Update on USDA Citrus Scion Breeding

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2019 Florida Citrus Show, Jan 23-24, 2019
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Cross/Nucellar seeding/Irradiation</th>
<th>Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minneola/Orlando/Seminole</td>
<td>1908-12 Swingle/Savage</td>
<td>1931 Swingle/Robinson/Savage</td>
</tr>
<tr>
<td>Lee/Osceola/Robinson</td>
<td>1942 Gardner/Bellows</td>
<td>1959 Reece/Gardner</td>
</tr>
<tr>
<td>Nova/Page</td>
<td>1942 Gardner/Bellows</td>
<td>1963-4 Reece/Gardner</td>
</tr>
<tr>
<td>Fairchild/Fortune/Fremont</td>
<td>~1960 Furr</td>
<td>1964 Furr</td>
</tr>
<tr>
<td>Bower</td>
<td>1942 Gardner/Bellows</td>
<td>1973 Wutscher</td>
</tr>
<tr>
<td>Sunburst</td>
<td>1961 Reece</td>
<td>1979 Hearn</td>
</tr>
<tr>
<td>Fallglo/Ambersweet</td>
<td>1962-3 Reece/Hearn</td>
<td>1987 Hearn</td>
</tr>
<tr>
<td>Flame</td>
<td>1973 Wutscher/Hearn*</td>
<td>1987 Hearn</td>
</tr>
<tr>
<td>Midsweet</td>
<td>1960 Reece</td>
<td>1987 Hearn</td>
</tr>
<tr>
<td>US Early Pride</td>
<td>1991 Hearn</td>
<td>2009 McCollum/Hearn</td>
</tr>
<tr>
<td>US Seedless Pineapple</td>
<td>1970 Hearn</td>
<td>2009 McCollum/Hearn</td>
</tr>
<tr>
<td>US Furr</td>
<td>1953 Reece</td>
<td>2014 Stover et al</td>
</tr>
<tr>
<td>US Furr-ST</td>
<td>1953 Reece</td>
<td>2014 Stover et al</td>
</tr>
<tr>
<td>US Seedless Surprise</td>
<td>1964 Furr</td>
<td>2017 Stover et al</td>
</tr>
<tr>
<td>US 7650, 7651, and 7652</td>
<td>1995-96 Hearn</td>
<td>2017 Stover et al</td>
</tr>
<tr>
<td>US Ortanique LS</td>
<td>1998 Chaparro</td>
<td>2018 Stover et al</td>
</tr>
<tr>
<td>US HoneyCoat</td>
<td>1973 Hearn</td>
<td>2018 Stover et al</td>
</tr>
<tr>
<td>US SunDragon (Gnarlyglo)</td>
<td>1999 Chaparro</td>
<td>2018 Stover et al</td>
</tr>
</tbody>
</table>

- ~28 cultivar releases. 17-63 years between cross & release. From Hearn retirement 1995 until 2009, no releases or even replicated trials established!

**Refilling the pipeline**

- Initially the wisdom was that HLB would kill ALL citrus. At a professional meeting in 2009, it was indicated that HLB might “cause extinction of Citrus”. We identified some HLB-tolerance in 2009, made first crosses for HLB-tolerance in 2010.

- Faster implementation means industry will need to take on more uncertainty regarding scion performance
Hybridizations:

- Majority focused on HLB resistance/tolerance: targeting sweet-orange-like, red GF, seedless mandarins all focusing on fruit/juice quality with HLB tolerance.
- 2010: >1000 flowers from 40 parental combinations
- 2011: 843 flowers representing 31 parental combinations
- 2012: 1029 flowers from 49 parental combinations,
- 2013: 1408 flowers from 86 parental combinations
- 2014: 870 flowers from 48 parental combinations
- 2015: 1400 flowers from 68 parental combinations
- 2016: 1316 flowers from 40 parental combinations
- 2017: 1700 flowers from 83 parental combinations
- 2018: 4000 flowers from 120 parental combinations

We now have 14,000 new hybrids in the ground with more in greenhouses. Planted 4,000 in 2017 alone.
Irradiated trees

We typically irradiate 250-500 buds at 30 and 50 gray, shooting for 50% mortality do create seediness. Trees are double budded. Vary wildly in sensitivity to radiation

- Ftp-6-16-172 GF-type 200 Planted with grower-cooperator
- FF-1-63-85 Mandarin 196 Planted at Whitmore
- FF-1-63-77 Mandarin 163 Planted at Whitmore
- FF-1-75-55 Peelable orange 105 Planted at Whitmore
- FF-1-84-2 Mandarin 38 Planted at Whitmore (Radiation sensitive)
- FF-1-32-67 Mandarin 71 Planted at Whitmore
- US Seedless Surprise 320 Planted with grower-cooperators
- Jackson Grapefruit 160 Planted with grower-cooperators – new 650 more
- Page ~100 Planted with grower-cooperator
- Nova ~200 Planted with grower-cooperator
- Red GF-like FF 1-83-179 Budded 276, Ftp 6-17-16 Budded 216, Ftp 6-17-48 Budded 288
  – All clean budwood from DPI, propagated and planted at Whitmore
Selections made

Selections are made as potential cultivars and parents for future cvs.

- 2011-2: 17 high quality mandarins; several high-quality candidates for cultivar release following irradiation.
- 2013: Seven new selections. All used as parents.
- 2014: 32 new selections of which 20 are Kishu hybrids. 3 are no to low-seeded mandarin selections which may have immediate potential as cultivars. Low-seeded Fortune x Encore (1-22-79 irr 1-42-65)!!
- 2015: 28 new hybrids selected for use as breeding parents; widely varied backgrounds with good levels of tolerance to HLB as well as other potentially useful traits. Substantial number are orange-like.
- 2016: 16 seedless Kishu hybrids, 8 HLB-tolerant sweet orange-like, 2 GF-like, 1 excellent tasting seedy mandarin
- 2017: 15 seedless Kishu hybrids; 1 mandarin w/ excellent color; 5 HLB-tolerant sweet-orange-like hybrids containing Poncirus; 1 Tangor derived from Poncirus; a lime-like fruit containing Poncirus; seedless 1-75-55
- 2018: 6 orange-like trifoliate hybrids; 4 SunDragon progeny which appear to have improved tolerance to HLB; several new seedless Kishu hybrids; 3 low seed irradiated Ftp-6-32-67 (high quality mandarin)
4.5 years in Ground: replicated trial at Picos Rd of 50 cultivars and selections. Valencia still in highest grouping for health but not growth

<table>
<thead>
<tr>
<th>Canopy density (%)</th>
<th>Tree health (5 is best)</th>
<th>Canopy vol (m³)</th>
<th>Canopy vol RGR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF1-42-70 Fortune x Encore</td>
<td>98.3 a</td>
<td>5.0 a</td>
<td>10.9 b-g</td>
</tr>
<tr>
<td>Bower Clem x Orlando</td>
<td>98.0 a</td>
<td>4.8 a-c</td>
<td>9.3 c-i</td>
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<tr>
<td>FP6-47-119 Orange-like w/Pt</td>
<td>97.5 ab</td>
<td>4.6 a-e</td>
<td>17.2 ab</td>
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<tr>
<td>FF1-4-2 Complex w/Pt</td>
<td>97.0 ab</td>
<td>4.2 a-g</td>
<td>19.9 a</td>
</tr>
<tr>
<td>FF1-34-11 5-51-2 x 1-57-105</td>
<td>96.7 a-c</td>
<td>4.8 ab</td>
<td>6.6 c-j</td>
</tr>
<tr>
<td>Nova</td>
<td>96.0 a-c</td>
<td>3.9 a-h</td>
<td>3.0 h-j</td>
</tr>
<tr>
<td>JacksonGF</td>
<td>95.0 a-c</td>
<td>4.3 a-f</td>
<td>8.0 c-j</td>
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<tr>
<td>Clementine</td>
<td>94.0 a-c</td>
<td>4.6 a-f</td>
<td>7.0 c-j</td>
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<tr>
<td>FP6-49-116 SunDragon-sib</td>
<td>93.3 a-c</td>
<td>4.6 a-e</td>
<td>13.7 a-c</td>
</tr>
<tr>
<td>SunDragon</td>
<td>93.0 a-c</td>
<td>4.6 a-e</td>
<td>12.2 b-e</td>
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<tr>
<td>Valencia</td>
<td>90.0 a-c</td>
<td>4.1 a-g</td>
<td>5.5 d-j</td>
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<tr>
<td>US119 Complex w/Pt</td>
<td>88.8 a-c</td>
<td>4.6 a-e</td>
<td>6.6 c-j</td>
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<tr>
<td>FF5-51-2 Clem x Orlando</td>
<td>88.8 a-c</td>
<td>3.8 a-h</td>
<td>3.0 h-j</td>
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<tr>
<td>Temple</td>
<td>85.0 a-d</td>
<td>3.5 a-i</td>
<td>4.8 f-j</td>
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<tr>
<td>USEarlyPride</td>
<td>82.5 a-d</td>
<td>4.1 a-g</td>
<td>5.7 d-j</td>
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<tr>
<td>Carrizo</td>
<td>75.0 a-e</td>
<td>3.9 a-h</td>
<td>4.9 e-j</td>
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<tr>
<td>Flame</td>
<td>55.0 ef</td>
<td>2.0 ij</td>
<td>2.3 ij</td>
</tr>
<tr>
<td>Sunburst</td>
<td>53.8 ef</td>
<td>3.1 d-i</td>
<td>1.7 j</td>
</tr>
<tr>
<td>USSSurprise</td>
<td>50.0 f</td>
<td>2.8 f-j</td>
<td>7.8 c-j</td>
</tr>
</tbody>
</table>
Improving Sweet Orange

• All sweet oranges are mutants of original hybrid (little variation for disease resistance)

• Would be great to create improved “sweet oranges” with enhanced disease resistance and other traits, by bringing in different genetics

• Attempts at breeding sweet oranges had largely been unsuccessful (Dr. Jack Hearn has laid the groundwork)

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THE EVOLUTION OF CITRUS SPECIES - METHODS TO DEVELOP NEW SWEET ORANGE CULTIVARS

C. J. HEARN
U.S. Department of Agriculture

Citrus and its wild relatives are native to southeastern Asia, New Guinea, Australia, the East Indian Archipelago, New Zealand, and Madagascar.
Volatile profile comparison of USDA sweet-orange-like hybrids vs. ‘Hamlin’ and ‘Ambersweet’

Jinhe Bai, Elizabeth Baldwin
Randall Driggers, Jack Hearn and Ed Stover

• Leading sweet orange cultivars have traits much-appreciated by consumers
• Critical to have close similarity to sweet orange
FF-1-75-55 Ambersweet x FF-1-30-52. Ripens about the same time as Hamlin, has orange appearance, taste, and aroma volatiles. Can be peeled by hand. Near Valencia Juice Color. Relatively few seeds. Easy peeling.
Several but not all sweet orange-like hybrids continue to look somewhat more HLB-tolerant than Hamlin at same maturity period.

1-75-55 loaded with fruit—new seedless variant

Sweet orange-like hybrids used as parents
Using sweet orange-like hybrids aggressively as breeding parents. Next generations of hybrids in field
Newly released

First released scion containing Poncirus for use as fresh fruit (1/16 Poncirus).

US SunDragon
Like Navel in alligator-hide

Apparent tolerance to HLB

Scored highly in sweet orange juice trial at USHRL

Used in many crosses.
Hybrids starting to fruit!
6-year-old trees at USDA Picos Rd Farm
SunDragon and Hamlin in replicated trial exposed to HLB at planting.
SunDragon progeny selections-2018

Not only interesting as a cultivar but as a parent as well
Greg McCollum-leads trials of new selections

- Has planted trees with numerous growers
- Replicated trials of best sweet-orange like hybrids and mandarin hybrids planted or being planted in 9 locations
- All replicated trials include standards such as Valencia
- Some include best new UF selections
- Data being collected on cropping growth and health
Improving Grapefruit

• Grapefruit appear to be THE most susceptible Citrus
• Making numerous crosses to generate GF-like material, have some seedy types irradiated
• Have shown that ‘Jackson’ GF is much more tolerant than standard GF
Planting in Jan 2010

Jackson Grapefruit-like hybrid

Marsh Grapefruit

Why use in crosses if one parent is HLB-susceptible? Example: Jackson is grapefruit x sweet orange. Re-assortment of genes can change response.

Planting in Jan 2014
Efforts to improve Jackson /Triumph

- These GF-like hybrids (Jackson is a low-seeded Triumph) are the most HLB-tolerant GF-like to date, but **white**
- Based on our work, including plantings in growers’ fields, some commercial plantings
- Jackson is similar to Marsh in seed number, it is also white
- We have irradiated numerous buds of Jackson in the hope of stimulating a red mutant
- Also attempting to use CRISPR to make red
- Crossing Triumph with red GF-like material
Late ripening pummelo hybrid with thin skin. It has exceptionally firm internal texture with small juice vesicles and deep pink color. Has mild taste and holds its color well.

Complex hybrid containing pummelo, orange, tangelo, and grapefruit. Deep red interior color, pronounced skin blush.

Irradiated GF-Like from USDA-ARS Breeding Program

Late ripening pummelo hybrid with thin skin. Firm internal texture with small juice vesicles and deep pink color. Has mild taste and holds its color well.

Early ripening pummelo hybrid with relatively thin skin and deep red color. Very mild, low acid taste with slight bitterness.
RESEARCH PROJECT: “Accelerating implementation of HLB tolerant hybrids as new commercial cultivars for fresh and processed citrus”

Elizabeth Baldwin, Ed Stover, Mikeal Roose, Jinhe Bai, Rhuanito Ferrarezi, Fred Gmitter, Goutam Gupta, Anne Plotto, John Manthey, Yu Wang

This work is supported by the USDA National Institute of Food and Agriculture USDA-NIFA-CDRE project 2018-70016-27453.

Objectives:
1) Identify HLB-resistant/tolerant hybrids with good flavor quality (including orange-like and grapefruit-like)
2) Identify DNA markers associated with tolerance to expedite screening and provide confidence in selecting scion genotypes considered promising and explore tolerance-related responses to pathogen effectors/pathogen-associated molecular patterns (PAMPs), for use as a screening tool
3) Develop a transgenic strategy to enhance cultivars resistance responses
4) characterize fruit and juice quality of HLB-tolerant scions, for use either as stand-alone varieties, hybrid classification as “orange” and/or development of juice combinations to supplement the current processing stream
5) Communicate these results to facilitate industry implementation of HLB-tolerant scion cultivars.

Dr. Ferrarezi: extension specialist
https://programs.ifas.ufl.edu

USDA-NIFA-CDRE project # 2018-70016-27453.

BRAND NEW PRODUCT!

HLB TOLERANT HYBRIDS AS NEW CITRUS COMMERCIAL CULTIVARS

This project is focused on identifying HLB-tolerant scion cultivars that can be quickly mobilized for use by the US citrus industry.

https://programs.ifas.ufl.edu/scion-guide/

From UF/IFAS Ferrarezi Citrus Hort Lab

CITRUS ROOTSTOCK SELECTION GUIDE

The rootstock guide is a convenient, easy-to-use reference to 20 characteristics of 45 citrus rootstocks. The rootstock information provided is a broad-based compilation of Florida information collected from field trials and commercial situations.

https://crec.ifas.ufl.edu/extension/citrus_rootstock/templates/guide/

(led by John Stephens, UF/IFAS IRREC Ferrarezi Citrus Hort Lab)
Surveys to determine consumer (general public), grower and processor reactions to and acceptance of new HLB-tolerant citrus cultivars:

Consumers (general public)

Growers

Processors

Inside your event bag

Your participation is greatly appreciated!!!

(Get at the back of the room when exiting; returned surveys will receive a *nice* 15-oz Gator mug in appreciation)

(led by Megan Eckman, UF/IFAS IRREC Ferrarezi Citrus Hort Lab)

USDA-NIFA-CDRE project # 2018-70016-27453.
Improving Mandarin hybrids

- Strong evidence of tolerance in some cultivars and selections. USHRL at forefront of demonstrating HLB-tolerance

- NVDMC-sponsored work contributing to new studies looking at potential value of using tolerant material in the juice stream

- Also many show promise as fresh cultivars
FF 1-22-79, irradiated FF 1-42-65 Fortune x Encore

- Probably our best un-released tangerine
- Good external & internal color
- Not a bad plugger
- Slightly pebbly skin usually come off in large chunks with little chipping
- Segment separation is usually good with little leakage
- Very rich flavor
- Ripening is usually around Christmas
- Fruit hold on the tree well into the new year

- Remarkably, its sib 1-42-70 is also one of most HLB-tolerant so far in trial!
Low seeded selections of Irradiated FF-5-51-2 (Clementine x Orlando)

- Seedy original hybrid growing many places and appears to have useful HLB-tolerance, with no evidence of HLB-affected fruit
- Good midseason tangerine (late Nov early Dec)
- Easy peeling, rich flavor, segments dry when separated. Dancy+ size.
- Appears to require cross pollination
- Trialing all 3 selections in case one has problems
- May release parent 2019
Newly identified first gen. seedless Kishu hybrid

- Seedling tree healthy in Leesburg but tolerance to HLB unknown (Kishu hybrids as a group look pretty good)
- Good overall tangerine: easy peeling and good taste
- Mid-Dec maturity, size of Dancy
- Will enter testing when clean

Newly identified second generation seedless Kishu hybrid

- Female parent seems to be very tolerant of HLB and male better than most
- This hybrid will be carefully tested in the field.

Using advanced materials in further breeding strategies
Thanks!

- USDA/ARS Base Funding
- Florida Citrus Research & Development Foundation
- New Varieties Development and Management Corp
- Florida Citrus Research Foundation (Whitmore)
- California Citrus Research Board
- DPI Budwood Office and USDA/APHIS

Jodi Avila          Abby Bartlett          Wayne Brown
Ellen Cochrane     Jacqueline Depaz       Belkis Diego
Lynn Faulkner      Wes Glover             Amber Holland
Diane Helseth      David Lindsey          Spencer Marshall
Steve Mayo         Kathy Moulton           Luc Overholt
Sean Reif          Mike Rutherford         James Salvatore
Matthew Sewell     Jefferson Shaw          Jeff Smith
Regina Tracy       Ashley Witkowskki       Patrick Zagorski

Jonathan Giandalone, Ivana Meservy, Shelby Durden, Chelsea Veith
Some of the folks who do the real work