Good Agricultural Practices (GAPs) for the Management of Phytophthora Brown Rot of Citrus in California

2018-19

Overview: Phytophthora brown rot is a disease of citrus fruit that is caused by several species of the fungal-like genus *Phytophthora*, including *P. citrophthora, P. syringae, P. hibernalis,* and *P. parasitica*. Phytophthora species can also cause root rot, foot rot, and gummosis of citrus. Brown rot develops mainly on fruit growing near the ground. Symptoms include olive-brown discoloration of the rind and a distinctive, pungent, aromatic odor of the fruit. Production of infectious propagules of the pathogen depends on environmental conditions, but for all species, temperature and the length of continuous wetness periods are the most important predictors of brown rot epidemics. Damage of citrus fruits from the disease is more likely to occur in the winter in many citrus-growing areas of California.

Observations and research have indicated that:

- *Phytophthora* species are present in all citrus growing areas in California.
- *Phytophthora syringae* and *P. hibernalis* are quarantine pathogens and are only active during the cooler months of the year.
- The soil/root/leaf litter and fruit disease phases of the pathogens are connected; thus, brown rot management requires integrated management. *Phytophthora citrophthora* is found in the soil; whereas *P. syringae* is mostly found in leaf litter. Orchards with high amounts of leaf litter under the tree canopy are more likely to have *P. syringae* causing brown rot.
- The *Phytophthora* pathogens can infect healthy tissue and do not need injuries for infection.
- At optimum temperatures, the pathogens require approximately 18 h to 24 h of wetness to form sporangia that produce the infectious propagules, the zoospores.
- Wetness (from rain or irrigation) during cool weather is the most important environmental factor determining disease outbreaks by the quarantine pathogens.
- In the field, brown rot develops on mature or nearly mature fruit and mainly on fruit near the ground where spores from the soil are splashed onto the tree.
- Symptoms develop after 6 to 28 days, depending on the temperature and species involved.
- Harvested fruit may be symptomless and disease develops during shipment and storage.
- Detection of brown rot and differentiation of the four pathogens can be done by culturing the organism, or more rapidly, by molecular PCR-based methods using species-specific primers.
- Effective registered preharvest and postharvest fungicide treatments are available and new compounds have been identified and are being developed for use in California.
- MRLs for potassium phosphite have not been established in international markets for postharvest fruit treatments. In the United States, the fungicide is exempt from tolerance.

I) Management of the disease: Efficacy of preharvest cultural practices and pre- and postharvest chemical treatments is cumulative and warrants a “systems approach” for control of Phytophthora brown rot of citrus.

A) Cultural practices:

1) Planting scions on resistant rootstocks (from UC Publ. No. 21477). Ratings for root rot:
   A. **Orange**: Sweet - susceptible, Sour - intermediate, Trifoliate hybrids - intermediate (e.g. Carrizo, Troyer) to tolerant (C-35, C-32, Swingle), and trifoliate - tolerant
   B. **Mandarin**: Cleopatra and Rangpur - susceptible
   C. **Lemon**: Volkameriana – rough lemon - susceptible, Macrophylla and Yuma ponderosa - tolerant
2) Planting on berms for adequate drainage.

3) Removal of lower branches or “skirt pruning” by mechanical or manual methods must be done to ensure no fruit or branches touch the ground allowing for infection by *Phytophthora* species. This practice should be utilized and maintained over the course of the year. There is no set height for removing lower branches, but grower horticultural records must document yearly skirt pruning activities.

4) Adjusting irrigation systems to minimize water splashing onto lower fruit and avoid excess soil moisture (long irrigation sets) conducive for growth of *Phytophthora* species.

5) Fruit planned for export to China must be harvested above 20 in/50 cm from the ground. This can be done in the field using various measuring methods such as marking ladders, hanging ribbons, or other types of measures. Growers should have a system in place to prevent mixing of fruit from 20 in/50 cm and below from fruit above 20 in/50 cm. Grower or packinghouse horticultural records for harvesting operations must be documented.

B) Fungicide treatments for direct application to fruit or soil surface for brown rot control:

1) Fungicide treatments (copper - FRAC Code M1; phosphonate fungicides – FRAC Code P07 formerly 33; and oxathiapiprolin – FRAC Code 49) can protect fruit from infection by *Phytophthora* spp. Copper fungicides include fixed coppers (e.g., basic copper sulfate, copper hydroxides, copper oxides, copper oxychloride/copper hydroxide mixtures) and Bordeaux mixtures including copper sulfate-lime or zinc sulfate-copper sulfate-lime mixtures. Phosphonate fungicides include fosetyl-Al and potassium phosphite products. Many phosphate (PO_4) fertilizers also contain phosphite (PO_3) and can be applied to maintain tree health. Postharvest fruit applications with labeled phosphonate fungicides may not be used because MRLs are not established in China. Orondis (oxathiapiprolin) was registered in early 2018 for foliar and soil application (e.g., chemigation) on citrus in California and the United States. Foliar treatments should be applied to the entire tree. When rainfall is excessive, multiple treatments may have to be applied during the harvest season (e.g., January, February, March, etc.). Treating the ground underneath the trees with a systemic fungicide such as mefenoxam (e.g., Ridomil Gold) or with a protectant/ locally systemic fungicide such as Orondis also reduces brown rot infections by reducing soil populations.

2) The first protective fungicide application must be a registered copper compound. If the alternative fungicides are used, copper needs to be included in the tank mixture for the first application. The application is **mandatory and must be done after the first rain** to all citrus planned for exportation to China. Historically, this application is made between **October 15 and November 30** for the central valley (District 1) of California. Growers in Coastal (District 2) and Desert (District 3) regions will be notified for the application by industry organizations.

3) Possibly, second and third applications may be needed and will be based on rainfall and temperature conditions experienced in each region. Industry-wide forecasting of favorable conditions for brown rot is planned for the three citrus growing regions: District 1 (Madera, Fresno, Tulare, and Kern Co.); District 2 (Coastal counties); and District 3 (Desert counties) (*see* Models below).

4) For the second or possible third applications, copper products, phosphonates, mefenoxam (this latter fungicide is used as a soil treatment), and oxathiapiprolin (Orondis – registered for foliar and soil use) are available for use. Preharvest foliar phosphite (PO_3) treatments (e.g., fertilizers containing PO_3,) may be used, but postharvest applications to fruit in the packinghouse are not allowed.

5) Foliar applications of copper sprays are effective for approximately 6 weeks. Phosphonate fungicides last approximately 3-4 weeks, whereas Orondis still shows efficacy after 6-8 weeks. Heavy rainfall will shorten the persistence of all foliar treatments. Phosphonates are best used within two weeks of harvest because they are systemic and will provide some efficacy during transit.

6) Pesticide Use Reports (spray records) **must** be available for inspection prior to the phytosanitary inspections.

C) Specific details for fungicide treatments:

1) **Zinc-copper-lime treatments:** When preparing triple mixtures of zinc, copper, and lime, the rate of zinc sulfate (neutral and acidic forms) should be based on the metallic zinc equivalent (mze) at a minimum of 2.5 lb mze per acre (Table 1). The rate of copper products such as copper hydroxide, copper oxide, or basic copper sulfate (i.e., **fixed or basic coppers**) should be based on the metallic copper equivalent (mce) at minimum of 1.65 lb mce per acre. A minimum of 2 lb hydrated lime should be added when using 1.65 lb copper (mce) and a minimum of 4 lbs hydrated lime when using 3 lb copper (mce) per acre. The material should be applied as a dilute application of no less than 200 gallons per acre to ensure spray penetration into the canopy and adequate coverage of fruit. Use spray cards to determine the coverage inside the canopy.

2) Higher rates of zinc, copper, and lime may be used as local conditions warrant or if higher disease levels were experienced the last season (Table 1).

3) **Bordeaux sprays:** If zinc-copper Bordeaux applications are used, 3.3 lb metallic zinc, 1.65-2.45 lb metallic copper, and 20-67 lb hydrated lime per acre in dilute application of no less than 200 gal/acre will meet the minimum requirement (Table 2). **The mix order for preparing Bordeaux or zinc-copper-lime treatments: first add zinc, then copper, followed by lime**.

4) **Registered alternative fungicides** Mefenoxam (e.g., Ridomil Gold-FRAC Code 4) should be applied to the soil surface under trees (see label). Preharvest phosphonates (fertilizers and fungicides containing PO_3) should be applied within two weeks of harvest in addition to required copper applications. Oxathiapiprolin (Orondis-FRAC Code 49) is registered for foliar and soil applications; foliar applications are highly effective against brown rot using labeled rates. Applications volumes used should provide sufficient coverage and may vary for the specific citrus crop (tree size and canopy density). Generally lower spray volumes per acre are needed than standard 400 gal/A rates. Trees less than 15-18 ft tall may be treated with lower gallonage (e.g., 100-200 gal/A). MRLs have been established (e.g., *see* fosetyl-Al – a FRAC P07, PO_3 fungicide) for many export countries, however, some countries do not have MRLs established for these fungicides. Check with the MRL database or the export country before making pre-harvest fungicide treatment/application decisions. ***See*** Table 3 below.

5) **Spray requirements for young trees** (6 years old or younger). If the trees have been planted less than or equal to six years ago, applications should be done to the entire tree at 100 gallons/acre. Use the lower rates according to the fungicide label.

6) **The spray should cover the entire tree**. Skirt sprays are not acceptable. All active ingredients in the spray mix (i.e., zinc, copper, and lime) are required to be reported to the county.

7) **Timing of additional fungicide applications based on environmental conditions and copper residues –** Timing of the second and third fungicide treatments will be based on

the amount of rainfall and duration of wetness periods at selected temperatures after copper residues are depleted. A model for copper persistence based on rainfall and time after application is being developed for the timing of additional fungicide treatments after the first application (e.g., copper). This model is based on one used in Florida (http://agroclimate.org/tools/Citrus-Copper-Application-Scheduler/) shown in Fig.1.

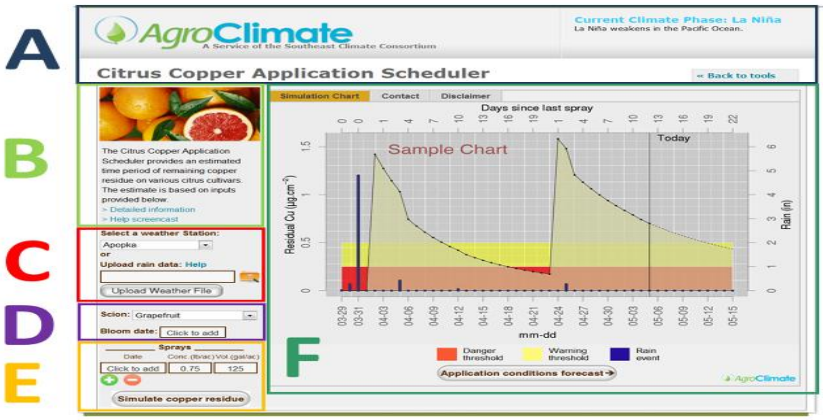

Fig. 1. Agroclimate - Citrus Copper Application Scheduler (A) and overview (B). Weather station or uploaded weather data (C) can be used for different citrus crops with their bloom date (D). Application attributes are entered for dates of application, amount of copper, volume of application (E).

Numerical Risk Model for Forecasting Brown Rot caused by P. syringae					
Temperature		*Risk Values*			
		Wetness period (h)			
(°F)	(°C)	<10	10-18	19-25	>25
<41	<5	0	0	1	1
≥41-50	≥5-10	2	3	3	3
>50-68	>10-15	1	2	2	2
>68-77	>15-20	0	0	0	0

Fig. 2. Preliminary numerical risk model for forecasting brown rot caused by *Phytophthora syringae* based on cardinal temperatures and wetness periods for growth, as well as inoculation studies at controlled temperatures.

8) A preliminary empirical forecasting model that provides a numerical risk based on published cardinal temperatures (i.e., minimum, optimum, and maximum temperatures) and wetness periods for growth and sporulation of *P. syringae*, as well as inoculation studies at controlled temperatures is as follows (Fig. 2, revised in 2016):

II) Monitoring and incubation guidelines:

All grower lots must be evaluated by field scouting. Fruit samples with symptoms described above can be identified in the field. Risk assessment should be based on scouting of orchards.

A) Monitoring risk categories:

1) **For counties other than Tulare Co. are as follows:** Phytophthora brown rot thresholds monitored above 20 in (50 cm) (a 2 category system):
   - Less than or equal to five (5) diseased fruit per acre – Accept for shipment to China
   - Six (6) or more diseased fruit per acre – Reject for shipment to China

2) **For Tulare Co. for the 2018-19 season are as follows:** Phytophthora brown rot thresholds monitored above 20 in (50 cm) (a 2 category system):
   - Zero (0) diseased fruit per acre – Accept for shipment to China
   - Any diseased fruit per acre – Reject for shipment to China

B) Symptomatic fruit may be submitted to a lab for positive ID if needed.

C) Monitoring frequency: Fields should be monitored monthly or within 14 days after every major rainfall, and one week before each harvest.

D) Amount of fruit surveyed in the orchard (1000 fruit per block, e.g., 10-25 A). Suggested design for sampling – Scout 25 fruit per 40 trees for a total of 1000 fruit per block (e.g., 10 A). Using an ATV, evaluate 10 trees on four rows per block (10-25 A).

E) Incubation (**Tulare Co. only for the 2018-19 season**) – In addition to monitoring, fruit incubation is required for Tulare Co. groves. Two weeks before harvest, fruit should be collected above 20 in (50 cm) from each grower lot as follows:

1) 100 fruit for the first 12.35 A (5 Ha) and 30 fruit for each additional 12.35 A (5 Ha) for each orchard block. (Example: for a 42 A block collect 190 fruit).
2) Collect fruit from several trees/row and several rows per block (e.g., 10 trees/row and 4 rows/block), place 30 fruit in a cardboard box until all of the fruit are in boxes (e.g., 180 fruit/30 fruit/box = 6 boxes. Label boxes with lot number and location (e.g., row or tree).
3) Incubate fruit in boxes at 5 C (41 F) for two weeks
4) Evaluate fruit for brown rot decay. If any brown rot is found, then the lot is ineligible for shipping to China. Fruit decayed by *Phytophthora* spp. is brown, leathery, and has a distinct pungent odor. At high humidity, whitish mycelium may cover the fruit (Figs. 3,4).
5) Records of results should be kept in the packinghouse for each grower lot.

Fig. 3. Brown rot of orange fruit caused by *Phytophthora* species. Early symptoms are shown in the upper images. Late symptoms are shown for brown, leathery decay with a distinct pungent odor (bottom, left) and brown rot decayed fruit at high humidity with white mycelium on the fruit surface (bottom, right).

III) Harvest –

A) A standard operating procedure (SOP) should be in place to document the method of separation of fruit harvested above (for export to China) and below (for other markets) 50 cm.

B) Containers for transporting fruit from the field to the packinghouse should be free of soil.

IV) Postharvest Management Guidelines:

A. Fruit treatments – Potassium phosphite has been registered for postharvest use on domestic fruit and for countries that have MRLs for postharvest usage. China is currently registering potassium phosphite for postharvest use. **At this time, fruit should NOT be treated with a postharvest packing line treatment of potassium phosphite or other phosphonate fungicide.** Fruit treated with this fungicide are not acceptable for export to China at this time.

B. Fruit should be treated with registered postharvest fungicides for the management of green and blue mold (Penicillium decays). Aqueous treatments of imazalil (e.g., Fungaflor, Deccocil, Freshgard, etc.), pyrimethanil (Penbotec), sodium bicarbonate, TBZ (Alumni), or other registered fungicide with approved MRLs in China should be applied prior to a fruit coating or wax. Fungicides may also be applied in a fruit coating and may include either imazalil, pyrimethanil, and/or TBZ. **Note:** Currently, MRLs for azoxystrobin and fludioxonil have not been established in China. Hot water treatments (minimum 54C-15 sec) can be an effective brown rot control practice but correct temperature and exposure are critical.

C. Grading - All fruit destined for China should be graded.

1. Fruit found with symptoms of brown rot should be identified and reported to packinghouse managers. If any brown rot decayed fruit are found at this stage, the fruit lot should be considered for ***other*** export markets. If any brown rot including *P. syringae* or *P. hibernalis* are discovered, then the lot number and orchard block is suspended for the season.
2. Remove any other types of decay found during grading.

D. Phytosanitary inspection prior to export –

1. APHIS will apply a 3% sampling and a 0% tolerance for any type of decay during inspection.
2. Any grower lot in a shipment displaying decay of any kind (brown rot, green mold, sour rot, etc.) will be rejected and not certified for the Chinese market.
3. All fruit lots that pass inspection shall be provided with a Phytosanitary Certificate and state the additional declaration: “This shipment complies with ‘The Protocol of Phytosanitary Requirements of California Citrus exported to China’ and ‘Supplementary Inspection and Quarantine Requirements for California Citrus to be Exported to China’.”

E. Fruit Storage – Recommendations for fruit destined for the China market are as follows:

1. Fruit should be stored at the lowest temperature recommended for each citrus species for example, oranges at 3-9°C (37-48°F) and lemons 10-13°C (50-55°F).
2. Fruit should not be stored more than one week following packing.
3. Packed fruit destined for China export should be stored separate from domestic or other export shipments to avoid mixing of the load.

F. Designated packinghouse personnel must ensure compliance by visiting groves for export to China prior to harvest. A list of those individuals will be

made available to APHIS.

Fig. 4. Brown rot of lemon fruit caused by *Phytophthora* species. Early symptoms are shown in the upper images. Late symptoms are shown for brown, leathery decay with a distinct pungent odor (bottom, left) and brown rot decayed fruit at high humidity with white mycelium on the fruit surface (bottom, right).

TABLE 1
First Application 2018-19 Season
Zinc-Copper-Lime Applications
Fixed coppers (e.g., copper hydroxide and copper oxide)

Application Volume		Metallic Zinc/100 gal	Metallic Copper/100 gal	Hydrated Lime/100 gal
200	gal/A	1.25-2 lb	0.83-1.5 lb	1.0-2 lb
400	gal/A	0.63-1 lb	0.41-0.75 lb	0.5-1.0 lb
600	gal/A	0.42-0.67 lb	0.28-0.5 lb	0.33-0.67 lb
Total*	lb/A	2.5-4	1.65-3	2-4

* - If brown rot was observed in a grower lot last season, use a higher rate of each spray component within the range provided.
** - Note that other fungicides can be used in rotation with copper.

TABLE 2
First Application 2018-19 Season
Zinc-Copper Bordeaux Applications
(Zinc monohydrate + Copper pentasulfate)

Application Volume		Metallic Zinc/100 gal	Metallic Copper/100 gal	Hydrated Lime/100 gal
200	gal/A	1.65 lb	0.83-1.23 lb	10-34 lb
400	gal/A	0.83 lb	0.41-0.62 lb	5-17 lb
600	gal/A	0.55 lb	0.28-0.41 lb	3.3-11 lb
Total*	lb/A	3.3	1.65-2.45	20-67

* - If brown rot was observed in a grower lot last season, use a higher rate of each spray component within the range provided.
** - Note that other fungicides can be used in rotation with copper.

Table 3. MRLs for pre- and postharvest fungicides used in orange and lemon production for disease management in CA.

Fungicide	Pre- / Post-harvest	Orange MRLs (ppm)							Lemon MRLs (ppm)						
		US	Codex	Korea	China	Hong Kong	Japan	Taiwan	US	Codex	Korea	China	Hong Kong	Japan	Taiwan
Azoxystrobin	+/+	15	15	10	---	15	10	10	15	15	10	---	15	10	10
Difenoconazole	+/-	0.6	0.6	0.6	---	0.6	0.6	0.6	0.6	0.6	0.6	---	0.6	0.6	0.6
Fluopyram	+/-	1	---	0.4	---	---	1	---	1	---	0.4	---	---	1	---
Fluxapyroxad	+/-	1	0.3	1	---	---	---	---	1	---	1	---	---	---	---
Fosetyl-Al	+/-	5	---	0.05	---	5	150	10	1	---	0.05	---	5	150	10
Pyraclostrobin	+/-	2	2	2	---	1	2	1	2	2	2	---	1	2	1
Trifloxystrobin	+/-	0.6	0.5	0.5	---	0.5	3	0.5	0.6	0.5	0.5	---	0.5	3	0.5
Mefenoxam	+/-	1	5	---	5	5	0.7	0.5	1	5	---	5	5	0.7	0.5
Fludioxonil	-/+	10	10	10	---	10	10	5	10	10	10	---	10	10	7
Imazalil	-/+	10	5	5	5	10	5	5	10	5	5	5	10	5	5
Natamycin	-/+	Exempt	---	---	---	---	---	---	Ex.	---	---	---	---	---	---
Oxathiapiprolin	+/-	0.06	---	0.05	---	---	0.01	---	0.06	---	0.05	---	---	0.01	---
Polyoxin-D	+/-	Exempt	---	Exempt	---	---	---	---	Exempt	---	Exempt	---	---	---	---
Propiconazole	-/+	8	9	8	---	---	0.05	4	8	---	8	---	---	0.05	4
Pyrimethanil	-/+	10	7	7	7	10	10	7	10	7	7	7	10	10	7
Thiabendazole	-/+	10	7	10	10	10	10	10	10	7	10	10	10	10	10

*- Data obtained from the Global MRL database (https://globalmrl.com).
**- Red-highlighted rows are the fungicides for brown rot management. Fosetyl-Al is the default for phosphonate fungicides including potassium phosphite fungicides. Mefenoxam is a soil treatment, whereas phosphonate and oxathiapiprolin fungicides can be applied as foliar or soil treatments.