

PHYTOPHTHORA ROT OF PEARS AND APPLES¹

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INTRODUCTION

On September 5, 1923, the junior author collected on the South Water Street Market, Chicago, Bartlett pears from Fennville, Mich., which showed black spots covering about half the pear. On the surface of these spots there was a scanty growth of mycelium (pl. 1, A). When the pears were cut through at these spots the flesh underneath was found to be for the most part very light brown in color but markedly darker brown in the vascular system (pl. 1, B). Mounts of the surface fungous growth under the microscope showed numerous conidia resembling those of *Phytophthora*, and plantings from the diseased flesh yielded a fungus which agreed in all important respects with published descriptions of *Phytophthora cactorum*. The pathogenicity of the fungus isolated from these pears and from apples and other pears collected later has been proved by inoculation into healthy pears and apples.

Further examination of fruits on the Chicago market showed that the disease is more widely distributed in the United States than had hitherto been suspected; a study of the fungus in culture and on the fruit brought out a number of facts concerning its morphology which seem not to have been observed by other workers. The present paper summarizes the results of this work and gives in addition a fuller description of the disease than is available in earlier publications.

DISTRIBUTION AND FIELD OBSERVATIONS

Following the collection of *Phytophthora* rot on the Chicago market on September 5, other collections were made as follows:

On September 11 a shipment of Clairgeau pears from St. Joseph, Mich., was seen on the Chicago market which showed a loss of about 30 per cent from a rot similar to that described above. It was learned later that the entire shipment consisted of windfalls.

On September 24 Anjou pears and on September 25 Clairgeau pears were found on the Chicago market which showed the symptoms of *Phytophthora* rot. Nothing was learned as to the origin of either of these lots of pears. It is probable, however, that they also came from Michigan, since they had been shipped in bushel baskets and Michigan was at that time the only Middle Western State shipping Anjou and Clairgeau pears in baskets into Chicago. Both varieties, if shipped from California or the Northwest, would have been packed in boxes.

On September 27 several orchards near St. Joseph, Mich., were visited and numerous cases of *Phytophthora* rot were found, on both pears and apples. The decay was found only on windfalls, never on fruit hanging on the tree. In some instances the windfalls under Clairgeau pear trees showed 100 per cent infection, particularly those under trees where there were indications that water had been standing on the soil. Moreover, pears which looked sound when viewed from above as they lay on the ground were usually found to have a black spot on the lower side if the ground was moist to the touch.

The varieties of pears found to be affected with *Phytophthora* rot were Clairgeau, Kieffer, Bosc, Howell, Bartlett, Anjou, and Angouleme (Duchess). The disease was also found to be serious among the windfalls on the following varieties of apples: Twenty-Ounce Pippin, Northern Spy, Tolman, Baldwin, Winesap, Jersey Sweet, Wealthy, Gideon, Rhode Island Greening, and Tompkins King. Cultures of a *Phytophthora* were obtained from all the varieties and all the collections mentioned above.

The influence of soil moisture was noted in two Kieffer pear orchards, both of which had been kept in clean culture. In one of these the soil was moist to the touch and practically all of the fruit on the ground showed the typical symptoms of *Phytophthora* rot. In the other orchard the surface soil

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was almost dusty and only about 10 per cent of the windfalls showed the disease.

On October 29, 1923, the junior writer assisted in the inspection of a car of Delicious apples at Chicago, shipped from Wenatchee, Wash. Many of the apples were incrustated with clay, and one of them showed the characteristic symptoms of *Phytophthora* rot. A pure culture of *Phytophthora* was obtained from this apple. On January 11, 1924, the rot was found in Rome Beauty apples from Boise, Idaho, inspected in cold storage at Chicago. Plantings from affected fruits yielded only *Phytophthora*.

DESCRIPTION OF THE DISEASE

A brief description of *Phytophthora* rot on pears has been given in the first paragraph of this paper. However, there are certain characteristics of the rot on both pears and apples which merit further consideration, since a search of the literature shows them not to have been described in any detail before. Throughout the following discussion, which is based on a study of naturally infected fruits and of fruits inoculated in the laboratory, it is to be understood that all statements refer to tissues affected by the fungus. In both pears and apples there is always a marked vascular browning, both in the larger bundles near the core and in the smaller ones throughout the flesh (pl. 1, B and D). Very often the browning in the larger bundles extends to the stem and into it for part or all of its length (pl. 1, B) in the manner described by Schoevers (12, p. 154).² In this connection it may be mentioned also that Rose (10) found marked vascular browning in strawberries parasitized by a fungus very similar to and apparently identical with *Phytophthora cactorum*. In apples the flesh surrounding the bundles is lightly browned, in pears scarcely at all. In some varieties of pears, notably Clairgeau, the flesh is in fact decolorized and has a clear, water-soaked appearance very much like that of apple flesh affected by water-core. The parasitized flesh of both apples and pears sometimes becomes slightly spongy, but is usually as firm as sound healthy flesh; it rarely becomes soft and mushy like that found in lesions

produced by *Rhizopus* or *Penicillium*. The only exception noted was that of pears of the Seckel variety, inoculated with *Phytophthora* in the laboratory. In cross-section, *Phytophthora* lesions on both pears and apples show indefinite boundaries so that it is impossible to make a clean separation of diseased from healthy flesh, as can so easily be done in fruits attacked by *Rhizopus* or *Penicillium*. The affected flesh has no marked odor or taste. Externally the lesions produced by *Phytophthora* on apples are light brown (pl. 1, C), on pears dark brown to black (pl. 1, A).

INOCULATION EXPERIMENTS

EXPERIMENT 1

Twelve Clairgeau pears were washed in soap and water and rinsed in sterilized tap water. They were then sterilized for 10 minutes in 1:1,000 mercuric chloride solution, rinsed again in sterilized tap water, and placed in two moist chambers. Six were inoculated with a pure culture of *Phytophthora* obtained from Clairgeau pears and six were used as controls.

On the fourth day all the inoculated pears showed the characteristic lesions, and all the controls were free from any symptoms of the disease. The lesions ranged in size from 33 to 44 mm. in superficial diameter, averaging 37 mm. On the tenth day the controls were still in perfect condition, while the lesions on the inoculated fruits varied from 70 to 77 mm. in superficial diameter, averaging 74 mm. Cultures from these lesions yielded only *Phytophthora*.

EXPERIMENT 2

Eighteen apparently uninjured Kieffer pears were sterilized in 1:1,000 mercuric chloride for 10 minutes. Six used for controls were placed in a moist chamber with water in the bottom.

A layer of cotton batting was placed in the bottom of a moist chamber and saturated with sterile water. On the cotton batting were placed six small pieces of an agar culture of the *Phytophthora* which had been isolated from Clairgeau pears. A sterilized pear was placed on each piece of agar culture. On the eighth day three of the pears, and on the thirteenth day all of them,

² Reference is made by numbers (italics) to "Literature cited," p. 468.

EXPLANATORY LEGEND FOR PLATE 1

- A.—Anjou pear five days after inoculation with the *Phytophthora* isolated from a naturally infected pear
 B.—Cross-section of the pear shown in A
 C.—Grimes Golden apple five days after inoculation with the *Phytophthora* isolated from a naturally infected pear
 D.—Cross-section of the apple shown in A (Color plate by J. Marion Shull)



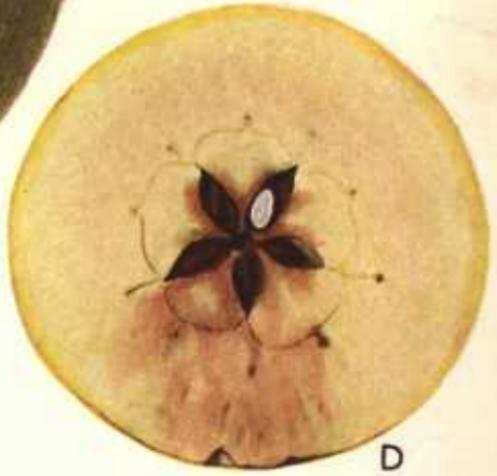
C



B



A



D

showed the characteristic symptoms of *Phytophthora*. The fungus was recovered from two of these pears by culturing. All of the others were cut up and were found to show the characteristic vascular darkening.

EXPERIMENT 3

Some of the clay soil from an orchard at St. Joseph, Mich., was placed in a moist chamber and sterile water was poured over it until water stood on the soil to the depth of about 2 cm. Six sterilized pears, apparently free of skin punctures, were then placed in the moist chamber on the soil. All of these pears developed *Phytophthora* rot, and pure cultures of the organism were obtained from every one of them. The first pear developed the rot on the thirteenth day, two more on the twenty-first day, and the remaining three on the twenty-second day. Similar results were obtained in another experiment which duplicated No. 3, except that apples were used instead of pears. Controls provided in both experiments remained sterile.

Nothing is known of how infection occurred in the moist chambers containing pears resting on soil covered by water. Quite evidently the fungus existed in the soil and continued to grow there even though entirely submerged. It is possible and indeed quite probable that the fungus grew out into the water; but whether the infection which occurred was brought about by zoospores or directly by the mycelium is a question to which the experiments and the observations made on them give no answer.

The results obtained in these experiments are strong evidence that the *Phytophthora* isolated from apples and pears is able to penetrate the uninjured skin of those fruits. Evidence to the same effect was seen in the orchards visited in Michigan.

MORPHOLOGICAL FEATURES

Twenty of the isolations from diseased pears and apples, including the three from Washington and Idaho apples, were subjected to comparative study after they had grown for 9 to 70 days on potato dextrose agar, on Sherbakoff's oatmeal agar, and on oatmeal paste. On potato dextrose agar they all produce conidia (pl. 2, A and B) and oogonia (pl. 2, C to H) in abundance and also large numbers of bodies which are very similar to the "sphaero-conidia" (pl. 2, I to L) described and figured for *Phytophthora*

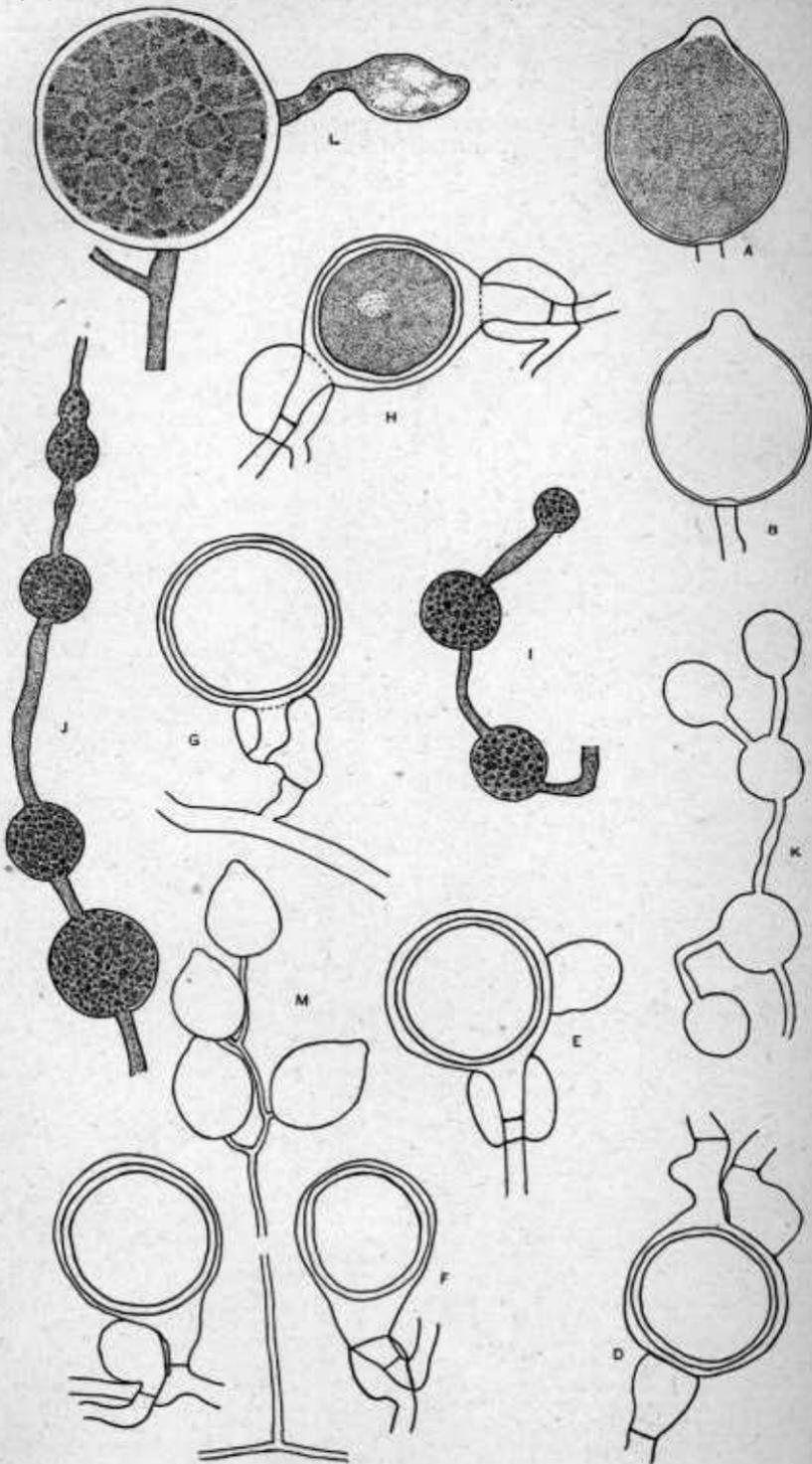
cactorum by Lafferty and Pethybridge (6, p. 37 and pl. II, fig. 13). On oatmeal agar they produced large numbers of conidia and oogonia, but very few "sphaero-conidia"; in some cultures there were none of these bodies. Measurements of the various spore forms were made for three cultures, which so far as could be told by examination with the microscope were representative of the whole 20. One of these cultures had been isolated from the Delicious apple from Washington, one from a pear from Michigan, and one from an apple from Michigan. The measurements can be summarized as follows: Oospores, 15 to 43 μ in diameter, average 26.6 μ ; conidia, length, 25 to 44 μ , average 34.4 μ ; conidia, width 21 to 31 μ , average 26.8 μ ; "sphaero-conidia," 25 to 45 μ in diameter, average 34.6 μ . All of these are in close agreement with the constants given for the spore forms of *Phytophthora cactorum* by other workers. (Rosenbaum (11) Beach (1) and measurements quoted by the latter from other papers.)

The conidiophores of this fungus have been found as (1) short branches of the mycelium bearing a single conidium, or (2) longer branches bearing conidia in groups of 2 to 10 or more (pl. 2, M). The largest number of conidia seen in a single group was 15. Both kinds of branches arise from the mycelium in the manner shown for one of the longer branches, in the lower portion of Plate 2, M.

All three of the spore forms mentioned above were found on the surface of both pears and apples collected on the market. They also appeared on the surface of pears and apples inoculated in the laboratory, usually within six or eight days from the time of inoculation. Favorable conditions for this external growth seemed to be a moist atmosphere and a temperature of 20° to 25° C. or even slightly higher. A few oogonia were seen in mounts of diseased tissue from the inside of a number of fruits.

Measurements of the various spore forms as found on diseased fruits can be summarized as follows: Oospores 20 to 35 μ in diameter, average 26.6 μ ; conidia, length 30 to 53 μ , average 40.3 μ ; conidia, width 19 to 32 μ , average 36.9 μ ; sphaero-conidia, for the few that were seen, 26 to 38 μ in diameter average 32.3 μ .

It will be seen that the conidia are slightly longer on the host than on culture media but that the other two spore forms average about the same size no matter where they are produced.



For explanatory legend see p. 467.

Antheridia are usually paragynous (pl. 2, C and D) but in old cultures on oatmeal paste a few have been found which were amphigynous (pl. 2, E, F, G, and H). Lafferty and Pethybridge (6, p. 36) have already reported this condition for cultures of *Phytophthora cactorum* obtained by them from various sources, including one furnished by H. H. Whetzel and said by him to have been isolated from a decayed apple grown in his own garden in Ithaca, N. Y. Rose (10) has also reported it for a *Phytophthora* isolated from decaying strawberries and shown by him to be very similar to *Phytophthora cactorum*. The writers wish to call attention, however, to an unusual form with two amphigynous antheridia shown in Plate 2, H. As seen under the microscope, the antheridia lay in approximately the same plane. It was thought at first that there were two oogonia, one lying over the other; but after repeated and vigorous tapping of the cover glass the object still remained as figured on Plate 2, one oogonium with two amphigynous antheridia.

The oogonium is apparently intercalary, but even so it is difficult to understand how it could have grown through two antheridia in the manner described by Pethybridge (9) for growth through one. In other words, the finding of the form here under discussion (pl. 2, H) raises the question whether for the apple and pear *Phytophthora* antheridia in the amphigynous position have that position because the oogonium has grown through them. The writers have no other explanation of how antheridia may become amphigynous but will merely add that at no time during a rather extensive study of the apple and pear *Phytophthora* have they seen early stages of the growth of the oogonium through the antheridium. Antheridia in the amphigynous position have been seen only in the final, fully developed stage and only in old cultures or in the older portions of cultures that were a month to six weeks old.

It should be added that an oogonium with two amphigynous antheridia has

been seen only once. Attention is called, however, to Plate 2, D and E, which shows two oogonia, each with one amphigynous and one paragynous antheridium. One of these aggregates lay in an open space between two masses of mycelium and was made to assume different positions by pressure on the cover glass. Study of it in these positions showed that the structures figured in Plate 2, D, were not merely in fortuitous juxtaposition but were actually parts of one whole. The other (pl. 2, E) lay in a matrix of agar and mycelium and was studied only in the position shown by the drawing. It would be possible of course for one antheridium to assume a position at the side of an oogonium after the latter had grown through another antheridium. The figures are included here merely on the chance that they may at some time help to explain the condition shown in Plate 2, H.

DISCUSSION

The finding of *Phytophthora* rot on fruits on the Chicago market is a new record, so far as the pathological work is concerned which is carried on in connection with the Food Products Inspection Service. That is, the rot has not heretofore been seen in the course of this work, or, if seen, has not been recognized. The finding of the rot on pears and apples from Michigan and on apples from Washington and Idaho is, so far as the writers are aware, a new record for each of those States, though not for the continent of North America. Whetzel and Rosenbaum (15) reported *Phytophthora cactorum* from New York on Duchess apples in 1916, Hesler (14, p. 172) from New York on apples in 1918, Güssow (4) from Canada on pears in 1919, Clinton (3, p. 454) from Connecticut on pears in 1919 and on apples in 1920 (3, p. 406), and Gardner (5, p. 53) from Indiana on apples in 1921. *Phytophthora cactorum* is a well-known parasite of pears and apples in Europe (Wormald, (16), Osterwalder (8), Lafferty and Pethybridge (6)

EXPLANATORY LEGEND FOR PLATE 2

Spore forms and sporophore of the *Phytophthora* isolated from apples and pears. (A, B, C, D, E, F, G, H, L \times 785. J, K, I, M \times 369)

A, B.—Conidia

C.—Oogonium with paragynous antheridium

D, E.—Oogonia, each with one paragynous and one amphigynous antheridium

F, G.—Oogonia, each with one amphigynous antheridium

H.—Oogonium with two amphigynous antheridia

I, J, K, L.—Various forms of Sphaero-conidia

M.—Conidiophore with conidia attached. Lower portion of the figure shows manner of origin from the mycelium

and other references cited below). The above account indicates that the rot of pears and apples caused by a *Phytophthora* is rather widely distributed in the United States. It is granted of course that the apples from Washington and Idaho are not known positively to have become infected with *Phytophthora* in the State where they originated. Nevertheless, in the absence of proof to the contrary, it is fair to assume that they did become infected there.

It is noteworthy that during this investigation *Phytophthora* rot was found in one lot, the storage lot of Rome Beauty apples from Idaho, approximately four months after the usual time for harvesting the variety named. Most of those who have studied this disease have found it either in fruit in the orchard or in fruit which had been taken from the orchard only a few days before. (Bubak (2), Clinton (3), Güssow (4), Hesler (14), Marchal (7), Schoevers (12), Unamuno (13), Whetzel and Rosenbaum (15), and Wormald (16).) The apples in which Lafferty and Pethybridge (6) found the rot had been picked on October 14 and were sent to them on November 20. The authors make the statement (6, p. 29) that it is not known whether infection occurred prior to gathering or in storage. Osterwalder (8, p. 440) reports that he did not see the fungus at any time on stored apples. From the context the natural inference is that he is referring to the rot.

What was thought to be *Phytophthora cactorum* was also reported in 1922 from Pennsylvania on growing apple fruits by Thurston (14).

SUMMARY

There has been found on the Chicago market in pears and apples from Michigan and in apples from Washington and Idaho a rot from which a species of *Phytophthora* has been isolated.

This *Phytophthora* when inoculated into healthy pears and apples reproduced the diseases and was easily recovered from the affected tissues.

Evidence is presented which indicates that the *Phytophthora* isolated from pears and apples is similar to and probably identical with *P. cactorum*.

The observations of Lafferty and Pethybridge (6) are confirmed, that the apple and pear *Phytophthora* produces "sphaero-conidia" and both paragnynous and amphigynous antheridia.

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