Control Measures

- Cultural controls
- Fungal diseases
- Citrus Canker
- Huanglongbing
- Fungicides
- Fungicide resistance
Introduction

Best approach to disease control is to integrate approaches

- No one control measure is 100% effective

- Practices such as crop rotation, planting time (not so easy for perennial crops), site selection, modification of fertilizer regimes, micro-climate modification and sanitation

- Pesticides
Site and Cultivar/Rootstock Selection

- **Site history**
  - What was there in the past; was there a disease or nematode problem?

- **Soil type**
  - pH; drainage; water table

- **What cultivar do I plan to grow?**
  - Highly susceptible to Alternaria; perhaps change planting distance; less vigorous rootstock
Nursery Trees

- Keeping trees clean important as grove foundation
- Covered nurseries started in Brazil to prevent Citrus Variegated Chlorosis infection
- Now law in Florida and Brazil to prevent spread of HLB
- Important to have reliable sources of budwood and rootstocks also
Nursery Trees cont.

- Keep trees off ground
- Clean potting media
- What other diseases are controlled in covered nurseries? Why?
- Alternaria brown spot, citrus scab, citrus canker, black spot and pseudocercospora fruit and leaf spot
Poor Quality Nursery Trees
Poor Quality Nursery Trees
Poor Quality Nursery Trees
Preventable Disease Problems
Preventable Disease Problems
Preventable Disease Problems
Other Cultural Controls

★ NO OVERHEAD IRRIGATION
★ Leaf litter management is helpful for which diseases? How?
  ➢ Greasy spot; black spot; Alternaria brown spot
  ➢ Discing; frequent irrigation to promote decomposition; mulch leaf litter; put urea or lime on the leaf litter
More Cultural Controls

- Reduce vigorous flush with fertilizer and water management
- Increase airflow within grove
- Remove dead wood and brush piles
- Adjust hedging practices
- Remove declining trees
- Younger groves for fresh production
Canker Specific Measures

🔗 Eradication and quarantine
- First introduced ~1910; eradicated 1933
- 1986 second introduction; eradicated 1994 (Tampa area)
- 1995 third introduction discovered (Miami area)
- Mandatory eradication ended January 11, 2006

🔗 Statewide mandatory eradication 579 m (1,900 ft) rule was implemented in 2000
- Quarantine areas established when citrus canker was detected
- All exposed citrus trees removed and destroyed

Gottwald et al, 2001
Canker Specific Measures

Why did eradication fail in Florida during the last outbreak?
- Epicenter of infection in urban area
- Removal of infected and exposed trees was delayed due to law suits in 2002
- The hurricanes of 2004-2005 increased the spread of canker

Currently, the removal of infected trees is voluntary
Canker Specific Measures

🔗 Decontamination

- Mandatory upon exit of a grove since April 2000 for personnel and equipment
- Quaternary Ammonium Chloride ‘QAC’ for equipment
- Antimicrobial soaps for personnel

🔗 http://www.doacs.state.fl.us/pi/chrp/schedules/decontamination.pdf
Windbreaks

Highly effective in slowing spread and reducing severity of canker

Infection occurs with windborne rain
  - Bacterium unable to actively penetrate host tissue
  - Needs 8 m/s (18 mph) wind to force bacteria into stomates and wounds

http://www.crec.ifas.ufl.edu/extension/windbreaks/
Effect of Windbreaks

◮ Nursery
- Considerably lower disease incidence and distance spread with windbreaks

Gottwald and Timmer, 1995
Windbreaks and Copper

Gottwald and Timmer, 1995
HLB Management

Asian Citrus Psyllid (Diaphorina asiaticus vector) control
Scouting for HLB infected trees
Removal of HLB infected trees (inoculum source)
Block of 200 trees sprayed with protein mark

Traps placed in radial fashion at distances from 0.1 km (0.06 miles) to 2.0 km (1.24 miles) away from sprayed area

Traps were collected 12 days after spray application and psyllids were tested for the marker protein
Central sprayed area

Red x’s indicate where the majority of marked psyllids were trapped

Lukasz L. Stelinski, CREC
Comparable levels of HLB infection in abandoned and managed groves

Percent of trees infected

Abandoned | Commercial
--------- | -------

Percent of psyllids infected

Abandoned | Commercial
--------- | -------

Lukasz L. Stelinski, CREC
Have confirmed that psyllid dispersal from abandoned into managed citrus moves the HLB pathogen

Less than 1% of psyllids captured were positive in these trials.
Asian Citrus Psyllid Control

CHMA!

Citrus Health Management Area

A grower defined grouping of citrus acreage where grower participants coordinate psyllid control efforts (year-round pesticide applications) and management of pesticide resistance development (coordinated rotation of Modes of Action)
Why develop CHMA’s?

- Slow the spread of HLB
  - Improved psyllid control***
- Prolong the usefulness of our current management tools
  - Pesticide resistance***
- Preserve current citrus grove acreage
- Facilitate adoption of new technology to better manage HLB
Tracking Progress / Measuring Success

當您いく週間のスカウティングを行い、アセスし、メスリッドの群を評価する

- Before and after pesticide applications
- When to retreat?

Identify hot spots and measures needed to minimize psyllid spread

Continually updated tracking / reporting (website)
http://www.crec.ifas.ufl.edu/extension/chmas/index.shtml
Central Highlands County
HLB Scouting

Groves should be scouted 4 or more times/year
  ➢ More often if HLB has been found nearby

Most difficult during spring flush and early summer

A combination of methods is generally bests
  ➢ Elevated platforms
  ➢ Walking
  ➢ ATV or small vehicle

Careful marking of row and tree is important
  ➢ Name and date
Symptoms
Tree Removal

- To be effective, needs to be done quickly after diagnosis
- Best to be clipped to be able kill all roots
- Must control sprouting from trunks
  - Sprouts reshoot more symptomatic and with a higher bacterial titer than the original tree
CHEMICAL CONTROL
General Fungicide Information

- Organic versus inorganic
  - Refers to chemical structure

- Inorganic chemicals
  - Sulfur or metal ions
  - Eg. Copper, tin, arsenic, mercury or cadmium
Contact (protectants)

- Remain on surface of plant
- Potentially phytotoxic
- Excellent for preventative use
- Potential problems?
  - Needs to be on the surface before an infection period leads to repeated applications
  - Wash off – rain or irrigation
  - UV degradation
Systemics (eradicants, penetrants)

- Absorbed into plant
- Locally systemic or translaminar
  - Across a leaf
- Weakly systemic
  - Intermediate distance
- Xylem mobile
  - unidirectional – which way?
- Phloem mobile
  - bidirectional – why?
Spectrum of Activity

- **Multi-site**
  - Often older contact fungicides
  - Usually effective against many fungal classes

- Few multi-site fungicides being developed
  - Regulatory tests
    - Toxicity (LD$_{50}$)
    - Environmental regulations (residuals and breakdown products)
Spectrum of Activity

♫ Single-site

- Active at a sole point in essential processes
- Highly specific toxicity to fungi therefore generally safe to be absorbed into plants
- Often systemic
- Greater potential for resistance
Copper

- Used since before the invention of Bordeaux mixture in 1885 (Millardet)
- Broad spectrum protectant
- Non-specific
- MOA: Soluble Cu ions (Cu$^{2+}$) bind tightly to sulfhydryl groups
  - Cystein residues
- Phytotoxicity reduced when made into water insoluble salts
Carbamates

- Discovered 1930’s
  - First group of fully synthetic fungicides
- Broad spectrum
- Non-specific inhibitors and are used as protectants
- The metal salts improve stability
- Possible MOA: complex with Cu

Ascomycetes/
Deuteromycetes/
Oömycetes
**Ethylenebisdithiocarbamate (EBDC)**

- **Second generation carbamates**
  - Generally more effective than carbamates
  - Broad spectrum
  - Non-specific inhibitors and are used as protectants
  - The metal salts improve stability

- **MOA: slow release of ethylene diisothiocarbamate**

- **Ascomycetes**/
- **Deuteromycetes**/
- **Oömycetes**
Trichloromethylthiocarboximides

- Discovered early 1950’s
  - Broad spectrum
  - Non-specific inhibitors and are used as protectants

- MOA: active group reacts with bases such as thiol groups – forms thiophosgene (highly reactive)
  - Can also be formed during water hydrolysis
  - Can cause phytotoxicity especially with oil

- Ascomycetes/Deuteromycetes

- Not registered for citrus
Benzimidazoles

- Commercialized in the 1970’s
  - Considered a breakthrough
  - Broad spectrum
  - Systemic with eradicant activity
  - Benomy and thiophanate-methyl convert to carbendazime in aqueous conditions

- Ascomycetes/
  Deuteromycetes/some
  Basidiomycete activity
Benzimidazoles cont.

- MOA: specific binding to fungal β-tubulin
  - Prevents polymerization of microtubules
  - Cells can no longer separate dividing nuclei
  - Can have a cytokinin effect on plants

- Resistance!
Sterol Biosynthesis Inhibitors - DMI

» First discovered in 1968

» Large class of fungicides
  - Broad spectrum due to 30 DMI’s available
  - Each has slightly different properties

» Active against Ascomycetes, Deuteromycetes and Basidiomycetes
  - Except Alternaria spp., Colletotrichum spp., Fusarium spp., Rhizoctonia spp. or Pyricularia oryzae
  - Reasons unknown
Sterol Biosynthesis Inhibitors – DMI cont.

大多数含有一个唑类基团（康唑醇）

系统性杀菌剂

作用机制：生物化学已经非常清楚地了解

- 类固醇对于膜是必需的
- 对于大多数真菌，是麦角甾醇
- 苯环氮基团扰乱了类固醇生物合成途径中的一个细胞色素P450
Sterol Biosynthesis Inhibitors – DMI cont

- Only essential feature of most DMI’s is the aromatic N
- The sterol precursors build-up and become incorporated into the membranes
- Normal membrane functions become disrupted
- Resistance?
Oömycete Specific Fungicides

Phenylamides

- Introduced in the late 1970’s
- Systemic with eradicant properties
- Stereo-isomers: activity with only the R-isomer
- MOA: specific for oömycetes
- Inhibits RNA polymerase to that synthesises ribosomal RNA
- Mechanism for oömycete specificity unknown
- Resistance?
Oömycete Specific Fungicides cont.

**Fosetyl-al**

- Discovered and developed early 1980’s
- Systemic and is translocated to the roots from the leaves (unusual)
- Has some activity against other pathogens including bacteria
- MOA: not understood
  - Possibly acting through phosphonic acid generated in plants or stimulation of plant defenses
- Resistance?
Strobilurins (QoI)

- Introduced in the late 1990’s
- Derived from secondary metabolites of Basidiomycetes
- Very broad spectrum
  - Ascomycetes/Deuteromycetes, Basidiomycetes and Oömycetes
- Systemic that has mild erradicant abilities
Strobilurins cont.

- MOA: Bind to cytochrome $bc_1$ and inhibit mitochondrial respiration
- Potent inhibitors of spore germination but don’t completely inhibit mycellial growth
- Alternate respiration
- Resistance?

www.cgm.cnrs-gif.fr/podospora/plus.html
Fungicide Resistance

- Where the target population is no longer sensitive enough to a fungicide to obtain sufficient control
- Occurs in response to the repeated use of a fungicide or related fungicides
  - Field resistance
  - Laboratory resistance
- Often becomes apparent with sudden total failure of control
Two types of Resistance

Qualitative

Quantitative

Brent and Holloman, 2007
Qualitative Resistance

- Sudden and marked loss of control
- Presence of two separate populations of resistant and sensitive pathogen isolates
- Usually a stable form of resistance
  - Lasts for decades
  - Occasionally will gradually diminish over time but returns rapidly when fungicide is reapplied without precautions
Quantitative Resistance

❖ Resistance appears less suddenly
  ➢ Decline in sensitivity of pathogen population and control can be observed

❖ Population tends to revert to sensitive if the fungicide is less used or is alternated with other MOAs
Cross-Resistance

- Obviously would be resistant to different fungicide with the same MOA
- Two separate mechanisms of resistance to unrelated MOAs occasionally occurs in pathogens – multiple resistances
Where does it come from?

- A minute proportion of the population carries the mutant resistance gene before the use of a fungicide.
- Without the fungicide the mutation confers no advantage to growth or survival of the pathogen.
  - Could even be deleterious.
- Mutation could disappear and reappear spontaneously several times.
Initial frequency 1:1000 million
Resistant individual

Increased frequency of resistant strain in population
Several Cycles

Time passes

Resistant population
If a fungicide is highly effective, resistance will be more rapid.

- Fewer sensitive strains in the population.

If fungicides are only 80% effective, then the buildup of resistance will be slower.
Mechanisms of Resistance

- Benzimidazoles
  - The inhibitor no longer bound to the β-tubulin
  - Resulted in rapid and absolute failure
- To control resistance most Benzimidazoles were mixed with older protectants to control resistant sub-populations
- Was mixed with another β-tubulin inhibitors (phenylcarbamates) but populations resistant to both became apparent
  - Up to 4 separate mutations in the β-tubulin gene
Mechanisms of Resistance

- DMI’s
- Fungal isolates had reduced sensitivity to the fungicides
  - The population was still controlled but it was less efficiently controlled
  - Slow emergence of resistance
- Several genes with additive effects but the number appears to be finite
- Mechanism is not well understood
Mechanisms of Resistance

- Phenylamide
- Similar situation to the Benzimidazoles
  - Complete fungicide failure
  - The RNA synthase was no longer inhibited
- Some products now have triple mixes of fungicides to try and control resistant sub-populations
Mechanisms of Resistance

Strobilurins

- Resistance occurred within two years of introduction

- Single mutation in the cytochrome bc$_1$ gene

  - G143A confers a high level of resistance
  - F129L confers a lower degree of resistance and can be managed by using the recommended rates
Resistance Management

- Do not use one product exclusively
  - Use in rotation or in a mixture with another MOA
- Restrict the number of applications or quantity of AI/area/year
- Maintain the recommended dose
- IPM
- Use as many AI’s as possible
- Spray when the population is smallest
Fungicides Alternaria

- **Copper** – Works well for fruit but not leaves
- **Ferbam** – Only moderately effective
- **Strobilurins** – Most effective but specific MOA
  - Azoxystrobin
  - Trifloxystrobin
  - Pyraclostrobin
- **Mixtures** (with strobilurins)
  - Difenconazole and azoxystrobin
  - Boscalid and pyraclostrobin
Spray Timing Alternaria

❖ First spray when spring flush ¼-1/2 full expansion; high inoculum another before full expansion or at petal fall
❖ Rest of the year maintain protective coating
Fungicides Greasy Spot

- Petroleum oil – gives adequate control on less susceptible cultivars
- Copper – more consistent control than oil
- Strobilurins – same concerns about MOA
  - Azoxystrobin
  - Trifloxystrobin
  - Pyraclostrobin
- Fenbuconazole – moderate risk for resistance
  - DMI fungicide or sterol biosynthesis inhibitors
- Mixtures (with strobilurins)
  - Difenoconazole and azoxystrobin
Spray Timing Greasy Spot

Less susceptible cultivars

- One spray between May and June often sufficient especially in Northern production regions

In South Florida, more susceptible cultivars and in groves with severe defoliation

- Two sprays; one mid-May – June, the second once flush has expanded
- Three applications; last in early August if disease severity last year high
Fungicides Melanose

✈  Copper – Most economical but can cause blemishes in hot dry weather

✈  Strobilurins – Low residual activity compared to copper but useful in hot weather
  ➢ Azoxystrobin
  ➢ Trifloxystrobin
  ➢ Pyraclostrobin

✈  Mixtures (with strobilurins)
  ➢ Difenconazole and azoxystrobin
  ➢ Boscalid and pyraclostrobin
Spray Timing Melanose

- **Oranges and Tangerines**
  - First spray mid to late April
  - One to two applications sufficient

- **Grapefruit (fresh market)**
  - First application when fruit \( \frac{1}{4} \) to \( \frac{1}{2} \) inch
  - Copper to be applied every 3 weeks until fruit resistant in late June to early July
  - There is a model to determine whether copper residues are sufficient to control disease based on weathering of copper and the growth rate of fruit
Fungicides Scab

- Copper
- Ferbam
- Strobularins – Most effective but specific MOA
  - Azoxystrobin
  - Trifloxystrobin
  - Pyraclostrobin
- Fenbuconazole
Spray Timing Scab

- Sprays are mainly for groves with a recent history of Scab
- First spray – spring flush 2-3 inches
  - can be omitted if severity was light
- Petal fall
- Three week after petal fall
Fungicides PFD

- Ferbam
- Strobularins – Most effective but specific MOA
  - Azoxystrobin
  - Trifloxystrobin
  - Pyraclostrobin
- Fenbuconazole
- Thiophanate methyl – Registration withdrawn on citrus
Black Spot Application Timing

Fruit is susceptible for 5-6 months post-petal fall

- Late Spring (April/May)
- Continue applications at 1 month intervals
- Use strobilurins when concerned about copper phytotoxicity

Copper
Copper and/or strobilurins
Copper
Copper and/or strobilurins
Copper
Fungicides for Black Spot

Registered fungicides with reported efficacy against black spot

- Copper - all formulations; use maximum label rate
- Strobilurins (Abound, Gem, Headline) - maximum label rate recommended
  - Recommended at temperatures > 94°F when phytoxicity is a concern
  - No more than 4 strobilurins applications can be made in a year for all diseases
  - Consecutive applications not recommended due to potential resistance development
Canker

☞ Copper - all formulations

☞ Spray Timing

➢ Traditionally applied every 21 days
➢ Can now use Citrus copper application scheduler to time applications (http://www.agroclimate.org/tools/cudecay/)

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| Valencia
| Tangerines and Hybrids
| Early Oranges
| Grapefruit
Sources

http://apsnet.org/education/IntroPlantPath/Topics/fungicides/default.htm


Sources cont.