

Breeding for Resistance to Soilborne Pathogens in Strawberry

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UCD Strawberry Breeding Program



Strawberry Breeding Program

22d Annual Strawberry Production Meeting in Ventura County;
09/12/2023



UCD Strawberry Team+

Pictured: Steven Knapp, Omar Gonzalez-Benitez, Hillel Brukental, Glenn Cole, Mitchell Feldmann, Marco Castellacci, Jade Dilla-Ermita, Dominique Pincot, Mishi Vachev, Marta Bjornson, Alicia Sillers, Nico Jimenez, Peter Henry, Isaac Rainwater, Cindy Ramirez Lopez, Randi Famula

Not Pictured: Eduardo Garcia, Nayeli Valencia, Margaret Honig, Paul Skillin, Caitlyn Morgan, Ella Halberstadt, Renata Wilson, Noah Kulchin



Thanks to our supporters, collaborators, and funding agencies!



USDA NIFA, California Strawberry Commission, FSGA, UC Davis, Michigan State University, UF University of Florida, USDA Agricultural Research Service, AG2PI, UC Santa Cruz, UC Riverside, Berkeley, University of California Agriculture and Natural Resources, Cal Poly San Luis Obispo, NC State University, Oregon State University, The University of Alabama, Johns Hopkins University & Medicine, Clemson University, Cornell University, University of Hohenheim, PacBio, JGI, Phytozome 12, Arizona Genomics Institute, HudsonAlpha Institute for Biotechnology, Ugentec, Bayer, Breeding Value, NIBIO, INRA, IRTA, NIAB-EMR, IFAPA, CGIAR, Excellence in Breeding Platform, GIFS, Breeding Insight, Diversity Arrays Technology, LGC Genomics, gencove, affymetrix, Highrolyph, Greaves Photography, Driscoll's, Good Farms, Naturipe, Global Plant Genetics Ltd, Fresa Fortaleza, Wish Farms, Advexure, Crown Nursery, Lassen Canyon Nursery, Inc., Red Dog Management, Inc., Cedar Point Nursery, California Giant Berry Farms, hi-phen.

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Thanks to the Organizers!



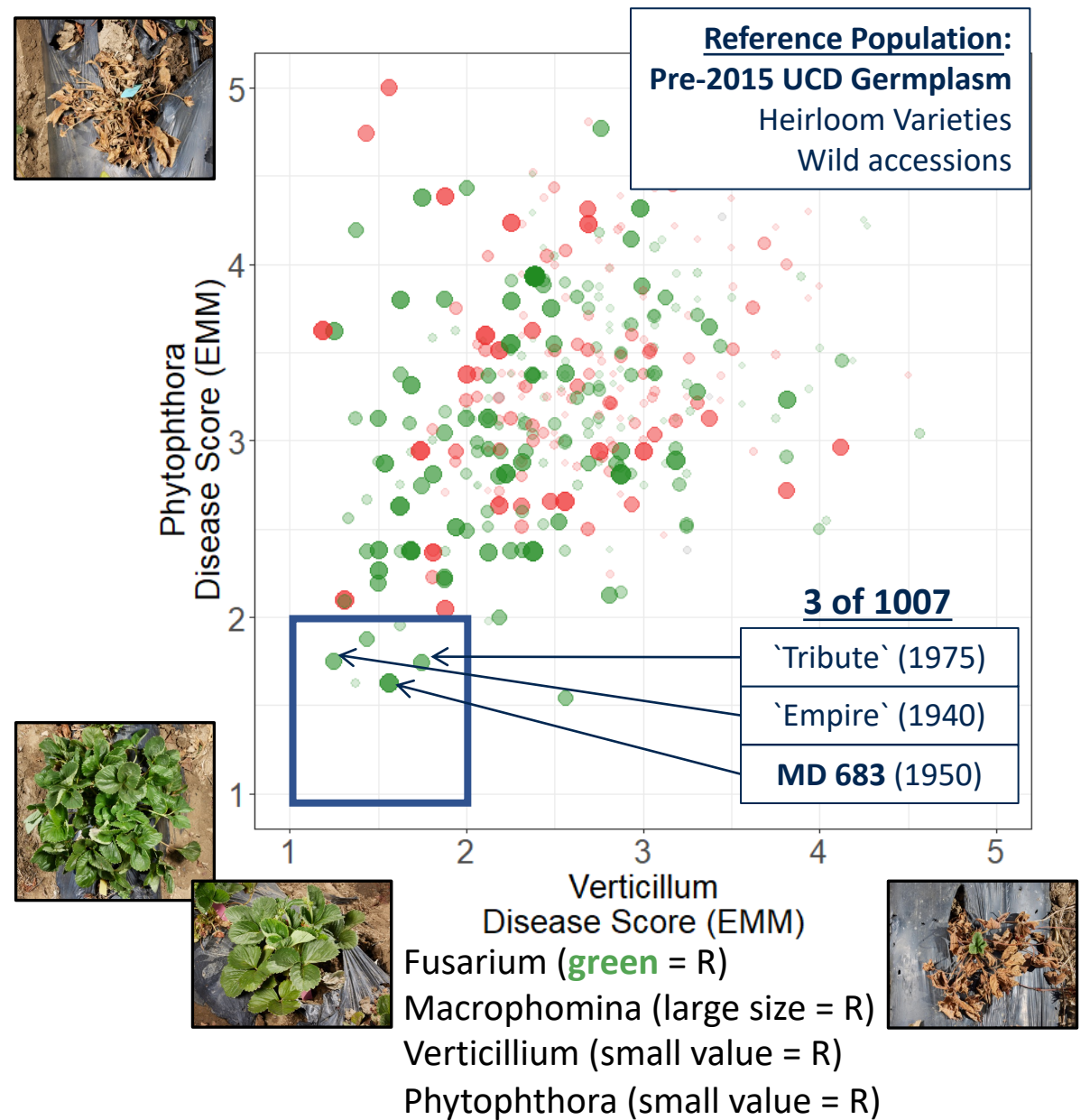
UC

CE University
of California
Cooperative
Extension

This talk in 2 slides

We select for Fusarium wilt, Macrophomina charcoal rot, Verticillium wilt, and Phytophthora crown rot—“the fearsome four”—resistant varieties under extreme disease pressure.

Provides a conservative estimate of risk and a high level of certainty of the resistance of a variety against multiple pathogens.



This talk in 2 slides

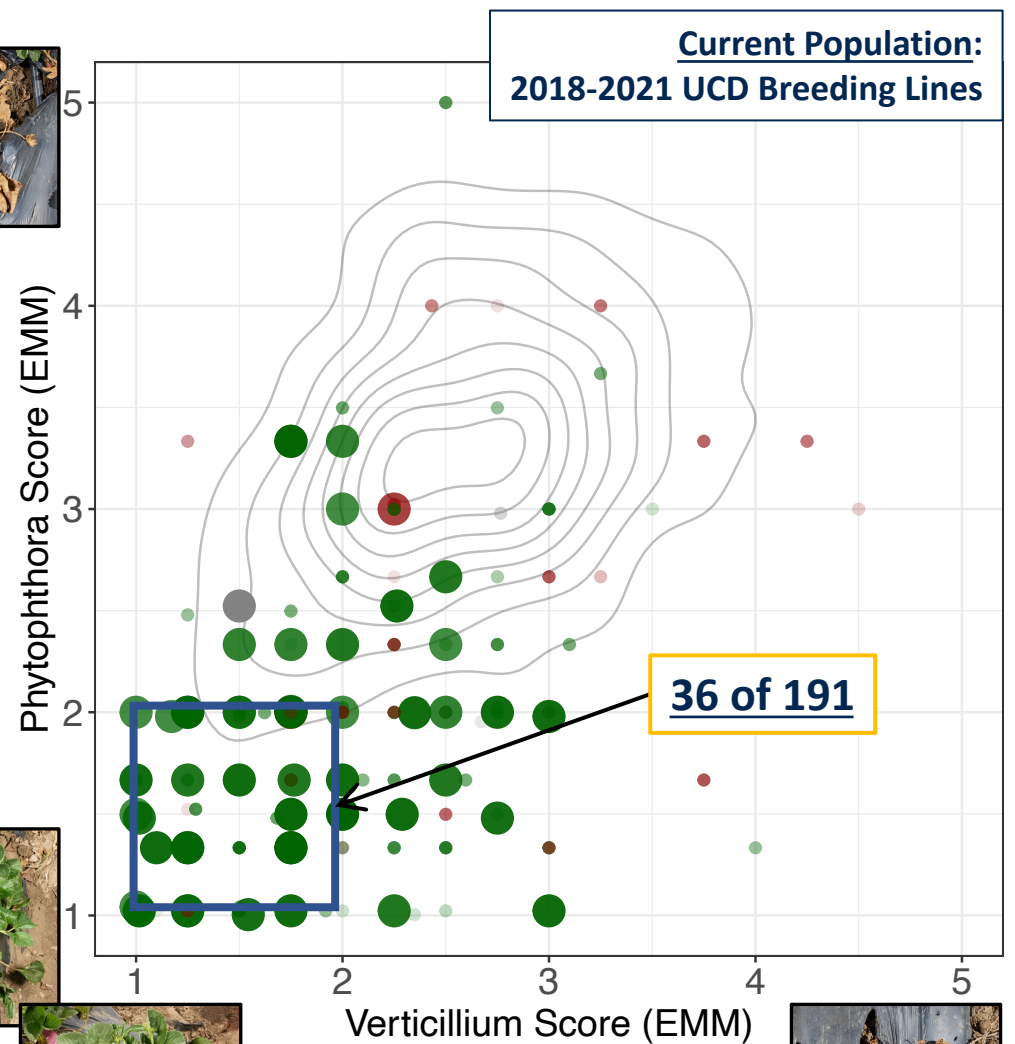
Intense phenotyping and modern genetic tools have greatly increased our ability to concentrate favorable traits and deliver value to stakeholders.

Our progress to date:

- Verticillium wilt resistance improved by 0.6 units (14.8%)
- Fusarium wilt resistance improved by 1.5 units (37.5%)
- Phytophthora crown rot resistance improved by 1.4 units. (35.8%)
- Macrophomina charcoal rot resistance improved by 1.6 units (40.6%)

Our goal:

Produce varieties with a complete disease-resistance package that are **high-yielding, producible** by nurseries, **shelf-stable, great tasting**, and **profitable** for growers.



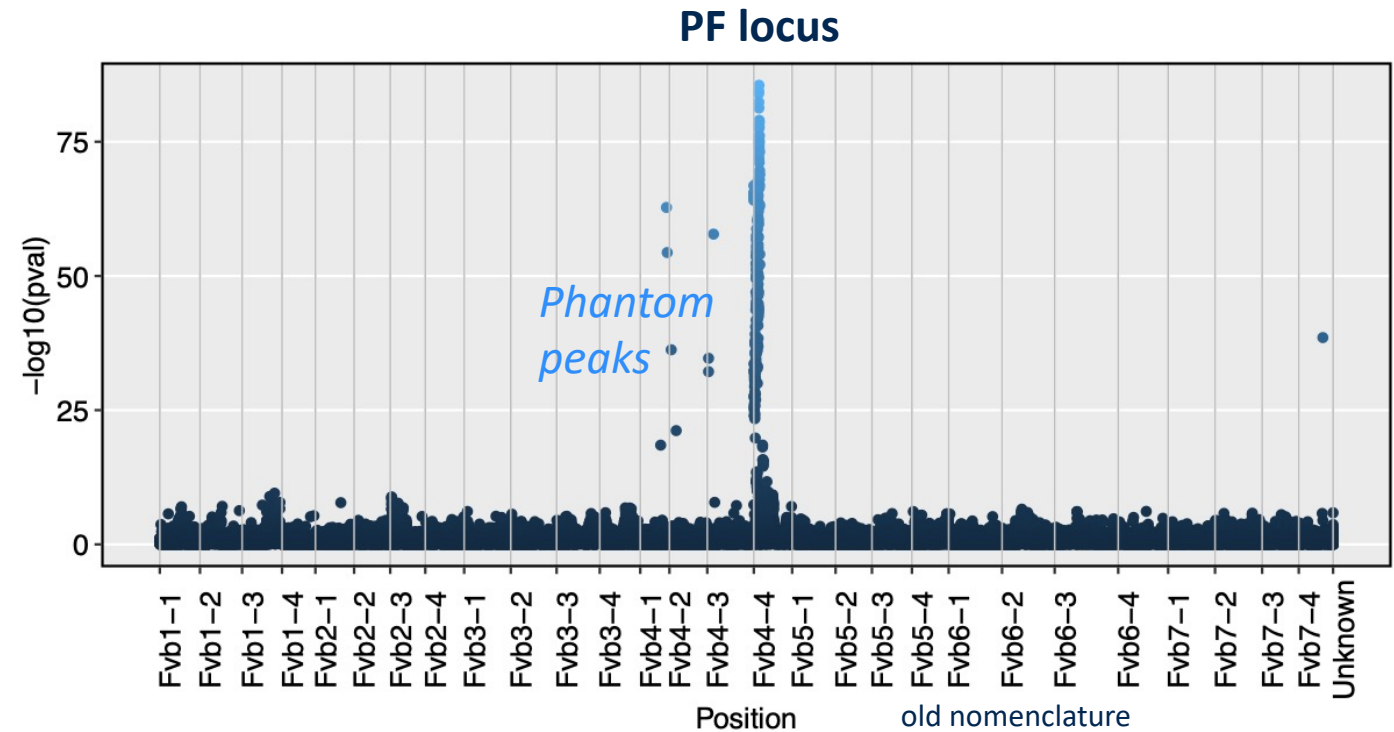
Fusarium (green = R)
Macrophomina (large size = R)
Verticillium (small value = R)
Phytophthora (small value = R)



Thank you for your attention!

The Strawberry Green Revolution

- One trait, one introgression, one breeding program that really changed the marketplace for strawberry and enabled year-round production of strawberry.



The Strawberry Green Revolution

- **Year-round production in California** (January through December).
 - The historical growing period with short-day varieties is January – June (early summer).
 - Day-neutral varieties can continue to produce high-quality fruit.
- **Large, firm fruit with incredible shelf-life** enabled strawberries to be produced in **CA** and distributed throughout the **United States** and elsewhere.
 - Historically, there were many local markets for strawberry for heirloom varieties with good flavor but poor shelf-life.
 - Maybe we should have called this the “Red” Revolution!

What traits were affected?

Genetic Gains Underpinning a Strawberry Green Revolution

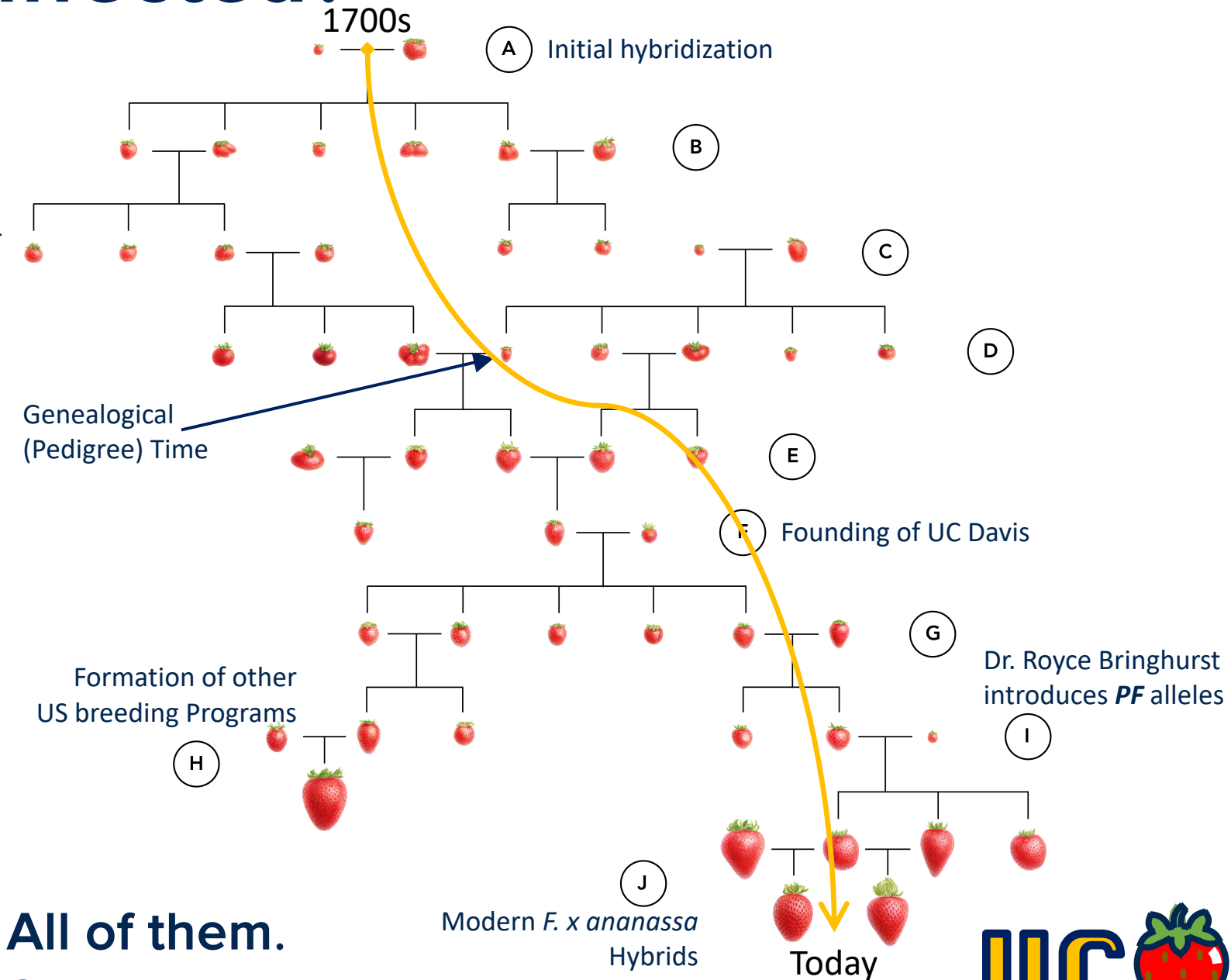
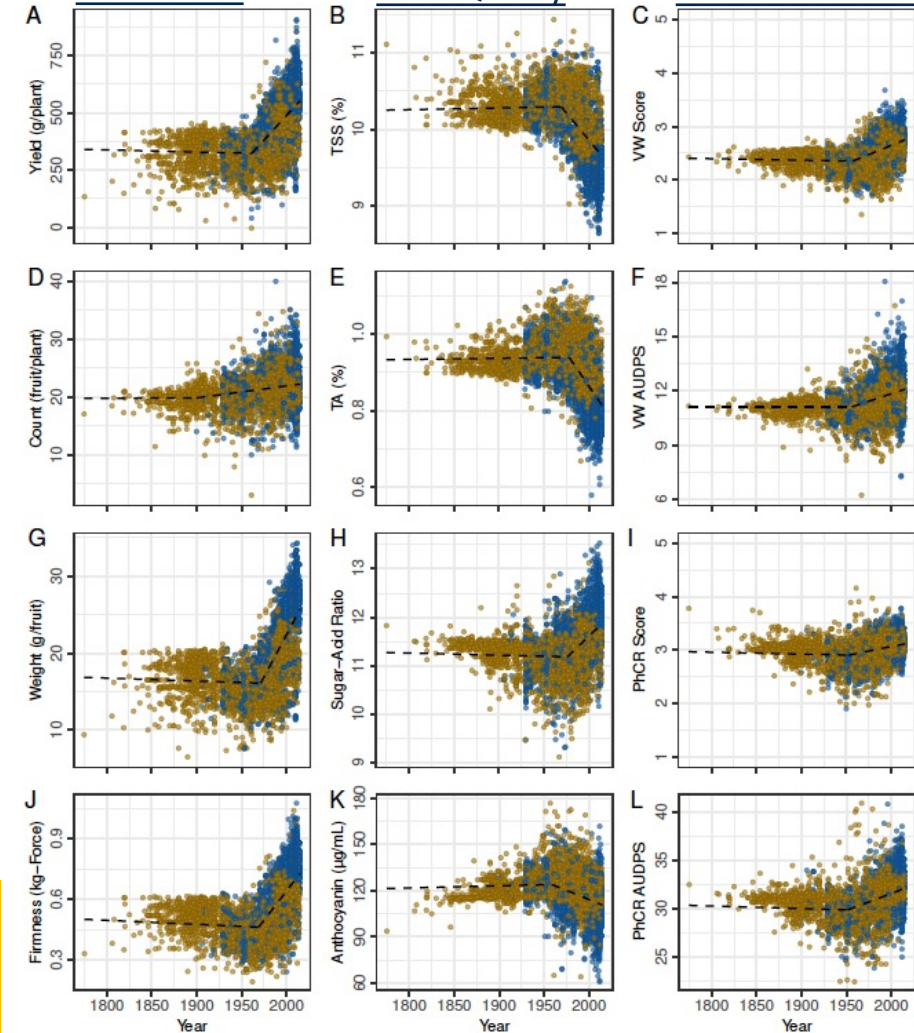
Mitchell J. Feldmann¹, Dominique D.A. Pincot¹, Glenn S. Cole¹ and Steven J. Knapp^{1*}

^{1*}Department of Plant Sciences, University of California Davis, One Shields Avenue, Davis, 95616, CA, USA.

Production

Fruit Quality

Disease Resistance



All of them.
Some more than others.



Selection on *Disease Resistance* was **RELAXED**

The Plant Genome

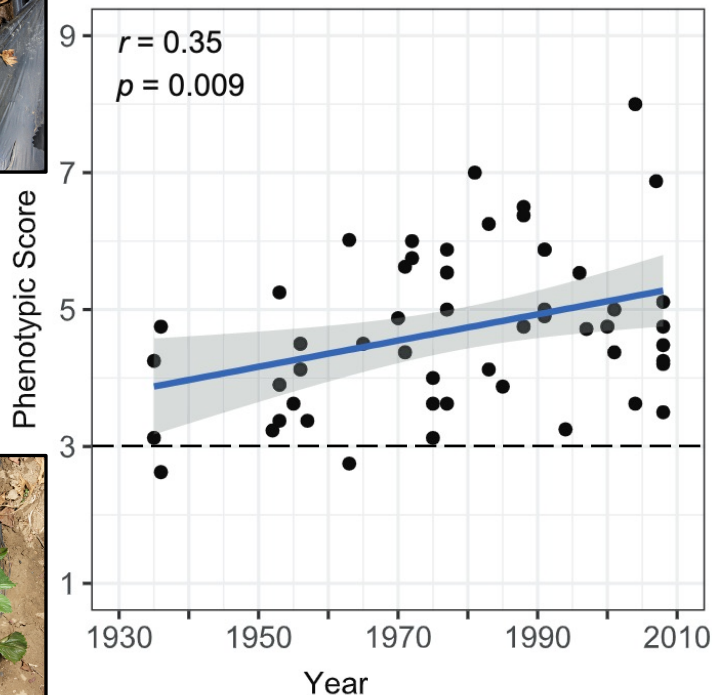
ORIGINAL RESEARCH

Accuracy of genomic selection and long-term genetic gain for resistance to *Verticillium* wilt in strawberry

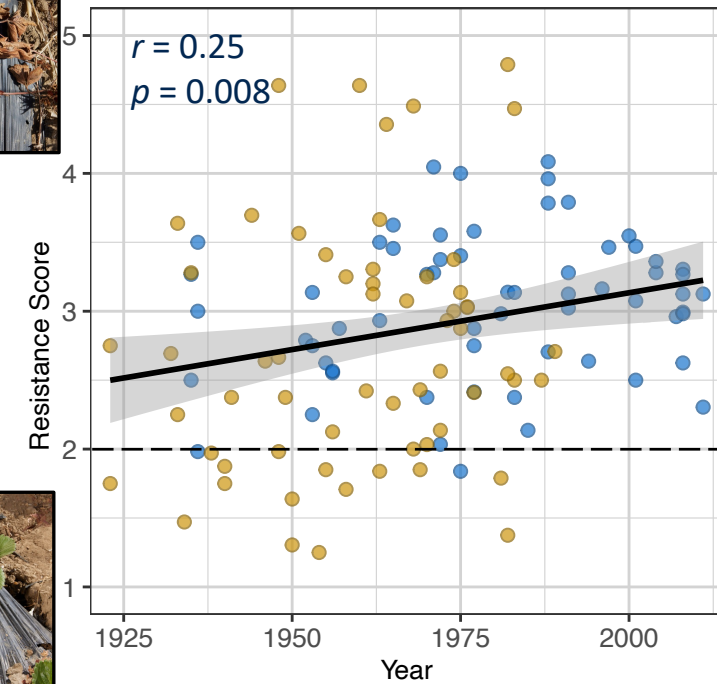
Dominique D. A. Pincot¹ | Michael A. Hardigan¹ | Glenn S. Cole¹ |
Randi A. Famula¹ | Peter M. Henry² | Thomas R. Gordon³ | Steven J. Knapp¹



Verticillium



Phytophthora



ORIGINAL ARTICLE

The Plant Genome

Harnessing underutilized gene bank diversity and genomic prediction of cross usefulness to enhance resistance to *Phytophthora cactorum* in strawberry

Nicolás P. Jiménez[#] | Mitchell J. Feldmann[#] | Randi A. Famula |
Dominique D. A. Pincot | Marta Bjornson | Glenn S. Cole | Steven J. Knapp

Brief History of Fusarium Wilt at UC Davis

Started studying FW (race 1) in 2015.

Discovered FW1 resistance QTL

Published in 2018

Discovered numerous more resistance QTL by 2020

Create durable resistance to FW Race 1

Published in 2022

Genetic marker designs and sources of resistance are available.

Genome-Wide Association Mapping Uncovers *Fw1*, a Dominant Gene Conferring Resistance to Fusarium Wilt in Strawberry

Dominique D. A. Pincot,^{*} Thomas J. Poorten,^{*} Michael A. Hardigan,^{*} Julia M. Harshman,^{*} Charlotte B. Acharya,^{*} Glenn S. Cole,^{*} Thomas R. Gordon,[†] Michelle Stueven,[†] Patrick P. Edger,[‡] and Steven J. Knapp^{*,1}

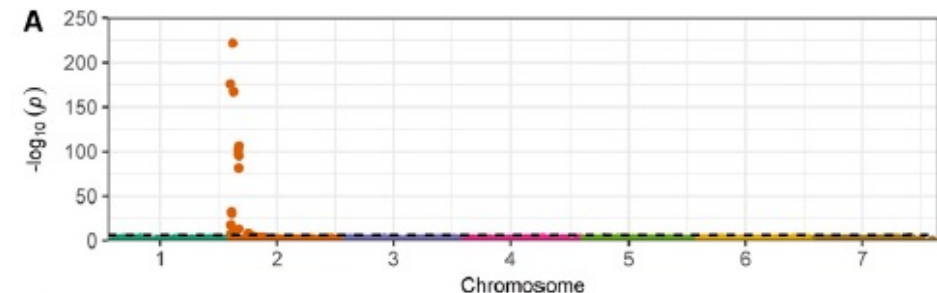
^{*}Department of Plant Sciences and [†]Department of Plant Pathology, University of California, Davis, California, 95616, and

[‡]Department of Horticulture, Michigan State University, East Lansing, Michigan 48824

ORCID IDs: 0000-0001-9768-0740 (T.J.P.); 0000-0002-5188-8084 (J.M.H.); 0000-0001-6498-5409 (S.J.K.)

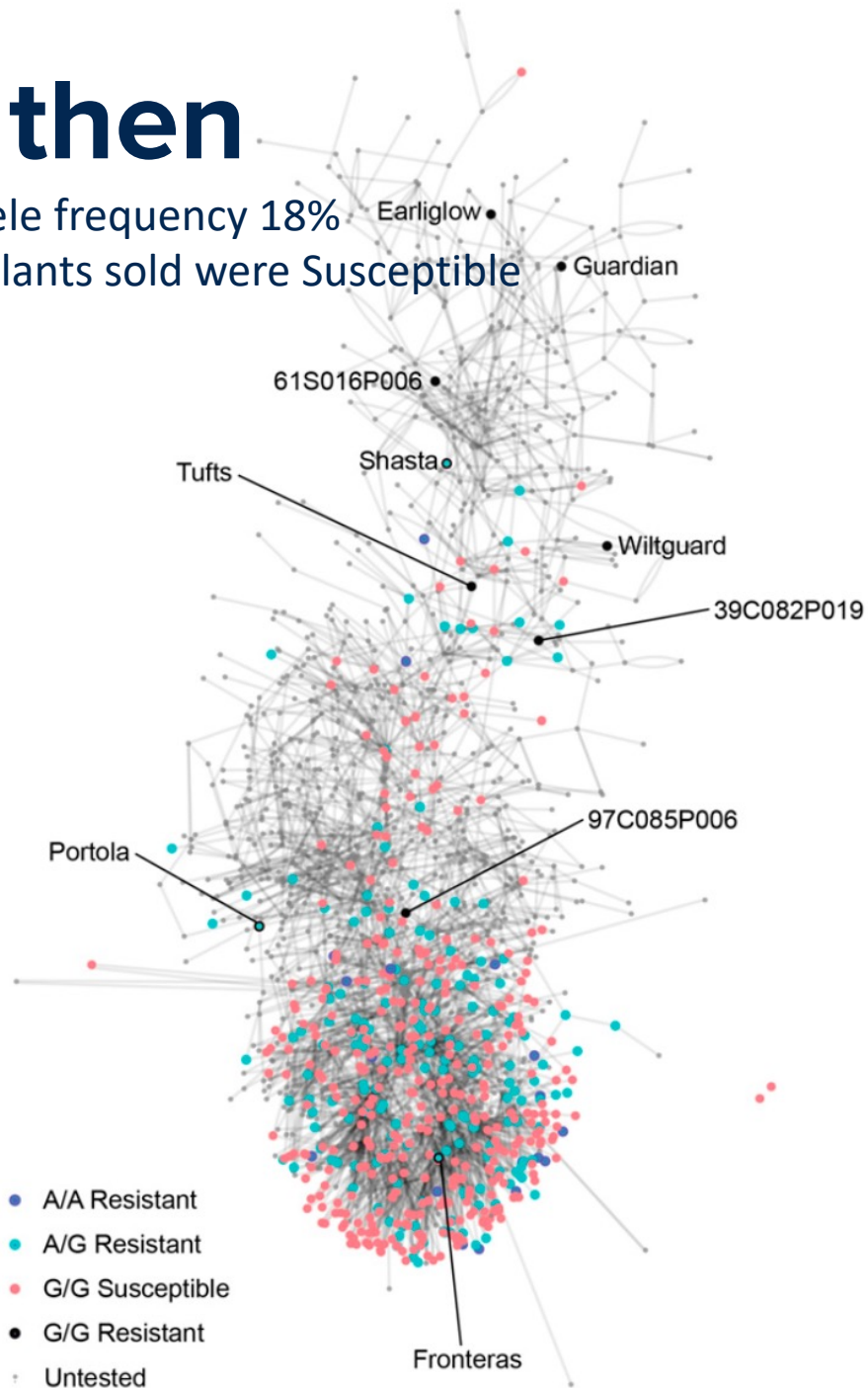
Novel Fusarium Wilt Resistance Genes Uncovered in the Wild Progenitors and Heirloom Cultivars of Strawberry

Dominique D. A. Pincot · Mitchell J. Feldmann · Michael A. Hardigan · Mishi V. Vachev · Peter M. Henry · Thomas R. Gordon · Alan Rodriguez · Nicolas Cobo · Glenn S. Cole · Gitta L. Coaker · Steven J. Knapp



FW1 then

Favorable allele frequency 18%
>50% of UC Plants sold were Susceptible



FW1 Now



Actions speaking louder than words

100% of new UC Davis varieties are **Resistant to Fusarium**
Consumer ratings were better than current commercial varieties.



'UC Surflin'



Short Day
Early fruiting & yield
Fusarium Resistant

'UC Monarch'



Short Day
Exposed fruit
Small plant canopy
Fusarium Resistant

'UC Golden Gate'



Day Neutral
Early to midseason
Excellent shelf-life
Fusarium Resistant

'UC Keystone'



Day Neutral
Mid-to-late season
High marketable yields
Fusarium Resistant

'UC Eclipse'




Extreme Day Neutral
Summer plant
Large Fruit
Fusarium Resistant



Regarding Race 2

- We aim to identify sources of resistance and develop genetic markers for rapid introgression of resistance.
- Our preliminary experiment informed us that we need to explore diverse germplasm.
 - We are ramping up a large project to evaluate 434 diverse accessions against the FW Race 2
- Recruited graduate students
- Preparing grants to FFAR, CDFA

First Report of *Fusarium oxysporum* f. sp. *fragariae* Race 2 Causing Fusarium Wilt of Strawberry (*Fragaria* × *ananassa*) in California

C. J. Dilla-Ermita,^{1,2} P. Goldman,² J. Jaime,² G. Ramos,² K. K. Pennerman,² and P. M. Henry^{2,+} 

¹ Department of Plant Sciences, University of California, Davis, CA 95616

² United States Department of Agriculture, Agricultural Research Service, Salinas, CA 93905

Losses to Fusarium wilt are likely to increase until genetic resistance to this strain of *Fof* race 2 is deployed in commercially viable cultivars.



Pictures of production field `X` where *Fof* Race 2 was identified in 2022.



Photo credit to Dr Peter Henry.

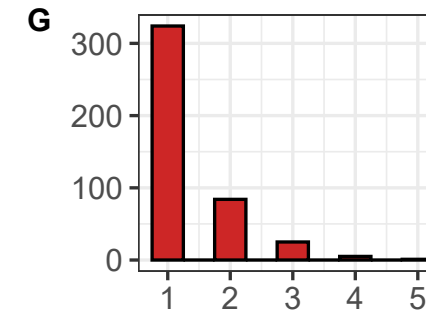
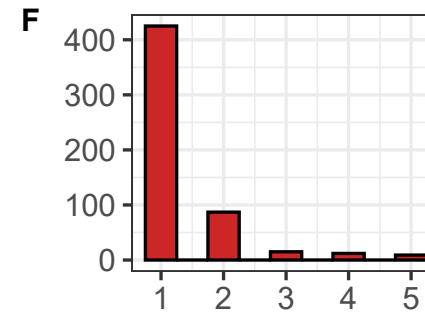
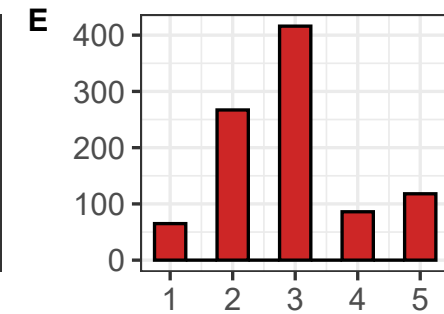
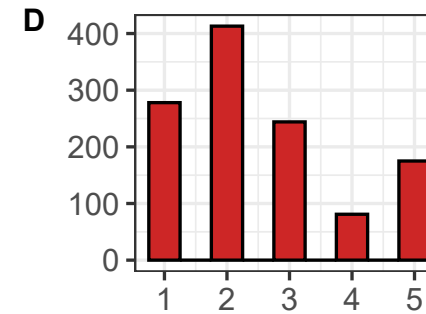
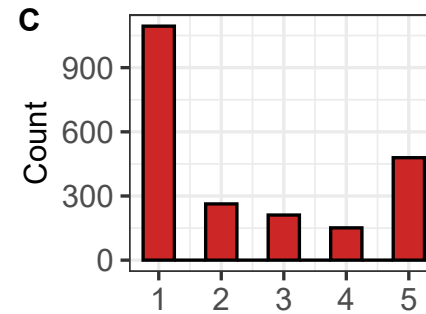
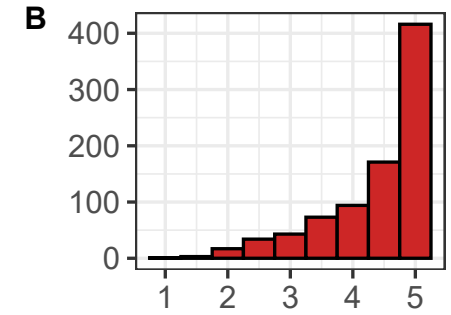
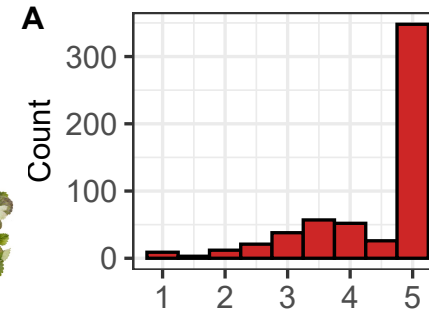


Brief History of Macrophomina Charcoal Rot at UC Davis

Started studying *Macrophomina* resistance in 2015.

Discovered 10 resistance QTL
Submitted Sept 11, 2023

Genetic marker designs and sources of resistance *will be* available upon publication (end of 2023).



Macrophomina resistance IS achievable

Resistant



Photos taken in Salinas, CA (2022) in artificially inoculated fields at the end of September
Plants experienced the same environment & disease pressure

Susceptible



Our Measurement Scale



1

2

3

4

5

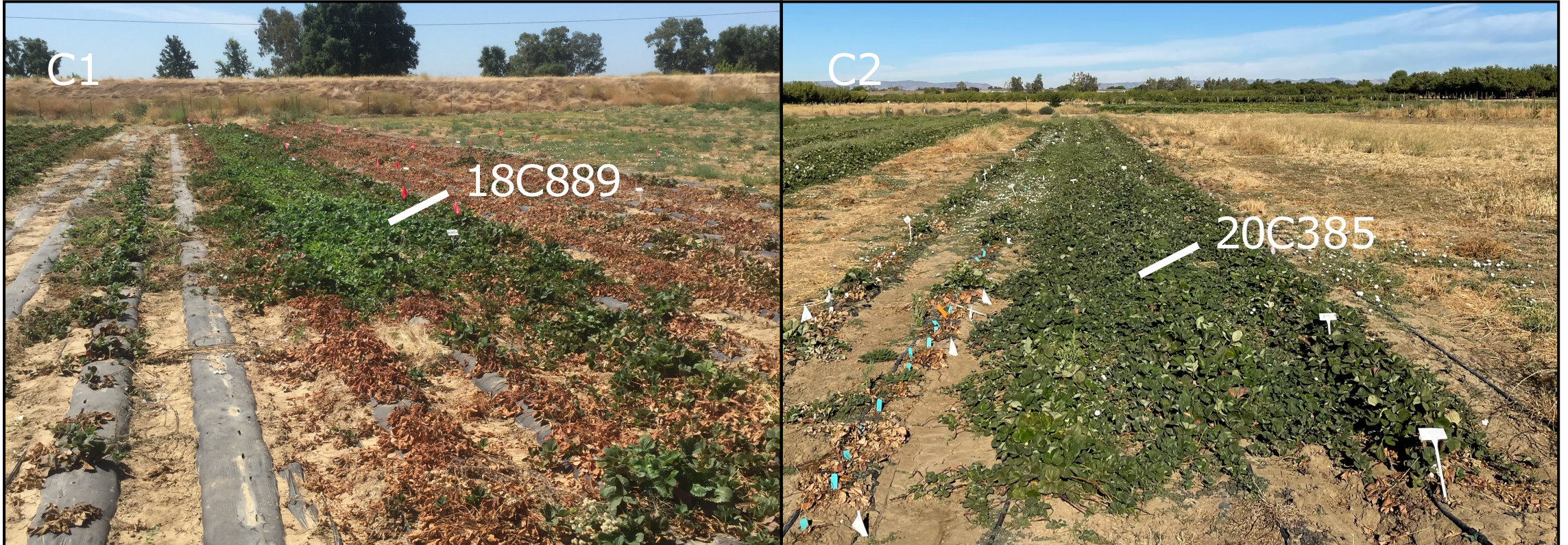
Resistant	Susceptible			
Asymptomatic	Symptomatic			Deceased

Examples of quality of resistance sources

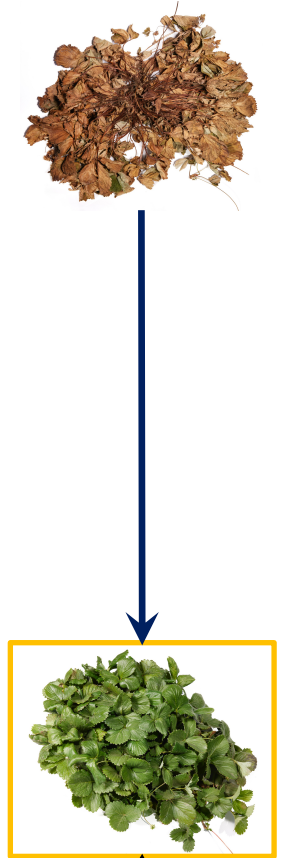
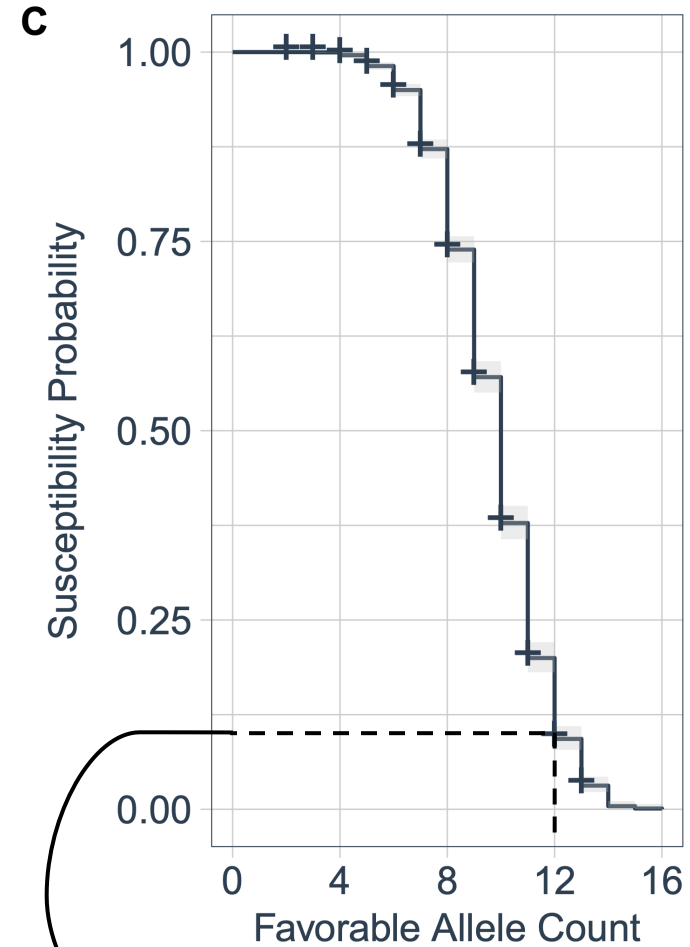
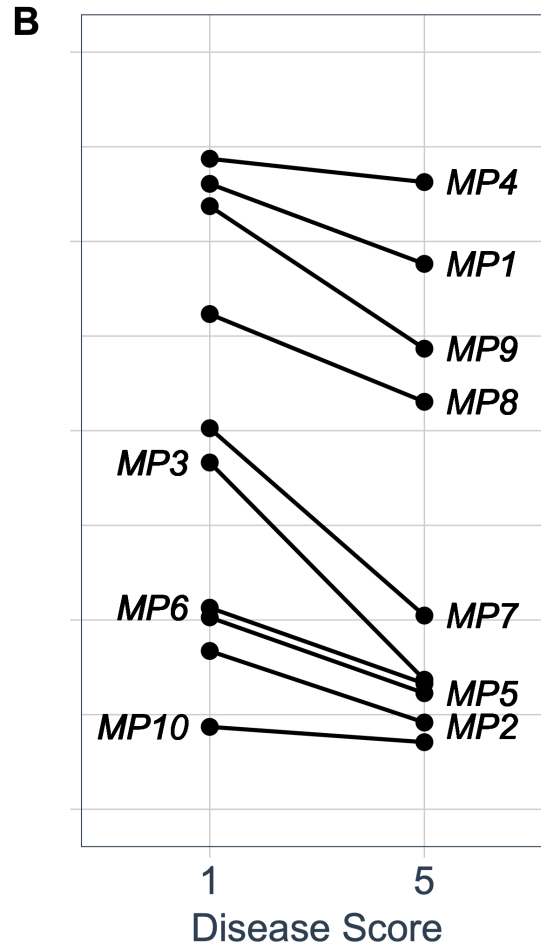
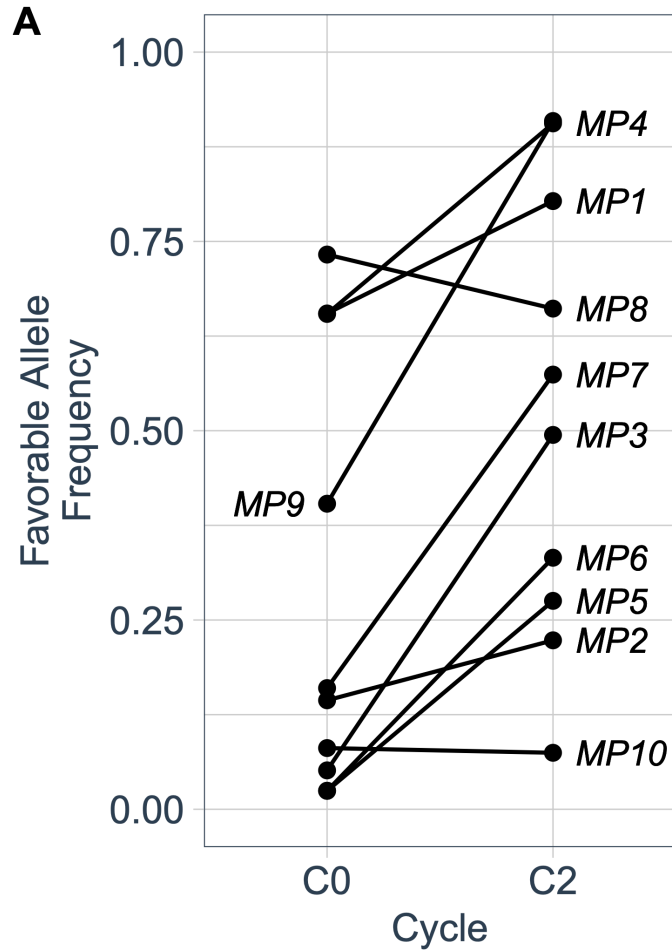
2019 Davis, CA

2021 Davis, CA

A



Concentrating favorable alleles creates plants Resistant to Macrophomina



12 (+) alleles across 10 loci (60%) yields a **90% probability of survival**



Article Submitted Sept 11, 2023

Transgressive Sergegation, Hopeful Monsters, and Phenotypic Selection Drove Rapid Genetic Gains and Breakthroughs in Predictive Breeding for Quantitative Resistance to *Macrophomina* in Strawberry

Steven J. Knapp^{1,*†} Glenn S. Cole^{1,†} Dominique D.A. Pincot^{1,†}
Christine Jade Dilla-Ermita^{1,2} Marta Bjornson¹ Randi A. Famula¹
Julia M. Harshman¹ Peter M. Henry² and Mitchell J. Feldmann^{1,†}

¹Department of Plant Sciences, University of California, Davis, One Shields Avenue, 95616, California, USA and ²Crop Improvement and Protection Research, USDA-ARS, 1636 E. Alisal Street, 93905, California, USA

*Corresponding author. sjknapp@ucdavis.edu.[†]These authors contributed equally to this study.



Resistant cultivars are soon to follow...

Our program is dedicated to bringing the highest quality genetics to the CA growers and nurseries that (1) solve disease problems, (2) improve consumer satisfaction, and (3) increase on-farm profitability.

'UC Surfline'



'UC Monarch'



'UC Golden Gate'



'UC Keystone'



'UC Eclipse'



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