Breeding to improve fruit quality, disease resistance, and productivity in tart cherry

Amy Iezzoni
Michigan State University
Tart Cherry Breeding

Which parents to use?

Which combinations to create?

Which seedlings to progress?

Which selections to trial?

Which advanced selections to commercialize?

Increase breeding efficiency and success at all stages through science-based decisions

Outline
1. Catastrophic crop losses
2. Fruit color
3. Disease resistance
Catastrophic crop losses
The U.S. sour cherry industry is essentially a monoculture of a 400 year old variety called Montmorency.

Michigan produces ~ 75% of the tart cherries in the U.S.
On April 21 & 22, 2002, an artic blast with temperatures below freezing froze the pistils within the Montmorency flowers.

The three year average U.S. sour cherry production was ~ 304 million pounds. In 2002 it was reduced to 60 million pounds.

Sour cherry production in Mich. was reduced to 2% of a normal crop (the lowest level recorded since 1945). There was no crop insurance for sour cherry.

On July 16 the Secretary of Agriculture issued a disaster declaration for 50 Mich. counties making growers eligible for low interest emergency loans.
In 2012 there was a 2nd major tart cherry crop loss in MI

Tart cherry production in Michigan in 2012 was lower than the previous low record set in 2002 (Statistics from the USDA)

The cherry pistil that develops into the fruit, is uniquely susceptible to freeze injury.
On April 21 and 22, an artic blast with temperatures below freezing, froze the pistils within the Montmorency flowers.

**Critical Temperatures (°F) for Blossom Buds**

**Tart Cherries**

*Michigan State University Research Report 220*

<table>
<thead>
<tr>
<th>Bud Development Stage</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>Possible Injury</td>
<td>-25 to +15 (^1)</td>
<td>15</td>
<td>24</td>
<td>26</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Severe Injury</td>
<td>-30 to 0 (^1)</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>24</td>
<td>24</td>
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</table>

\(^1\) Wide range, depending on time of year.

*Bud development stages: 0 - dormant, 1 - first swelling, 2 - side green, 3 - green tip, 4 - tight cluster, 5 - open cluster, 6 - first white, 7 - first bloom, 8 - full bloom.*

Prudencio et al. 2018
Variation for very late bloom time is present in tart cherry

One solution to reduce the likelihood of crop loss is to delay bloom time.

May 10, 2007 – branches from late blooming and early blooming selections grown together at MSU’s research station in Clarksville, Mich.
Tart Cherry

Sweet Cherry (2n=2x=16) × Ground Cherry (2n=4x=32) → Tart Cherry (2n=4x=32)
The sour cherry center of diversity is in Eastern Europe.

Cherry germplasm importation to the U.S. was previously non-existent due to the Iron Curtain and quarantine restrictions.
In general, sour cherry cultivars bloom significantly later than sweet cherry, but can bloom as late as ground cherry.
Sweet cherry

Tart cherry cv. ‘Montmorency’

Ground cherry

Tart cherry cv. ‘Tamaris’

Sweet cherry cv. Bing
Tart cherry cv. Montmorency
Ground cherry
Tart cherry cv. Tamaris
The flowers on ‘Tamaris’ survived the multiple freezes in Michigan in 2012.

Branches collected from MSU’s Research Station on May 4, 2012

The pistils in the late blooming ‘Tamaris’ flowers were undamaged by the freeze events while many of the pea-sized fruit on ‘Montmorency’ were frozen.
Breeding has successfully resulted in even later bloom times than ‘Tamaris’

Montmorency (left) and MSU seedling 26e-04-20
Picture taken May 17, 2015 at MSU’s Clarksville Station

<table>
<thead>
<tr>
<th>Cultivar/ Selection</th>
<th>50% bloom HU accumulation(^1)</th>
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<tbody>
<tr>
<td>Montmorency</td>
<td>317</td>
</tr>
<tr>
<td>26e-04-20</td>
<td>562</td>
</tr>
<tr>
<td>Ujfehertoi Furtos</td>
<td>322</td>
</tr>
<tr>
<td>Tamaris</td>
<td>429</td>
</tr>
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</table>

\(^1\)Heat units accumulated from January 1\(^{st}\) using simple averages and a base temperature of 4.4°C

Parents of 26e-04-20 are Tamaris (from Michurinsk, Russia) & Ujfehertoi Furtos (from Ujfeherto, Hungary)
What is the underlying cause of the late bloom time?

The extremely late bloom time delay exhibited by this sour cherry germplasm is due to differences in how the plant responds to heat after breaking dormancy.

Floral bud development in Tamaris and 26e-04-20 just takes more heat accumulated to progress from the end of dormancy to full bloom.

Prudencio et al. 2018
Two major loci control bloom time in all *Prunus* crops studied

**Chromosome 1**
Major bloom time locus that determines how much chilling is needed to break dormancy
~ chill requirement

**Chromosome 4**
Major bloom time locus
~ heat requirement
Analysis of these two major bloom time loci in tart cherry
Alleles for the bloom time loci were given letter designations

<table>
<thead>
<tr>
<th>Parents</th>
<th>Bloom date (GDD)</th>
<th>QTL haplotype genotypes</th>
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<tr>
<td></td>
<td></td>
<td>qP-BD1.2^m</td>
</tr>
<tr>
<td>M172</td>
<td>323</td>
<td>c-e-f-g</td>
</tr>
<tr>
<td>Montmorency</td>
<td>359</td>
<td>c-d-h-i</td>
</tr>
<tr>
<td>25-14-20</td>
<td>330</td>
<td>b-c-d-e</td>
</tr>
<tr>
<td>25-02-29</td>
<td>315</td>
<td>a-b-c-d</td>
</tr>
<tr>
<td>UF</td>
<td>350</td>
<td>c-d-e-e</td>
</tr>
<tr>
<td>Surefire</td>
<td>376^b</td>
<td>c-e-i-j</td>
</tr>
<tr>
<td>RS</td>
<td>376</td>
<td>b-c-e-k</td>
</tr>
<tr>
<td>ET</td>
<td>NA^c</td>
<td>c-e-l-m</td>
</tr>
</tbody>
</table>

UF ‘Újfehértói Fürtös’, RS ‘Rheinische Schattenmorelle’, ET ‘Englaise Timpurii’

^a Different haplotypes are indicated by different italic letters where four haplotypes represent four chromosomes in a tetraploid. SNP haplotypes for QTL on G1, G2, G4, and G5 are in Supplementary Figs. S3, S4, S5, and S6, respectively.

^b ‘Surefire’ is reported to bloom after ‘Rheinische Schattenmorelle’ (Andersen et al. 1999)

^c Data not available as ‘Englaise Timpurii’ is no longer in the orchard.
Average effect of the ‘k’ allele for the chromosome 4 bloom time locus in an F1 progeny population

At the locus on chromosome 4, late bloom time in sour cherry is significantly associated with the number of ‘k’ alleles the plant has.

Data from the Ujfeherto Furtos x Tamaris population - both UF and Tamaris have one ‘k’ allele for the bloom time locus
Ground cherry exhibits later bloom time than any of the *Prunus* crops

The *Prunus* center of origin is China

May 10, 2019

Peach

Ground cherry

Dead peach pistil (H.J. Larson)
Crop loss of peach

Spring freeze damage

- Insufficient chilling temperatures
  - Decrease chilling requirement
  - Increase heat requirement

90 percent of South Carolina’s peach crop destroyed

A devastating March freeze dealt a severe blow to South Carolina’s peach crop.

John Hart | Apr 02, 2017

Farm Progress
The jewels are the ground cherry - derived alleles for the two major bloom time loci

Chromosome

1 2 3 4 5 6 7 8

Bloom time

K allele

Spring 2016

Peach
‘Tamaris’ tart cherry
Many important loci cluster together on chromosome 4

Michigan spotted wing Drosophila update -
July 30, 2019

Spotted wing Drosophila numbers are higher than ever recorded at this time of year in Michigan; take action to protect susceptible fruit.

Juliana Wilson, Rufus Isaacs and Larry Gut, Michigan State University Extension, Department of Entomology - July 31, 2019

Puncture hole left by female SWD as she laid an egg inside the tart cherry fruit.

Photo: Annie Klodd
Red Color
Flesh color in tart cherries
Different continents, different cherries, different products

‘Montmorency’ tart cherry
U.S. type

‘Balaton’ tart cherry
European type
‘Balaton’ led to new products made in the U.S.
What should be my flesh color breeding target?

- ‘Montmorency’
- ‘Balaton’
- ‘Jubileum’
Genetic control of red fruit color
Leveraged shared ancestry

Apple
chrom 9

Cherry
chrom 3

Peach
chrom 3

MYB1/10 Fruit skin & flesh color

MYB1/10 Fruit skin & flesh color

MYB1/10 Fruit skin color

Cs locus (red color around stone) & QTL for flesh bleeding
Knowledge of causal differences in the DNA enable the design of genetic tests that are predictive of color.
Inheritance of flesh color alleles in tart cherry

Flesh rating

1
2
3
4
5

Ujfehertoi
Furtos  Surefire
“d”   “e”

M172  25-02-29
“l”   “p”

<table>
<thead>
<tr>
<th></th>
<th>“d”</th>
<th>“e”</th>
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<tr>
<td>+</td>
<td>4.8 a</td>
<td>3.0 b</td>
</tr>
<tr>
<td>-</td>
<td>4.5 a</td>
<td>1.9 c</td>
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<table>
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<th></th>
<th>“l”</th>
<th>“p”</th>
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<tr>
<td>+</td>
<td>4.2 a</td>
<td>3.2 b</td>
</tr>
<tr>
<td>-</td>
<td>3.6 c</td>
<td>1.3 d</td>
</tr>
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Use of a DNA test that is predictive for flesh color

Fruit colors available in tart cherry

Desirable fruit color: ‘Montmorency’ bright red

Predicted to have brilliant red color (keep)

Predicted to have dark purple color (discard)
Cherry leaf spot
Cherry Leaf Spot on tart cherry

‘Montmorency’ is extremely susceptible
- Estimated to cost the industry ~ $7.5 million/year
- Up to 10 fungicide applications per season

Defoliation results in poor fruit quality and increased likelihood of mid-winter cold damage

Fungicide resistance and availability are looming threats
Susceptible -- Tolerant -- Resistant

Susceptible ‘Montmorency’

Tolerant sweet cherry cultivar

Resistant *P. canescens* derived seedling
CLS defoliation depending on germplasm source

Andersen et al. 2019
CLS tolerance is likely controlled by recessive genetic factors

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>Low infection without sporulation</td>
<td>Low infection with sporulation</td>
<td>Moderate infection with sporulation</td>
<td>Severe infection, slow progression</td>
<td>Severe infection, fast progression</td>
</tr>
<tr>
<td>0-35% final defoliation</td>
<td>&lt; 35% final defoliation</td>
<td>40-60% final defoliation</td>
<td>&gt; 65% final defoliation</td>
<td>75% defoliation by mid-July</td>
</tr>
</tbody>
</table>

Diagram a.

Diagram b.

Table: | Variety | English Name | Disease Progression | Defoliation |
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<thead>
<tr>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>English Early</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>English Late</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kansas Early</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kansas Late</td>
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</tbody>
</table>

Legend:
- Low infection without sporulation
- Moderate infection with sporulation
- Severe infection, slow progression
- Severe infection, fast progression

Diagram details:
- English Winter: Low infection without sporulation, 0-35% final defoliation
- English Early: Low infection without sporulation, < 35% final defoliation
- English Late: Moderate infection with sporulation, 40-60% final defoliation
- Kansas Early: Severe infection, slow progression, > 65% final defoliation
- Kansas Late: Severe infection, fast progression, 75% defoliation by mid-July

Diagram notes:
- Disease progression shown in stages with corresponding defoliation percentages.
Susceptible
‘Montmorency’

Tolerant sweet cherry cultivar
Diploid breeding strategy for tart cherry

Sweet Cherry (2n=2x=16) × Tart Cherry (2n=4x=32) → Interspecific hybrid (2n=3x=24) → Goal (2n=2x=24)

Success will depend on my ability to make science-based decisions of which parents to choose, which crosses to make, and which offspring to progress.

- Maintain CLS tolerance exhibited by sweet cherry
- “Transfer” late bloom time and fruit quality characteristics desired for tart cherry
Tart cherry breeding

Which parents to use?

Which combinations to create?

Which seedlings to progress?

Which selections to trial?

Which advanced selections to commercialize?

Increase breeding efficiency and success at all stages through science-based decisions

Three Trait Examples
1. Catastrophic crop losses
2. Fruit color
3. Disease resistance
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