flax crop has been plowed under. Lesions develop first on the cotyledons (pl. 2, A) and later on other leaves (pl. 1), but rarely if ever on the stems of very small plants. The lesions on the leaves are more or less circular in outline, varying in color from greenish yellow in the early stages to dark brown in the advanced stages of development (pl. 1). Pycnidia develop abundantly both in cotyledons and in the other leaves.

In the field the disease first becomes noticeable to the grower only a short time before harvest. Brown areas develop here and there which enlarge and in time may cover a considerable part or all of the field. The plants at the margins of the spots are only slightly infected and in general may appear almost free from the disease. If examined closely, only small lesions may be seen on the stems, while the leaves may be so slightly infected that they still remain turgid. Toward the center of a spot the disease appears successively more and more severe on the plants. The lesions are larger and some of the leaves are withered or fallen. At the center many of the plants are completely defoliated and the stems are brown and dry. Spores from these diseased plants blow to neighboring plants and, by secondary infections, spread the disease over considerable areas.

On the stems of the plants the lesions develop first on the lower portions. In the early stages the lesions are very small, somewhat elongated, and extend only part way around the stem. Later, they occur on all parts of the stems and develop sufficiently to encircle them and extend up and down the stem for several centimeters. At this stage of development the infected portions alternate with irregular bands of uninfected green portions, displaying a mottled appearance of the stems and pedicels. This mottling is very characteristic of diseased plants (pl. 1). The browned lesions often


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coalesce so as to cover large portions, or even all of the plant. These display about the same range of color changes as do lesions on the leaves and become thickly dotted with pycnidia. Often white spore-tendrils or spore-horns develop (pl. 2, C), which give the infected areas a grayish, pubescent appearance.

When an application of infested straw was used as inoculum in experimental plats very severe infection developed. The symptoms of the disease in this case varied somewhat from the usual in that infection developed earlier. Some time before the mottled appearance occurred, large lesions developed on the stems at the soil line. Many of the plants bent and in some cases broke over at these points. This condition resulting from the disease has not been observed in fields where infection came about through natural means.

THE FUNGUS

When studies of this disease were first begun the question arose as to the generic classification of the fungus, which somewhat resembles certain species of Septoria. The pycnidia, however, are not limited to the leaves, but also occur in lesions on the stems, and are more or less incomplete at the top, as shown in Plate 3. The fungus was tentatively placed in the genus Phlyctaena and thought to be the same as that causing the pasmo disease in South America. In 1911 Spegazzini described the disease in South America and attributed it to the fungus which he described and named *Phlyctaena linicola.* In 1922 specimens of the disease in the United States were sent to Spegazzini for examination and comparison. These were definitely identified by him as typical of the pasmo disease as it occurs in Argentina. Specimens of *Phlyctaena linicola* on flax from Argentina also were kindly sent by Spegazzini, and they agree morphologically with the fungus in the United States.

The following is the original description of the fungus *Phlyctaena linicola,* as given by Spegazzini:[7]

Diag. Partes infectae primo lutescentes serius pallescenti-arescentes; perithecia minutissima subepidermica discreta confertiuscula pusilla subincompleta; sporulae e cylindraceo subfusoideae non v. lenissime curvulae mediocres hyalinae continuae.

Hab. Ad folia caulesque *Lini usitatissimi,* morbum vulgo "passmo" vocatum efficiens, vulgata in campis prope La Plata, Dec., 1909.

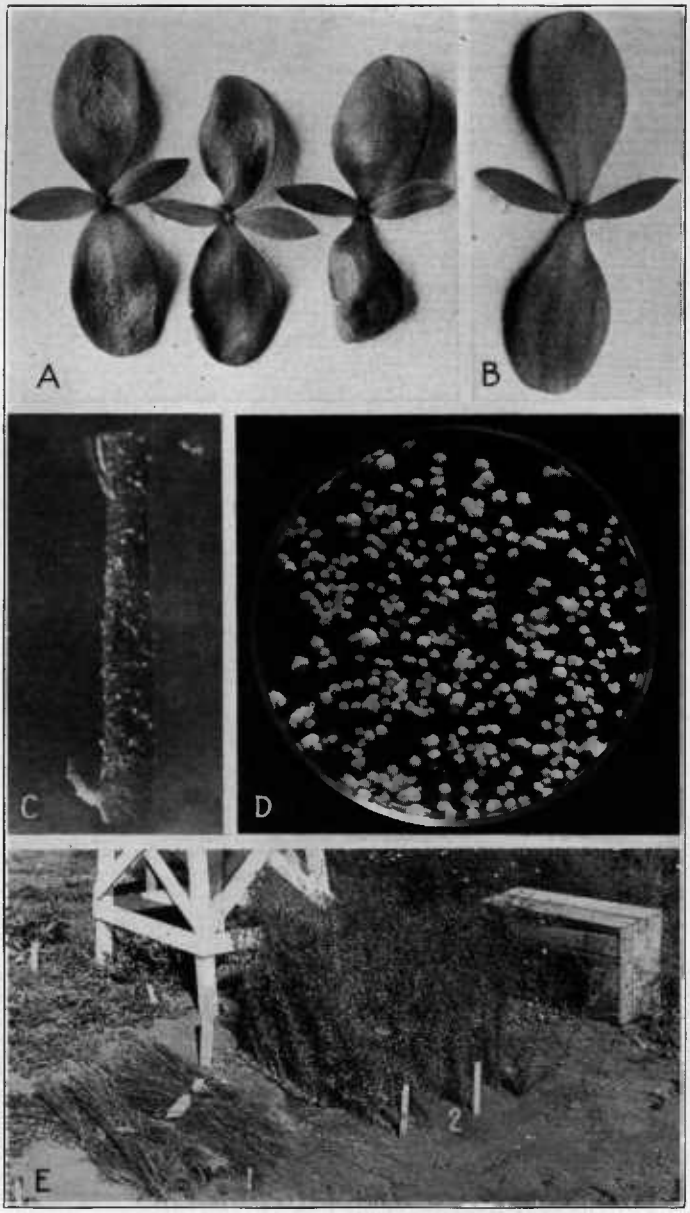
Obs. Species plantae hospitanti summopere obnoxia. Matrices primo pallescenti-flavescentes, serius lutescentes postremo arescentes; perithecia cortice v. parenchymate innata, epidermide tecta, numerosa, primo fulvescentia, superne incompleta subhyalina late fimbriato-ostiolata serius fusca subcompleta minute ostiolata, lenticularia (75–150 μ diam.); sporulae utrinque subattenuatae sed subobtusiusculae (20–30$\mu \times 1$, 5—3 μ) eguttulatae.

The fungus grows readily in artificial culture. On plates of potato-dextrose agar it grows slowly, forming small, raised colonies with sparse, white aerial mycelium (pl. 2, D). In a test tube on the same agar the growth spreads slowly in a circular manner until it reaches the sides of the tube, after which it elongates somewhat, but not sufficiently to cover the entire surface of the agar. A very limited to medium amount of mycelium develops in culture and pycnidia

[7] SPEGAZZINI, C. MYCETES ARGENTINENSES. An. Mus. Nac. Buenos Aires (III) 13: 389-390. 1911.

EXPLANATORY LEGEND FOR PLATE 1

Flax plants showing the effects of the pasmo disease on different parts. Flower buds, bolls, and leaves are blighted. The mottled appearance of the stems is typical of the disease



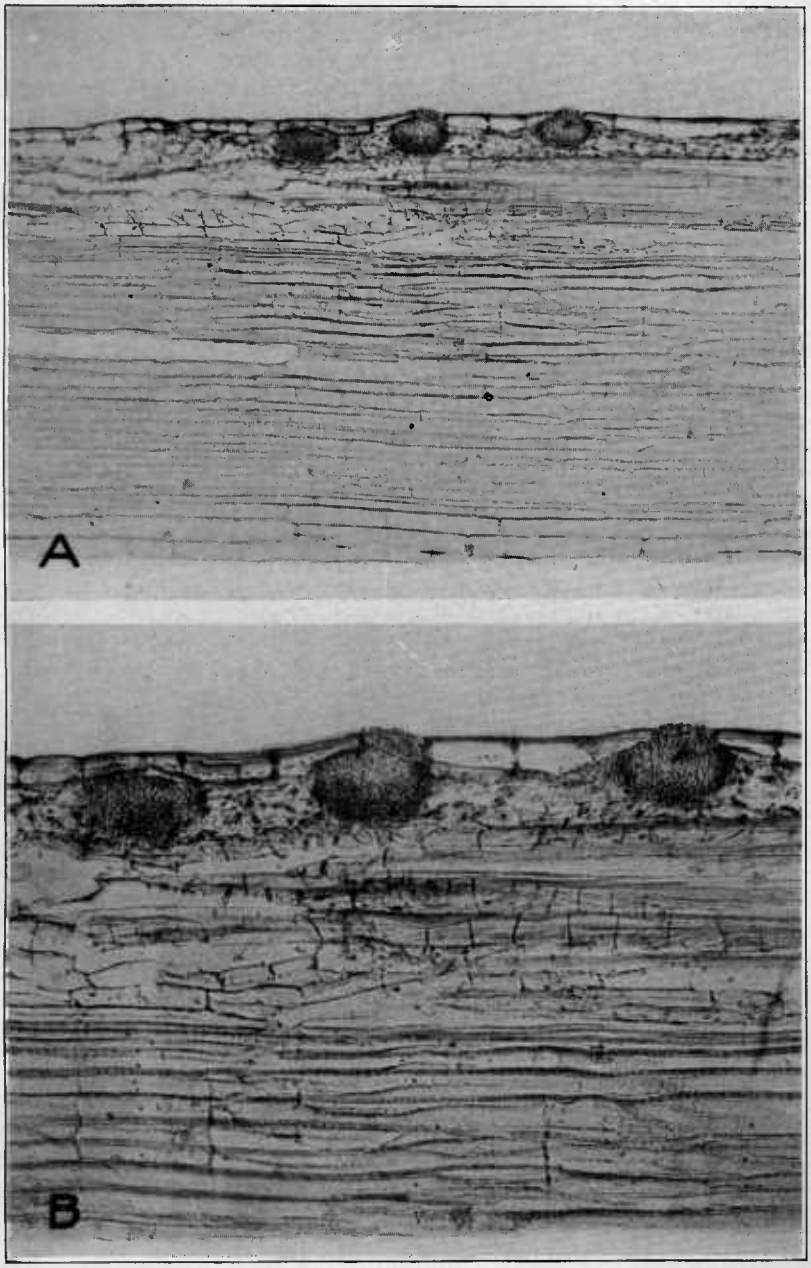
A—Infections on cotyledons of flax, a selection of the Argentine type, C. I. No. 280, (N. D. R. No. L. 79), from artificial inoculations with *Phlyctaena linicola*

B—Cotyledons of same flax, uninoculated. This strain is very susceptible to pasmo

C—Portion of pasmo-infected flax stem, showing "spore-horns" projecting from pycnidia

D—Eight-day-old agar-plate culture of *Phlyctaena linicola*, showing small, raised, white, mycelial colonies.

E—(1) Bundles of old pasmo-infected straw, from the crop of the year before and overwintered outdoors, lying near growing flax. (2) Growing flax. The plants in the rows nearest to the old infested straw were the first to show pasmo infections, and on the stems the infections were most abundant on the side toward the infested straw



Longitudinal sections of diseased flax stems, showing the pycnidia of *Phlyctaena linicola* beneath the epidermis and the mycelium extending to the region of the bast-fiber cells

develop abundantly (pl. 4). The spores form in raised masses, often extending from 1 to 5 mm. above the surface of the medium. Sometimes a circle of mycelium forms around the raised mass of conidia in the cultures. Usually this mycelium is almost white, although it may vary to dark olive gray in color. The center of the growth becomes more or less thickly set with papillated masses of conidia of an auburn color. Sometimes tendril-like spore masses protrude, which resemble somewhat the spore-horns on the stems of plants, but are larger and slightly colored. The substratum becomes variously discolored, sometimes becoming geranium pink while at other times becoming maroon or almost black. In old cultures the fungus frequently develops pycnidia.

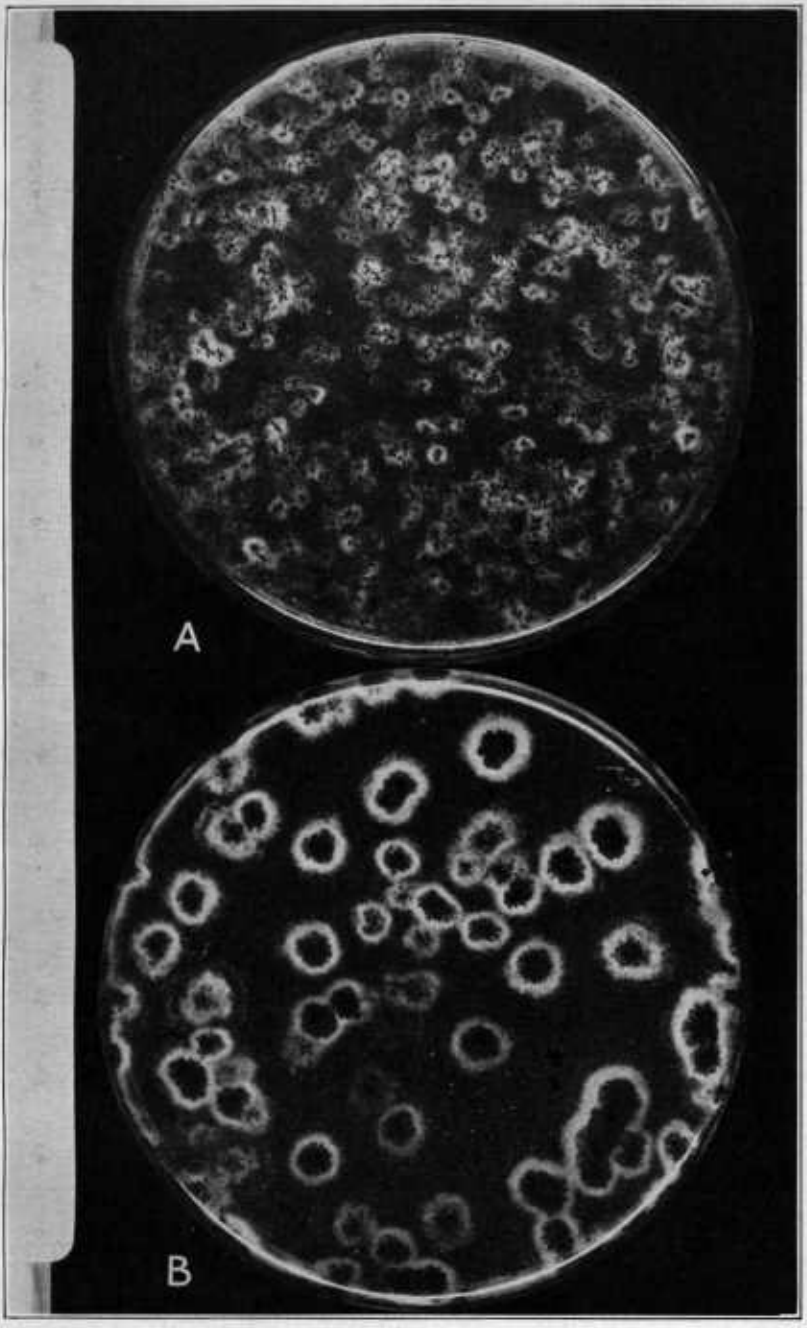
The lesions on flax plants, on both stems and leaves, contain many pycnidia. These range from about 63 μ to 126 μ in diameter on the specimens. The pycnidia are lens-shaped, largely incomplete in the early stages, but later almost complete, with small ostioles. They develop beneath the epidermis of the leaves and stems, and on the latter extend to the region of the bast-fiber cells (pl. 3).

The pycnospores are hyaline, subcylindrical, tapering slightly at the ends, straight, curved or angularly bent, usually 3-septate. From the specimens studied the average measurements were 2.8 μ by 21.7 μ. The conidia from a 3-day-old culture on potato-dextrose agar averaged 2.7 μ by 26.7 μ. These spores were very slightly narrower and somewhat longer than the pycnospores from flax plants. In culture, conidia frequently develop heavy-walled spherical-shaped structures with granular contents (fig. 1). Each of the four cells of a spore forms what appears to be a chlamydospore. This transformation was very noticeable in a 13-day-old culture of the fungus on potato-dextrose agar.

PATHOGENICITY

Pure cultures of the fungus were obtained from diseased portions of plants. Generally, when a culture was needed for inoculation purposes it was grown from a single-spore isolation. The diseased part of a plant on which pycnidia occurred was placed in a small amount of sterile water for a few minutes until the pycnospores oozed out. This spore suspension was then diluted until only a few spores occurred in a small drop of the water. Small drops of the water suspension were then placed by means of the loop within small circles marked on the bottom of Petri dishes. These drops were then allowed to dry partially and then sterile agar was poured into the dishes. After the agar had hardened, single spores were located and marked by making a dot on the bottom of the dish with a fine pen. Small bits of agar, each containing a single spore, were then cut out (by means of a circular cutter made on the end of a platinum needle) and transferred to other agar-poured plates and allowed to grow until the culture was ready for use in inoculations.

In 1922 inoculations were made simultaneously on flax plants of six different sizes. In order to provide flax plants at the different stages of growth for the inoculation experiments, six sowings were made at intervals of one week, beginning early in the spring. At each sowing three varieties—North Dakota No. 155, North Dakota Resistant No. 52, and Chippewa (C. I. No. 178)—were sown, one rod row of each. On July 15, when the first inoculations were



Thirty-day-old agar-plate cultures of *Phlyctaena linicola*

A.—Crowded colonies with numerous pycnidia
B.—Scattered colonies with relatively few pycnidia

made, there were plants from six different sowings in the following stages of development: (1) plants from the first sowing, with many green bolls forming; (2) plants from second sowing, in full bloom; (3) plants from third sowing, beginning to bloom; (4) plants from fourth sowing, 12 to 14 inches high; (5) plants from fifth sowing, 4 inches high; (6) plants from sixth sowing, emerging.

About one-third of each row in each series was inoculated by atomizing onto the plants a water suspension of spores which contained approximately 359,000 spores per cubic centimeter. These inoculations were made in the evening, about sundown. A canvas was erected between the area to be inoculated and that which was not to be inoculated in order to prevent the sprayed inoculum from going to the uninoculated plants when the inoculations were being made.

The first inoculations failed to induce infections, and on August 26 the same rows were again inoculated in a similar manner. Five days later the infection was very pronounced on the inoculated plants, while the control plants were free from disease. The infection was severe only in the first three sowings—that is, only on the older plants. On the last three sowings—that is, on the younger plants—there were only traces of infection. Chippewa was most severely infected, while North Dakota Resistant No. 52 and North Dakota No. 155 were moderately and about equally infected.

Later in the season, on October 9, the disease was observed in the fourth sowing. The disease, however, was less severe and the varieties showed scarcely any differences in the amount of infection.

On several occasions inoculations were made in the greenhouse. Different varieties of flax were inoculated in the greenhouse at Arlington Experiment Farm, Rosslyn, Va., when the plants were about 2 inches tall. Spores were atomized onto the plants, after which the plants were placed in moist chambers made of tubs covered with panes of glass. They were left to incubate in the tubs for 3 days, after which the pots were placed on a bench in the greenhouse. Eight days after the inoculation a high degree of infection appeared on the cotyledons of most of the plants (pl. 2, A). Other leaves had not developed when the inoculations were made.

The degree of infection on North Dakota Resistant No. 52 and North Dakota Resistant No. 114 was noticeably less than that on Chippewa (C. I. No. 178), Cantania (C. I. No. 182), and a selection of the Argentine type, C. I. No. 280 (North Dakota Resistant No. L. 79). Photographs of a few of the infected cotyledonary leaves are shown in Plate 2, A.

When the infection becomes established on the cotyledonary leaves of a few plants, from that time on the neighboring plants may be considered to be subjected to a more or less continuous stream of spores. Whether or not these spores germinate and bring about secondary infections depends very much upon the prevailing weather conditions. Temperature and moisture conditions appear to have a very important bearing upon the development and spread of the disease in the field. Unfortunately, it has not yet been possible to make more than a limited study of these factors. In culture the fungus grows well with a temperature range of from 17° to 29° C. The optimum temperature for mycelial growth is about 21°, while at the extreme temperatures of 5° and 32° there was very little growth.

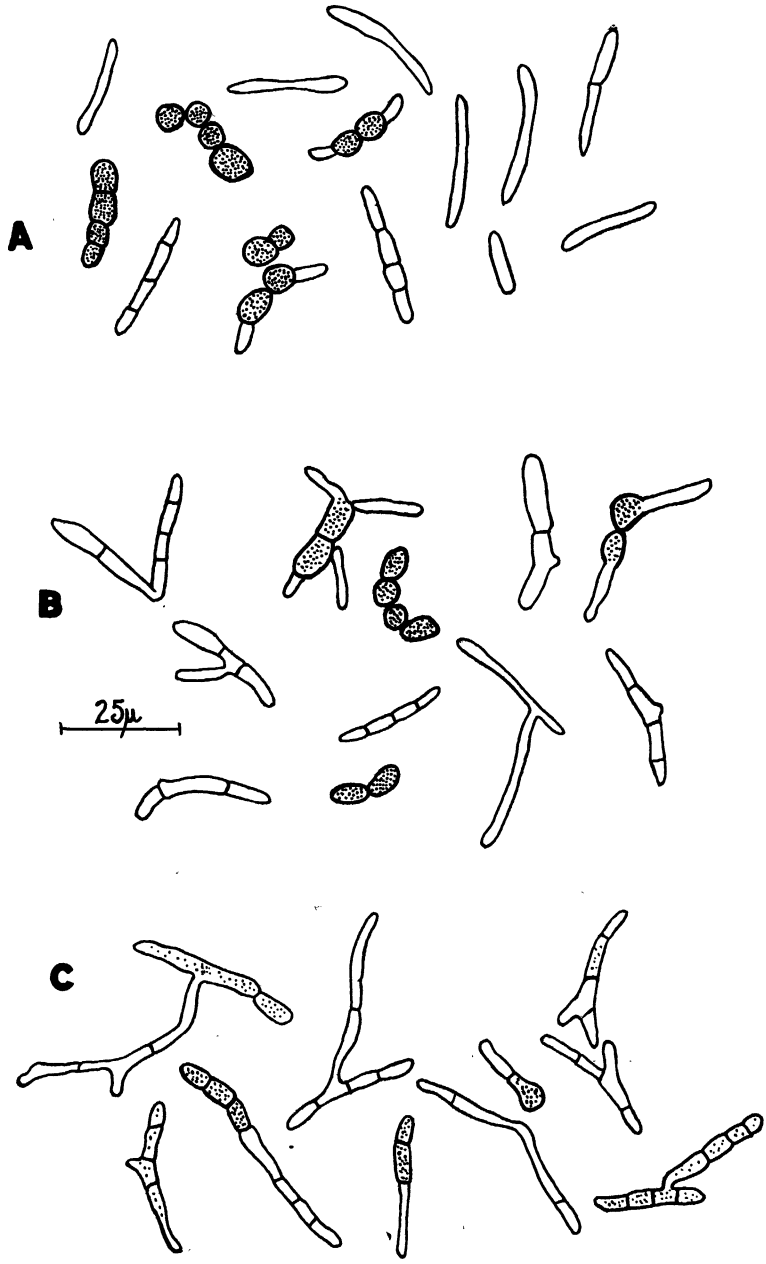


FIG. 1.—*A*, Spores from a 13-day-old culture of *Phyctaena linicola* grown on potato-dextrose agar, showing chlamydospore-like bodies with granular contents. *B*, The chlamydospore-like bodies germinating in water after 24 hours' incubation. *C*, Same as *B*, except 48 hours' incubation

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It has been observed frequently that pasmo was severe in certain low areas of a field where moisture was more abundant. In more elevated and drier areas of the same field the disease was noticeably less severe, indicating that relatively moist conditions favor infection and spread of the disease. On young plants the fungus is somewhat slow to develop.

In parallel inoculations, *Colletotrichum linicolum*, the fungus that causes flax anthracnose, was found to be much more vigorous in its attack on flax plants than *Phlyctaena linicola*. Under average conditions the latter fungus appears to be scarcely more than able to maintain itself on young green flax plants. But later, when the plants begin to flower and develop seed, the disease becomes virulent and spreads with marked rapidity from any viable spores that may be present.

DISSEMINATION

An ascigerous stage of the causal fungus has not been observed by the writer. Pycnospores overwinter on diseased straw and stubble, from which the infection originates in the spring. In March, 1924, stubble which remained in a diseased field of the previous year was collected. The old pycnidia were found to contain numerous pycnospores. These spores germinated well, and when used as inoculum developed severe infection on flax plants. Owing to the presence of many other faster growing organisms on the stubble, it was difficult to obtain a pure culture of Phlyctaena. A water suspension of spores was prepared for the inoculations by placing pieces of the diseased material in water for a few minutes until many pycnospores oozed out. The suspension, containing many species of fungi and bacteria, was then sprayed on young flax plants 6 to 8 inches tall. In about 10 days after the inoculations were made well-developed lesions appeared on the leaves of the plants. Several of the leaves were disinfected in a solution of mercuric chloride and placed on agar in Petri dishes. After two days a pure growth of *Phlyctaena linicola* appeared from each lesion.

The above experiment demonstrated the ability of overwintered pycnospores to produce infections on growing flax plants. Also, the methods used in the experiment were very satisfactory for establishing a pure culture of the fungus and proving its pathogenicity within a short time.

Severe infection developed in the plats at Fargo, N. Dak., in 1922. A small lot of straw from one of the plats was removed to a near-by plat, on which flax had not grown during that season, where it remained over winter. In the following spring flax was sown close by and around the straw for about 50 feet each way (pl. 2, E). The flax plants were observed frequently for the development of disease. On July 7 fully developed lesions were found on the cotyledonary leaves of a few plants nearest the straw. These proved to be infections by *Phlyctaena linicola*. The plants were then from 3 to 4 inches high. The disease was causing scarcely any damage, but lesions which were producing numerous spores occurred here and there on the plants close to the old straw. The number of lesions that had developed on plants growing farther from the source of infection was noticeably smaller. Later in the season, when the plants were blooming and a few bolls had developed, the infection on the plants adjacent to the straw was severe (pl. 5). The plants

Portions of two flax plants, from rows shown at 2 in Plate 2, E, showing characteristic pasmo symptoms on stems and leaves. In addition to the brown lesions on stems and leaves, the leaves showed marked yellowing

were practically covered with brown lesions. Spore tendrils projected abundantly from the pycnidia, giving the infected parts a grayish appearance (pl. 2, C). After a brief time the disease had spread more or less uniformly over the entire plat.

It is not known how late in the season infected straw and stubble may continue to act as a source of infection. In this experiment the plants emerged June 5, which is relatively late, and became infected from such a source.

Spores of the fungus may be transmitted by means of seed. Infested seed of an Argentine variety was examined. One hundred seeds were washed in a few cubic centimeters of sterile water, and the number of spores thus brought into suspension was determined by means of a Levy counting chamber. It was calculated that each seed gave off approximately 560 spores to the suspension. The seed came from a plat in which the infection was severe. The load of spores carried was the result of natural inoculations under the usual method of harvesting and threshing.

In 1923 a field of fiber flax near East Lansing, Mich., was studied.[8] About 4 acres, which had not grown flax for several years, if ever, was sown to Saginaw fiber flax. Likewise, the fields near by had not produced flax for several years, and during the season the nearest flax was in certain experimental plats about 2 miles away. About one-half of the field, the east side, was sown with seed from plants infected with pasmo the previous year. The west half was sown with seed from a plat which was practically free from the disease in 1922. The east half, sown with infected seed, when examined about the middle of August, had many brown areas, centers of infection from which the disease was spreading, ranging from a few to several feet in diameter. The west half of the field, sown with practically clean seed, showed very few diseased areas. The indications, therefore, were very strong that the original infection had come with the seed.

The same field served to demonstrate the effect of moisture on the spread and development of the disease. The east half of the field which was severely infected, sloped to the south. In the south part of this half the disease was much more severe than in the upper part, indicating that the greater amount of moisture of the lower favored the development of the disease.

CONTROL

Indications are that the disease may be controlled in farm practice. Experiments have shown that the use of sanitary measures will aid considerably in preventing spread and development of the disease. It is essential that all infested straw and stubble be destroyed as soon as possible after harvest. Burning and plowing under of infested stubble should be beneficial. It is important to avoid sowing flax on land cropped to flax the previous year, especially if pasmo had occurred there. If an infested field is sown to flax a second year pasmo would be almost certain to develop again.

Seed from infested fields has been found to carry numerous surface-borne spores. It is very probable that these find their way to

[8] The field was sown to increase certain fiber selections, and was under the direction of L. R. Davis, of the Office of Fiber Plant Investigations, United States Department of Agriculture, cooperating with the Michigan Agricultural Experiment Station.

the young plants and start the infection early in the season. In this connection seed treatment as recommended for wilt seems to be beneficial. Treatments with dust fungicides have not yet been perfected sufficiently to recommend their use. It is hoped, however, that a satisfactory dry treatment may be developed so as to avoid the difficulties encountered by wetting flaxseed.

A wide range in the degree of resistance of different varieties and selections was apparent during the past two years. The most susceptible ones were selections from Argentine type. The commercial varieties of seed flax—North Dakota Resistant No. 52, North Dakota Resistant No. 114, and North Dakota No. 155—were more resistant than the Argentine selections. A few hybrids, which have not yet been grown, except in the experimental plats, appeared to be almost immune from the disease.

The development and spread of the disease depend largely upon temperature and moisture conditions prevailing during the growing season. Infection may not occur on the plants, even when grown in an infested field, owing to adverse weather conditions.

SUMMARY

As it occurs in the United States, the pasmo disease of flax, caused by *Phlyctaena linicola*, seems to be identical with that described from Argentina. Its introduction into the United States with imported seed seems probable.

With environmental factors favorable, the disease may cause considerable damage to both seed and fiber flaxes.

In the field the disease becomes evident as marked brownish areas ranging from a few feet to a rod or more in diameter.

The leaves and bolls of infected plants are blighted, and the invaded portions of the stems become more or less brown, giving the plants a mottled appearance, which is characteristic of the disease. The lesions become thickly set with pycnidia and often extrude spore tendrils.

On potato-dextrose agar the parasite is very prolific in producing spores but develops scarcely any mycelium. The optimum temperature for vegetative development is about 21° C.

A relatively high degree of soil moisture favors the development of the disease. Lower areas of a field usually are more severely attacked than the somewhat higher portions.

On young plants the fungus is a weaker parasite than *Colletotrichum linicolum*, which causes flax anthracnose. On plants which are blooming and developing seed *Phlyctaena linicola* is vigorous in its attack and spreads with marked rapidity.

An ascigerous stage of the fungus has not been observed. Pycnospores overwinter on straw and fragments of diseased plants and initiate infections the following year.

Spores of the parasite may be disseminated in large numbers by means of infested seed.

Treating of seed with formaldehyde, burning of infested straw, and rotating crops aid in controlling the disease. Some varieties and selections show considerable resistance to the disease.