Influence of \textit{Fusarium solani} on citrus root rot caused by \textit{Phytophthora parasitica} and \textit{Phytophthora citrophthora}

L.M. DANDURAND\textsuperscript{1} and J.A. MENGE

\textit{Department of Plant Pathology, University of California, Riverside, CA 92521, USA.} \textsuperscript{1}Present address: Division of Plant Pathology, University of Idaho, Moscow, ID 83843, USA

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\textbf{Abstract}

Interactions between \textit{Fusarium solani} and \textit{Phytophthora parasitica} or \textit{F. solani} and \textit{P. citrophthora} influenced the development of root rot of citrus but depended on the temporal order of inoculation with \textit{F. solani} or the two \textit{Phytophthora} spp. Inoculation of citrus with either \textit{Fusarium solani} and \textit{Phytophthora parasitica} or \textit{F. solani} and \textit{P. citrophthora} increased root rot compared to inoculation with \textit{P. parasitica} or \textit{P. citrophthora} alone when plants were inoculated with \textit{Phytophthora} by dipping their roots in zoospore suspensions and subsequently transplanted into soil infested with \textit{F. solani}. However, root rot was not increased by simultaneous co-inoculation of \textit{P. parasitica} and \textit{F. solani} or when plants were inoculated with \textit{F. solani} first. Root rot was not increased when heat-stressed or non-stressed plants were inoculated with \textit{P. parasitica} 30 days after transplanting into soil infested with \textit{F. solani}. In most but not all experiments, \textit{F. solani} alone reduced growth of tops or roots a small but significant amount.

Co-inoculation of citrus by root-dipping into zoospore suspensions of \textit{P. parasitica} and transplanting into soil infested with \textit{F. solani} reduced feeder root length by 62\% and root weight by 61\% but did not significantly reduce the percentage of living roots when compared to inoculation with \textit{P. parasitica} alone. When citrus roots were immersed in zoospore suspensions of \textit{P. citrophthora} and transplanted into soil infested with \textit{F. solani}, feeder root length was reduced by 68\%, but feeder root weight and the percentage of living roots were not significantly reduced when compared to plants inoculated with \textit{P. citrophthora} alone.

Propagation densities of both \textit{P. parasitica} and \textit{P. citrophthora} in the rhizosphere of plants inoculated by root-immersion and then transplanting into soil infested with \textit{F. solani} were not significantly different than propagule densities from plants transplanted into non-infested soil. Propagule densities of \textit{P. parasitica} were suppressed an average of 41\% when citrus was inoculated with \textit{P. parasitica} 30 days after transplanting into soil infested with \textit{F. solani} and by 41\% when citrus was co-inoculated by transplanting into soil infested with both \textit{F. solani} and \textit{P. parasitica}.

\textbf{Introduction}

\textit{Fusarium solani} (Mart.) Sacc. emend. Snyd. and Hans. [teleomorph \textit{Nectria hematocca} Berk. and Br.] is the predominant fungus isolated from roots and rhizosphere soil of citrus (Carpenter et al., 1959; Martin, 1947; Martin and Joseph, 1968; Nemec et al., 1978; Sherbakoff, 1953). Several studies have characterized \textit{F. solani} as an opportunist interacting with citrus root pathogens to increase disease (Bender, 1985; Fawcett, 1923; Martin, 1950; Menge et al., 1981;
As early as 1923, Fawcett (1923) reported that co-inoculation of *Phytophthora citrophthora* (Sm. and Sm.) Leonian and *F. solani* increased gummosis of citrus caused by *P. citrophthora*. In co-inoculation studies of citrus with *Tylenchulus semipenetrans* Cobb and *F. solani*, plant dry weight was reduced when seedlings were co-inoculated compared to inoculation with the citrus nematode alone (O'Bannon et al., 1967; Van Gundy and Tsao, 1963). *Fusarium solani* alone did not reduce plant dry weight unless soil temperatures were low (15 and 20°C) (Nemec and Zablotowicz, 1981; Van Gundy and Tsao, 1963) or high (30°C) (O'Bannon et al., 1967). *Fusarium solani* is also the causal agent of dry root rot of citrus (Bender, 1985), a disease of the crown and scaffold roots. However, citrus trees usually are not affected by dry root rot even though *F. solani* can be isolated from healthy roots. Dry root rot developed consistently only when citrus was stressed by co-inoculation with *Phytophthora citrophthora* (Bender, 1985; Menge et al., 1981). Non-stressed plants did not develop dry root rot. Stress may be important in pre-disposing the citrus plant to infection and disease caused by *F. solani*.

Most of the damage to feeder roots of citrus in southern California is caused by *Phytophthora parasitica* Dast. and *P. citrophthora* (Klotz et al., 1958). In Florida, *F. solani* has been reported to cause feeder root rot of citrus when seedlings were root-dipped into Fries medium containing macroconidia of *F. solani* (Nemec et al., 1981). However, feeder root rot did not occur when citrus seedlings were dipped in aqueous conidial suspensions or planted into soil infested with conidia.

Few studies have been done to determine the effect of co-inoculation of *F. solani* with *P. parasitica* or *P. citrophthora* on feeder root rot of citrus. Klotz et al. (1958) tested the effect of co-inoculating *P. citrophthora* with fungi commonly isolated from citrus roots, such as *F. solani*, on decay of feeder roots. Roots decayed only when *P. citrophthora* was present, whether it was alone or in combination with the other fungal species tested. However, the amount of root rot which occurred for the different treatments was not quantified. Co-inoculation of *P. citrophthora* with the fungi tested may have increased the amount of root rot as compared to *P. citrophthora* alone.

The objectives of this study were to determine whether: 1) *F. solani* influenced root rot of citrus caused by *P. parasitica* and *P. citrophthora*, 2) *F. solani* alone caused feeder root rot, and, 3) heat-stress influenced the susceptibility of citrus to feeder root rot when inoculated with both *F. solani* and *P. parasitica*.

**Materials and methods**

**Fungal isolates and inoculum preparation**

Isolates of *F. solani* were obtained from feeder roots of citrus from a grove in Highland, California, and a grove near Visalia, California. Isolations were made by surface sterilizing 1-mm root segments for 5 min in 0.5% sodium hypochlorite. The samples were rinsed several times in sterile distilled water and plated onto the Fusarium-specific medium described by Nash and Snyder (1962). *Fusarium solani* was stored in autoclaved 1% cornmeal blowsand (Bender, 1985). Inoculum for each experiment was prepared by placing particles from the soil tubes onto citrus twig agar (Bender, 1985). Plates were incubated under continuous fluorescent lights at ambient root temperature for 4–6 wk. Macroconidia were scraped from the surface of the twigs, suspended in sterile water, and adjusted to the desired density.

Single zoospore isolates of *P. parasitica* and *P. citrophthora* were obtained from rhizosphere soil of citrus from Highland, California, by soil dilution plating (Lutz and Menge, 1991). Single zoospore isolates were obtained and identified by colony morphology. Chlamydospores were produced and harvested as described by Tsao (1971). Zoospores were produced according to the methods of Menyonga and Tsao (1966).

**Plant material and soil**

Grapefruit (*Citrus paradisi* Macf.), pineapple...