PHYTOPHTHORA ROT OF HONEYDEW MELON[1]

By C. M. TOMPKINS, *assistant plant pathologist, California Agricultural Experiment Station*, and C. M. TUCKER, *plant pathologist, Missouri Agricultural Experiment Station*[2]

INTRODUCTION

On September 5, 1935, a rot of Honeydew melon fruits (*Cucumis melo*. L. var. *inodorus* Naud.), caused by *Phytophthora capsici* Leonian (*5*),[3] was observed in part of an extensive planting near Modesto, Calif. The crop was a total loss within the diseased area, involving approximately 2 acres. Visits to other sections of the San Joaquin Valley where Honeydew melons are grown commercially failed to reveal further evidence of the disease. An investigation of the disease, with special reference to cause, factors favoring infection, and host range, seemed desirable because of the economic importance of this and other cucurbitaceous crops grown in the interior valleys of California.

DISEASE FAVORED BY WET SOIL AND HIGH TEMPERATURES

Phytophthora rot of Honeydew melon occurred on heavy, waterlogged soil during the season of prevailing high temperatures. The infested area, lower than the rest of the field, had been improperly graded and lacked adequate drainage outlets. Frequent and heavy irrigations during the latter part of the growing season, necessitated by crop requirements, caused the soil to become waterlogged. Excess water accumulated in small, shallow pools, in and between the rows, and some plants were partly submerged. High temperatures and the contact of the fruits with the wet soil established ideal conditions for infection. The disease did not occur elsewhere in the same field where drainage facilities were good.

SYMPTOMS OF THE DISEASE

In this disease of the Honeydew melon plant, only the fruits are susceptible to natural infection by *Phytophthora capsici*. Both immature and mature fruits, if in contact with or near the surface of the soil, may be attacked. The disease is comparable to a rot of watermelon fruits, recently described by Brown and Evans (*1*) in Arizona and attributed by them to *P. cactorum*.

Two types of incipient lesions may arise after infection occurs—(type 1) small, brown spots, 1 to several millimeters in diameter, with an irregular margin (fig. 1, *A*) which, upon enlarging, may give rise to somewhat larger brown lesions with a water-soaked, outer margin (fig. 1, *C*), or large, slightly zonate, brown, water-soaked lesions

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[3] Reference is made by number (italic) to Literature Cited, p. 944.

(fig. 1, *D*); (type 2) small, water-soaked lesions, 1 to several millimeters in diameter (fig. 1, *B*), which rapidly increase in size to form large,

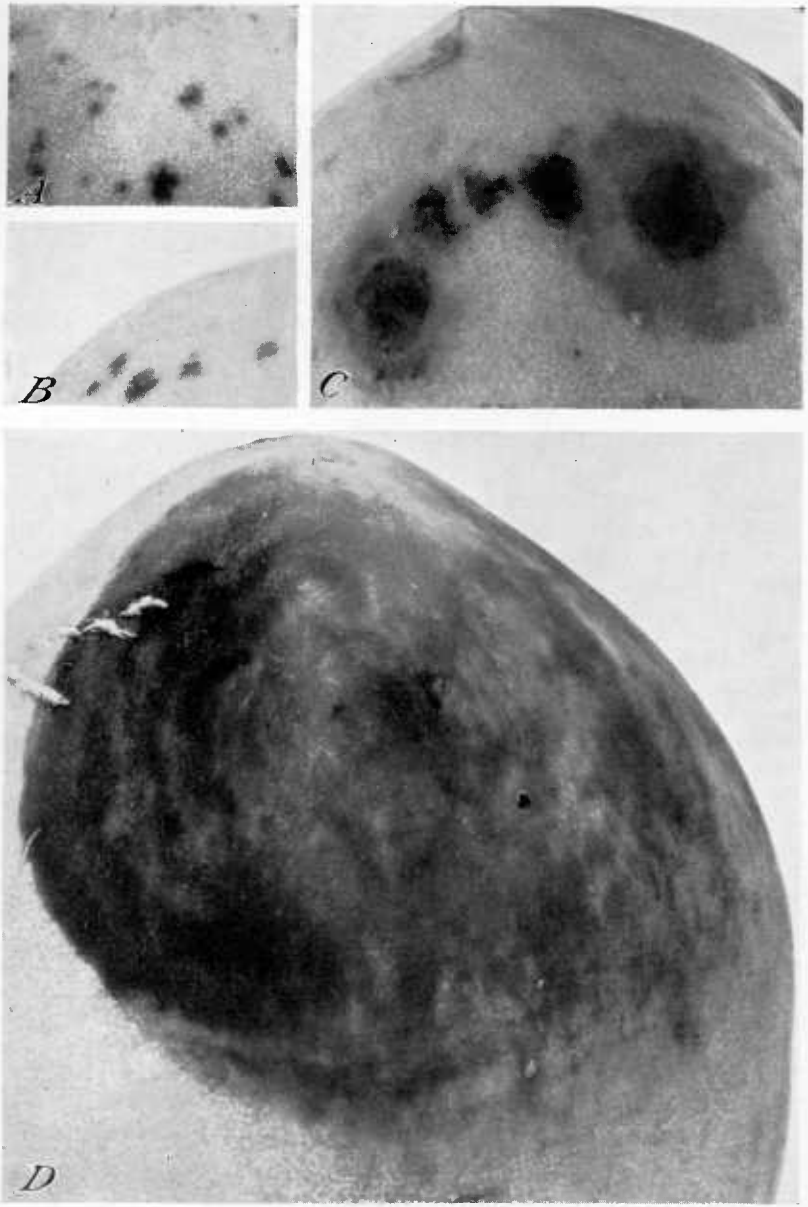

FIGURE 1.—Symptoms of phytophthora rot of Honeydew melons: *A*, Incipient infection showing as small brown spots; *B*, incipient infection showing as small, water-soaked areas; *C*, brown lesions, and brown lesions surrounded by water-soaked areas which arise from incipient brown spots shown in *A*; *D*, slightly zonate, brown, water-soaked lesions arising from incipient brown spots shown in *A*.

water-soaked areas (fig. 2). Of the two types mentioned, the latter is of more common occurrence.

Lesions vary in number on individual fruits from a few to many (fig. 1, *A*, *B*, *C*), but ultimately some of them may fuse. Frequently the water-soaked lesions are covered with a dense, closely adpressed, grayish-white, nonzonate, velvety mycelial mat which contains

FIGURE 2.—Water-soaked lesions on mature Honeydew melon resulting from incipient infection as shown in figure 1, *B*.

sporangia. In advanced stages of the disease, lesions are slightly sunken in appearance.

Internally, healthy tissues of diseased fruits are sharply delimited from the invaded, water-soaked area, but there is no change in color of the lesion at its margin such as characterizes the advancing edge of

lesions in the roots of sugar beet (*Beta vulgaris* L.) produced by *Phytopthora drechsleri* Tucker (*10*). The fungus spreads rapidly within the fruit, or fleshy berry or pepo (*4*), from the epicarp or exocarp through the spongy parenchymatous cells of the mesocarp and into the endocarp. The decaying tissues have a soft, watery, mushy consistency and lack odor. Sometimes aerial mycelium of the fungus is found in the cavity of the fruit as well as on the surface of the seed coats, to which reference is later made.

While infected fruits show no indication of cracking of the epidermis and underlying tissues, yet they lack mechanical firmness and are easily broken upon removal from the vines.

THE CAUSAL FUNGUS, PHYTOPHTHORA CAPSICI

ISOLATION

The fungus was readily isolated from naturally infected Honeydew melons by removing aseptically small tissue fragments from the advancing, internal part of a lesion, planting on malt-extract agar (*7*) in Petri dishes, and incubating at room temperature. After 48 hours, pure cultures of the fungus were established on agar slants by transferring hyphal tips from the edge of the colonies. A total of 56 tissue plantings was made from 14 diseased fruits, from which 55 colonies were obtained. One pure culture from each fruit was reserved for further study; of these, 13 were identified as *Phytophthora capsici* and 1 as *P. drechsleri*.

RELATION TO HOST TISSUE

Small blocks of tissues from artificially infected Honeydew melons were fixed in formal-acetic-alcohol. Sections were cut 15μ in thickness and stained with Magdala red and fast green. *Phytophthora capsici* was found to be well distributed throughout diseased areas but was confined to the intercellular spaces. There was no indication of intracellular invasion.

IDENTITY

The isolations of *Phytophthora capsici* from Honeydew melons were very similar in most characteristics. All produced abundant aerial mycelium and sporangia in oatmeal agar tubes and in flasks of moist corn meal; none developed chlamydospores in culture. In plate cultures on Difco corn-meal agar the growth was smoothly circular from the inoculum, usually cottony and homogeneous without the development of tufts of hyphae; however, in two isolates sectoring occurred, conspicuous areas in which the hyphae radiated from the center, giving the mycelium a combed appearance; the fungus spread over the medium more rapidly in the sectors. Some transfers from the sectors continued to produce the divergent type of growth, and others continued developing sectors of both types. Leonian (*6*) has demonstrated the marked tendency toward sectoring exhibited by other species.

All isolations produced sporangia on oatmeal agar or hyphae transferred from pea broth to distilled water or to Petri's solution (fig. 3, (*A–D*). The sporangia from solid media ranged in size from 26μ to 55μ by 18μ to 38μ, with average dimensions of about 42μ by 31μ. Those produced after 3 days on hyphae transferred from pea broth

to Petri's solution measured 28μ to 67μ by 21μ to 48μ, averaging about 48μ by 34μ. When transferred from pea broth to distilled water and incubated 3 days at 20° C. (*6*), the hyphae produced larger sporangia somewhat earlier and more abundantly than in Petri's solution, rang-

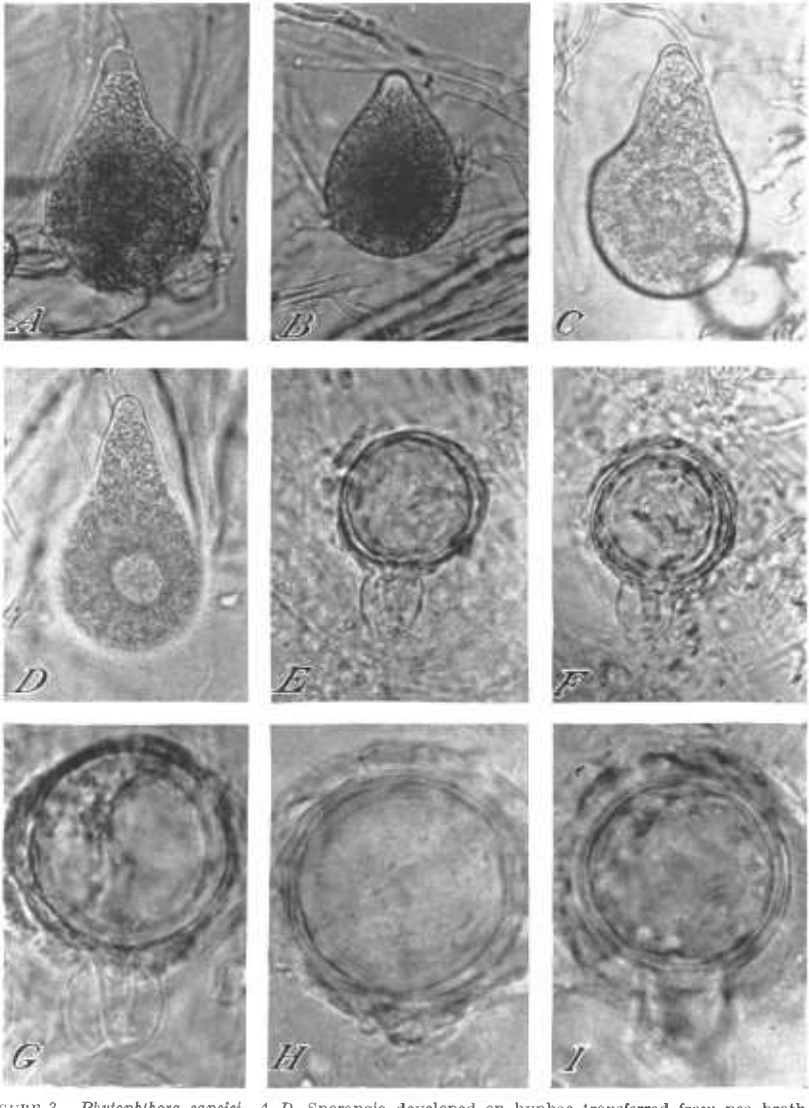

FIGURE 3.—*Phytophthora capsici*. *A–D*, Sporangia developed on hyphae transferred from pea broth to distilled water. × 460. *E–F*, oogonia, oospores, and antheridia from oatmeal agar cultures. × 460. *G*, oogonium partially cleared in a lactophenol solution. × 780. *H–I*, oogonia cleared in a potassium hydroxide solution. × 780.

ing from 31μ to 71μ by 24μ to 57μ, with an average of about 54μ by 39 μ.

The sporangia were papillate in all cultures. On oatmeal agar they were mostly sphaero-limoniform and fairly uniform in shape. Sporangia developed in liquid cultures were larger and more fre-

quently irregular in shape, with a marked tendency toward elongation in the apical region; two or more papillae were occasionally present. These differences suggest the "hydrosporangia" and "aerosporangia" described by Curzi (*2*) from infected tissues in water and in the air. Germination occurred by the development of germ tubes or by zoospores which were differentiated within the sporangium. Chlamydospores were not observed, but occasional undifferentiated ovoid to subspherical hyphal swellings were found in oatmeal-agar cultures.

Ten of the thirteen isolates produced oogonia and oospores in oatmeal agar cultures incubated 4 months at 15° C. The oogonia were usually embedded in the medium and were most abundant at the upper, dried end of the slope. They were subspherical and thin-walled, but the wall was generally encrusted with a dark-brown material, apparently composed of irregular crystals, which increased the apparent diameter of the oogonia and obscured the antheridia. Mounting in a lactophenol preparation caused partial clearing, and soaking in concentrated potassium hydroxide solution removed the deposit (fig. 3, *G–I*). The oogonia of the isolates were quite uniform in size and appearance, varying from 27.5μ to 46.4μ and averaging 38.2μ in diameter. The oospores were spherical, thick-walled, smooth, yellow to amber, 19.9μ to 38.9μ, averaging 30.7μ in diameter. The oogonia and oospores were significantly larger than those obtained by one of the writers (*11*) under higher temperature conditions. Leonian (*5*) describes oospores 25μ to 35μ in diameter; Curzi (*2*) reported oospores 28μ to 35μ in diameter including the persistent oogonial wall, which was at first hyaline but quickly became amber to dark yellow. The antheridia were amphigynous and persistent on the oogonial stalk (fig. 3, *E–G*).

The Honeydew melon isolates agree fairly well with the descriptions of *Phytophthora capsici* in morphologic characters, except for the one culture of *P. drechsleri*.

TEMPERATURE RELATIONS

One of the writers (*11*) used the temperature relations of the species as an aid in distinguishing it. Observations were made on the growth of the 13 isolates on Difco corn-meal agar plates, in triplicate, in controlled temperature chambers at intervals of 5° from 15° to 35° C. (table 1).

TABLE 1.—*Mycelial growth of Phytophthora capsici on Difco corn-meal agar* [1] *plates at different temperatures*

Isolate no.	Average diameter of growth after 96 hours at—					Isolate no.	Average diameter of growth after 96 hours at—				
	15° C.	20° C.	25° C.	30° C.	35° C.		15° C.	20° C.	25° C.	30° C.	35° C.
	Millimeter	*Millimeter*	*Millimeter*	*Millimeter*	*Millimeter*		*Millimeter*	*Millimeter*	*Millimeter*	*Millimeter*	*Millimeter*
1	28	31	58	51	26	8	23	38	55	49	11
2	25	35	58	56	35	9	27	35	56	50	11
3	28	43	64	54	15	10	28	39	54	51	24
4	28	36	64	56	30	11	30	35	58	50	29
5	26	33	56	53	15	12	24	31	54	50	23
6	23	35	50	55	10	13	23	30	55	44	16
7	28	39	59	55	31						

[1] The pH was 6.1.

The optimum temperature probably is slightly under 30° C.; there was usually but little difference in the growth at 25° and 30°, with 12 isolates making more growth at the former. All isolates made some growth at 35°, but there was considerable difference in the amounts. The Honeydew melon isolates exhibited temperature relations typical of *Phytophthora capsici*.

DISTRIBUTION

Although this is the first definite record of the occurrence of *Phytophthora capsici* on a curcurbit, there are a few records of phytophthora infections in which there is a possibility that the species was involved. Drechsler (*3*) in 1926 isolated a species with prominently papillate sporangia from a Honeydew melon from Colorado or California. In 1929 the occurrence of *P. citrophthora* on watermelon, squash, and pumpkin fruits was reported in California (*8*). There are similarities between *P. capsici* and *P. citrophthora*, and it is possible that the species involved was the former.

PATHOGENICITY

A pure culture of *Phytophthora capsici*, isolated from a ripe, partially decayed Honeydew melon, was used in all infection experiments. The fungus was grown on malt-extract agar in Petri dishes, incubated at room temperature, and used for inoculum when 4 days old. Healthy immature, and mature Honeydew melons, selected from a field where the disease was absent, were washed in running tap water, rinsed in distilled water, and dried. A small square of inoculum was placed on the uninjured epidermis and kept moist with absorbent cotton under an inverted preparation dish. No fruits were wounded in any of the inoculation tests. For controls, fruits were handled in the same manner except that sterile agar was substituted for the inoculum.

Six mature Honeydew melons were inoculated, and within 6 days four fruits were infected. The water-soaked, slightly sunken lesions averaged 5 cm in diameter. These artificially induced lesions were identical in color and consistency with those resulting from natural infection. The two noninoculated control fruits remained healthy. The fungus was reisolated from each infected fruit, and three mature melons were inoculated with the reisolated fungus. After 4 days, the lesions on the three infected fruits averaged 7 cm in diameter. The noninoculated controls continued healthy.

Similarly, 12 immature Honeydew melons were inoculated, with 4 melons for controls. After 4 days, seven melons showed typical lesions which averaged 6 cm in diameter. The noninoculated, control melons were healthy. Subsequently, reisolations from infected fruits and inoculations with the reisolated fungus were successful and yielded comparable results.

The approximate daily increase in size of some of the artificially induced lesions was determined by marking their circumferences with an indelible pencil. Lesions of both immature and mature fruits increased in diameter at the rate of more than 2 cm per day.

The results of the inoculation tests indicate that *Phytophthora capsici* is an aggressive parasite, capable of penetrating the uninjured epidermis of either immature or mature Honeydew melons, and that it is the cause of the fruit rot herein discussed.

Inoculations of mature Honeydew melons with *Phytophthora drechsleri* caused water-soaked lesions which differed from those

induced by *P. capsici* in their firmer texture and nonsunken character. Lesions caused by *P. drechsleri* did not tend to split when the fruit was handled, as did the soft, sunken lesions caused by *P. capsici*. *P. drechsleri* spread through the tissues much less rapidly than *P. capsici*.

TESTS FOR SEED TRANSMISSION

Under aseptic conditions, 16 seeds were removed from each of three naturally infected Honeydew melons and planted on poured plates of malt-extract agar. Of the 48 seeds, 18 yielded colonies of *Phytophthora capsici*. While this indicates that the fungus is found on some of the seed coats, it is questionable whether it can survive after the seeds have been removed from the fruit and dried.

Seeds were removed from three naturally infected Honeydew melons and dried at room temperature. Later, 200 seeds from each melon were planted in 6-inch pots of autoclaved soil in a high-temperature greenhouse. Before, during, and after seedling emergence there was no damping-off. The number of seeds which germinated were: Fruit no. 1, 169; fruit no. 2, 157; and fruit No. 3, 155. All pots were watered heavily each day in order to favor possible infection, but none of the seedlings became diseased.

Seeds from a healthy Honeydew melon were planted in pots of autoclaved soil. When the seedlings were 4 inches high, a pure culture of *Phytophthora capsici* on sterilized cracked wheat was added to the soil without injuring the roots. Sterilized cracked wheat was used for the controls. All inoculated and control plants were healthy after 3 weeks. It is of interest to note in this connection that the fungus was not cultured from roots or stems of field-grown plants on which diseased melons were found. These facts suggest that the plant itself is not subject to infection.

Seeds from the three infected and one healthy fruit, previously mentioned, were stored in paper bags at room temperature for approximately 4 months, following which 36 seeds from each fruit were planted on agar plates. *Phytophthora capsici* was not recovered in culture.

Further attempts to isolate the fungus were made by placing 48 seeds from infected fruits and 16 from the normal fruit in slits in mature apple fruits, a method that has proved valuable in isolating some species of *Phytophthora* when other fungi or bacteria are present (*11*). *P. capsici* was not obtained. In every case in which a fungus invaded the apple tissue from the seeds it proved to be a species of *Penicillium* or *Rhizopus*.

As a final test, 25 seeds from each of the 3 infected fruits and 25 seeds from the normal fruit were placed in a germinator at 26° C. After 1 week the seeds from infected fruits showed the following percentages of normal germination: No. 1, 60 percent; no. 2, 24 percent; no. 3, 24 percent. The seeds from the normal fruit produced 80 percent normal seedlings. When seeds from infected fruits that failed to germinate were cultured, *Penicillium* sp. and *Rhizopus* sp. were obtained. Microscopic examination of the seeds failed to reveal sporangia of *Phytophthora capsici*.

The evidence indicates that *Phytophthora capsici* is not transmitted in the seed. Like some other species of *Phytophthora*, the fungus probably lives in the soil as a saprophyte, becoming parasitic only when favorable environmental conditions, such as excess soil moisture and high temperatures, obtain.

EXPERIMENTAL HOST RANGE

In testing other fruits, roots, stems, and tubers for susceptibility to infection by *Phytophthora capsici*, the inoculation technique previously described was used. A suitable number of noninoculated controls was reserved for each species tested. They continued healthy for the duration of the experiments, which were conducted at room temperature (20° to 23° C.). Reisolations were made from all diseased specimens. The reisolated fungus from a particular host was then tested by inoculation into healthy specimens of that host. After infection occurred, isolations were made and the organism was recovered in pure culture.

The host range of the isolate of *Phytophthora capsici* from Honeydew melon, as determined by artificial inoculations in the laboratory, includes 14 species in 11 genera belonging to 6 families, and is as follows:

Lauraceae:
Persea gratissima Gaertn. (avocado).
Rosaceae:
Prunus persica Sieb. and Zucc. (peach—var. Elberta).
Pyrus malus L. (apple—var. Delicious, Jonathan, Esopus Spitzenberg).
Umbelliferae:
Daucus carota L. var. *sativa* DC. (carrot).
Ebenaceae:
Diospyros kaki L. (persimmon).
Solanaceae:
Solanum melongena L. var. *esculentum* Nees (eggplant).
S. muricatum Ait. (pepino).
Lycopersicum esculentum Mill. var. *vulgare* Bailey (tomato—var. Early Santa Clara Canner).
Capsicum annuum L. var. *grossum* Sendt. (bell or green sweet pepper).
Cucurbitaceae:
Cucurbita maxima Duchesne (squash—var. Banana).
C. pepo L. var. *condensa* Bailey (pumpkin—var. Early White Bush Scallop, Pie, Yellow Crookneck, Zucchine).
Citrullus vulgaris Schrad. (watermelon—var. Klondyke).
Cucumis melo L. (muskmelon—var. Dark Green Honeyball, Melo Dew, U. S. No. 45).
C. melo L. var. *inodorus* Naud. (casaba).
C. melo L. var. *reticulatus* Naud. (Persian melon).
C. sativus L. (cucumber).

Infection occurred within a range of 3 to 6 days, depending upon the host involved. In general, decay of tissues was rapid, with slight to marked sinking of the affected areas. Some fruits were completely rotted within a few days. Water-soaked lesions were produced on all hosts except avocado (Hay's maroon),[4] Elberta peach (Saccardo's olive), Delicious and Esopus Spitzenberg apples (chestnut-brown and tawny-olive), eggplant (warm sepia), Yellow Crookneck pumpkin (onion-skin pink), Klondyke watermelon (army brown), and casaba melon (dark olive-buff). Internally, infected tissues of all hosts also were water-soaked in appearance except avocado, apple, eggplant, and watermelon fruits, which showed discolorations comparable to those produced by their surface lesions.

Any fruits, roots, stems, or tubers which failed to become infected at the end of 3 weeks after inoculation were considered to be resistant. Negative results, covering a range of nine families, were obtained: *Ananas sativus* Schult. (pineapple), *Beta vulgaris* L. var. *crassa* Alef. (garden beet), *Brassica campestris* L. var. *napo-brassica* DC. (ruta-

[4] Color determinations were made with the aid of Ridgway's (9) manual.

baga), *B. rapa* L. (turnip), *Pyrus communis* L. (pear—var. Bartlett), *P. malus* L. (apple—var. Bellflower and Yellow Newtown), *Citrus aurantifolia* Swingle (lime), *C. limonia* Osbeck (lemon), *C. grandis* Osbeck (grapefruit), *C. sinensis* Osbeck (orange—var. Valencia), *Pastinaca sativa* L. (parsnip), *Ipomoea batatas* Poir. (sweetpotato), *Solanum tuberosum* L. (potato—var. Russet Burbank), *Cucurbita pepo* L. (pumpkin—var. Cream or Spring and Danish), *C. pepo.* L. var. *ovifera* Bailey (gourds), and *Sechium edule* Swartz (chayote).

In a comparative study of the species of *Phytophthora* one of the writers (*11*) obtained infection and killing of pepper stems inoculated near the tip with cultures of *Phytophthora capsici.* Inoculations with

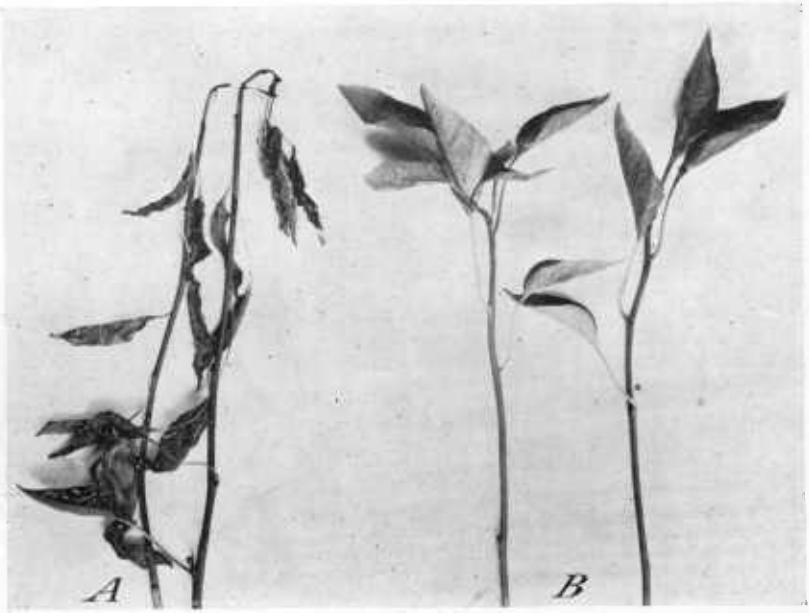

FIGURE 4.—California Wonder pepper plants 10 days after inoculation near the tips: *A*, Inoculated with *Phytophthora capsici* isolated from a Honeydew melon; *B*, inoculated with *Phytophthora parasitica* isolated from a tomato stem.

cultures of other species gave negative results; the pathogenicity of *P. capsici* to pepper stems was, therefore, regarded as a useful criterion for its identification. Pepper plants (California Wonder) 8 to 12 inches tall, were inoculated by placing a bit of mycelium from 2-week-old oatmeal-agar cultures in a small slit near the tip of each stem. Five plants were inoculated with each of two cultures from Honeydew melons identified as *P. capsici.* Both isolates proved virulently pathogenic; after 10 days the terminal portions of the plants were dead and the fungus had invaded and killed the stems to a distance of 3 to 6 inches below the point of inoculation (fig. 4). The results of the inoculations supply confirmatory evidence of the identity of the Honeydew melon fungus.

Parallel inoculations with cultures of *Phytophthora parasitica* isolated from tomato and rhubarb, and with a culture of *P. drechsleri* isolated from a Honeydew melon gave negative results (fig. 4).

Green pepper fruits were inoculated with *Phytophthora capsici* and other species by placing a small tuft of mycelium in a small slit which did not extend into the seed cavity. The wounds were covered with petrolatum and the fruits were incubated in moist chambers at 25° C. The following isolations were used: *P. capsici* (four from Honeydew melons and two from peppers); *P. drechsleri* (one from Honeydew melon); *P. parasitica* (one from *Robinia pseudoacacia* L. and one from *Rheum rhaponticum* L.); *P. citrophthora* (two from *Citrus* in Louisiana and Florida). After 3 days, short tufts of white mycelium appeared in an area about 1 inch in diameter surrounding the wounds in fruits inoculated with *P. capsici;* there was no browning of the tissue; all isolations of this species caused similar symptoms. *P. drechsleri, P. parasitica,* and *P. citrophthora* caused a brown discoloration of the fruit tissue in a small area surrounding the wounds, and there was no development of aerial hyphae. After 7 days the fruits inoculated with *P. capsici* were nearly covered with a dense, short, velvety growth of mycelium with some sporangiophores and sporangia. Invasion by the fungus was followed by a bacterial soft rot and the fruits were collapsing; there was no browning of the invaded tissue, but a fading of the normal dark green to a lighter green in the invaded areas. Fruits inoculated with *P. drechsleri, P. parasitica,* and *P. citrophthora* showed brown, firm areas nearly 1 inch in diameter at the wounds; there was no aerial mycelium and no soft rot and collapse of the tissues. The inoculations of pepper fruits supplied further evidence that *P. capsici* exhibits certain characteristic pathogenic properties that are uniform in cultures from different hosts and of some value in distinguishing this from other species.

Ten California Wonder and 20 Barbanera no. 1 bell pepper plants were inoculated by mixing 11-day-old cultures of *Phytophthora capsici* from a Honeydew melon with the soil in which they were growing. After 10 days more than half the plants were wilted; after 20 days all California Wonder plants and 19 of the 20 Barbanera no. 1 bell pepper plants were badly wilted and dying.

DISCUSSION

Although the occurrence of phytophthora rot, as shown by surveys of the melon-producing areas of the San Joaquin Valley, was limited to Honeydew melon, it seems probable that this disease might cause damage to other melon crops, such as watermelon, casaba, cantaloup, and Persian, not to mention the many different varieties of squash and pumpkin, if environmental conditions were favorable for the propagation of the fungus and for infection. Careful irrigation and well-drained soil are essential if the disease is to be avoided.

SUMMARY

A rot of honeydew melons was found in part of a commercial planting near Modesto, Calif. The soil had become water-logged owing to lack of proper drainage.

The disease affects both immature (green) and mature (ripe) fruits, but not the vines.

Symptoms of the disease consist of small, incipient brown or water-soaked spots which enlarge to form predominantly large, water-soaked

lesions. Occasionally infected fruits show zonate lesions. Internally, the invaded tissues are soft, water-soaked, and odorless.

The causal organism has been identified as *Phytophthora capsici* Leonian.

Infection of Honeydew melons was obtained by placing inoculum on the unbroken surfaces of the fruit and covering with moist absorbent cotton under an inverted preparation dish.

The incubation period varied from 4 days for immature fruits to 6 days for mature fruits.

Infection of Honeydew melons by *Phytophthora drechsleri* was also demonstrated. However, the fungus spread less rapidly through the tissues which remained firm.

Excessive irrigation, poor drainage, and high temperatures were found to be the chief predisposing factors to infection.

Negative results were obtained in tests for transmission of the fungus in the seed.

In addition to Honeydew melon, the fungus was shown to be pathogenic to 14 species in 11 genera belonging to 6 families.

Avoidance of the disease involves good soil drainage and careful irrigation practice.

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