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

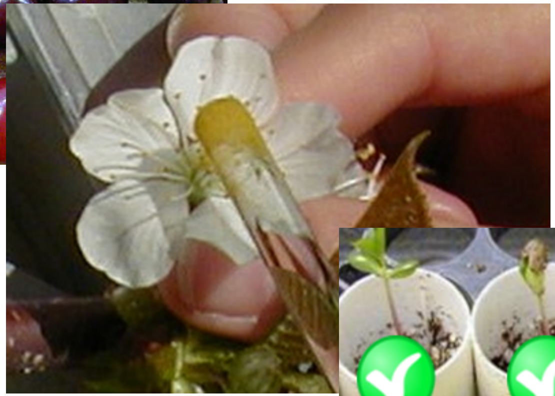
Amy Iezzoni

Michigan State University

Tart Cherry Breeding

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

Which parents to use?



Which combinations to create?

Which seedlings to progress?

Which selections to trial?

Which advanced selections to commercialize?

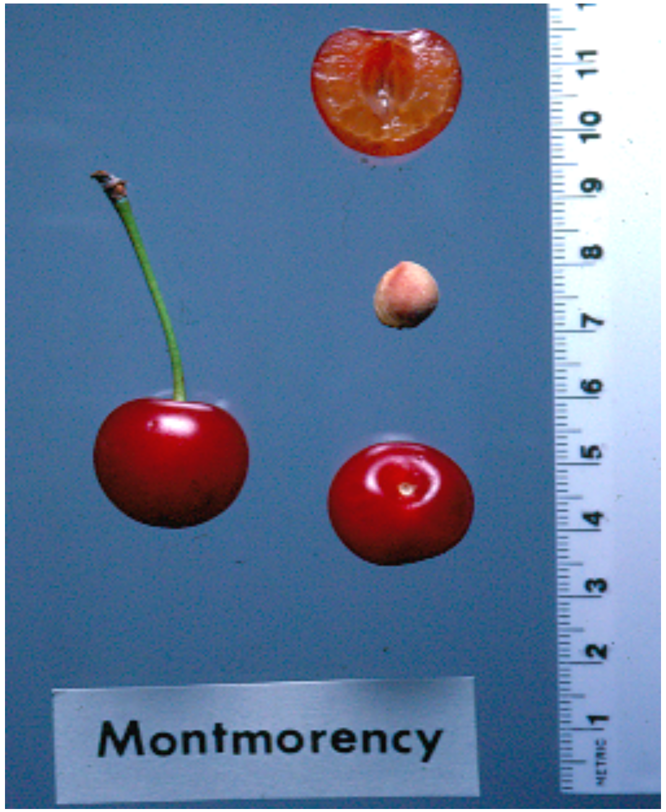
<u>Outline</u>

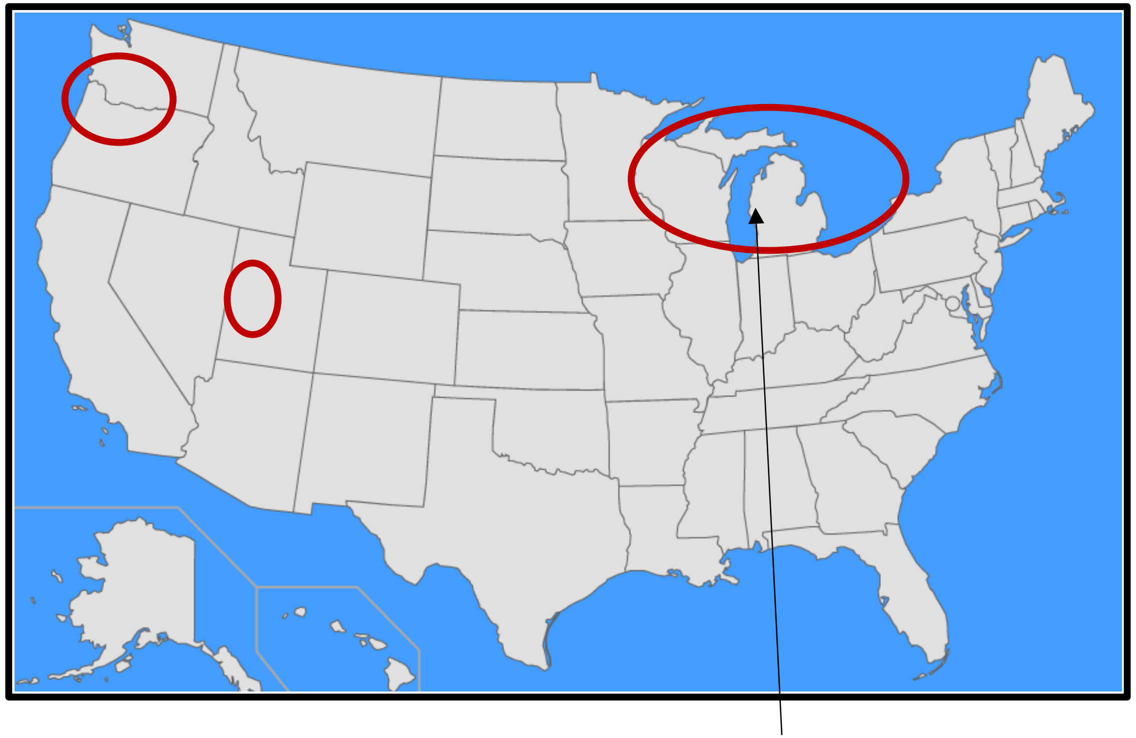
1. Catastrophic crop losses
2. Fruit color
3. Disease resistance

Catastrophic crop losses

Genetic Uniformity and Geographical Concentration

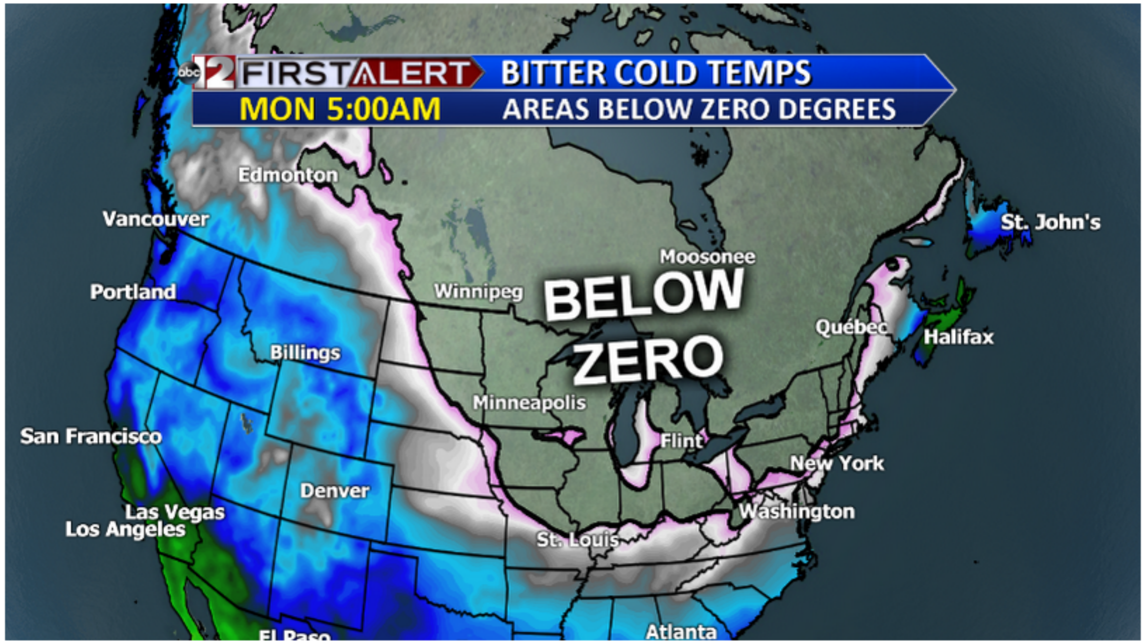
The U.S. sour cherry industry is essentially a monoculture of a 400 year old variety called Montmorency.





Michigan produces ~ 75% of the tart cherries in the U.S.

Arctic blast aims for Mid-Michigan



By Brad Sugden | Posted: Wed 2:02 PM, Jan 16, 2019

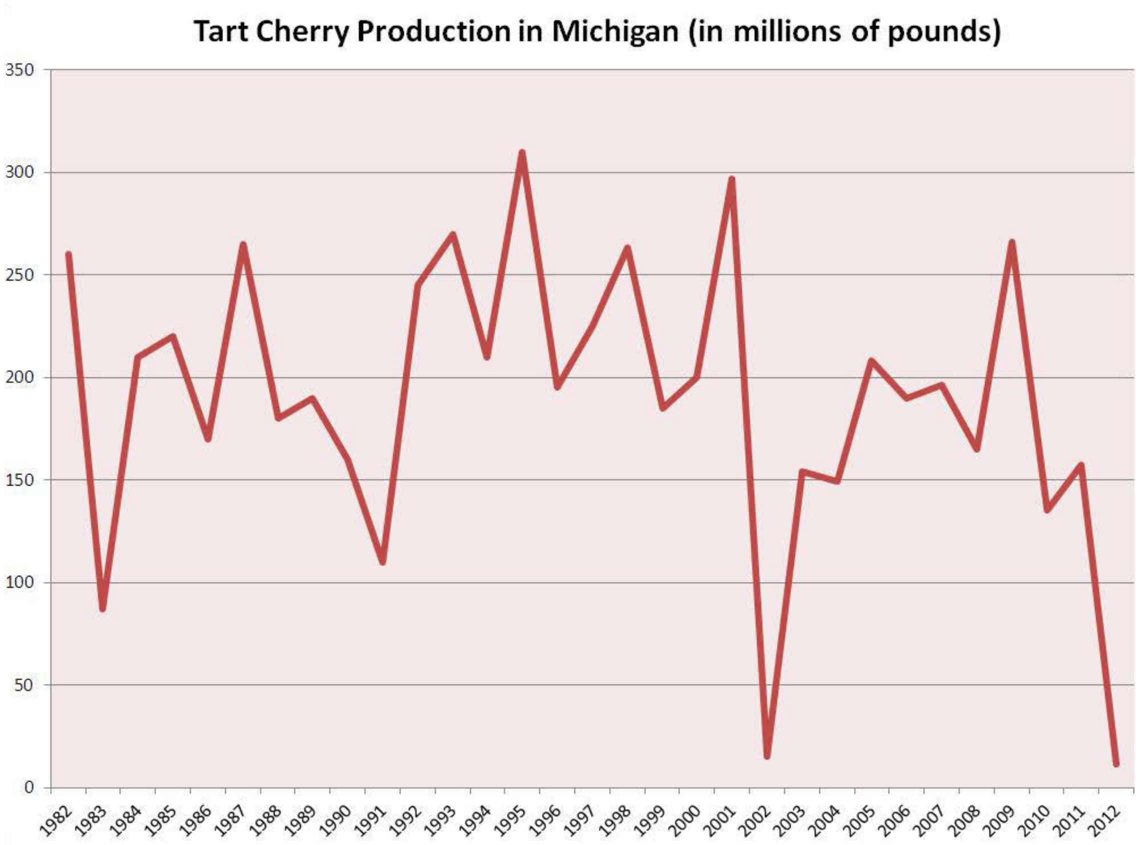
On April 21 & 22, 2002, an artic blast with temperatures below freezing froze the pistils within the Montmorency flowers

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.

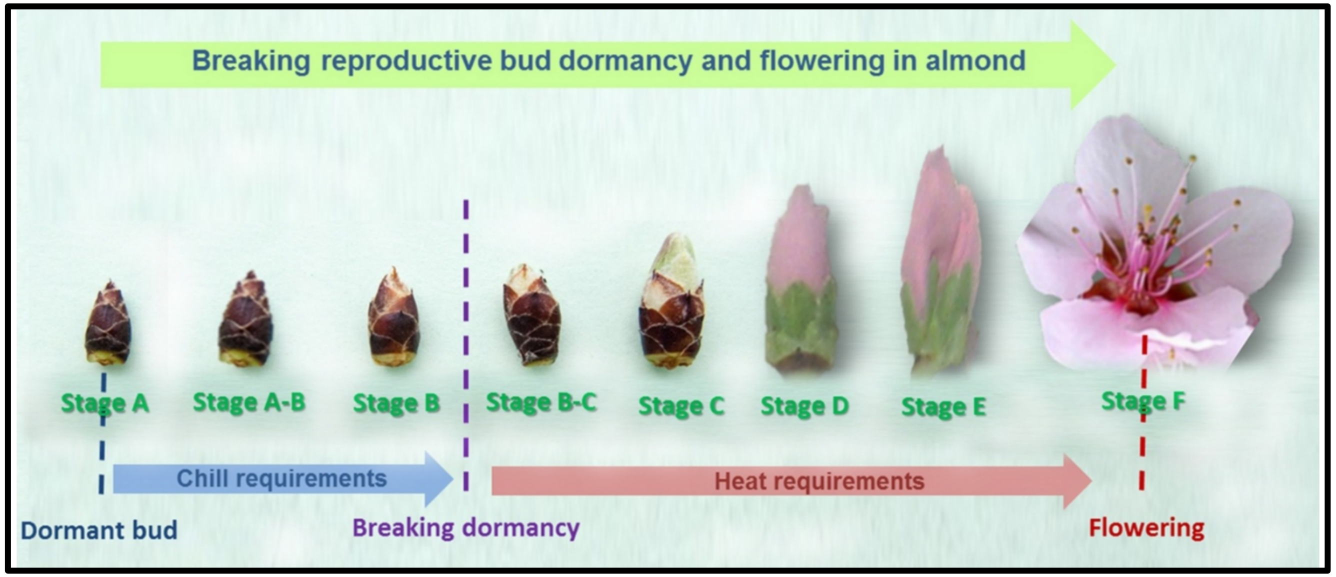
CRITICAL TEMPERATURES (°F) FOR BLOSSOM BUDS Tart Cherries

Michigan State University Research Report 220

Bud Development Stage*	0	1	2	3	4	5	6	7	8
Possible Injury	-25 to +15[1]	15	24	26	26	28	28	28	28
Severe Injury	-30 to 0[1]	0	10	20	22	24	24	24	24

* 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.

[1] Wide range, depending on time of year.



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



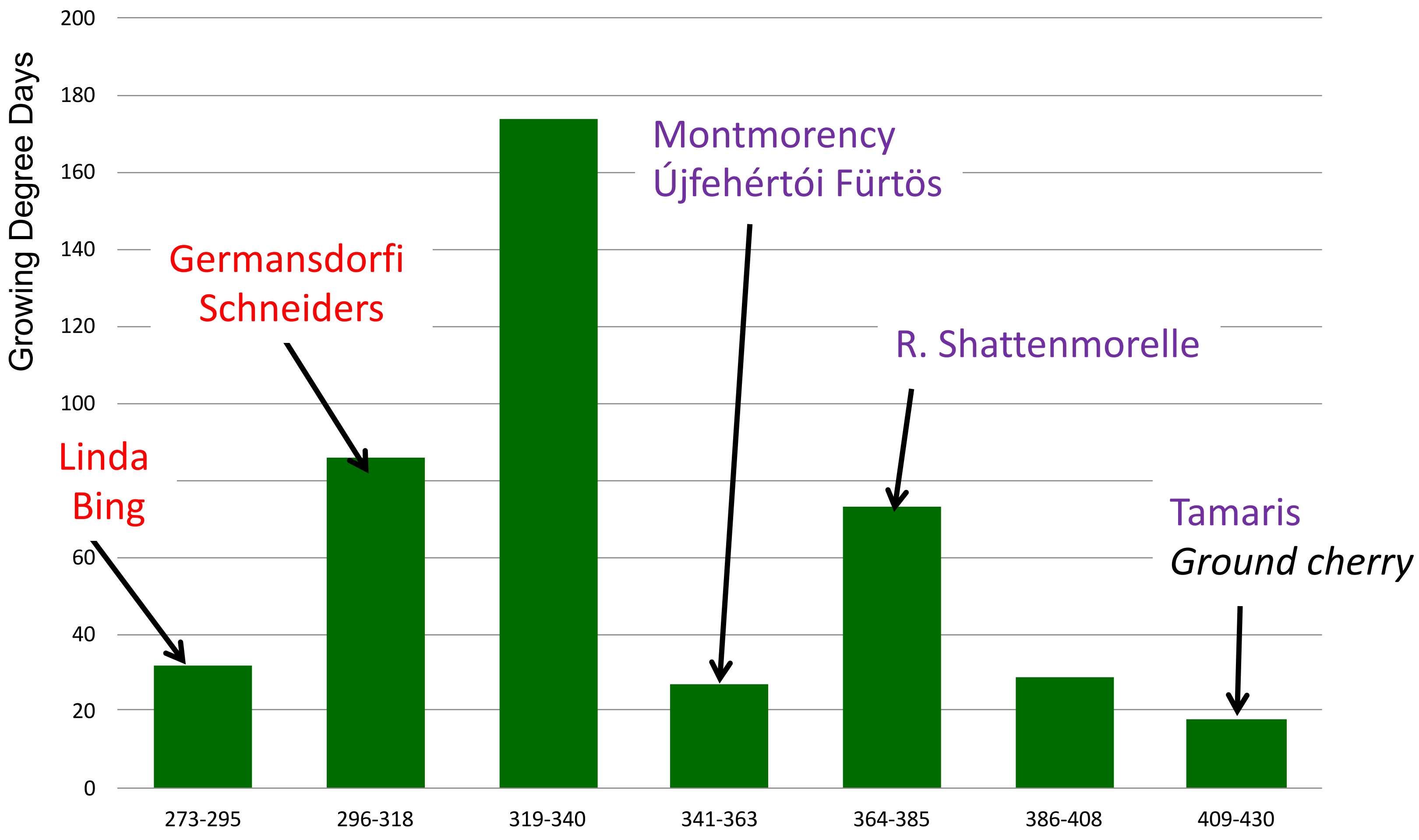
Sweet Cherry (2n=2x=16) × Ground Cherry (2n=4x=32) → Tart Cherry (2n=4x=32)



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



May 10, 2019: MSU Research Station, Clarksville, Mich.

Tart cherry cv.‘ Montmorency’

Sweet cherry

Ground cherry

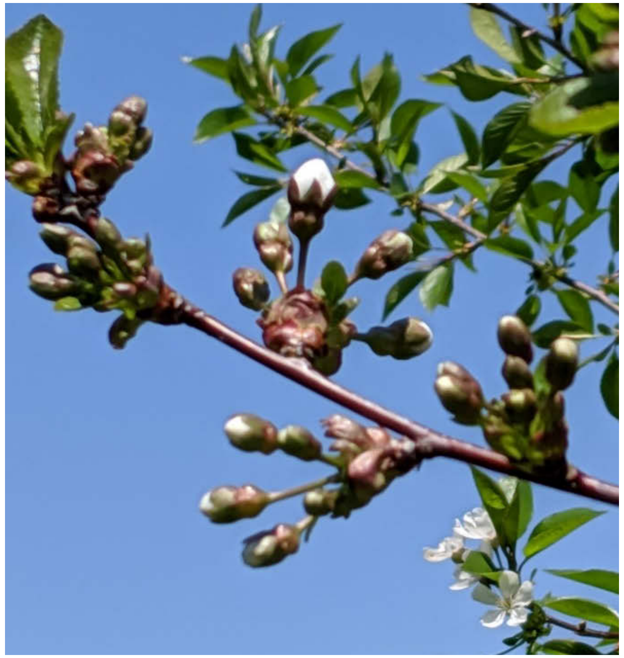
Tart cherry cv. ‘Tamaris’

May 14, 2019 – MSU Research Station, Clarksville, Mich.

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.

‘Tamaris’ ‘Montmorency’

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

Cultivar/ Selection	50% bloom HU accumulation[1]
Montmorency	317
26e-04-20	562
Ujfehertoi Furtos	322
Tamaris	429

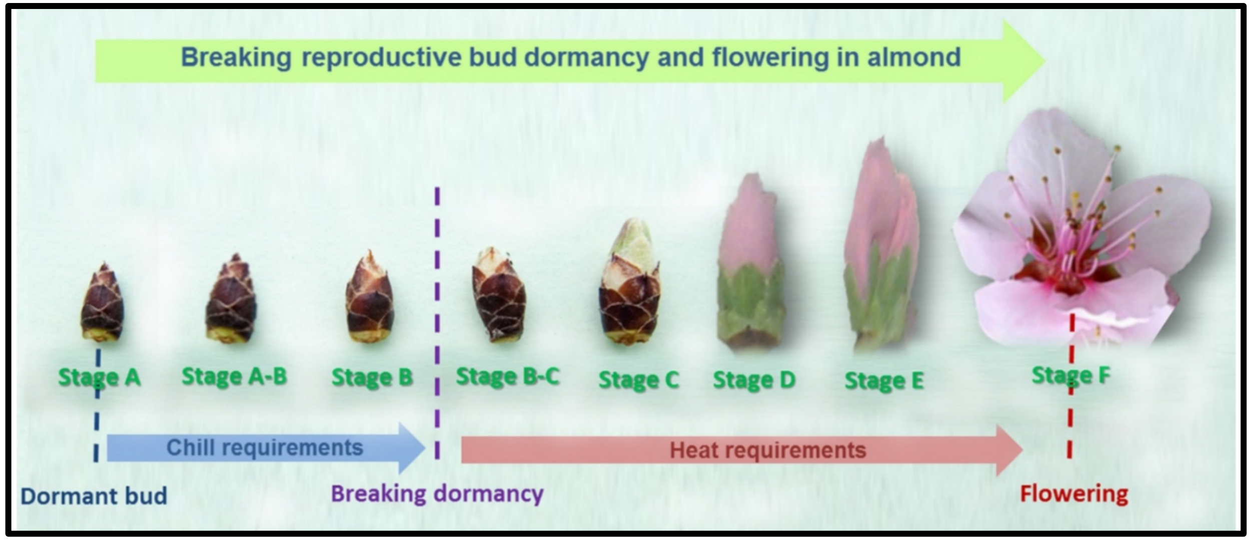
[1]Heat units accumulated from January 1st using simple averages and a base temperature of 4.4°C

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

<u>Chromosome 1</u>

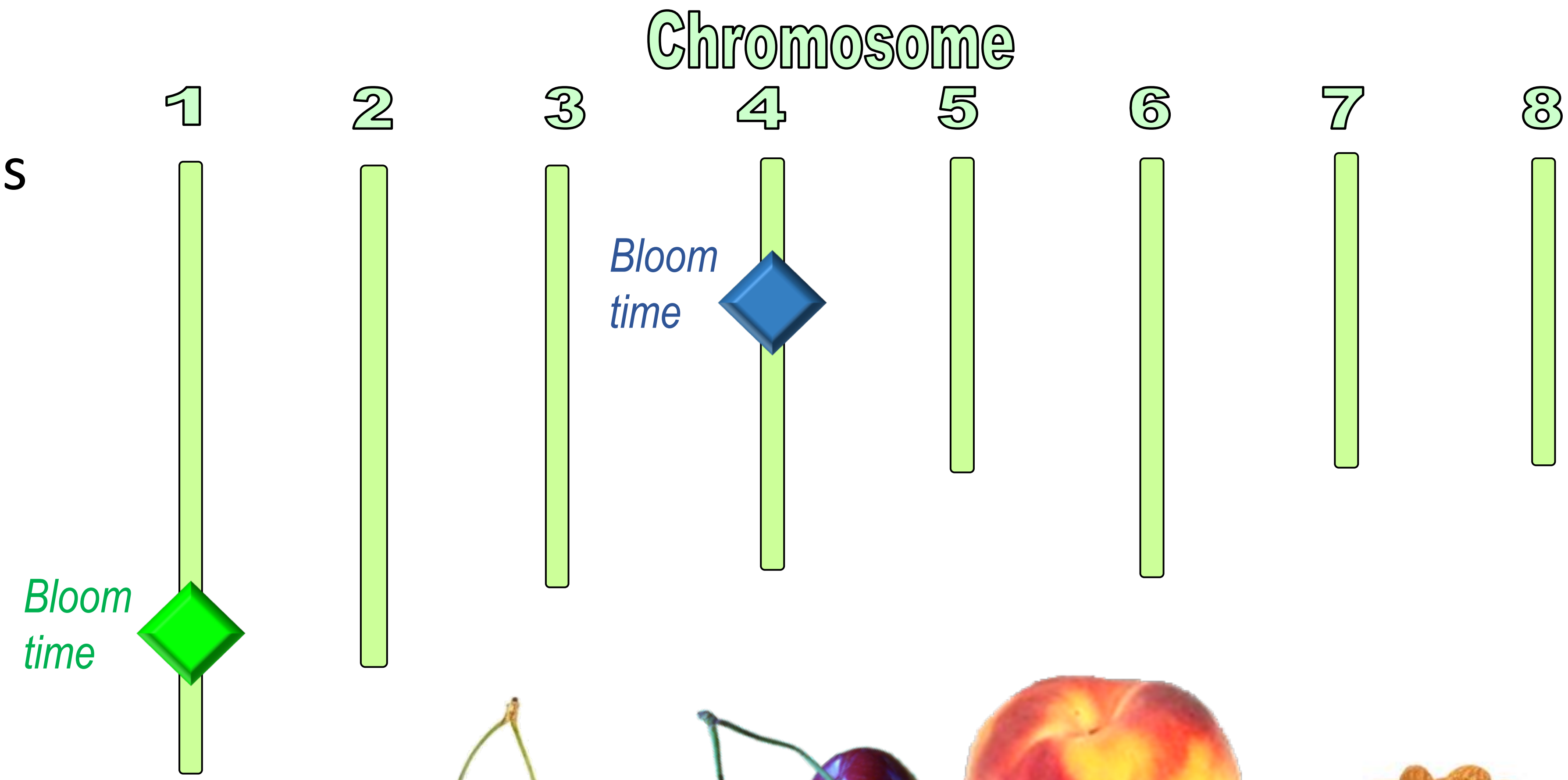
Major bloom time locus that determines how much chilling is needed to break dormancy

~ chill requirement

<u>Chromosome 4</u>

Major bloom time locus

~ heat requirement



Analysis of these two major bloom time loci in tart cherry

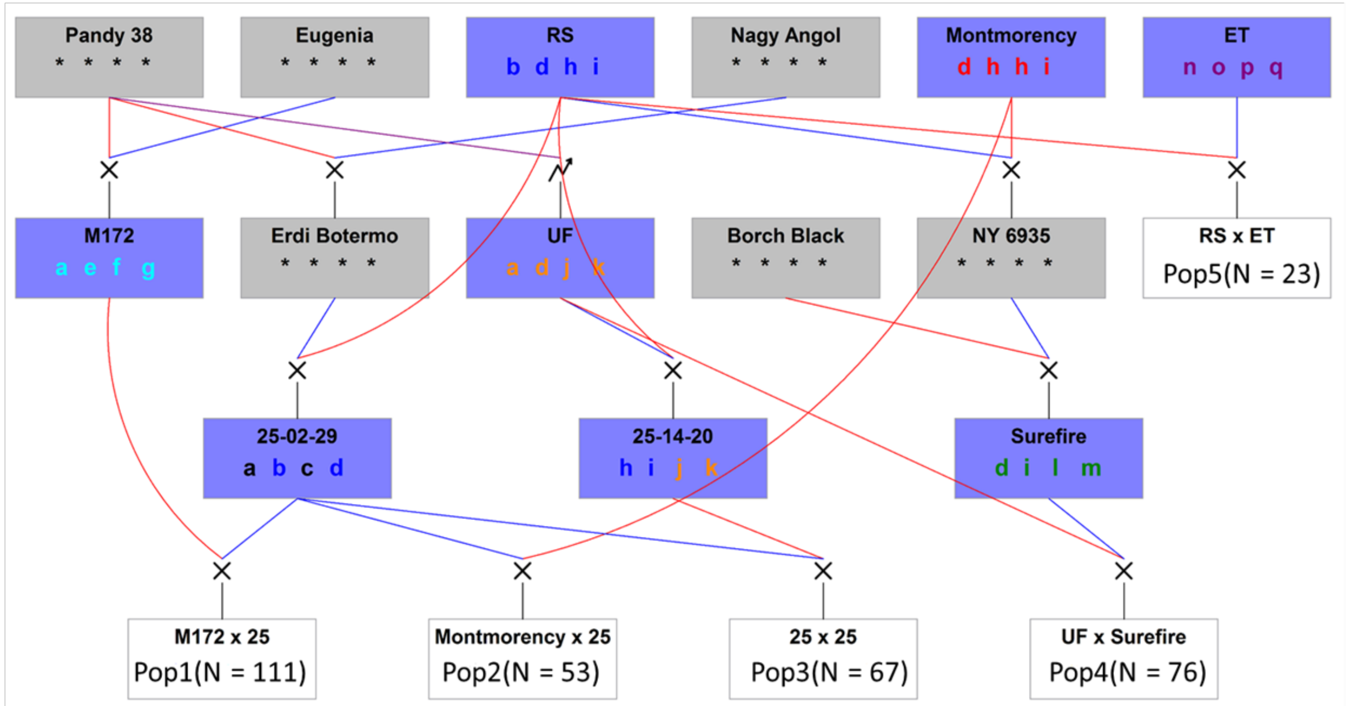
Tree Genetics & Genomes (2018) 14: 22
https://doi.org/10.1007/s11295-018-1236-2

ORIGINAL ARTICLE

Identification of bloom date QTLs and haplotype analysis in tetraploid sour cherry (*Prunus cerasus*)

Lichun Cai[1] • Travis Stegmeir[1] • Audrey Sebolt[1] • Chaozhi Zheng[2] • Marco C. A. M. Bink[3] • Amy Iezzoni[1]

a



b

SNP	Chr	Physical position (bp)	Genetic position (cM)	G2 QTL Haplotypes																
				a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*
ss490547139	2	15,584,544	20.9	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B
ss490549109	2	17,033,717	26.9	A	B	A	A	B	B	A	B	B	A	B	B	B	A	A	A	B
ss490549121	2	17,503,996	28.6	B	A	B	B	A	B	B	A	A	B	A	B	A	B	A	B	B
ss490549172	2	17,862,597	29.0	A	A	A	A	B	B	A	B	A	A	A	A	B	A	A	A	B
ss490556795	2	18,223,481	29.2	A	B	B	B	B	B	B	B	B	A	A	B	B	B	B	B	B
ss490549216	2	18,914,293	29.7	B	A	A	A	A	B	A	B	B	A	B	B	B	A	B	A	B
ss490549287	2	19,324,328	32.8	A	A	A	A	A	B	A	B	A	A	A	A	A	A	A	A	B
ss490549295	2	19,354,729	33.0	A	A	B	B	A	A	A	A	B	B	A	B	A	B	B	B	A
ss490547200	2	19,582,376	33.8	A	A	B	B	A	A	A	A	A	A	A	A	A	A	A	A	A
ss490549435	2	20,106,573	40.1	B	B	B	A	B	B	B	B	B	B	B	B	B	A	B	B	B

Alleles for the bloom time loci were given letter designations

Table 3 Bloom date (presented as growing degree days) and QTL haplotype genotypes for the eight parents

Parents	Bloom date (GDD)	QTL haplotype genotypes			
		qP-BD1.2[m]	*qP-BD2.1*[m]	*qP-BD4.1*[m]	*qP-BD5.1*[m]
M172	323	*c-e-f-g*[a]	*a-e-f-g*	*d-e-f-h*	*e-f-g-h*
Montmorency	359	*c-d-h-i*	*d-h-h-i*	*a-d-i-l*	*d-e-i-j*
25-14-20	330	*b-c-d-e*	*h-i-j-k*	*a-g-h-j*	*k-k-l-m*
25-02-29	315	*a-b-c-d*	*a-b-c-d*	*a-b-c-d*	*a-b-c-d*
UF	350	*c-d-e-e*	*a-d-j-k*	*a-h-k-n*	*a-g-k-l*
Surefire	376+[b]	*c-e-i-j*	*d-i-l-m*	*g-i-k-o*	*a-c-m-n*
RS	376	*b-c-e-k*	*b-d-h-i*	*b-d-g-i*	*c-d-k-m*
ET	NA[c]	*c-e-l-m*	*n-o-p-q*	*a-m-n-p*	*g-h-m-o*

UF 'Újfehértói Fürtös', *RS* 'Rheinische Schattenmorelle', *ET* 'Englaise Timpurii'

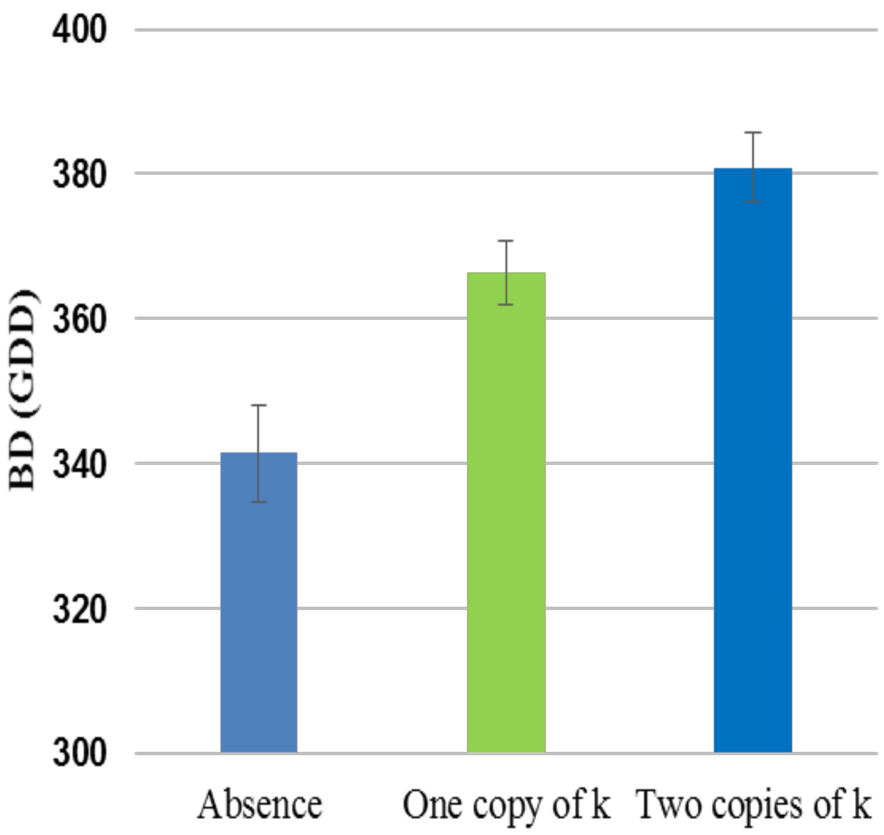
[a] Different haplotypes are indicated by different italic letters where four haplotypes represent four chromosomes in a tetraploid. SNP haplotypes for QTL on G1, G2, G4, and G5 are in Supplementary Figs. S3, S4, S5, and S6, respectively

[b] 'Surefire' is reported to bloom after 'Rheinische Schattemorelle' (Andersen et al. 1999)

[c] Data not available as 'Englaise Timpurii' is no longer in the orchard

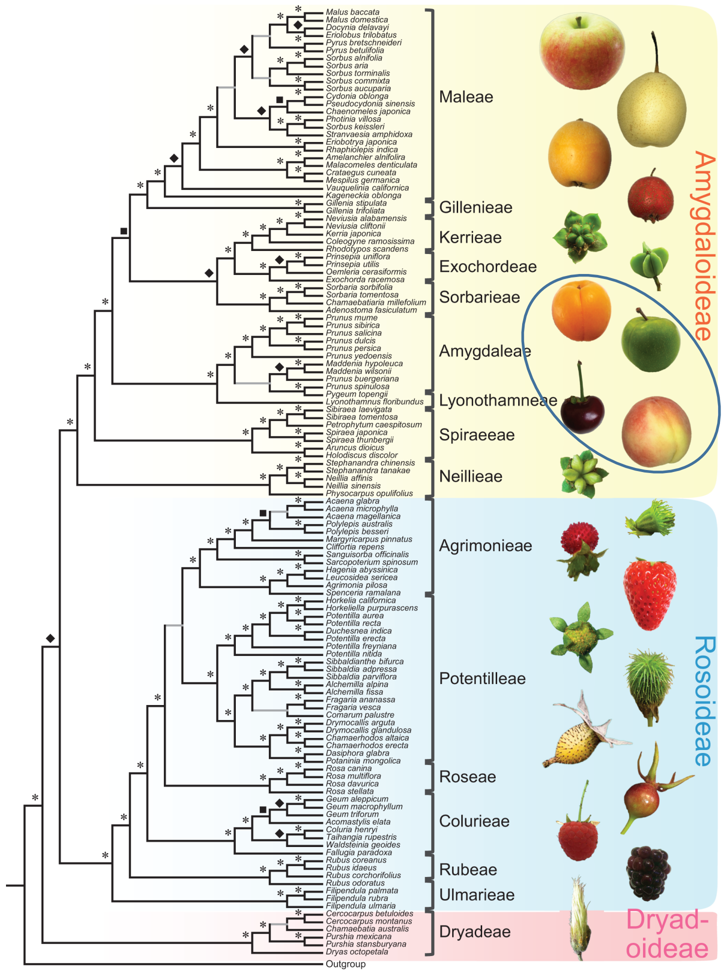
Average effect of the 'k' allele for the chromosome 4 bloom time locus in an F1 progeny population

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 Ujfehertoi 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

Xiang et al. 2019.

Molecular Biology and Evolution, Volume 34, Issue 2, February 2017, Pages 262–281, https://doi.org/10.1093/molbev/msw242

May 10, 2019

Peach

Ground cherry

Dead peach pistil (H.J. Larson)

Crop loss of peach

Spring freeze damage

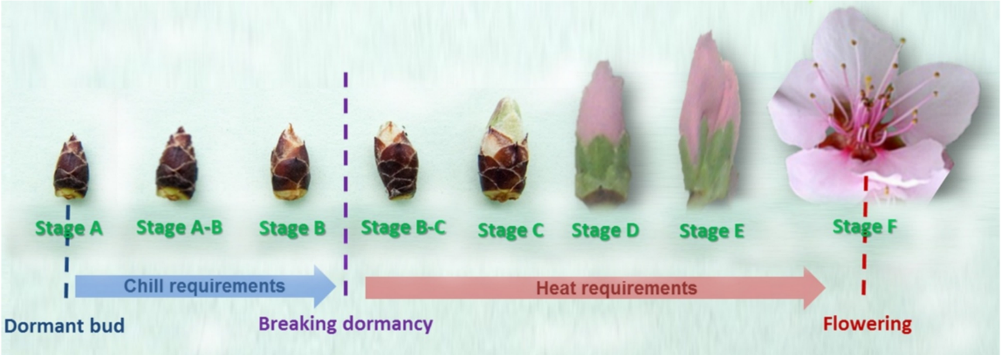
90 percent of South Carolina's peach crop destroyed

Freeze-damaged peaches at TItan Farms in Ridge Springs, S.C.

A devastating March freeze dealt a severe blow to South Carolina's peach cr

John Hart | Apr 02, 2017

FarmProgress



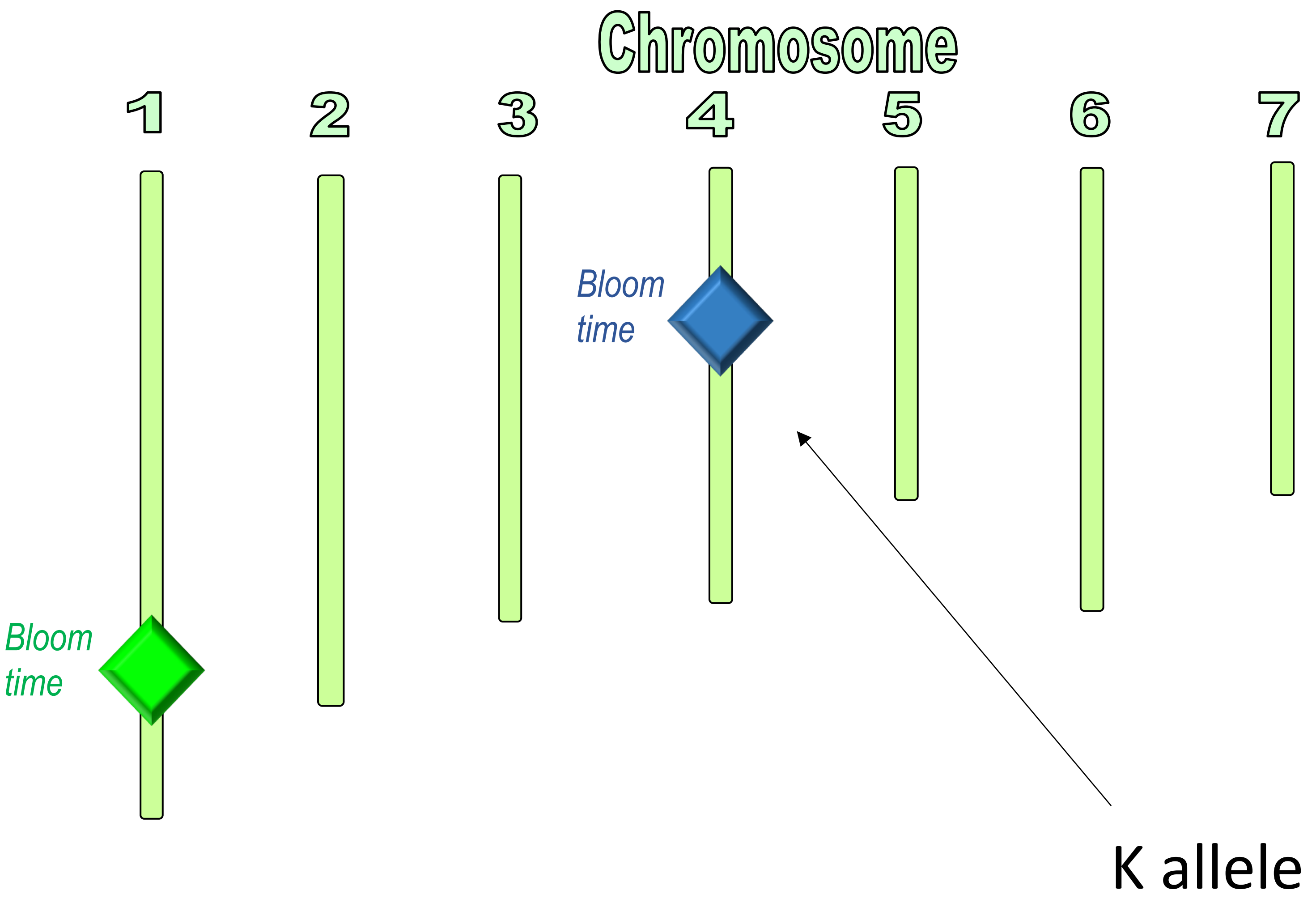
Insufficient chilling temperatures

Scaffolds shown on an insufficiently chilled peach tree. Note adequately chilled trees in background. (Photo: Gregory L. Reighard)

Decrease chilling requirement

Increase heat requirement

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

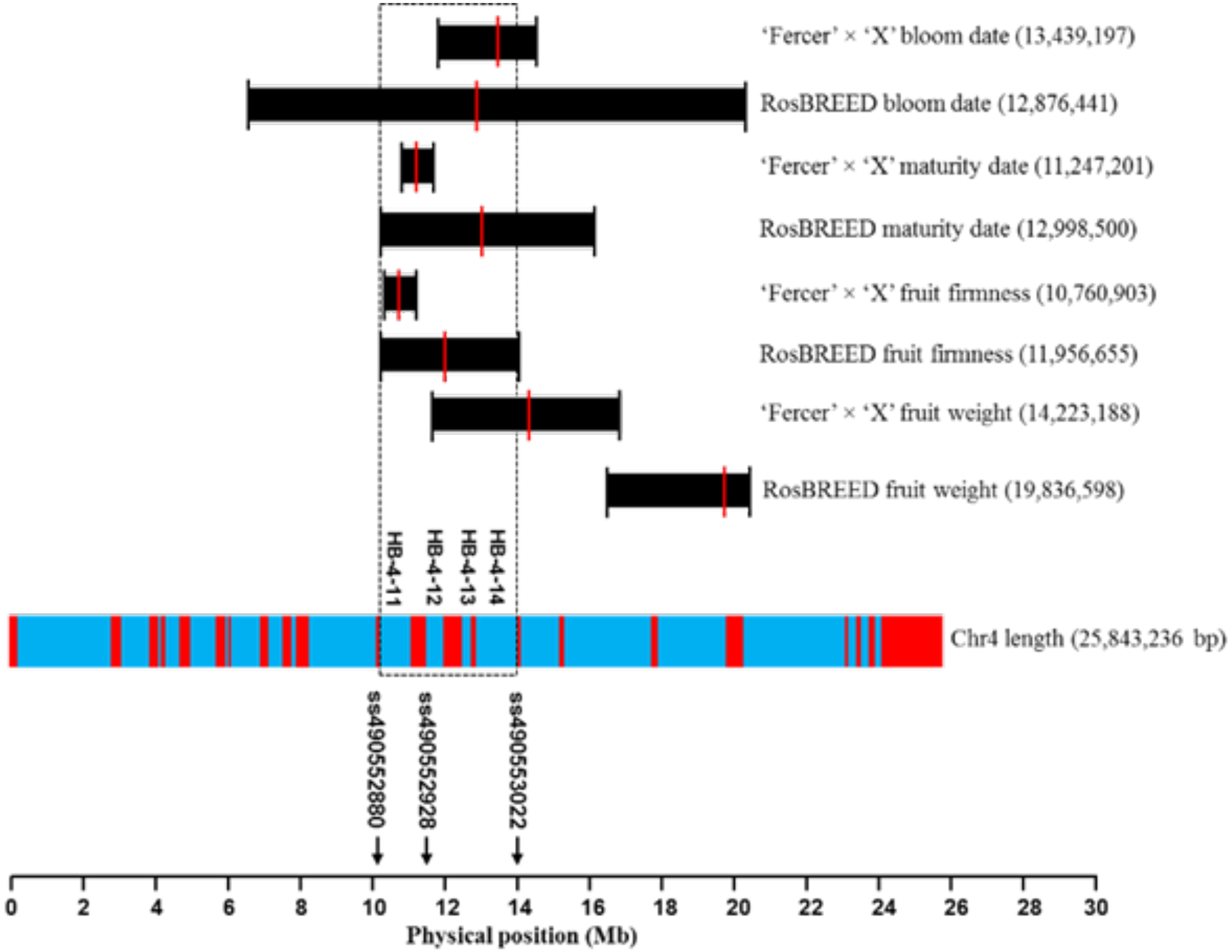


Spring 2016

Peach

'Tamaris' tart cherry

Many important loci cluster together on chromosome 4



Sweet cherry 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.

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

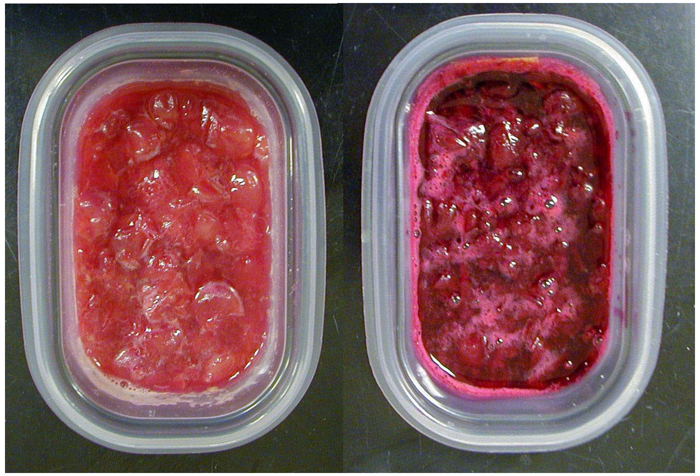
Puncture hole left by female SWD as she laid an egg inside the tart cherry fruit.
Photo: Annie Klodd

Red Color

Flesh color in tart cherries

Different continents, different cherries, different products

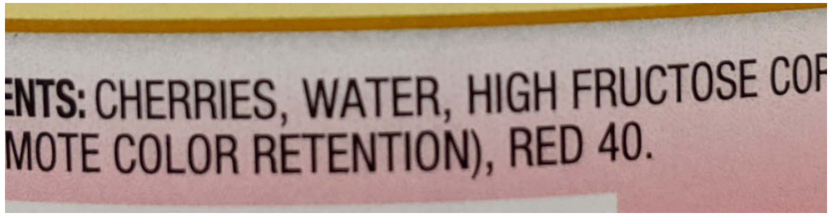
‘Montmorency’ tart cherry
U.S. type



‘Balaton’ tart cherry
European type

‘Balaton’ led to new products made in the U.S.

What should be my flesh color breeding target?



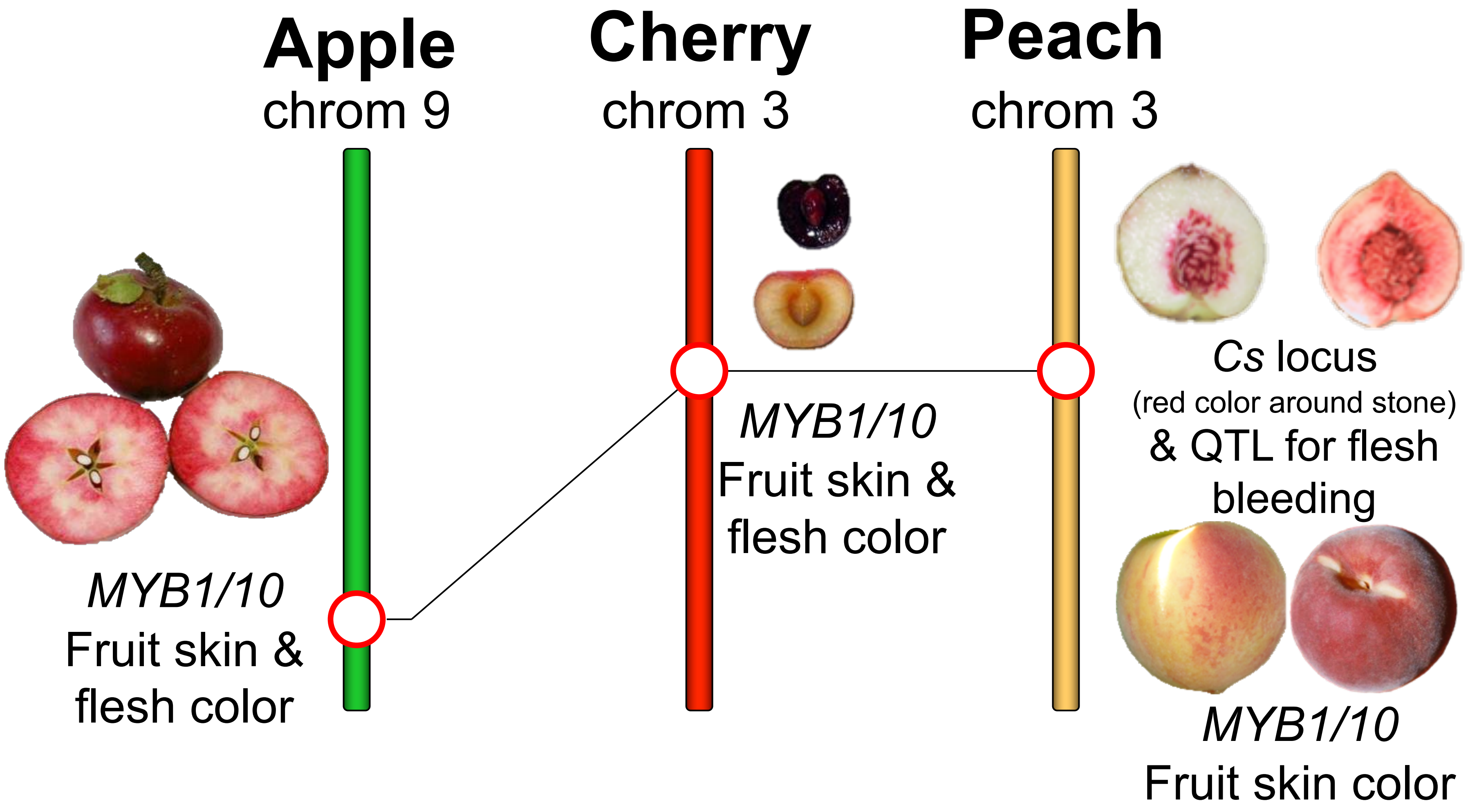
Cherries

‘Montmorency’

‘Balaton’

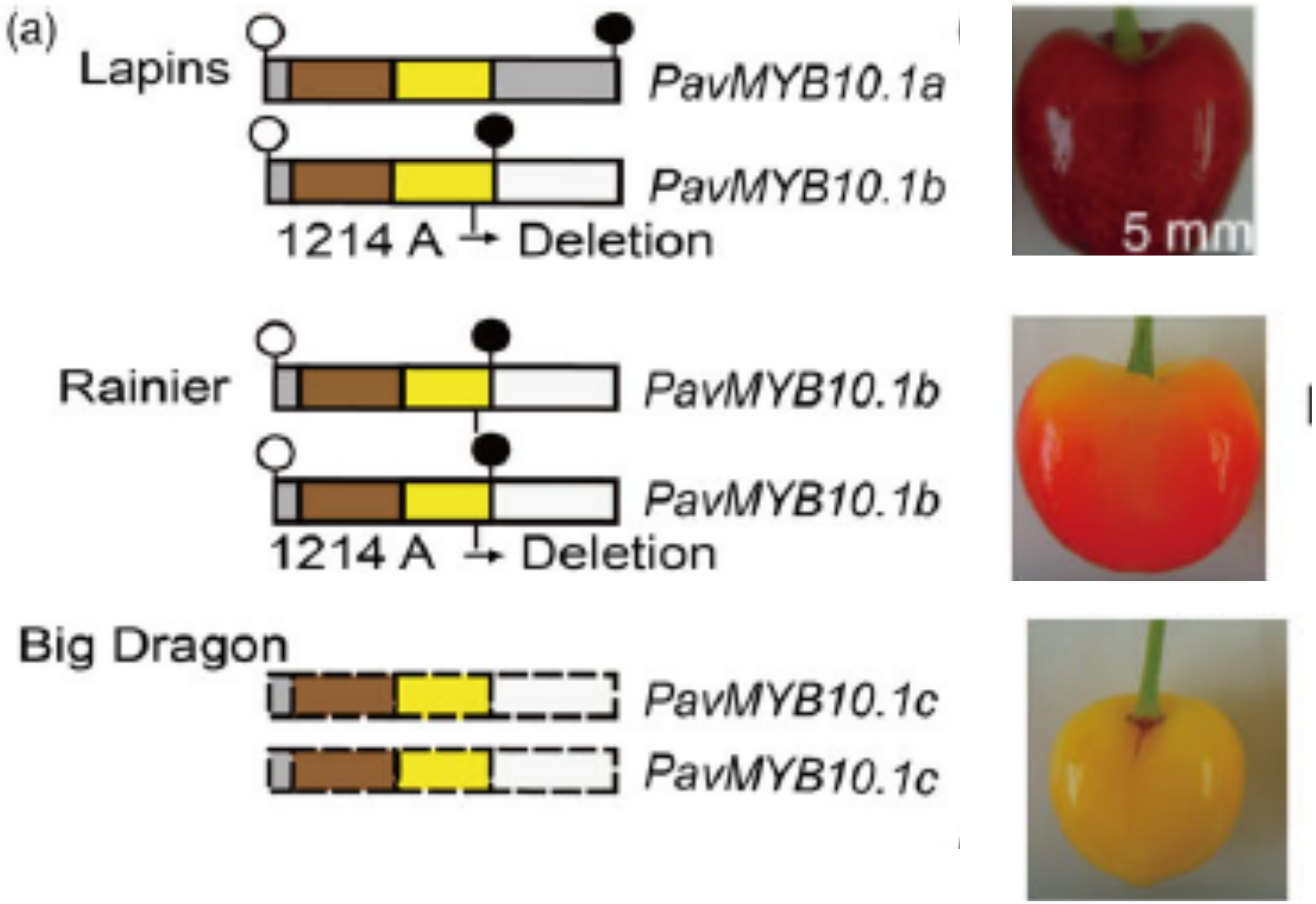
‘Jubileum’

Genetic control of red fruit color
Leveraged shared ancestry

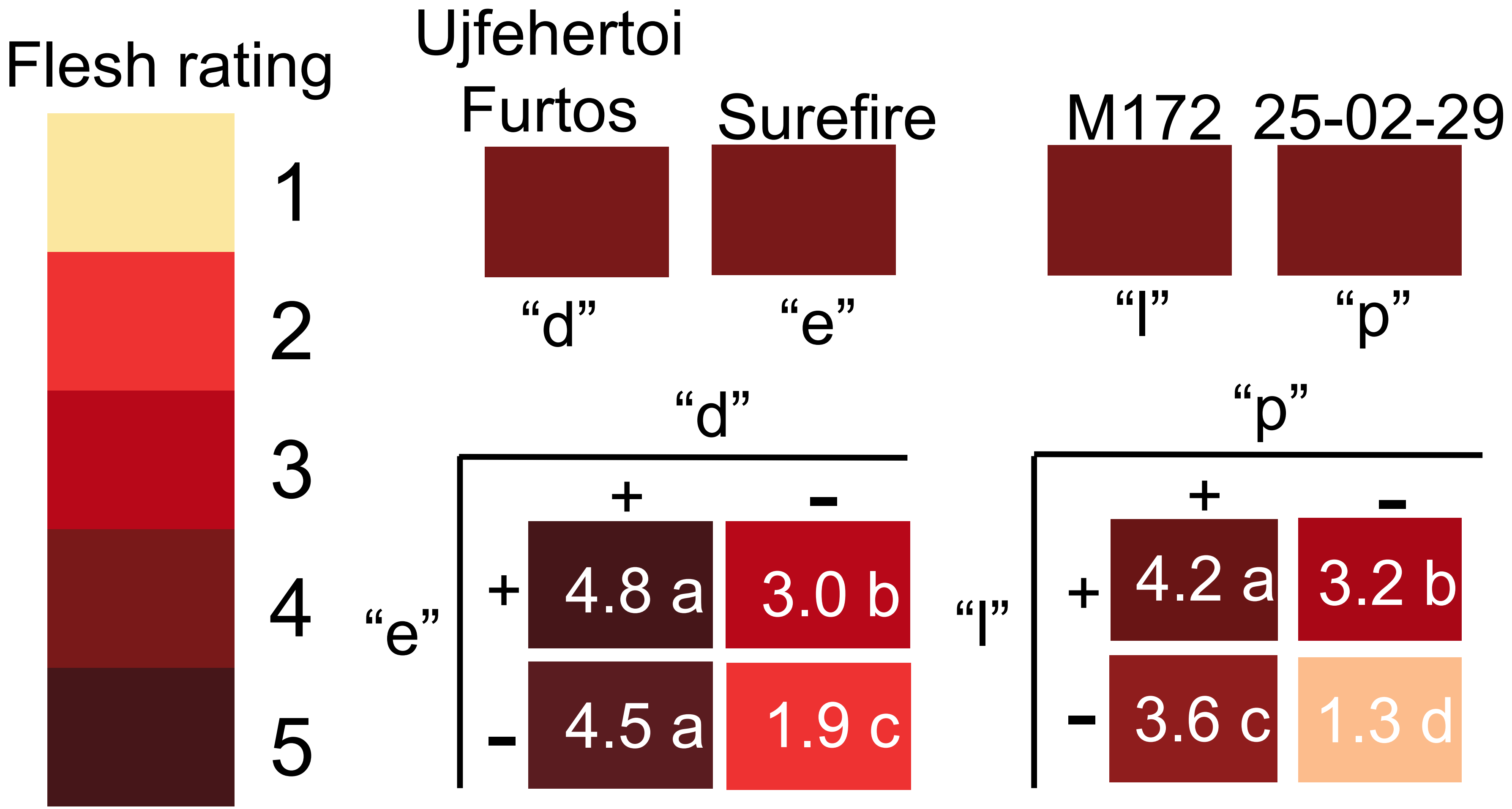


Knowledge of causal differences in the DNA enable the design of genetic tests that are predictive of color

Jin et al. (2016)
Plant Biotech J
14:2120-2133



Inheritance of flesh color alleles in tart cherry



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

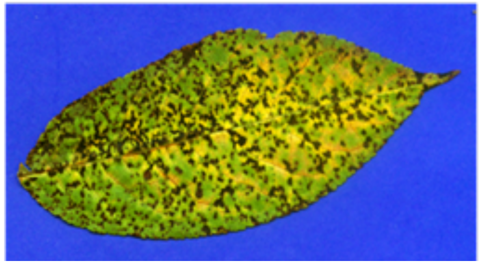
- Estimated to cost the industry ~ $7.5 million/year
- Up to 10 fungicide applications per season

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

Fungicide resistance and availability are looming threats

Susceptible -- Tolerant -- Resistant

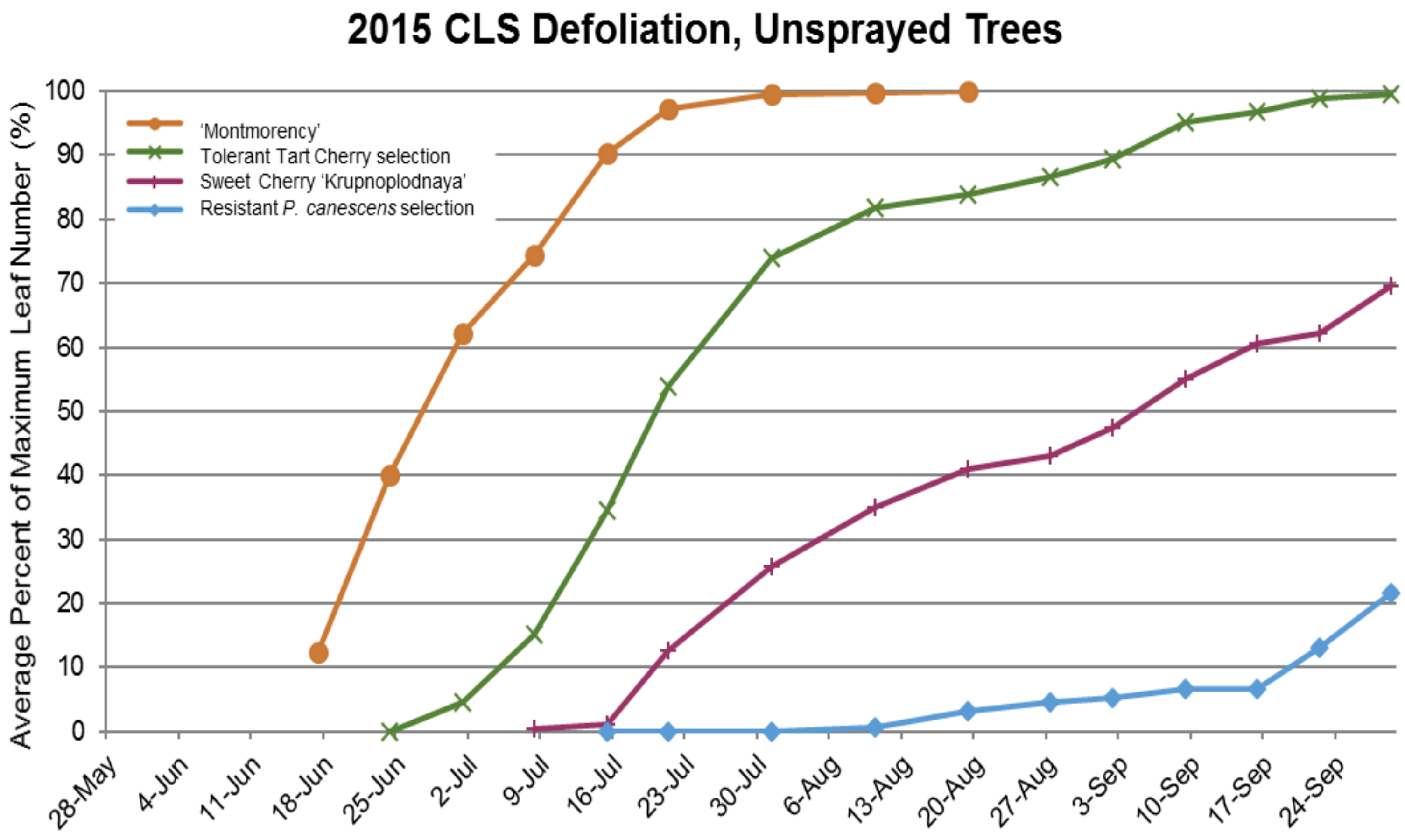
Susceptible
'Montmorency'



Tolerant sweet
cherry cultivar

Resistant *P. canescens*
derived seedling

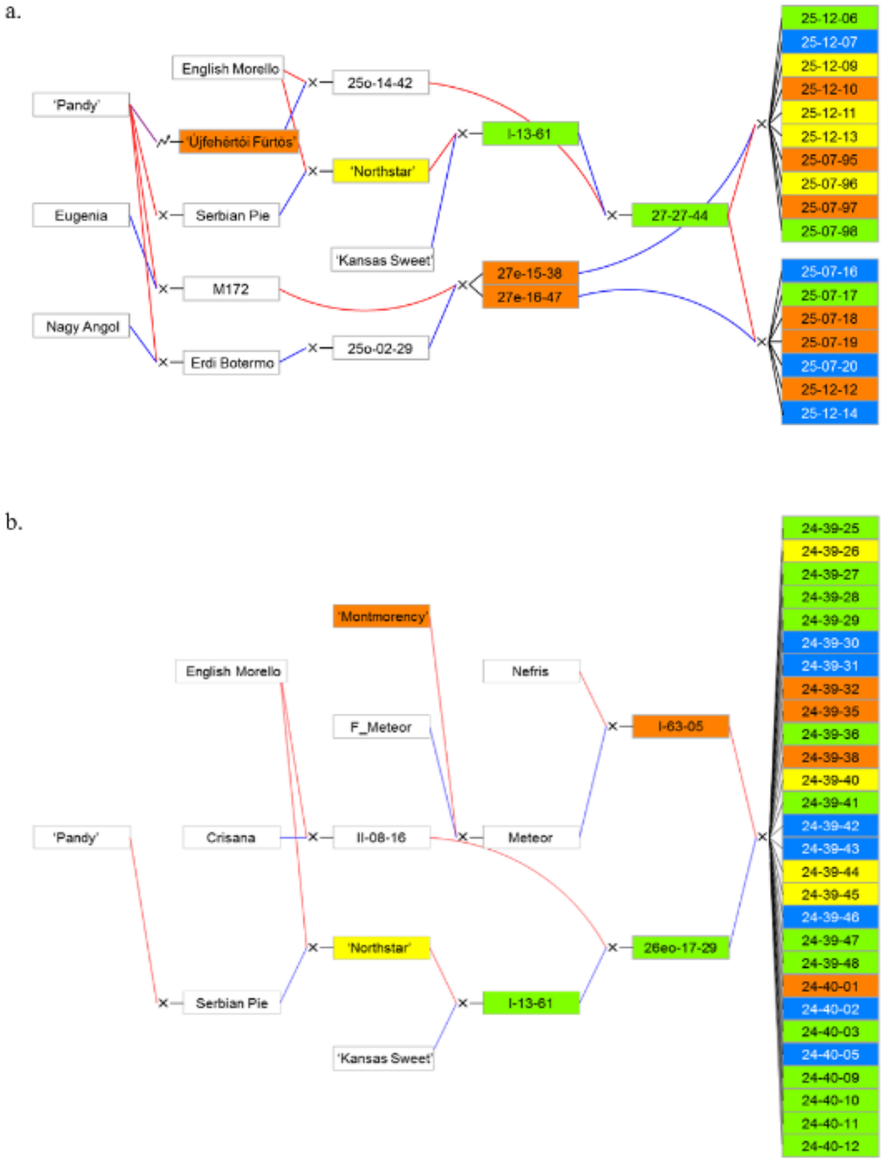
CLS defoliation depending on germplasm source



Andersen et al. 2019

CLS tolerance is likely controlled by recessive genetic factors

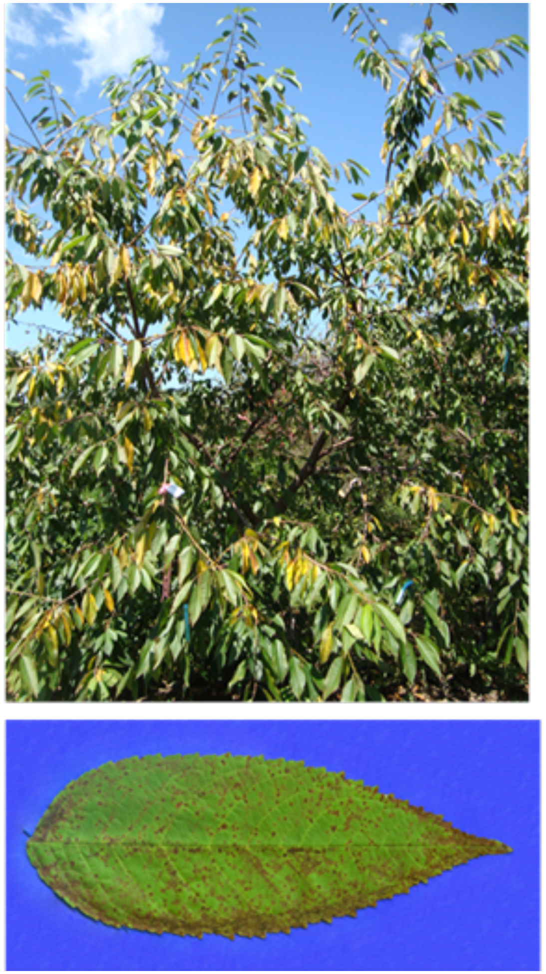
1	2	3	4	5
Low infection <u>without</u> sporulation 0-35% final defoliation	**Low infection <u>with</u> sporulation** < 35% final defoliation	**Moderate infection with sporulation** 40-60% final defoliation	**Severe infection, <u>slow</u> progression** > 65% final defoliation	**Severe infection, <u>fast</u> progression** 75% defoliation by mid-July



Susceptible → Tolerant

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

Three Trait Examples

1. **Catastrophic crop losses**
2. **Fruit color**
3. **Disease resistance**

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

Acknowledgements

Iezzoni lab

- Audrey Sebolt
- Kristen Andersen
- Umesh Rosyara
- Jim Olmstead
- Suneth Sooriyapathirana
- Travis Stegmeir
- Lichun Cai
- Nita Basundari

Collaborators

- George Sundin (MSU)
- Cameron Peace & Stijn Vandersande (WSU)
- Mirko Schuster (Dresden)
- Elisabeth Dilewanger & Jose Quero - Garcia (INRAE, France)
- Ana Wunsch (Spain)
- Marco Bink & C Zheng (Biometris, The Netherlands)

Funding

Michigan Cherry Committee

Specialty Crop Research Initiative

USDA United States Department of Agriculture National Institute of Food and Agriculture

'RosBREED' projects