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PYTHIACEOUS FUNGI on citrus in California were investigated during the season 1939–40. In the course of this investigation, citrus roots were examined for the presence of fungi, inoculation experiments were performed on citrus fruits with pythiaceous fungi from citrus in general, and growth-temperature relations of *Phytophthora* species found on citrus were studied. This paper reports the results of this work, and includes a compilation of records on the geographic distribution of *Phytophthora* on citrus and a description of all *Phytophthora* and *Pythium* species recorded on citrus.

PYTHIACEOUS FUNGI ON ROOTS OF CITRUS

In previously reported work on the isolation of fungi from roots of citrus, Fawcett (*3*)[4] states that species of *Pythium* and *Phytophthora* have been found to be associated with the damping-off and death of young citrus trees. Weindling (*11*) isolated *Phytophthora parasitica* Dastur and *Pythium* spp. from citrus seedlings affected with this disease in California, and Perlberger (*5*) found *Phytophthora citrophthora* (Sm. and Sm.) Leonian and *Phytophthora parasitica* in the same connection in Palestine. Fawcett (*1*) recorded the finding of *Phytophthora citrophthora* and *Phytophthora parasitica* in 1923 on large citrus roots and showed that the former would attack small roots of lemon trees. He (*2,3*) also found *Phytophthora megasperma* Drechsl. on the fibrous roots of orange trees dying back in heavy clay soil in Tulare County, California. In 1935, Petri (*6*) found *Pythium megalacanthum* de Bary and *Pythium de Baryanum* Hesse associated with root rot of oranges in Catania, Italy.

In order to explore the possibility that species of *Phytophthora* or some other fungi might be playing a more active part in producing disease in citrus trees in California than had hitherto been suspected, large numbers of roots were examined from citrus trees that showed a

[1] Received for publication May 19, 1941.

[2] Paper No. 456, University of California Citrus Experiment Station, Riverside, California.

[3] Plant Pathologist, Union of South Africa Department of Agriculture. On Commonwealth Fellowship in collaboration with the Division of Plant Pathology, University of California Citrus Experiment Station, Riverside, California, September, 1939, to June, 1940.

[4] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

dying-back, or decline. Orange and lemon trees growing in various localities in southern California were inspected.

Roots from the diseased trees were carefully washed in water; portions of the dead fibrous roots, about 1 cm long, were then surface-sterilized and placed on petri dishes poured with oatmeal agar. Culture tests were made from 320 fibrous roots of orange and 152 fibrous roots of lemon. The nonpythiaceous fungus *Fusarium Solani* (Mart.) App. and Wr.[5] was found on most of the roots from all localities.[6] Table 1 shows the pythiaceous fungi found and the frequency of their occurrence.

TABLE 1

PYTHIACEOUS FUNGI ISOLATED FROM FIBROUS ROOTS OF CITRUS TREES VARIOUSLY LOCATED*

Fungus	Orange roots		Lemon roots	
	Number of localities where found	Number of roots infected, of 320 tested	Number of localities where found	Number of roots infected, of 152 tested
Phytophthora citrophthora	4	6	1	3
Phytophthora parasitica	1	1	0	0
Pythium de Baryanum	1	1	0	0
Pythium rostratum	1	1	0	0
Pythium ultimum	9	31†	3	7
Pythium vexans	2	3	1	2

* Root samples were from citrus trees in 22 different localities.
† Of these roots, 20 (of 24 tested) were from 1 locality.

Pythium ultimum Trow was the fungus most frequently found in these root samples, occurring on 38 out of 472 roots from 12 out of 22 localities. *Phytophthora citrophthora* was next, occurring on 9 roots from 5 localities. *Pythium vexans* de Bary was found on only 5 roots from 3 localities; and the other fungi (table 1) came from only 1 locality each. The absence of a given fungus from a few samples of roots from a

[5] Identified by W. C. Snyder, Assistant Professor of Plant Pathology and Assistant Plant Pathologist in the Experiment Station.

[6] Culture tests made from roots of citrus trees affected with a condition known as "dry root rot" have generally yielded *Fusarium Solani*. Attempts by various workers (*3*), however, to reproduce the disease by inoculation, with this fungus, of trees growing under healthy conditions, have yielded negative results.

To test the possible effect of *Fusarium* further, large numbers of young citrus trees, including some three-year-old trees growing in 5-gallon cans, were inoculated with the *Fusarium Solani* common in the more recent isolation tests by introducing the fungus, growing on sterilized wheat kernels, into the top layers of the soil without disturbing the roots. A month later, a number of these plants were submerged in larger containers of water for periods varying from 3 days to 3 weeks. They were then drained rapidly and were watered thereafter whenever necessary. During the following 6 months, none of these plants showed any ill effects from the presence of the fungus or from the period of submersion.

given tree is not much of an indication, however, that it was not to be found on that tree. In a study of fungi on avocado roots (*10*), *Pythium ultimum* was found on 1 root and *Pythium vexans* on 20.

INOCULATION OF CITRUS FRUIT WITH PYTHIACEOUS FUNGI

Inoculations were made on orange and lemon fruits with all the pythiaceous fungi recorded by Fawcett (*3*) and by Fawcett and Bitancourt (*4*), namely, *Phytophthora citrophthora* (Sm. and Sm.), *Phytophthora parasitica* Dastur, *Phytophthora palmivora* Butler, *Phytophthora Syringae* Kleb. (=*P. hibernalis* Carne), *Phytophthora cactorum* (L. and C.) Schroet. (=*P. citricola* Saw.), *Phytophthora megasperma,* and *Phytophthora Cinnamomi* Rands; and by Wager (*8, 9*), namely, *Pythium irregulare* Buis. from a rotting orange and *Pythium ultimum* Trow from the navel end of a young orange. These fungi included all the Pythiaceae previously obtained from citrus, with the exception of *Pythium megalacanthum* de Bary.

The relative importance of deep and shallow wounds (that is, those which penetrate the juice sacs and those which do not) in the production of rots caused by *Alternaria Citri* Ellis and Pierce and *Fusarium lateritium* Nees has been demonstrated (*9*). Accordingly, in these tests, inoculum (fungus growing on agar) was placed on the surface of the fruit and in shallow wounds, being covered in both cases with damp absorbent cotton; or it was placed in deep wounds made with a cork borer and sealed with vaseline. The results are presented in table 2.

Phytophthora citrophthora, P. parasitica, P. palmivora, and *P. cactorum* produced a brown rot of fruits, whether the inoculum was placed on the surface of the uninjured fruit or in shallow or deep wounds. The fruits inoculated with *P. Syringae* were kept at 18° C; there was no infection through uninjured epidermis, and the rot developed very slowly both in shallow and in deep wounds.

Phytophthora megasperma did not produce infection through uninjured epidermis, but did induce a slow, brown, leathery rot through shallow or deep wounds. *P. Cinnamomi* was also unable to pierce uninjured epidermis; through wounds, it produced a firm, brown, leathery rot, which was inclined to be of a drier type inside than that produced by the other species.

Pythium ultimum and *Pythium de Baryanum* were able, in a few cases, to infect through uninjured skin. Both of these fungi, through shallow or deep wounds, produced a brown rot and wrinkling of the skin, grew rapidly to the core, and traveled to both ends of the fruit,

TABLE 2

INFECTION OF CITRUS FRUITS BY INOCULATION WITH PYTHIACEOUS FUNGI

Fungus, culture no., and source of culture	Number of fruits infected (of 3 inoculated) and rate of infection (R, rapid; S, slow)				
	Oranges		Lemons		
	Surface inoculation	Deep wound	Surface inoculation	Shallow wound	Deep wound
Phytophthora cactorum:					
2016,* from lemon fruit, Brazil	3 R	3 R	3 R	3 R	3 R
292,† from grapefruit, South Africa	3 S	3 S	2 S	3 S	2 S
Phytophthora Cinnamomi:					
2009,* from orange bark, Brazil	0	3 R	0	3 R	3 R
385,‡ from avocado root, South Africa	0	3 S	0	3 S	3 S
6, from avocado root, California	0	3 S	0	3 S	3 R
15, from avocado root, California	0	3 S	....	....	....
Phytophthora citrophthora:					
1309,* from lemon bark, California	3 R	3 R	3 R	3 R	3 R
3222,‡ from orange fruit, South Africa	3 R	3 R	3 R	3 R	3 R
29, from orange root, California	2 S	3 R	3 R	3 R	3 R
52, from lemon root, California	2 R	3 R	....	....	....
Phytophthora megasperma:					
1851,* from orange root, California	0	3 S	0	3 S	2 S
Phytophthora palmivora:					
2003,* from orange bark, Argentina	2 S	3 S	2 S	3 R	3 R
Phytophthora parasitica:					
2011,* from orange bark, Brazil	3 S	3 R	3 R	3 R	3 R
32,‡ from orange root, California	3 R	3 R	3 R	3 R	3 R
Phytophthora Syringae:					
1894,* from orange fruit, California	0	3 S	0	3 S	3 S
1839,* from orange fruit, California	0	3 S	0	3 S	3 S
Pythium de Baryanum:					
13, from orange root, California	0	3 R	1 R	3 R	3 R
Pythium irregulare:					
90, from orange fruit, South Africa	0	1 S	0	2 S	1 S
Pythium rostratum:					
37, from orange root, California	0	0	0	0	0
Pythium ultimum:					
1, from orange root, California	1 R	3 R	0	3 R	3 R
42, from lemon root, California	1 R	3 R	1 S	3 R	3 R
Pythium vexans:					
30, from orange root, California	0	3 S	0	3 S	3 S
38, from orange root, California	0	3 S	0	3 S	3 S

* Isolated by Fawcett.
† Isolated by Doidge.
‡ Isolated by Wager.

which then also showed infection. The decay was a much softer and slushier type than that produced by the *Phytophthora* species. *Pythium irregulare* behaved similarly, but was much less virulent and rotted only a few of the inoculated fruits. *Pythium vexans* produced a distinctive rot both in shallow and in deep wounds; it progressed slowly, developed a sunken, brown, slushy area with a water-soaked zone surrounding it,

TABLE 3

GROWTH-TEMPERATURE RELATIONS OF *Phytophthora* SPECIES

Fungus, culture no., and source of culture	Radial growth* of fungus after 4 days at 25° C and 4 days at different temperatures												
	1°	4°	7°	10°	13°	16°	19°	22°	25°	28°	31°	34°	37°
Phytophthora cactorum:	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
2016,† from lemon fruit, Brazil	0	0	3	5.0	9.5	15.5	17.0	22.0	27.5	28.0	4.0	0.0	0
292,‡ from grapefruit, South Africa	0	0	4	10.0	15.0	22.0	27.5	26.5	24.0	23.5	5.0	1.5	0
Phytophthora Cinnamomi:													
2009,† from orange bark, Brazil	0	0	0	0.0	3.0	15.5	16.5	21.0	20.0	21.5	21.5	20.0	0
385,§ from avocado root, South Africa	0	0	0	2.5	11.0	22.5	30.5	38.0	41.0	37.0	22.5	2.0	0
Phytophthora citrophthora:													
1309,† from lemon bark, California	0	0	3	4.5	10.5	14.5	16.5	19.5	21.0	21.0	18.5	6.0	0
190,§ from grapefruit bark, South Africa	0	0	0	5.0	13.0	20.0	22.0	25.5	32.0	31.5	27.5	2.0	0
3222,§ from orange fruit, South Africa	0	0	0	5.5	13.5	19.0	27.0	29.0	28.5	25.0	20.0	2.0	0
Phytophthora megasperma:													
1851,† from orange root, California	0	2	8	12.0	16.5	20.0	22.5	19.5	18.5	17.5	2.0	0.0	0
Phytophthora palmivora:													
2003,† from orange bark, Argentina	0	0	0	0.0	3.5	8.5	17.0	22.0	25.0	23.5	23.5	17.0	4
Phytophthora parasitica:													
2011,† from orange bark, Brazil	0	0	0	0.0	4.0	18.0	22.5	24.5	29.0	30.0	32.0	27.0	5
Phytophthora Syringae:													
1894,† from orange fruit, California	0	2	3	5.0	5.5	5.5	1.0	0.0	0.0	0.0	0.0	0.0	0
1839,† from orange fruit, California	0	0	6	6.0	9.5	7.0	2.0	0.0	0.0	0.0	0.0	0.0	0
296,‡ from orange fruit, South Africa	0	0	4	8.0	11.0	11.0	1.0	0.0	0.0	0.0	0.0	0.0	0

* Average of three cultures. † Isolated by Fawcett. ‡ Isolated by Doidge. § Isolated by Wager.

and was soft and slushy inside. *Pythium rostratum* Butler and one strain of *Pythium vexans* (with coiled antheridial branch) did not produce any infection at all.

GROWTH-TEMPERATURE RELATIONS OF PHYTOPHTHORA SPECIES

The growth-temperature relations of *Phytophthora* species, based on radial growth of the mycelium in culture, are shown in table 3. The results agree with those of Fawcett and Bitancourt (*4*). *P. parasitica* has a slightly higher maximum than *P. citrophthora;* and *P. parasitica, P. palmivora,* and *P. Cinnamomi* from citrus in Brazil grew well at 34° C. *P. Syringae* is a low-temperature fungus, not growing at 22° or above and showing maximum growth between 13° and 16°. *P. megasperma* also has a low maximum, 19°.

DISTRIBUTION OF PHYTOPHTHORA SPECIES ON CITRUS

The world distribution of the *Phytophthora* species on citrus, as compiled from Fawcett's (*3*) records and from a survey of phytopathological literature up to 1940, is as follows:

Phytophthora cactorum:
- Argentina
- Brazil
- Japan
- South Africa

Phytophthora Cinnamomi:
- Brazil
- United States—California

Phytophthora citrophthora:
- Argentina
- Australia—New South Wales, Queensland, South Australia, Victoria, and West Australia
- Azores
- Belgian Congo
- Brazil
- Cyprus
- Egypt
- India
- Italy
- Japan
- Mexico
- Mozambique
- New Zealand
- Palestine
- Portugal
- Sicily
- South Africa
- Southern Rhodesia
- Spain
- United States—California and Florida
- West Indies, including Puerto Rico

Phytophthora megasperma:
- United States—California

Phytophthora palmivora:
- Argentina
- Ceylon
- East Indies, including Java
- India
- Malaya
- Philippine Islands
- Surinam
- Tanganyika Territory
- Uruguay
- West Indies, including Puerto Rico and Trinidad

Phytophthora parasitica:
- Argentina
- Australia—New South Wales
- Azores

Phytophthora parasitica (continued)
Brazil
Cuba
East Indies—Java
Italy
Japan
Mexico
Palestine
Paraguay
Philippine Islands
Portugal
Sicily
Spain
United States—California and Florida
Uruguay
West Indies, including the Lesser Antilles, Puerto Rico, and Trinidad

Phytophthora Syringae:
Australia—New South Wales, South Australia, Victoria, and West Australia
Azores
Portugal
South Africa
United States—California

IDENTIFICATION OF PYTHIACEOUS FUNGI ON CITRUS

For convenience in identifying Pythiaceae found on citrus, the characteristics of *Phytophthora* species are given in table 4 (see also fig. 1), and those of *Pythium* species in table 5 (see also fig. 2). All cultures described in these tables were examined by the writer except *Pythium megalacanthum.*

According to Tucker (*7*), the names *Phytophthora hibernalis* and *P. citricola* should be discarded in favor of *P. Syringae* and *P. cactorum,* respectively. Fawcett's cultures 1894 *P. Syringae* and 1839 *P. hibernalis* were found very similar in their cultural and morphological characters and in their reactions when inoculated into citrus fruits and are herein considered to be *P. Syringae.*

TABLE 4

MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERS OF *Phytophthora* SPECIES ON CITRUS

Fungus, culture no., and source of fungus	Characters of the isolates used in this study					Characters recorded in original description of species
	Distinguishing characters	Oögonia and oöspores	Antheridia	Chlamydospores	Sporangia	
Phytophthora cactorum (L. and C.) Schroet.:						
2016,* from lemon fruit, Brazil	Profuse production of oögonia with paragynous antheridia	Oögonia 18–42, commonly 30μ in diameter; oöspores about 6μ less; light yellow-brown	Paragynous	Only a few seen; 26μ in diameter; thin-walled, not colored	Papilla not prominent; 20–30 × 25–40μ in size; sparsely produced†	Oögonia average 26–29μ in diameter; chlamydospores very scarce; sporangia 25 × 32–42μ in size
292,‡ from grapefruit, South Africa	Profuse production of oögonia with paragynous antheridia	Oögonia 28–33, average 29.3μ in diameter	Paragynous	16–33, commonly 30μ in diameter	20–36 × 43–73μ, average 31 × 58μ in size	Oögonia average 26–29μ in diameter; chlamydospores very scarce; sporangia 25 × 32–42μ in size
Phytophthora Cinnamomi Rands:§						
2009,* from orange bark, Brazil	Production of chlamydospores in bunches	Oögonia 28–36, commonly 33μ in diameter; very rare in culture; oöspores 3–5μ less in diameter, with very thick wall	14–18μ in diameter; amphigynous; golden-brown	15–50, commonly 40μ in diameter; occurring in bunches; thin-walled	Ovoid; nonpapillate; 25–35 × 40–60μ, commonly 30 × 50μ in size; proliferous	Oögonia average diameter 32μ (Ashby) or 28μ (Tucker); chlamydospores 28–60, average 41μ in diameter; sporangia 18–43 × 25–100μ, average 33 × 57μ in size
Phytophthora citrophthora (Sm. and Sm.) Leonian:						
1309,* from lemon bark, California	Absence of oögonia; optimum growth at 25–27.5° C, none at 32.5°	Not found	Not found	Spherical; thin-walled; 20–40, commonly 30–35μ in diameter	Prominently papillate, 12–40 × 20–50μ, commonly 25 × 40μ in size	Oögonia unknown; chlamydospores commonly 28μ in diameter; sporangia 20–60 × 30–90μ, average 35 × 50μ in size; may retain a pedicel
190,¶ from grapefruit bark, South Africa	Absence of oögonia; optimum growth at 25–27.5° C, none at 32.5°	Not found	Not found	Very rare; 25–30μ in diameter	20–40 × 23–56μ, average 35 × 41μ in size	Oögonia unknown; chlamydospores commonly 28μ in diameter; sporangia 20–60 × 30–90μ, average 35 × 50μ in size; may retain a pedicel
Phytophthora megasperma Drechsl.:						
1851,* from orange root, California	Large size of oögonia and absence of chlamydospores	Oögonia 30–54, average 43μ in diameter; oöspores about 6μ less, with thick yellow wall	12–15μ in diameter; usually paragynous but may be amphigynous	Not found	Ovoid or sometimes papillate; 25–42 × 35–54μ, commonly 35 × 46μ in size; proliferous	Oögonia 16–61, average 47.4μ in diameter; sporangia 6–45 × 15–90μ in size

TABLE 4—(*Continued*)

Phytophthora palmivora Butler: 2003,* from orange bark, Argentina	Absence of oögonia; optimum growth at 27.5–30° C; will grow at 32.5°	Not found	Not found	Produced in abundance; spherical; may be intercalar; 25–40, commonly 30μ in diameter; thin-walled	Prominently papillate; 22–35 × 35–55μ, commonly 32 × 40μ in size	Oögonia produced only in paired cultures; oöspores 22–24μ in diameter; antheridia amphigynous; chlamydospores 32–42μ in diameter; sporangia 25–35 × 40–60μ in size, with short, stout pedicel
Phytophthora parasitica Dastur: 2011,* from orange bark, Brazil	Optimum and maximum growth temperatures about 3° higher than that for *P. citrophthora*	Oögonia 27–36, commonly 32μ in diameter; oöspores 3–5μ less, thick-walled, yellow-brown	Mainly amphigynous	Produced in abundance; 27–42, commonly 30μ in diameter; thin- or thick-walled; may be yellow	Prominently papillate; 15–30 × 18–48μ, commonly 28 × 40μ in size	Oögonia group microspora, 12–24μ in diameter, average under 20μ; macrospora 20–35μ in diameter, average over 20μ; chlamydospore ±30μ in diameter; sporangia average more than 25 × 30μ in size
32,¶ from orange root, California	Optimum and maximum growth temperatures about 3° higher than that for *P. citrophthora*	Oögonia 24–33, commonly 30μ in diameter		28–54, commonly 30μ in diameter	21–45 × 24–60μ, commonly 35 × 48μ in size	Oögonia group microspora, 12–24μ in diameter, average under 20μ; macrospora 20–35μ in diameter, average over 20μ; chlamydospore ±30μ in diameter; sporangia average more than 25 × 30μ in size
Phytophthora Syringae Kleb.: 1894,* from orange fruit, California	Grows at low temperatures; optimum growth at 13–16°C	Oögonia 27–36, commonly 32μ in diameter; oöspores 3–5μ less, thick-walled, light yellow	Small, 9–12μ in diameter; paragynous	Not found	Papilla flattened or protruding but without hyaline plug; 15–18 × 24–42μ, commonly 18 × 36μ in size; thin persistent pedicel 10–25μ long	Oögonia, average diameter 28.4μ (Tucker), 40.8μ (Carne); sporangia 15–33 × 28–41μ, average 17.9 × 34.4μ (Tucker), 16.1 × 34.6μ (Carne)
296,‡ from orange fruit, South Africa	Grows at low temperatures; optimum growth at 13–16° C	Oögonia 26–40, commonly 35.2μ in diameter		Not found	15–25 × 26–57μ, commonly 20 × 37.5μ in size	Oögonia, average diameter 28.4μ (Tucker), 40.8μ (Carne); sporangia 15–33 × 28–41μ, average 17.9 × 34.4μ (Tucker), 16.1 × 34.6μ (Carne)

* Isolated by Fawcett.

† In one test with *Phytophthora cactorum*, a culture on oatmeal agar was flooded with pea broth, and sporangia were produced in abundance, very irregular in shape, mostly elongated, and very variable in size (45–90, commonly 60 x 30μ).

‡ Isolated by Doidge.

§ This fungus from citrus was compared with *Phytophthora Cinnamomi* from roots of avocado from South Africa and from California. All were found to be very similar morphologically and all produced oögonia on oatmeal-agar tubes that had been kept in the laboratory over winter and were 3 to 6 months old.

¶ Isolated by Wager.

TABLE 5

MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERS OF *Pythium* SPECIES ON CITRUS

Fungus and source of culture	Characters of isolates used in this study			Characters recorded in original description of species*
	Oögonia and oöspores	Antheridia	Sporangia	
Pythium de Baryanum Hesse, from orange root,†‡ California	Oögonia 16–26, commonly 20μ in diameter; usually terminal; may be intercalar; oöspores about 3μ less in diameter	Commonly 1 or 2 per oögonium, may be more; arise on same hypha as, and some distance from, the oögonium or on separate hypha	14–28, commonly 22μ in diameter; terminal and spherical or may be intercalar and oval; thin-walled; production of zoöspores not observed	Oögonia 15–28, average 21μ in diameter; sporangia 15–26, average 19μ in diameter; zoöspores produced
Pythium irregulare Buis., from orange fruit,‡ South Africa	Oögonia 16–24, commonly 22μ in diameter; may be terminal; mostly intercalar; spherical, oval, irregularly lobed, or with few blunt, digitate spines; oöspores about 3μ less in diameter	Commonly 2 or 3 per oögonium; clavate and crook-necked, usually with fairly long stalk arising from same or neighboring hypha	13–28μ in diameter; very variable in shape: terminal and spherical or may be intercalar and elliptic or irregular in shape; evacuation tube usually ⅓ to ½ length of oögonium	Oögonia 16–18μ in diameter; sporangia 10–20μ in diameter; zoöspores produced
Pythium megalacanthum de Bary,§ from orange root,¶ Italy	Oögonia 36–45μ in diameter, exclusive of spines; terminal or intercalar; spines 6–9μ long, conical, acutely tipped; oöspores smooth	One or more per oögonium; diclinous	Terminal or intercalar; spherical to subspherical; frequently proliferous, forming a second sporangium above the primary; zoöspores produced	Oögonia 42–54μ in diameter; sporangia frequently proliferous; zoöspores produced
Pythium rostratum Butler, from orange root,†‡ California	Oögonia 12–27, commonly 21μ in diameter; occasionally terminal; usually intercalar; may occur in chains; oöspores usually filling oögonia	Usually 1, rarely 2 or 3 per oögonium; may arise at base of oögonium or may be a portion of oögonial stalk; sometimes swollen	15–27, commonly 24μ in diameter; usually spherical; may be intercalar and oval, or barrel-shaped; thin-walled; production of zoöspores not observed	Oögonia usually 21μ in diameter and intercalar; sporangia 23–34, average 28μ in diameter; zoöspores produced
Pythium ultimum Trow, from orange root,†‡ California	Oögonia 18–24, commonly 21μ in diameter; usually terminal and spherical; may be intercalar; oöspores about 3μ less in diameter	Usually 1, curved, arising immediately below the oögonium; usually sessile or from a different hypha	16–26, commonly 21μ in diameter; usually terminal and spherical; may be intercalar, thin-walled	Oögonia 19.6–22.9, average 20.6μ in diameter; sporangia 12–28, average 20μ in diameter; zoöspores not produced
Pythium vexans de Bary, from orange root,†‡‖ California	Oögonia 15–24, commonly 20μ in diameter; mostly terminal; few intercalar; oöspores about 3μ less in diameter	Usually 1, rarely 2 per oögonium; swollen, clavate or bell-shaped, usually on long branch arising from hypha bearing oögonium	12–26, commonly 22μ in diameter; usually terminal and spherical; may be intercalar and elliptic or irregular in shape; evacuation tube usually ⅓ to ½ length of oögonium	Oögonia 15–28, average 22μ in diameter; sporangia 17–24, average 21μ in diameter; zoöspores produced

* Middleton, John T. Taxonomy of the genus *Pythium* Pringsheim. Thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy, University of Missouri, 1940. (Typewritten.) Copy on file in the Library of the University of Missouri, Columbia.

† Fibrous roots.

‡ Isolated by Wager.

§ This fungus was not seen by the writer; the description given is that of its author, de Bary.

¶ Isolated by Petri.

‖ One fungus isolated from lemon rootlets differed from the typical *P. vexans* in having a coiled antheridial branch and mostly irregular-shaped sporangia, as shown in fig. 2, *D*, *E*, and *H*. Zoöspores were produced in the same manner as those of other cultures of *P. vexans* and measurements of oögonia and sporangia were not materially different. Middleton considers this fungus a strain of *P. vexans*.

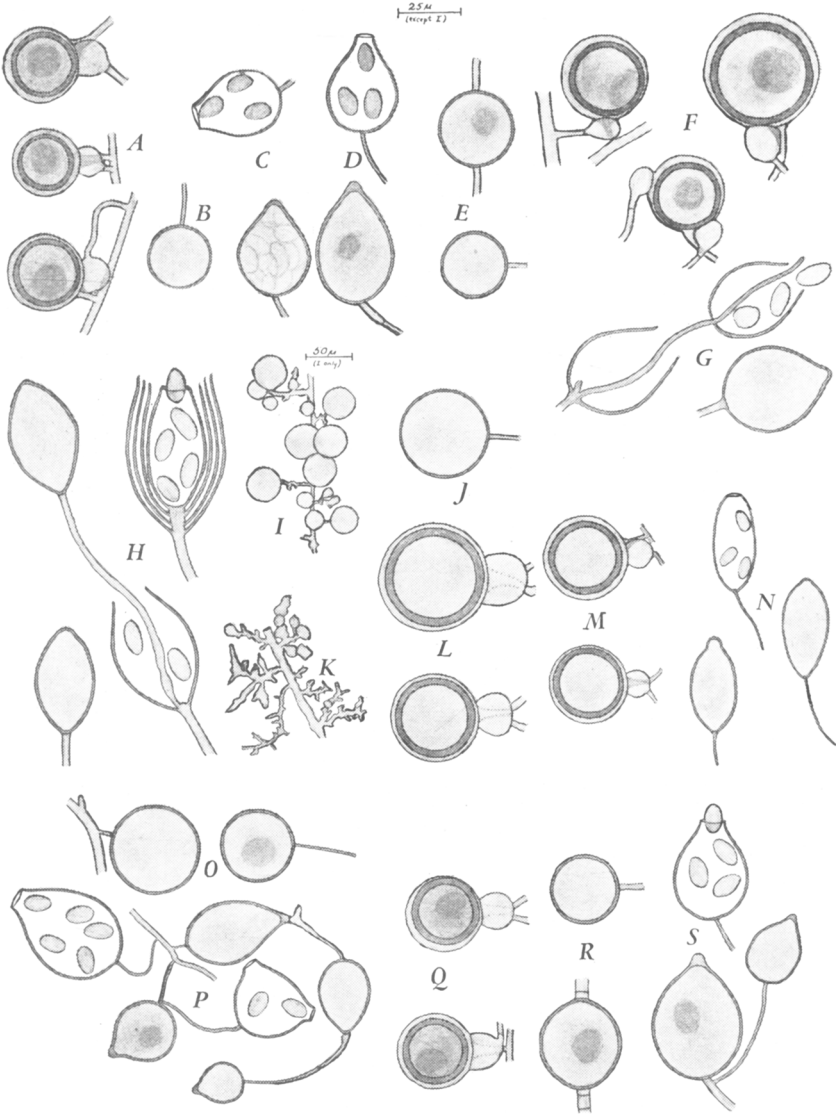

Fig. 1.—*Phytophthora* species. *A–C, Phytophthora cactorum* (L. and C.) Schroet.: *A,* oögonia and paragynous antheridia; *B,* chlamydospore; *C,* sporangia. *D–E, Phytophthora palmivora* Butler: *D,* sporangia; *E,* chlamydospores. *F–G, Phytopthora megasperma* Drechsl.: *F,* oögonia and paragynous antheridia; *G, sporangia. H–L, Phytophthora Cinnamomi* Rands: *H,* sporangia; *I, J,* chlamydospores; *K,* mycelium; *L,* oögonia and amphigynous antheridia. *M–N, Phytophthora Syringae* Kleb.: *M,* oögonia and paragynous antheridia; *N,* sporangia with persistent pedicels. *O–P, Phytophthora citrophthora* (Sm. and Sm.) Leonian: *O,* chlamydospores; *P,* sporangia. *Q–S, Phytophthora* parasitica Dastur: *Q,* oögonia and amphigynous antheridia; *R,* chlamydospores; *S,* sporangia.

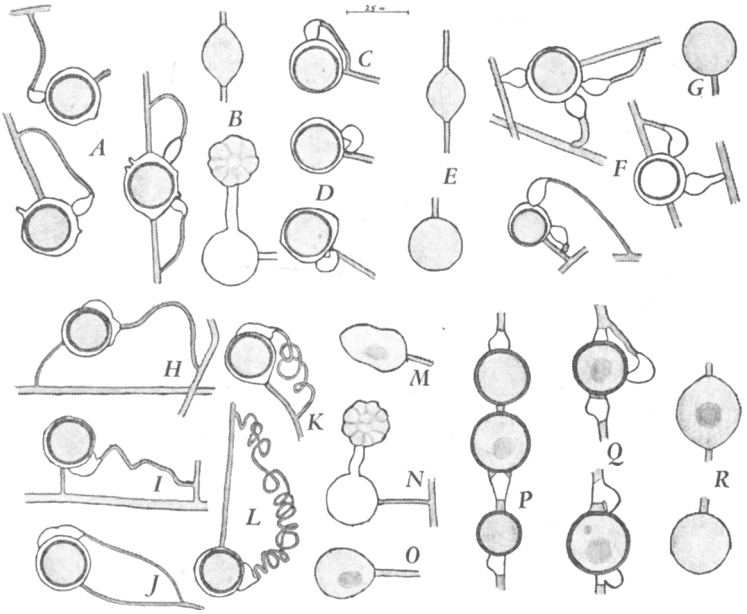

Fig. 2.—*Pythium* species. *A–B, Pythium irregulare* Buis.: *A,* antheridia and oögonia; *B,* sporangia. *C–E, Pythium ultimum* Trow: *C,* stalked antheridium that occurs rarely; *D,* common type of antheridium and oögonium; *E,* sporangia. *F–G, Pythium de Baryanum* Hesse: *F,* antheridia and oögonia; *G,* sporangium. *H–O, Pythium vexans* de Bary: *H, I, J, K, L,* oögonia and antheridia; *M, N,* and *O,* sporangia; *K, L,* and *M* are of a strain of the fungus from lemon rootlets and differ somewhat from other forms in having a coiled antheridial branch and irregular-shaped sporangia. *P–R, Pythium rostratum* Butler: *P* and *Q,* antheridia and oögonia; *R,* sporangia.

SUMMARY

Cultures were made from fibrous dead roots of orange and lemon trees growing in various localities in southern California and showing a dying-back, or decline.

Pythium ultimum, Pythium de Baryanum, Pythium vexans, Pythium rostratum, Phytophthora citrophthora, and *Phytophthora parasitica* were found on some of these roots, *Pythium ultimum* being the most frequent. The occurrence of the last-named fungus was very infrequent, however, in comparison with that of the nonpythiaceous fungus *Fusarium Solani,* which was found on almost every root.

The results of inoculation tests on orange and lemon fruits with the aforementioned *Pythium* species, with *Pythium irregulare,* and with all the *Phytophthora* species that have been isolated from citrus, namely, *Phytophthora citrophthora, Phytophthora parasitica, Phytophthora palmivora, Phytophthora Syringae, Phytophthora cactorum, Phytophthora Cinnamomi,* and *Phytophthora megasperma* are reported in this paper.

The distribution of the *Phytophthora* species and descriptions of the morphological characters of the *Phytophthora* and *Pythium* species which have been recorded on citrus are given.

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