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Towards control of Fusarium wilt of celery, caused by F. oxysporum f. sp. apii race 4, with resistant germplasm

California Celery Research Advisory Board
UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources
University of California
Hansen Trust

Today

- A brief introduction to celery & *Fusarium oxysporum* f. sp. *apii* (*Foa*) races 4 and 2
- Our program for introgression of disease resistance to *Foa* race 4 into celery germplasm

Fusarium oxysporum f. sp. apii (Foa) race 2

Appeared in ca. 1959

Causes the disease "Fusarium yellows in celery"

The pathogen first spread in California & then to other states in the U.S.

Foa race 2 an be controlled with resistance, e.g., cv. Challenger

Foa race 4

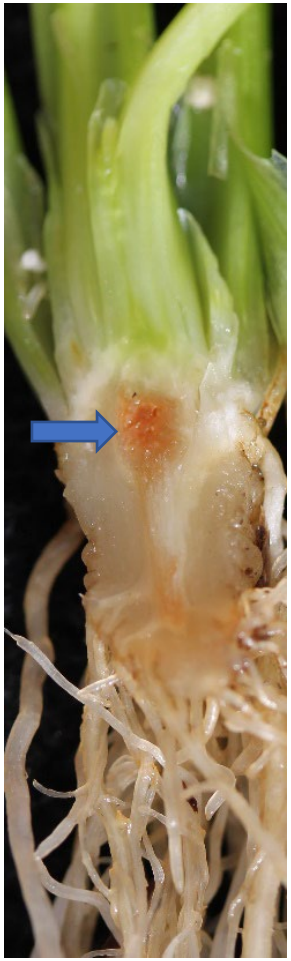
Appeared in ca. 2011 (in Ventura Co.). Recently, also in parts of Monterey Co.

Causes the disease "Fusarium wilt of celery"

Foa race 4 is relatively unrelated to *Foa* race 2

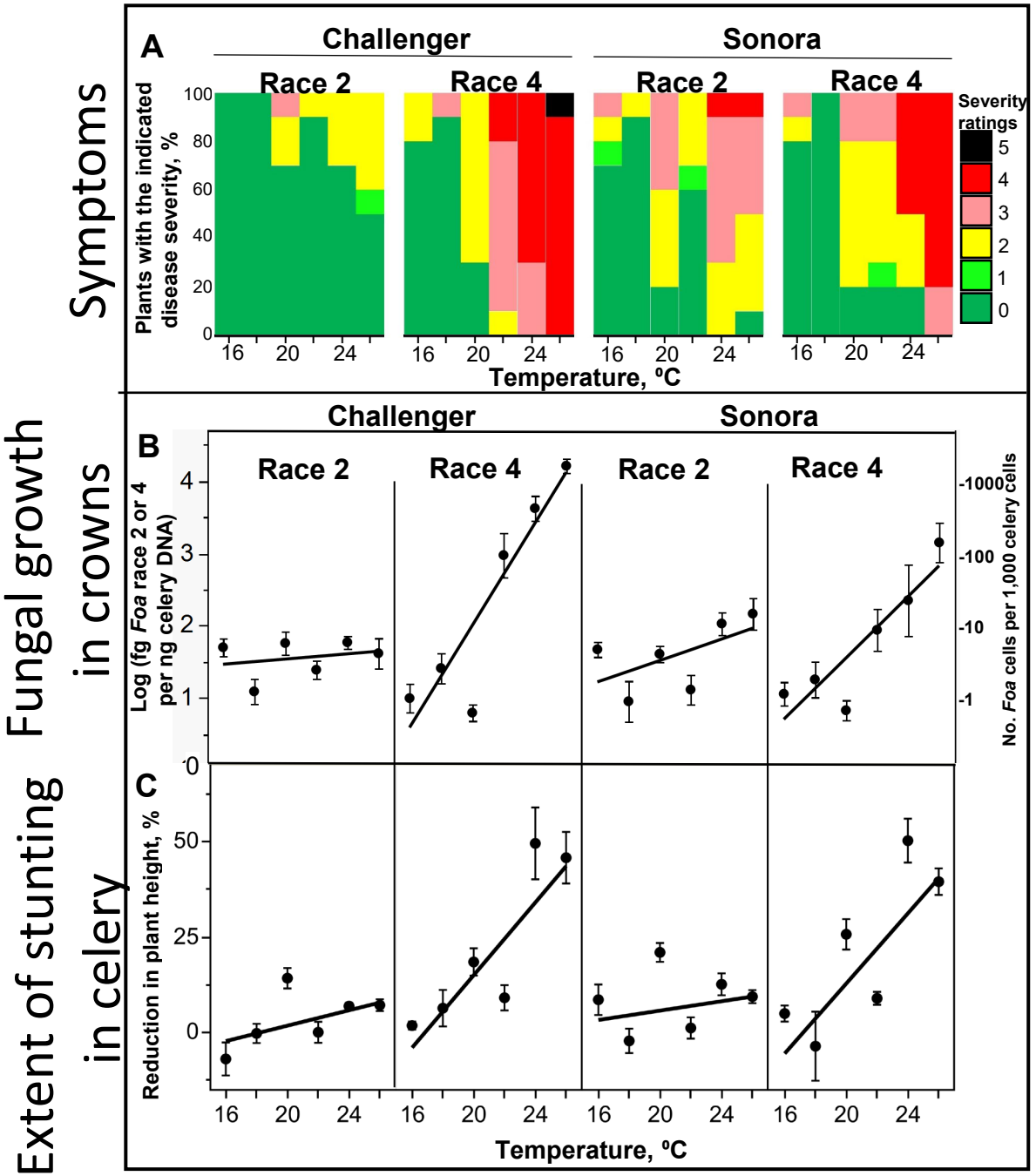
Foa race 4 is more virulent than *Foa* race 2

Celery responds to infection with either *Foa* race 4 or race 2 by producing an orangish to brownish pigment in the vascular parenchyma cells



Differences between *Foa* races 2 and 4:

- Race 4 is particularly virulent at temperatures greater than 72 °F



Temperatures from 61 °F to 79 °F

Kaur et al. 2022

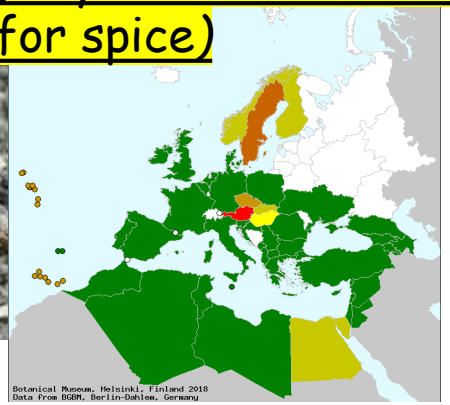
Celery: *Apium graveolens* var. *dulce*

Celeriac: *A. graveolens* var. *rapaceum*

https://www.gardenersworld.com/plants/apium-graveolens-var-rapaceum/

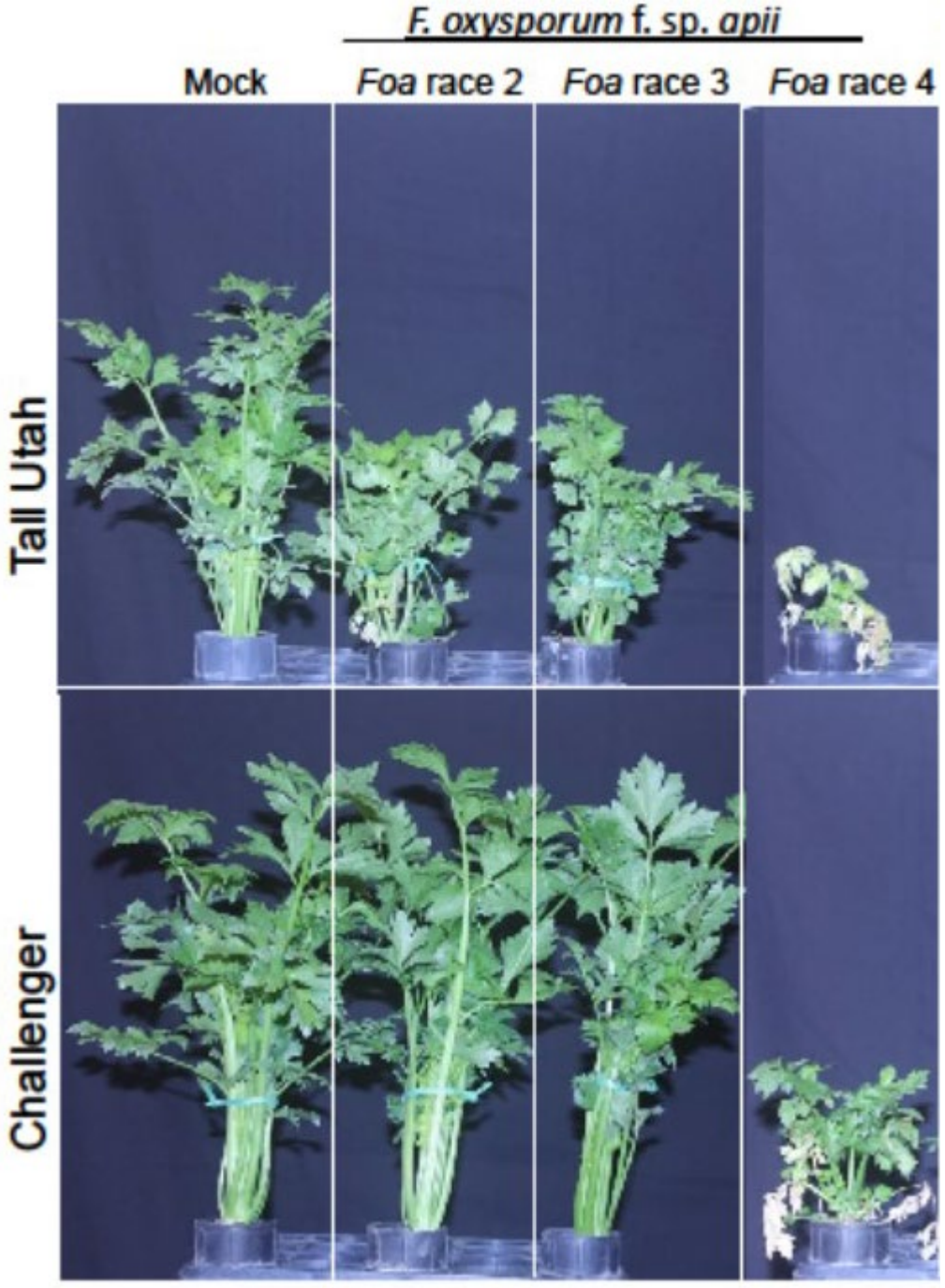
Cutting celery/smallage: *A. graveolens* var. *secalinum*

Wild Progenitor: *Apium graveolens* var. *graveolens* (may also be used for seed for spice)



Breeding for *Foa* race 2 resistance

Celeriac X



Henry et al. 2020

Some cultivars from the CCRAB trial in Camarillo, CA in Nov. 2013 in soil with *F. oxysporum* f. sp. *apii* race 2

Two of the *Fusarium*-tolerant varieties that were bred by the UC Davis Breeding Program: UC390S-2 & UC12A45

A commercial, *Fusarium*-resistant variety developed using material from the UC Davis Breeding Program

Fusarium-susceptible Tall Utah 52-70 Improved

Camarillo, Celery Research Advisory Board trial, 28 May 2013

Results: We identified a new race ("race 4") of *Fusarium oxysporum* f. sp. *apii* that is highly virulent on all tested celery cultivars (with some resistance in Rijk Zwaan's Earthrace RZ F1)

Parents of F_1 in

Foa race 4-infested soil

Resistant

Susceptible

A0134, =PI 181714

cv. Challenger

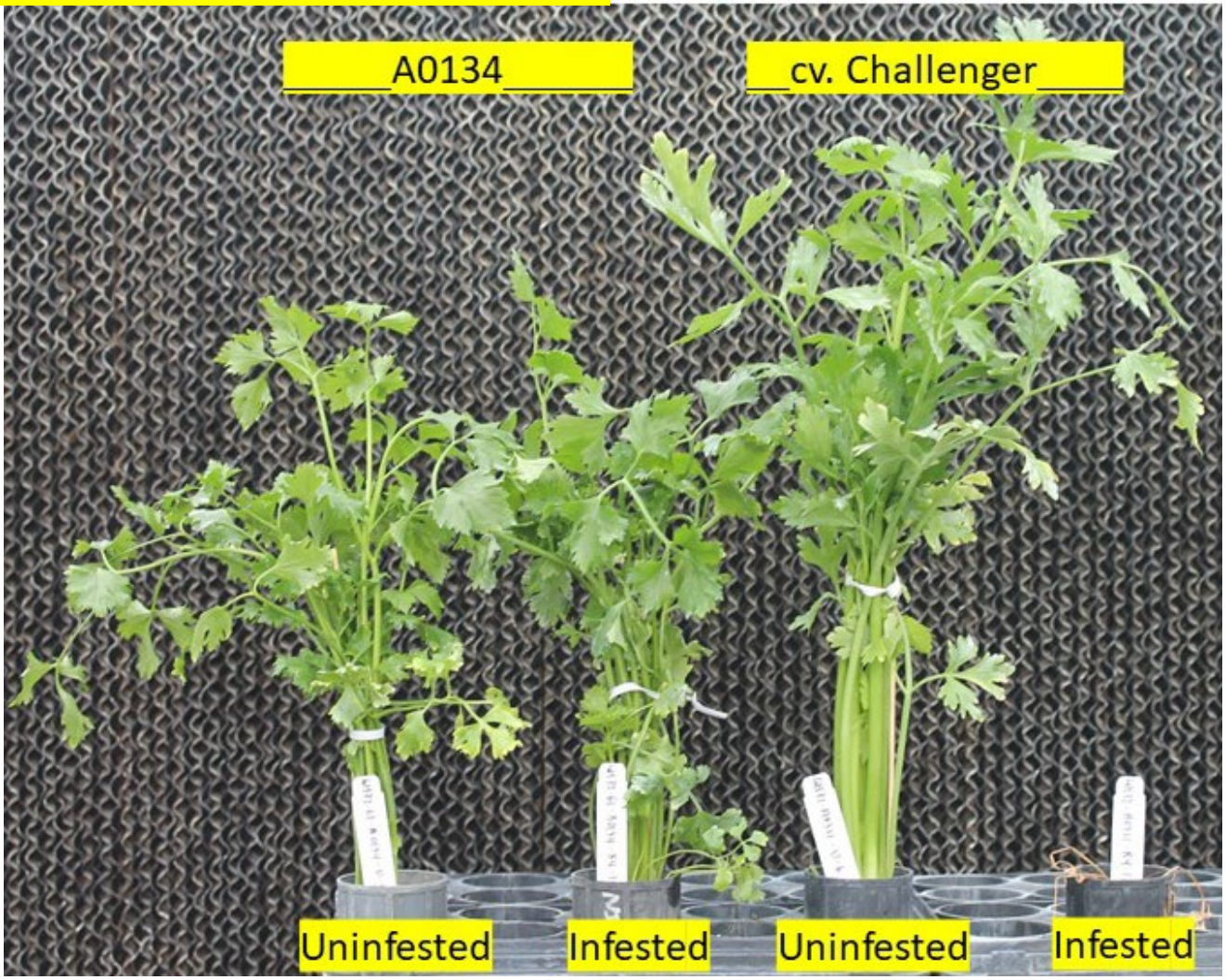
Parents of F_1

Uninfested soil

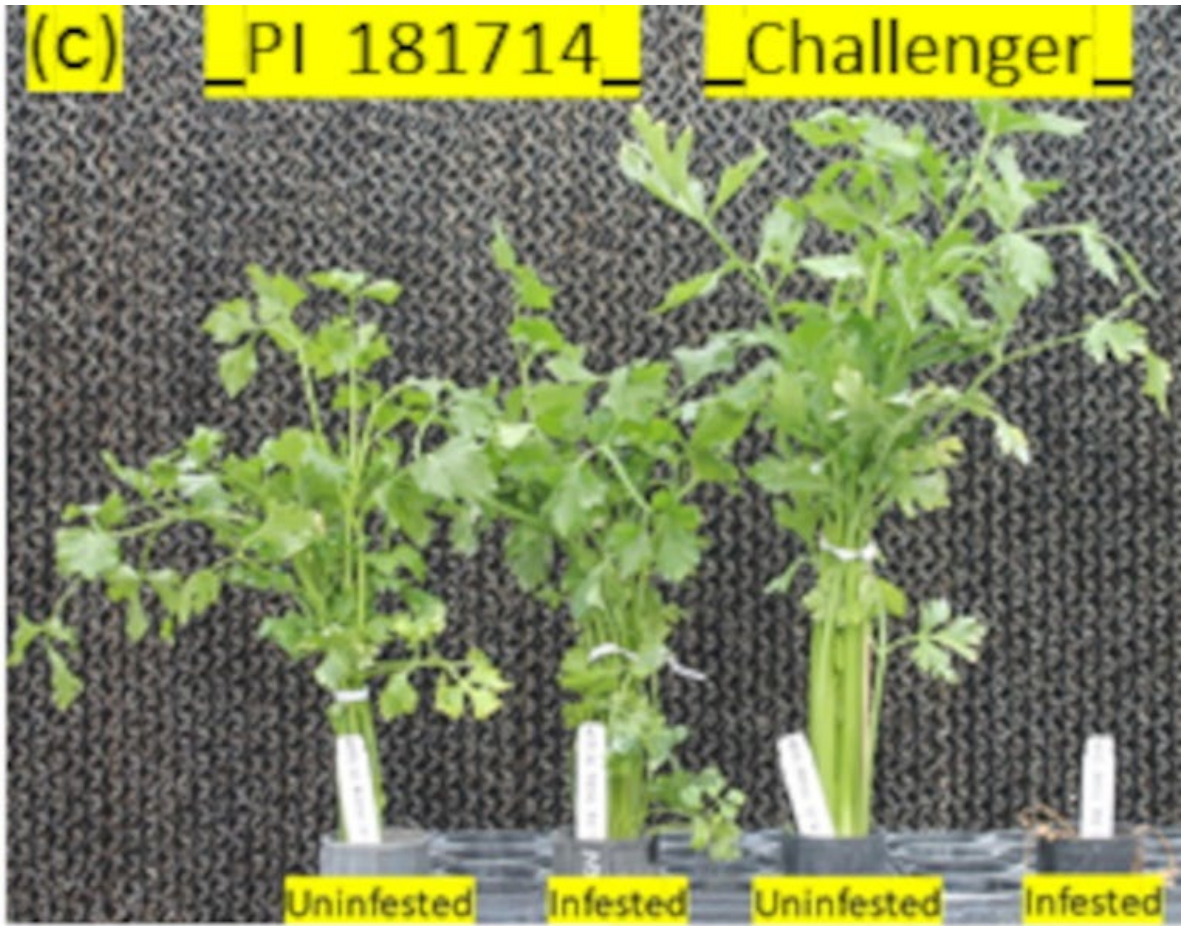
"Celeriac"A0134

cv. Challenger

Parents of F_1 in Foa race 4-infested and uninfested soil



A0134/
PI 181714 Challenger __A0134__



race 4

race 4

Dr. Sukhwinder Kaur

Development of resistant germplasm to *Foa* race 4

Our germplasm

2 parents (each presumably homozygous at every locus):

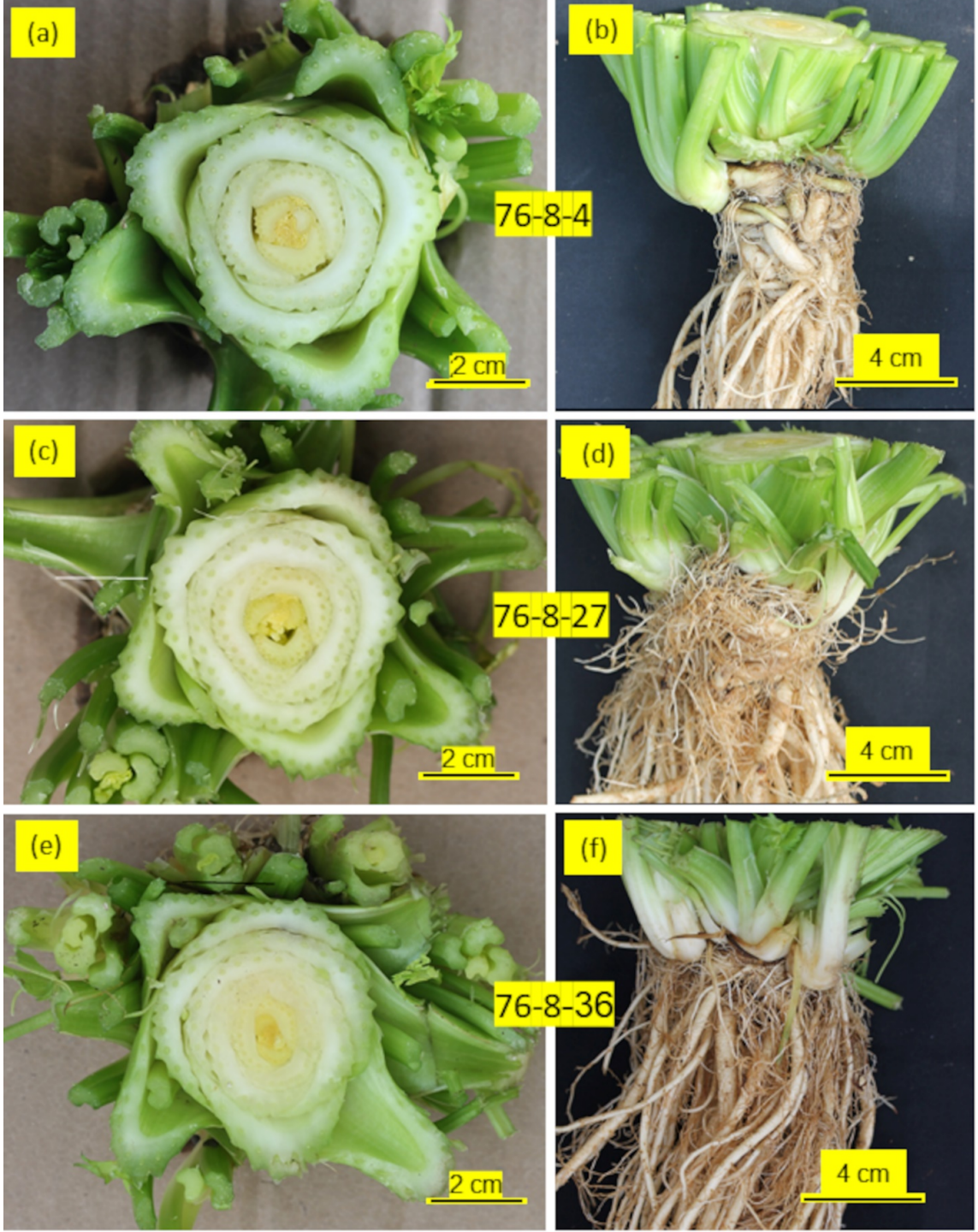
Challenger (celery-type, *Foa*R4^{S}, *Foa*R2^{R}) X
A0134 (not celery-type, *Foa*R4^{R}, *Foa*R2^{R})

F1 (assuming each parent is inbred/homozygous, then the F1 are heterozygous at every locus that differs between the two parents

An individual **F1** plant that is **selfed**, produces a population of F1S1. We selected resistant individuals with celery type.

An individual F1S1 plant that is **selfed**, produces a population of F1S2. We selected resistant individuals with celery type.

An individual F1S2 plant that is **selfed**, produces a population of F1S3. We selected a resistant population.



Representative plants from our field trial in

Results of one of two mini-trials in *Foa* race 4-infested soil in Camarillo in 2021

(Parent of F1) or F1S2 family that was derived from F1S1 76-8	Fraction that died	Fraction of survivors				
		Asymp=tomatic above-ground	Asymptomatic below-ground	Solid petioles	Celery-type growth habit¶	Compactly-arranged petioles
(PI 181714)	0.00 a	1.00 a	1.00 a	0.00 b	0.00 c	0.00 b
(Challenger)	0.28 b	0.49 b	0.15 b	1.00 a	1.00 a	1.00 a
F1S2 76-8-4	0.00 a	1.00 a	0.90 ab	1.00 a	0.96 abc	0.96 ab
F1S2 76-8-15	0.00 a	1.00 a	0.92 ab	1.00 a	0.99 ab	0.99 ab
F1S2 76-8-19	0.00 a	0.98 ab	0.86 ab	1.00 a	0.86 abc	0.86 ab
F1S2 76-8-27	0.00 a	1.00 a	0.85 ab	1.00 a	0.85 abc	0.85 ab
F1S2 76-8-28	0.01 ab	0.95 ab	0.83 ab	1.00 a	0.78 abc	0.78 ab
F1S2 76-8-36	0.00 a	1.00 a	0.98 a	1.00 a	0.67 abc	0.67 ab

Representatives from the CCRAB field trial in Salinas, CA in 2021 in Foa race 2-infested soil

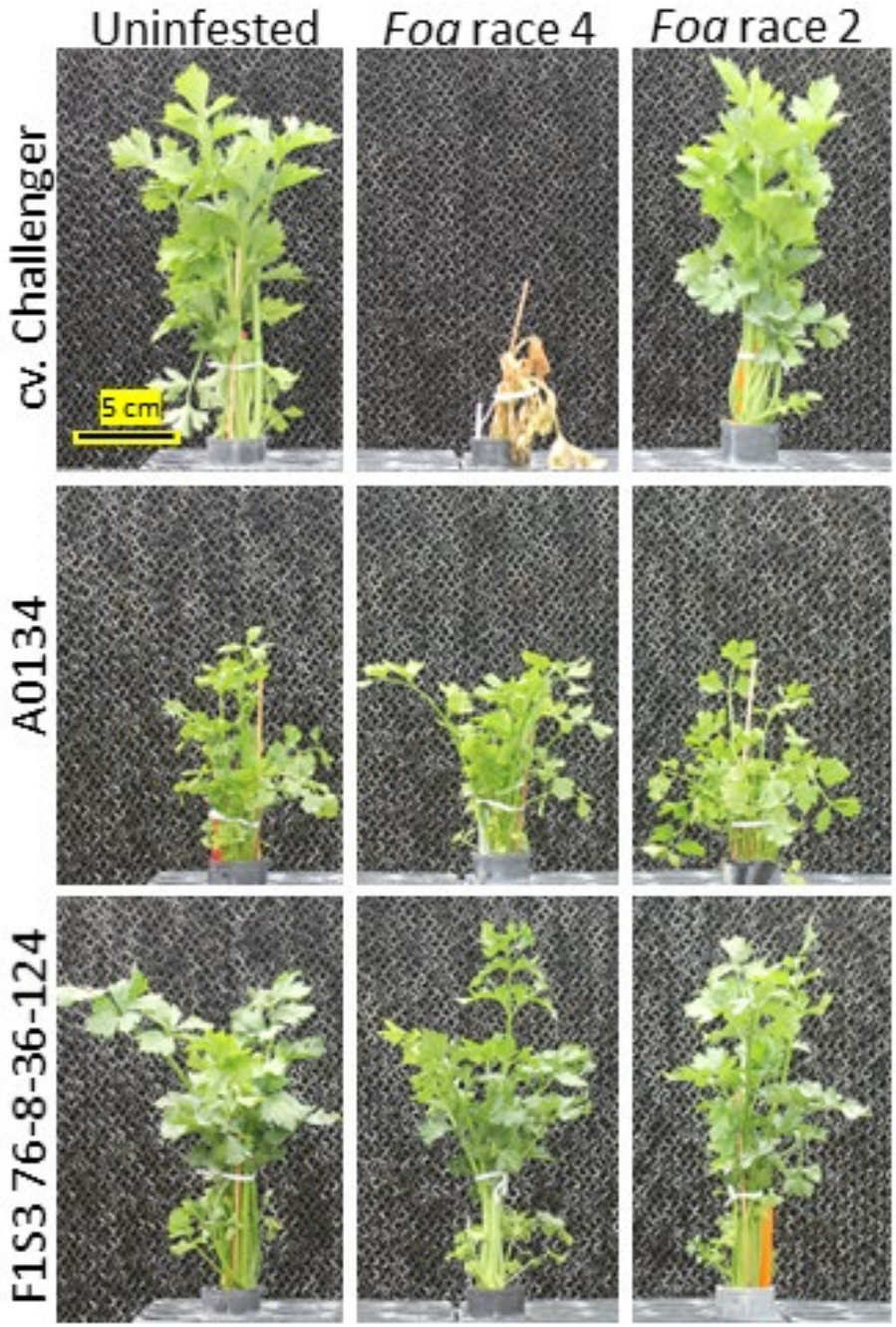
The parents, F1S2 76-8-36 and F1S3 from nine selfed 76-8-36: vascular discoloration-based symptoms, and celery vs. celeriac type in Foa race 4-infested soil in the greenhouse

		Plants in each category, %									
		Vascular discoloration (vd)-based score from 0 (asymptomatic) to 5 (dead)						Celery type	Celeriac type	Resistant, % (vd score ≤ 2)	n
Generation	Plant ID	0	1	2	3	4	5				
Parent of F1	A0134	**95**	0	2	2	0	0	0	100	98	44
F1S2	76-8-36	89	0	2	9	0	0	71	0	91	45
F1S3	76-8-36-124	**96**	0	2	2	0	0	**82**	0	98	45
F1S3	76-8-36-133	96	0	0	4	0	0	73	0	96	45
F1S3	76-8-36-151	84	0	2	14	0	0	93	0	86	44
F1S3	76-8-36-103	30	55	5	10	0	0	100	0	90	20
F1S3	76-8-36-127	91	0	0	9	0	0	54	0	91	35
F1S3	76-8-36-139	89	9	0	2	0	0	42	0	98	45
F1S3	76-8-36-146	95	5	0	0	0	0	35	0	100	20
F1S3	76-8-36-105	83	10	0	8	0	0	25	0	93	40
F1S3	76-8-36-148	93	0	2	4	0	0	98	0	98	44
Parent of F1	Challenger	0	0	0	2	**18**	**80**	**100**	0	0	45

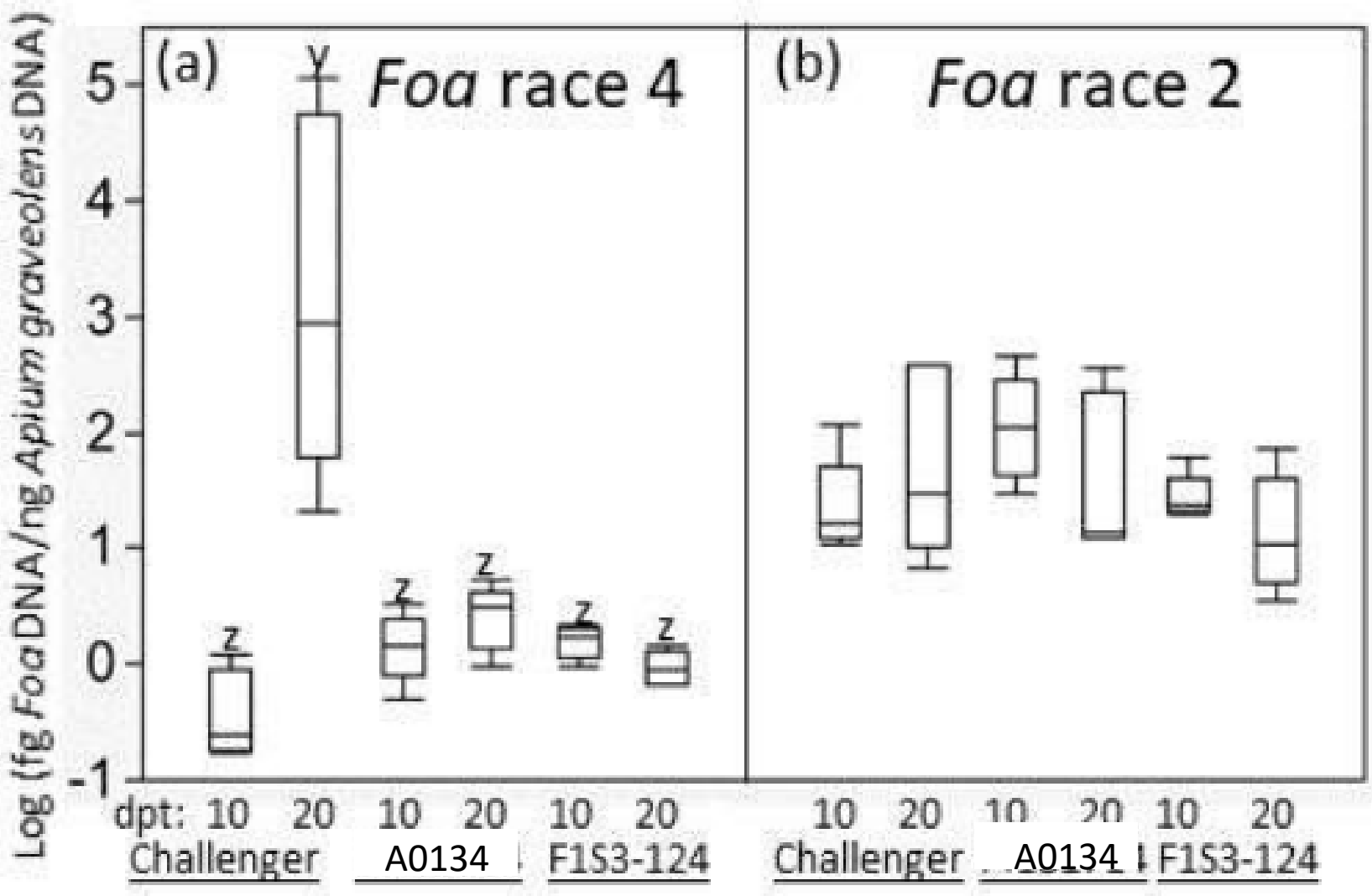
The parents, F1S1 76-8, three F1S2, and F1S3 76-8-36-124: the percentage with symptoms of Fusarium wilt in *Foa* race 4-infested soil, and celery vs. celeriac type in a greenhouse trial.

		Symptoms of Fusarium wilt from *Foa* race 4							Plant architecture				
		Vascular discoloration-based score from 0 (asymptomatic) to 5 (dead)						Asymp-tomatic above-ground	All solid peti-oles	Growth habit			
Generation	Plant ID	0	1	2	3	4	5			Celery	Mix of celery & celeriac	Celer-iac	
		Plants, %											n¶
F1 parent	A0134	**94**	0	0	4	***2***	***0***	**100**	0	0	0	100	47
F1 parent	cv. Challenger	**0**	0	0	0	***38***	***63***	**0**	100	**100**	0	0	48
F1S1	76-8	54	3	1	15	***21***	***6***	**64**	19	53	44	3	80
F1S2	76-8-4	49	11	0	11	***16***	***11***	**73**	100	91	9	0	79
F1S2	76-8-27	68	0	2	12	***18***	***0***	**82**	100	84	16	0	125
F1S2	76-8-36	84	13	4	0	***0***	***0***	**100**	100	63	37	0	80
F1S3	76-8-36-124	**95**	0	0	5	***0***	***0***	**99**	100	85	15	0	80

Epstein & Kaur, In press



Conclusion: We have germplasm that is fixed for *Foa* race 4 (& *Foa* race 2) resistance



Epstein & Kaur, In press

Technically, A0134 & F1S3-124 are at least somewhat immune to Foa race 4 (and race 2)

The following UC Davis (UCD) seed can be obtained [after signing a material transfer agreement (MTA) with UCD] by contacting lepstein@ucdavis.edu

F1S3 76-8-36-124
F1S2 76-8-36
F1S2 76-8-27
F1S2 76-8-4
Resistant Parent USDA PI 181714 (UC A0134)

Terms of the UCD MTA:

Seeds available to anyone for research

For commercial breeding, UCD requires a non-exclusive license with UCD

What's next?

- Renee Eriksen at the USDA in Salinas is taking over the CCRAB-sponsored breeding program and the field testing

- We have a team for developing DNA tools that will facilitate breeding for disease resistance to Foa

  Chaehee Lee, Allen van Deynze, Grey Monroe, Lynn Epstein, Peter Henry, Renee Eriksen

How the DNA data could be used

-To streamline breeding for Foa race 4 and race 2 resistance

-To gain insight into the celery – *Foa* race 4 and celery - Foa race 2 interactions

(thanks partly to you all, we already have annotated genomes of Foa races 2 & 4)

-To see if there's potential for "stacking" genes for race 2 resistance

-To enable efficient and productive hypothesis-driven research on a variety of stresses for California-grown celery

IPM for control of *Foa* race 4

- Include cultural controls:

EXCLUDE Foa race 4 from currently uninfested fields (make sure that equipment that's been in an infested field doesn't enter an uninfested field with infested soil & plant debris)

If you see an infection locus in a field, try your best to quarantine it—don't move equipment through it

Avoid planting celery and celeriac in an infested field

If a field is infested, and you are planting celery or celeriac, don't plant (Aug.-Sept) when the crop might experience temperatures greater than 72 °F

https://epstein.faculty.ucdavis.edu/

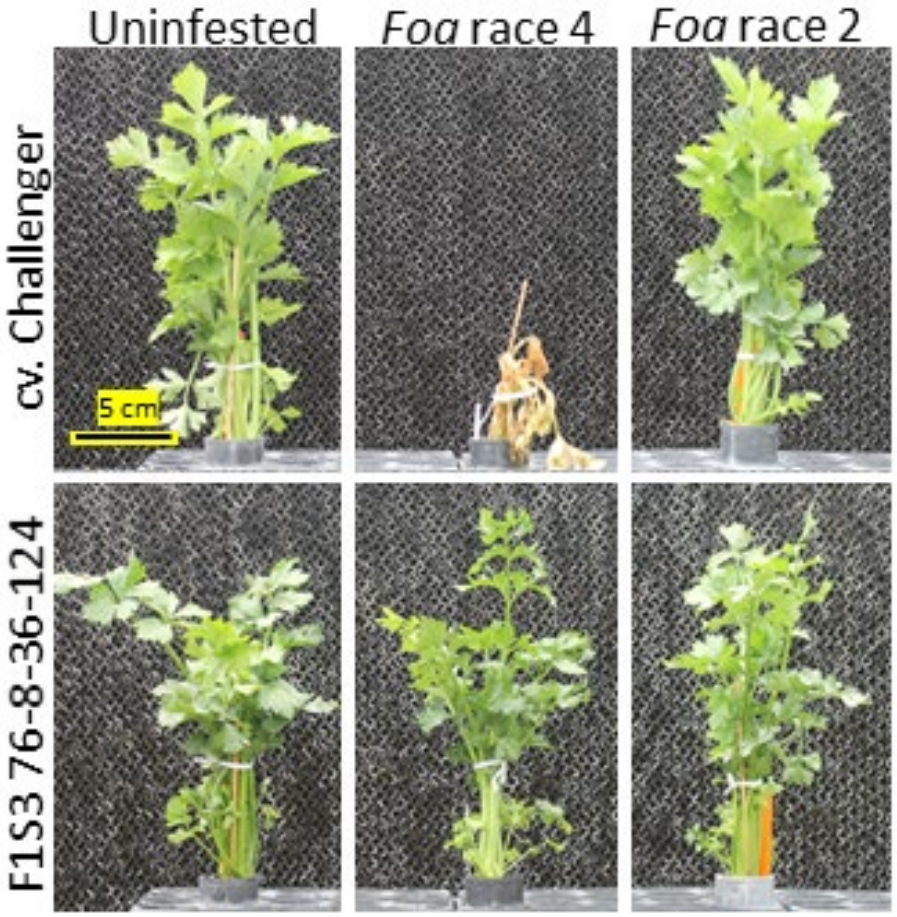
PI 181714 is a source of resistance to *Fusarium oxysporum* f. sp. *apii* race 4 in celery (*A. graveolens* L. var. *dulce*). Epstein, L, Kaur, S. *Plant Breeding* (In Press)

The effect of temperature on disease severity and growth of *Fusarium oxysporum* f. sp. *apii* races 2 and 4 in celery. 2022. Kaur S, Barakat R, Kaur J, Epstein L. *Phytopathology* 112:364-372. [Supplemental file]

The emergence of *Fusarium oxysporum* f. sp. *apii* race 4 and *F. oxysporum* f. sp. *coriandrii* highlights major obstacles facing agricultural production in coastal California in a warming climate: a case study. Epstein L., Kaur S., Henry PM. 2022. Frontiers in Plant Science 13: 9211516. doi: 10.3389/fpls.2022.921516

Genomic differences between the new *Fusarium oxysporum* f. sp. *apii* (*Foa*) race 4 on celery, the less virulent *Foa* races 2 and 3, and the avirulent on celery f. sp. *coriandrii*. Henry P, Kaur S, Pham QAT, Barakat R, Brinker S, Haensel H, Daugovish O, Epstein L. 2020. *BMC Genomics* 21:730. [Supplemental files]

Races of the Celery Pathogen *Fusarium oxysporum* f. sp. *apii* are polyphyletic. Epstein L. Kaur S, Chang P, Carrasquilla-Garcia N, Lyu G, Douglas Cook D, Subbarao K, Kerry O'Donnell K. 2017. *Phytopathology 107:463-473.* Suppl. Fig. S1. Suppl. Table S1. Suppl. Table S2. Suppl. Table S3.



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SRA: Dr. Sukhwinder Kaur

On-going breeding: Renee Eriksen, USDA-ARS, Salinas & colleagues

Development of molecular tools to facilitate breeding:
UCD Plant Sciences:
Chaehee Lee, Grey Monroe, & Allen van Deynze
USDA-ARS, Salinas:
Renee Eriksen & Peter Henry
UCD Plant Pathology: Lynn Epstein

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