California
CELERY RESEARCH
ADVISORY BOARD

2020-21 Annual Report

531-D North Alta Avenue, Dinuba CA 93618
559-591-0434 (PH) 559-591-5744 (FX)

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The program was established in October 1976 under provisions of the California Marketing Act, following written assent of a majority of the industry's producers. The program is administered by the Celery Advisory Board, which is nominated at district meetings every three years by industry and appointed by the Secretary of Food and Agriculture.

The function of the Board is to ascertain research needs that will benefit the widest spectrum of the industry in all producing districts, to establish priority of need, enter into agreements with approved agencies to initiate or continue such research, develop a budget for funding, give impetus, direction and evaluation to the conduct of the work, and report results to the industry periodically.

The Board represents the entire industry, and all its actions and recommendations are subject to the approval of the California Secretary of Food and Agriculture. Board members serve without compensation. Funds budgeted by the Board for research projects amount to about one-fourth the total cost of the projects, with the University of California supplying the remaining three-fourths in supervisory research personnel, plant facilities and major equipment. Research initiated by the Board would not be conducted without the industry's contribution --- through equitable assessment --- for certain special equipment, supplies, staff research assistants, expenses, travel, etc., since neither funds nor nonpartisan direction are available from other sources.

RESEARCH PRIORITIES

Production

- ✓ Evaluate insect management tools, alternatives to organophosphates and carbamates (especially products which are subject to restriction or loss due to FQPA and other regulations - e.g., acephate, diazinon, carbamates)
- ✓ Study the biology and management of soil pests
- ✓ Study management of Sclerotinia (airborne and soil borne)
- ✓ Evaluate new celery varieties for resistance to insects and diseases
- ✓ Evaluate biofumigants as tools for pest control in celery
- ✓ Develop resistance management strategies for all pest categories
- ✓ Continue weed control research to find complimentary or replacement products for Lorox/linuron Caparol/prometry and Caparol/Prometryn
- ✓ Evaluate the secondary effect of loss of methyl bromide as a tool used in rotational crops on celery production areas

Regulatory

- ✓ Registrants should insure that air and chemigation labels are a part of all new product registrations
- ✓ Address REI issues/concerns for products used in late season (e.g. aphicides)
- ✓ Multiple products should be allowed under 24(c) and Section 18's for resistance management
- ✓ Expedite registration of Dual Magnum/S-metolachlor for nutsedge control

Educational

- ✓ Educate regulators, legislators, and policy makers on need for more than one product for a particular pest for effective resistance management
- ✓ Educate regulators on what a suitable replacement product is and what constitutes commercially acceptable levels of control
- ✓ Educate growers, PCAs, agencies and the urban community on the relationship of waterway management to weed and insect pests
- ✓ Educate the urban population about agricultural practices necessary for celery production
- ✓ Educate the public on the nutritional values of California grown celery and the high level of food quality standards established for this commodity

CALIFORNIA CELERY RESEARCH BOARD

September 1, 2020 through August 31, 2023

DIST	MEMBER	ALTERNATE
2	**Adrian Zendejas** Desert Mist Farms	**Jeff Percy** Desert Mist Farms
DIST	**MEMBER**	**ALTERNATE**
3	**Hank Laubacher Jr** Laubacher Farms	**Alfredo Esquivias** Tanimura & Antle
3	**Geremy Olsen** Deardorff Family Farms	**Greg Lewis - RES COMM** Duda Farm Fresh
3	**Danny Pereira – Chairman** Rio Farms - **RES COMM**	**Vicki Pierce** Duda Farm Fresh
3	**Steve Adams – Res/Vice Chair** Boskovich Farms - **RES COMM**	**Mike Naumann - RES COMM** Naumann Farms
3	**Ryan Coultas** Coultas Vegetable	**Will Terry** Terry Farms
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5	**Dean Diefenthaler** Duda Farm Fresh	**Larry Pierce - RES COMM** Duda Farm Fresh
5	**Kevin Brink - RES COMM** Ocean Mist Farms	**Paul Sheid** Ocean Mist Farms
PUBLIC MEMBER		
	Steve Donovan - RES COMM	

STAFF		
	Oleg Daugovish UC Liaison UCCE – Ventura County 805-645-1454 odaugovish@ucanr.edu	**Ben Kardokus** CDFA 560 J St, Ste 170-A, Sacramento 95814 916-900-5018 ben.kardokus@cdfa.ca.gov
	JD Allen Manager 531-D North Alta Ave, Dinuba 93618 559-591-4792 jdallen@tabcomp.com	**Austin Hurtado** Assistant Manager 531-D North Alta Ave, Dinuba 93618 559-591-4792 austin@tabcomp.com

CELERY RESEARCH ADVISORY BOARD

FISCAL YEAR ENDING 9/30/21

September 30, 2022 (FINAL)

INCOME		**CARRYOVER**	**231,763**	
		BUDGET	**YTD**	**BALANCE**
30-110	Current	310,000	308,891	1,109
30-111	Prior	-	-	-
30-120	Interest Income	4,000	3,903	97
30-140	Other Income	-	1,549	1,549
TOTAL INCOME		**314,000**	**314,343**	**(343)**
EXPENSES				
30-305	Management Services	52,800	52,800	-
30-315	Audits	3,800	4,075	(275)
30-320	Office Supplies	600	350	250
30-330	Telephone	600	629	(29)
30-335	Postage	600	-	600
30-355	Travel & Mileage	1,200	1,031	169
30-360	Meetings	500	681	(181)
30-365	Annual Report	50	-	50
30-370	Insurance	600	738	(138)
30-390	Miscellaneous	100	-	100
30-392	Website	250	275	(25)
30-551	Production Research - UC Davis	128,356	114,552	13,804
30-552	Production Research - UC Riverside	55,500	55,500	-
30-556	Production Research - Outside	23,628	23,628	-
30-710	Marketing Branch	16,500	15,660	840
30-711	Market Enforcement Branch	2,500	800	1,700
TOTAL EXPENSES		**287,584**	**270,720**	**16,864**

NET INCOME	**$**	**43,623**
CASH BALANCE	**$**	**275,386**

RESEARCH PROJECTS

2020-21

RESEARCHER	PROJECT TITLE	2020-21 APPROVED
Lynn Epstein *UC Davis*	Fusarium Yellows in Celery: Breeding and Maintaining Resistance, and Integrated Control	**128,356**
Richard Hurstak *Crop Science Svcs*	Celery Cultivar and Germplasm Evaluations and Field Demonstrations for Observations of Fusarium Yellows Resistance	**23,628**
Tom Perring/Greg Kund *UC Riverside*	Integrated Pest Management on Celery	**55,500**
TOTAL REQUEST		**$207,484**

Layman's summary

CALIFORNIA CELERY RESEARCH ADVISORY BOARD
RESEARCH PROJECT REPORT
for the period of:
October 1, 2020 - September 30, 2021

PROJECT TITLE: Fusarium yellows in celery: breeding and maintaining resistance, and integrated control.

PROJECT LEADER: Lynn Epstein, Department of Plant Pathology, University of California, Davis, California 95616

COOPERATING PERSONNEL: Sukhwinder Kaur, Richard Hurstak, Peter Henry, Priya Tumuluru, Alejandro Palma-Carias, Ioannis Stergiopoulos, and Allen van Deynze

The new *Fusarium oxysporum* f. sp. *apii* (*Foa*) race 4 apparently first appeared in a single field in Camarillo, CA ca. 2011. Within a decade, *Foa* race 4 was present in all five celery production areas in Ventura County, and in at least one field in Monterey Co., apparently largely because of transportation of infected celery debris on equipment. *Foa* race 4 isolates are highly virulent on all celery cultivars that we have tested, except for Rijk Zwaan's stick variety "Earthrace," which has some but not complete resistance. Our recent primary focus has been on the production of a breeding line that can be distributed to celery breeders preferably by summer 2022. Previously, we identified one "celeriac" accession (A0134) with resistance to *Foa* race 4. After we produced F1 from a cross of celery cv. Challenger (*Foa* race 2-resistant but *Foa* race 4-susceptible) X A0134 (*Foa* race 2-resistant and *Foa* race 4-resistant, but not a celery-type), we screened for race 4 resistance and then selfed selected individuals to produce what we now denote as a F1S1. We then screened for race 4 resistance and celery type with solid petioles, selected families of interest in a race 4-infested field trial, selected vigorous individuals with celery-type in a race 4-infested field, and rescreened clones of individuals from the field trial for race 4 resistance. We then selfed selected individuals to produce F1S2, and screened them in the greenhouse and the field for race 4 resistance and celery type. We have multiple families with acceptable levels of race 4 resistance and celery-type for a breeding line, but all of these families are still segregating for resistance, i.e., race 4 resistance is not fixed in any of the F1S2 families. We are currently screening 9 F1S3 families that were derived from the F1S2 76-8-36 for race 4 resistance. In accordance with the CCRAB wishes, we plan to release selected F1S2 before resistance is fixed. Currently, we plan to release F1S2 lines 76-8-4, 76-8-27, and 76-8-36 to breeders in early summer, 2022 so that they can start the process of crossing this germplasm with their own lines. The only restriction to those breeders will be that the resistance and genes *per se* for resistance to *Foa* race 4 must remain in the public domain, and may not be patented.

CALIFORNIA CELERY RESEARCH ADVISORY BOARD
RESEARCH PROJECT REPORT
for the period of:
October 1, 2020 - September 30, 2021

PROJECT TITLE: Fusarium yellows in celery: breeding and maintaining resistance, and integrated control.

PROJECT LEADER: Lynn Epstein, Department of Plant Pathology, University of California, Davis, California 95616, 530-760-6150, lepstein@ucdavis.edu

COOPERATING PERSONNEL: Sukhwinder Kaur, Richard Hurstak, Peter Henry, Priya Tumuluru, Alejandro Palma-Carias, Ioannis Stergiopoulos and Allen van Deynze

II. OBJECTIVES**:**
The purpose of the research in this proposal is to provide long-term control of Fusarium yellows in California celery, caused by *Fusarium oxysporum* f. sp. *apii* (*Foa*).

Specific objectives:

1. To continue to breed, select and test germplasm that has resistance/tolerance to the new *Foa* race 4 in order to distribute it to the celery-breeding community as soon as the genes are "fixed;"
2. To estimate the number of genes involved in resistance of *Foa* race 4, and to start the process of determination of molecular markers for resistance from each gene;
3. To identify the DNA sequence of the *Fu1* gene from celeriac that confers tolerance to *Foa* race 2 in cv. Challenger, to develop and test a molecular marker for it, and to determine whether expression of the gene is suppressed by *Foa* race 4;
4. To write-up our protocols for *Foa* pathogen-testing, and screening for resistance;
5. To continue to monitor any spread of the new *Foa* race 4 in celery fields in California;
6. To investigate the possibility of the expansion of the UCD germplasm collection with additional accessions from the Mediterranean in Europe of the progenitor of celery, *Apium graveolens* ssp. *graveolens*, i.e., truly wild *Apium graveolens*, preferably that is more adapted to higher temperatures

RESULTS. Please note that data tables and figures are limited to those that were not in a previous report, i.e., those that were evaluated between Dec. 15, 2020 and Feb. 15, 2022, except in the one summary table (Table 1 Part C). We also note that these Objectives were written in June 2020, and, in some cases, results in the four-month period before the start of the grant impacted our research plan.

Objective 1. *To continue to breed, select and test germplasm that has resistance/tolerance to the new Foa race 4 in order to distribute it to the celery-breeding community as soon as the genes are "fixed."*

In fall 2021, the CCRAB indicated that they wanted useful germplasm released as soon as possible, regardless of fixation.

Fig. 1 shows the non-celery, prostrate habit of *A. graveolens* A0134 and Fig. 2 shows the resistance of A0134 vs. the susceptibility of celery to *Foa* race 4. Figs 3 and 4 illustrate the introgression of the genes for resistance to *Foa* race 4 from A0134 into two of the F1S2 families.

Fig. 1. The two *Apium graveolens* parents in uninfested soil in the greenhouse: on the left A0134 (resistant to *Foa* races 2 and 4- resistant but with small diameter and non-solid petioles), and on the right, celery cv. Challenger (*Foa* race 2 resistant but *Foa* race 4- susceptible). A0134 produces less aerial growth but has a larger root system than Challenger.

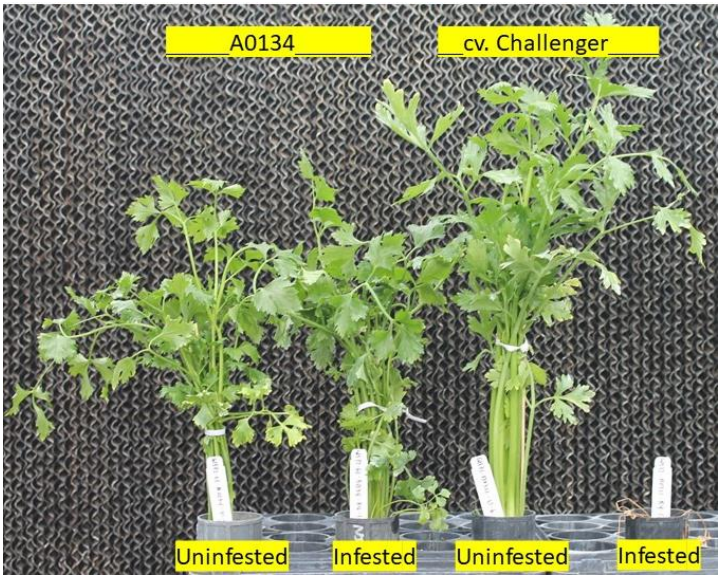

Fig. 2. The two *Apium graveolens* parents in the greenhouse in either uninfested or soil infested with *Foa* race 4. The *Foa* race 4-resistant A0134 in infested soil is barely affected while the susceptible cv. Challenger on the far right has died.

In the past year, we continued our greenhouse assays of the F1S2 for resistance to *Foa* race 4 and celery-type (Table 1). This involved testing some previously untested F1S2, and, to a more limited extent retesting a few F1S2 that we had selected as families of potential breeding interest last year. We note that we selected F1S1 of interest (*Foa* race 4 resistance and celery-type) from either a UCD-Dole trial in a race 4-infested field (marked as FS in the right-most column in Table 1 Parts A and B) or from our greenhouse trials (marked as GH). For the accessions marked "FS," in the F1S1 field trial at harvest time, in the two families of interest in that trial (76-8 and

76-21), we trimmed all of the plants to approximately 10 cm above the soil line, and then selected plants with excellent vigor and good celery-type. Based on Table 1 and our data from last year, the selections of individuals from a field trial as opposed to a greenhouse trial were a necessary part of getting good celery-type selections. The field selections were presumably critical because genes for resistance and celeriac-type in the A0134 parent are linked, one can visualize celery type on mature plants better than can be seen in our greenhouse assay, and we could survey a larger number of individuals in the field trial than in our greenhouse.

Fig. 3. Representative results from a greenhouse trial. F1S2 76-8-36 in uninfested (left) and race 4-infested soil (middle). On the right (yellow arrow), the parent cv. Challenger in infested soil died.

Fig. 4. Representative results from a greenhouse trial. F1S2 76-8-15 in uninfested (left) and race 4-infested soil (middle). On the right, the parental cv. Challenger in uninfested soil. We note that 76-8-15 looked excellent in greenhouse trials, but didn't perform horticulturally sufficiently well in field trials.

Table 1. Segregation of F1S2 progeny for vascular discoloration (from 0 asymptomatic to 5 dead), celery vs celeriac type, solid vs. hollow petioles, and average vascular discoloration ratings[a]

Table 1 Part A) GH72

F1S1 family or (parent)[b]	In the F1S1, the ID of the selfed plant	No. of progeny[c]											Selection[f]
		Vascular discoloration rating from 0 (asymptomatic) to 5 (dead)[d]							Celery vs. celeriac type[e]		Petiole type[e]		
		Avg.	0	1	2	3	4	5	Celery	Celeriac	Solid	Hollow	
76-8	15	0.6	16	0	0	4	0	0	20	0	20	0	FS
76-8	4	1.2	13	0	0	5	1	1	16	3	19	0	FS
76-8	29	1.0	15	0	0	1	3	1	4	14	18	1	FS
76-8	19	2.0	8	0	2	5	5	0	20	0	19	1	FS
76-8	28	2.3	8	0	0	5	5	2	14	2	16	1	FS
76-8	22	2.7	7	0	0	3	5	5	9	6	10	5	FS
76-2	19	0.5	17	0	0	3	0	0	0	20	0	20	GH
76-2	6	1.8	11	0	0	2	5	2	6	11	3	15	GH
76-2	5	2.9	3	0	2	8	6	1	0	19	15	4	GH
76-2	9	3.0	5	0	0	5	6	4	0	16	15	1	GH
76-6	14	2.2	8	0	0	7	3	2	0	18	0	18	GH
76-21	8	2.2	10	0	0	2	2	6	8	6	14	0	FS
76-21	10	2.7	5	0	0	7	7	1	12	7	15	4	FS
77-27	5	3.0	2	0	1	11	6	0	1	19	7	12	GH
77-27	15	3.6	0	0	0	8	12	0	0	20	3	15	GH
77-27	16	3.1	3	0	1	6	9	1	0	19	0	19	GH
77-34	9	3.0	3	0	1	9	4	3	2	15	5	12	GH
77-34	10	3.8	0	0	0	7	10	3	0	17	3	14	GH
(A0134)[g]	.-	0.3	18	0	1	1	0	0	0	20	0	20	NA
(Challenger)[h]	-.	5.0	0	0	0	0	0	20	0	NA[i]	NA	NA	NA

Table 1 Part B) GH73

F1S1 family or (parent)[b]	In the F1S1, the ID of the selfed plant	No. of progeny[c]											Selection[f]
		Vascular discoloration rating from 0 (asymptomatic) to 5 (dead)[d]							Celery vs. celeriac type[e]		Petiole type[e]		
		Avg.	0	1	2	3	4	5	Celery	Celeriac	Solid	Hollow	
76-8	36	0.7	23	0	1	5	1	0	16	0	29	0	FS
76-8	119	1.2	19	0	2	6	1	2	14	9	8	20	GH
76-8	110	1.2	19	0	1	5	5	0	6	8	30	0	GH
76-8	27	1.3	20	0	0	3	4	3	21	3	27	0	FS
76-8	20	2.7	10	0	0	4	11	5	18	5	25	0	FS
76-8	10	2.9	6	0	1	10	10	3	10	14	26	0	FS
76-8	35	3.0	7	0	0	11	4	8	19	0	22	0	FS
76-8	9	5.0	0	0	0	0	1	29	NA	NA	NA	NA	FS

76-12	1	3.0	8	0	1	4	9	8	1	14	0	19	GH
76-21	6	1.4	19	0	0	3	8	0	4	10	30	0	FS
76-21	103	3.6	3	0	3	7	5	12	1	6	15	1	GH
(A0134)	-.	0.2	26	0	3	0	0	0	0	29	0	29	NA
(Challenger)	-.	5.0	0	0	0	0	1	29	NA	NA	NA	NA	NA

Table 1 Part C) Compiled results from this year's (in either Part A or B) and last year's greenhouse trials of three of the seven F1S2 families in the 2021 CCRAB trial in *Foa* race 4-infested soil in Camarillo, CA.

F1S1 family[b]	In the F1S1, the selfed plant ID	No. of progeny[c]										
		Vascular discoloration rating from 0 (asymptomatic) to 5 (dead)[d]						Celery vs. celeriac type[e]		Petiole type[e]	
		Avg.	0	1	2	3	4	5	Celery	Celeriac	Solid	Hollow
76-8	36	0.7	38	1	1	9	1	0	34	1	49	0
76-8	110	0.9	36	0	1	7	6	0	10	24	50	0
76-8	27	1.6	29	0	1	6	8	6	32	9	44	0

[a]There were typically 20, 30 and 50 plants in infested pots/family in Parts A, B, and C, respectively. Each trial also had 10 uninfested plants/family; none of the uninfested plants were symptomatic (vascular discoloration rating 0, data not shown). Families indicated in green were selected for the CCRAB field trial in *Foa*-race 4 infested soil in Camarillo, CA in 2021 (see Table 2).

[b]Crosses that start with "76" were from a single Challenger X A0134 (3-4 pollen donors); crosses that start with 77 were from a single A0134 X Challenger (3-4 pollen donors) .

[c]For celery vs. celeriac type and solid vs. hollow petioles, results are only shown for the survivors in the infested (vascular discoloration rating from 0 to 4) pots. No evaluation was made when there were fewer than 5 survivors/family.

[d]Disease scores are as follows: 0, asymptomatic; 1, some discoloration in the lateral root vasculature; 2, some discoloration in the main root vasculature; 3, some discoloration in the crown vasculature; 4, extensive discoloration in the crown vasculature, i.e., involving >25% of the crown circumference; and 5, plant dead. Plants with scores of 3 and 4 can be considered debilitated by the pathogen.

[e]Celery petioles are wider and fewer than celeriac petioles, which are more numerous and less wide. Some plants were scored as having a mixed celery/celeriac type or a more mixed solid/hollow type; those "mixed" plants were not included in the totals in this column.

[f]FS, were selected for celery type and solid petioles from the FS1 family in a race 4-infested field. Vegetative clones that passed a screening in the greenhouse were used to produce the F1S2. Although the F1S1 families were observed in a field trial(s), the individual greenhouse (GH) plants were only screened in the greenhouse in an assay with and without race 4-infested soil.

[g]The *Foa* race 4-resistant parent *Apium graveolens* A0134.

[h]The Foa race 4-susceptible, celery parent cv. Challenger.

[i]NA, not applicable. For example, there were no survivors of the infested Challenger in the trial in part A.

Because both the Challenger and A0134 parents of the F1S2 are *Foa*-race 2 resistant, it is probable that the selected F1S2 are also resistant. Nonetheless, it is important to test this, and to see how our breeding material performs horticulturally in celery production areas in California. Consequently, we took the opportunity of planting selected F1S2 (76-8-4, 76-8-36, 76-8-15 and 76-8-10) in the 2021 CCRAB trial in Santa Maria in *Foa* race 2-infested soil. At harvest time, we selected random plants from each of our four F1S2 and from three controls: the commercial hybrid Earthrace, the moderately race 2-susceptible open-pollinated Conquistador and the standard race 2-susceptible Tall Utah 52-70 R Improved. At harvest, we selected 20 from each of the two replicate plots of each of our F1S2 and 10 random plants from each of the three replicated plots of the standard cultivars. We then washed the roots and rated each of the plants on our standard vascular discoloration scale; we note that the scale is slightly different from the one that we use in the greenhouse because we cannot recover fine roots from the field and none of the plants appeared to have died. Our Fusarium score is also slightly different from the one that Richard Hurstak uses in his evaluations. Fig. 5 indicates that all four F1S2 families performed well in terms of *Foa* race 2-resistance.

However, of the four F1S2 in the Santa Maria trial, we deleted two (76-8-15 and 76-8-10) as preferred candidates for future breeding because, compared to 76-8-4 and 76-8-36, they did not grow as well in the field, had no advantages in terms of disease resistance or celery type, and did not taste as good (data not shown). Fig. 6 shows two selected F1S2 (76-8-4 and 76-8-36) in comparison to CG390, a Challenger-like race 2-resistant celery cultivar from Cal Grow.

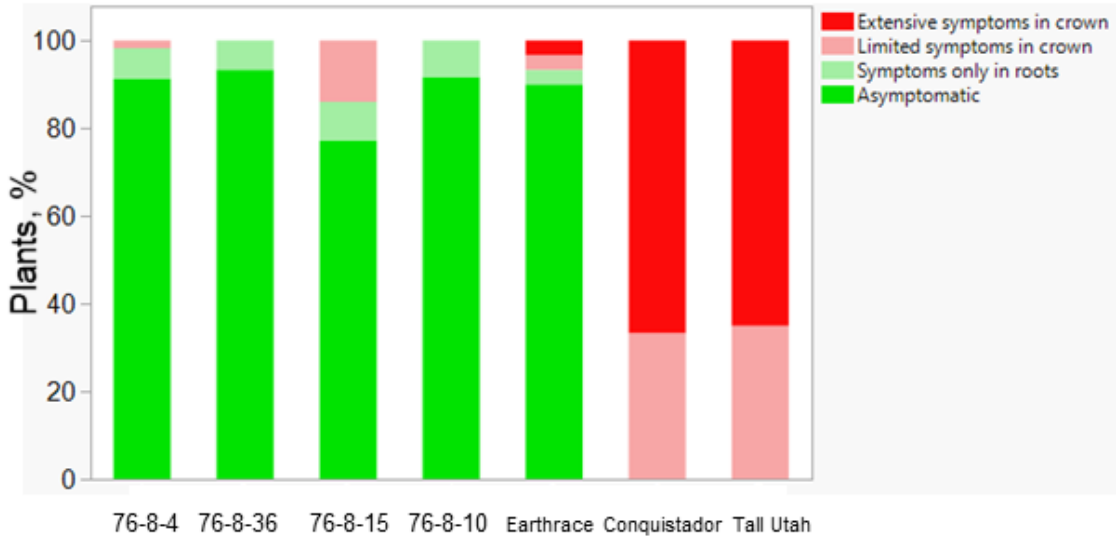

Fig. 5 A vascular discoloration-based assessment of four F1S2 selections and three commercial cultivars that were grown in 2021 in a field in Santa Maria, CA that was infested with *Foa* race 2.

Fig. 6. Growth of representative F1S2 76-8-36 and 76-8-4 in the CCRAB field trial in soil infested with *Foa* race 2 in Santa Maria, CA in 2021. The F1S2 are compared to the Challenger-like *Foa* race 2-resistant CG390, the moderately susceptible Conquistador and the highly susceptible Tall Utah 52-70R Improved.

Details about the CCRAB-sponsored field trial in race 4-infested soil in Camarillo are indicated in Richard Hurstak's report; it was transplanted on Aug. 18, 2021. The CCRAB trial was comprised of three mini-trials each in a completely randomized design; the moderately-race 2 resistant but race 4-susceptible cv. Command was planted in each of the mini-trials, and indicated that inoculum levels were reasonably similar in all three mini-trials. One of the replicated mini-trials had five of our F1S1 families of greatest potential interest (76-8, 76-21, 76-2, 76-6; and 77-41); results were not quantified, but indicated that none of the F1S1 appeared to have superior race 4 resistance and celery-type as the currently selected F1S1 76-8. Data from the replicated CCRAB mini-trial with 7 F1S2 accessions and the two parents are shown in Table 2; this trial had four replicated plots. The treatments in the F1S1 and F1S2 CCRAB mini-trials were also planted in an unreplicated UC-Dole trial; only whole-plot visual assessments were made at the UC Dole trial. In no cases did plant performance in the UC-Dole trial appear to differ from those in the CCRAB trial.

Based on a comparison of our results in greenhouse and field trials, disease pressure in the CCRAB field trial in 2021 was not particularly high; overall, temperatures were less frequently in the range (75 °F and higher) (Table 3) that most favors *Foa* race 4 (Kaur et al. 2022). In the field trial, only 28 $\pm$ 10% (SEM) of the Challenger died, and 15 $\pm$ 4% were asymptomatic on the vascular discoloration scale (Table 2). In contrast, typically in our greenhouse trials, 95% of the Challenger plants die and none are entirely asymptomatic (see two examples in Table 1). To summarize, the disease pressure in the CCRAB trial was insufficiently strong to see segregation for disease resistance in the field. However, the CCRAB trial was very useful in showing that disease resistance was successfully introgressed into a cv. Challenger X germline. Both A0134 and the F1S2 76-8-110 had a more fibrous root structure than the other F1S2. **We selected 76-8-4, 76-8-27, and 76-8-36 as our most promising celery breeding lines (Fig. 7).** We note that we included 76-8-110 in the field trial solely because it had had consistently high disease resistance in greenhouse assays; however, as in the greenhouse trials, it had more features of a non-celery type (Fig. 8). Three other F1S2 in the trial were also classified as second tier breeding material. Although 76-8-15 consistently performed well in greenhouse trials, visually, it did not grow as well in either the *Foa* race 2 trial in Santa Maria or in this *Foa* race 4 trial. F1S2 76-8-19 and 76-

8-28 did not appear to have any advantages All the second tier selections (Fig. 8) have a less compact arrangement of celery petioles than the top tier selections.

Table 2. Evaluation of *Foa* race 4 resistance and celery phenotype of two parents of an F1 and seven of their F1S2 in a field trial in soil that was infested with *Foa* race 4[a].

Parental accession or F1S2 family that was derived from F1S1 76-8	Fraction that died[b]		Fraction of asymptomatic plants above-ground		Fraction of survivors with no below-ground vascular discoloration		Fraction of survivors with solid petioles		Fraction of survivors with celery-type growth habit	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
A0134	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Challenger	0.28	0.10	0.49	0.05	0.15	0.04	1.00	0.00	1.00	0.00
F1S2 76-8-4	0.00	0.00	1.00	0.00	0.90	0.07	1.00	0.00	0.96	0.04
F1S2 76-8-15	0.00	0.00	1.00	0.00	0.92	0.03	1.00	0.00	0.99	0.01
F1S2 76-8-19	0.00	0.00	0.98	0.03	0.86	0.03	1.00	0.00	0.86	0.06
F1S2 76-8-27	0.00	0.00	1.00	0.00	0.85	0.04	1.00	0.00	0.85	0.10
F1S2 76-8-28	0.01	0.01	0.95	0.03	0.83	0.07	1.00	0.00	0.78	0.09
F1S2 76-8-36	0.00	0.00	1.00	0.00	0.98	0.02	1.00	0.00	0.67	0.16
F1S2 76-8-110	0.00	0.00	1.00	0.00	0.94	0.04	1.00	0.00	0.14	0.08

[a]There were four replicate plots/family or accession in a completely randomized design. The parents are *Apium graveolens* var. *dulce* cv. Challenger and *A. graveolens* A0134. Two-month old seedlings were transplanted on Aug. 18, 2021. On Oct. 6, 2021, 20 plants/plot were randomly selected and flagged. At harvest on Nov. 16, those previously selected plants were dug, washed, and examined for symptoms of *Foa* infection.
[a]Of the randomly selected plants, mortality was limited to 28% of the Challenger, and a single plant in the F1S2 76-8-28.

Table 3. Average monthly temperatures in Camarillo CA in 2019 through 2021 for August plantings[a]

Month	Year		
	2021	2020	2019
	Average daytime/nighttime temperatures, °F		
Aug.	76/58	79/59	76/57
Sept.	74/56	79/55	77/56
Oct.	73/50	73/50	77/50
Nov.	71/49	70/45	70/46

[a]https://ceventura.ucanr.edu/Com_Ag/?weather=station&station=152.

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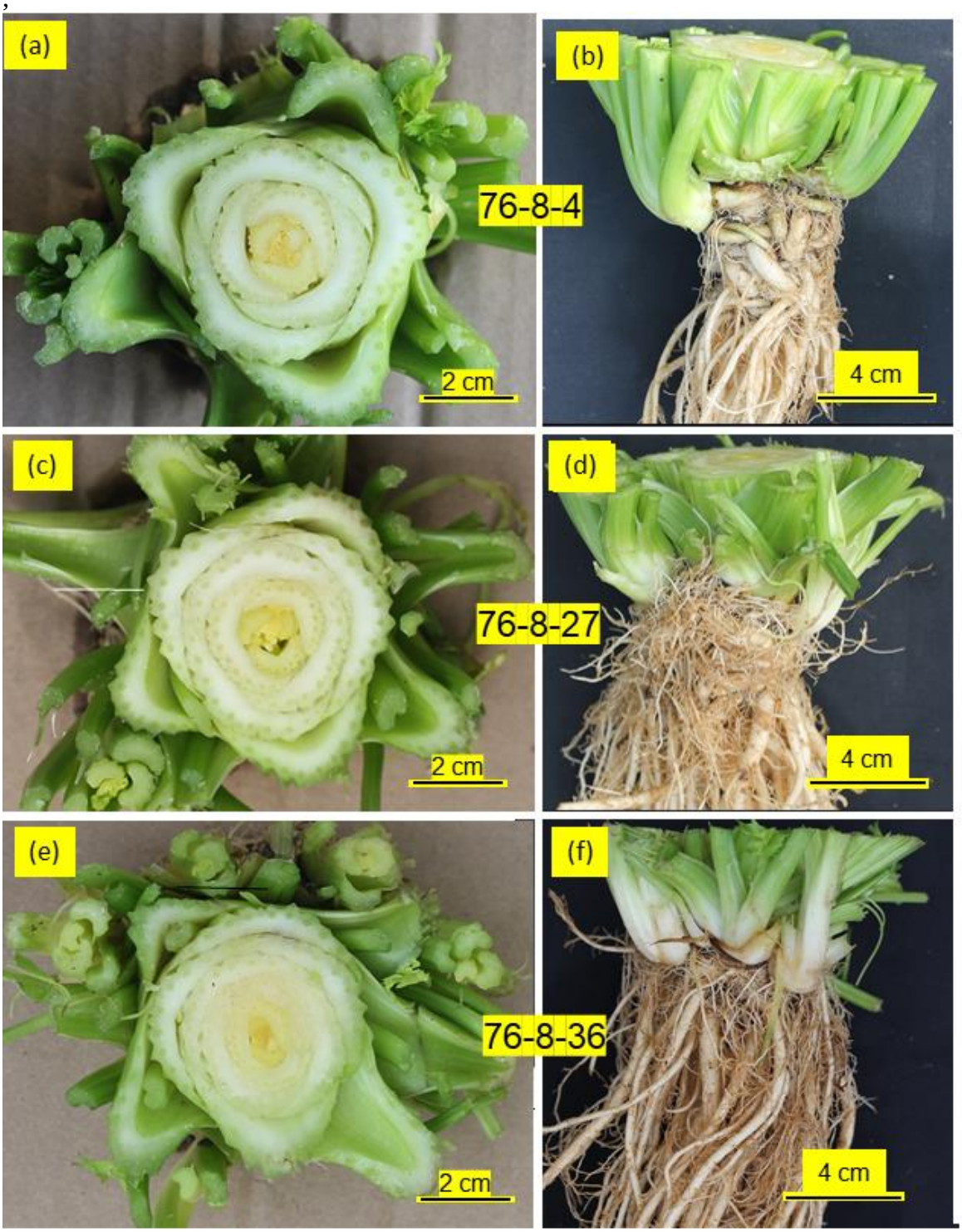

Fig 7. Photographs of representative field-grown F1S2 from a 2021 field trial in Camarillo, CA in *Foa* race 4-infested soil. These plants are from the families that we have selected as breeding lines for distribution.

Fig. 8. Photographs of representative field-grown F1S2 from a 2021 field trial in Camarillo, CA in *Foa* race 4-infested soil. These families were judged as less useful breeding lines, primarily in terms of having a less compact celery type.

<u>Objective 2.</u> To estimate the number of genes involved in resistance of Foa race 4, and to start the process of determination of molecular markers for resistance from each gene;

In last year's report, we showed that neither the backcross nor the previous year's selfed data gave a clear answer about the probable number of genes required for resistance. While it's reasonable to assume that Challenger is uniformly homozygous for resistance because it is a highly inbred, it's conceivable that A0134 might be less of a homogenous population for resistance; we have GBS data for A0134 as part of the Challenger genome project, but won't be able to analyze it and the other accessions until the Challenger genome is finished, hopefully by June 2022. Also, when we categorize the populations on the vascular discoloration (vd) scale, it seems obvious that, except for the occasional escape, a vd=0 (asymptomatic) or 1 (discoloration limited to the fine roots) and probably 2 (discoloration in the main roots but not in the crown) is resistant and a vd=4 (discoloration in the crown on >25% of the crown circumference) or 5 (dead) is susceptible. A vd=3 is the most ambiguous, especially since *Foa* race 2 in Challenger is resistant, but we always have some vd=3 in our *Foa* race 2-Challenger assays. Indeed, our greenhouse assay is designed to give an extremely vigorous test of resistance, and consequently in an attempt to reduce "false positives" for resistance, we may be mis-categorizing some individuals that are indeed resistant but completely overwhelmed by the inoculum. Regardless, in the data shown in Table 1 and last year, there are segregation ratios that are not consistent with segregation of a single gene, and consequently it seems likely that more than one gene must be introgressed from A0134.

Because there is a molecular relationship between genes for resistance in the host and genes for virulence in the pathogen, a potential strategy to identify resistance genes in celery is to identify virulence genes in the pathogen. In addition, in previous years, we have had an objective to determine the genetic mechanism of virulence in race 4, particularly in comparison to race 3, which is closely related to race 4 but has the reduced virulence of a race 2 strain, even in cultivars such as Tall Utah that are susceptible to race 2. In general, we can postulate the hyper-virulence of race 4 may be due to either 1) race 4 acquiring a gene that race 3 doesn't have or 2) race 4 losing an "avirulence" gene that has served to alert the host that it is being invaded. As reported somewhat in Henry et al. (2020), we didn't find evidence that race 4 had potential "virulence" genes that encoded for highly expressed, secreted proteins that weren't in race 3. Interestingly, we identified a gene in race 3 (*Foa* race 3 PGN.19912 on contig C48) (Fig. 9), that encodes for a small secreted protein of unknown function, was entirely absent in race 4, and is expressed in plants that were infected with race 3, and was only expressed "*in planta*," i.e., the gene was only expressed when race 3 was in contact with the plant and not when race 3 was grown in culture (based on TagSeq data in Henry et al., data not shown here). Experimentally, we tested the hypothesis that race 3 PGN.19912 is an avirulence gene by genetically disabling the gene by homologous recombination (Gold et al. 2017); if race 3 PGN.19912 is an avirulence gene, then genetic knock-outs should be more virulent than the control strains. However, strains in which race 3 PGN.19912 was genetically disrupted were no more virulent than any of the control strains. Consequently, and disappointingly, the presence of PGN.19912 in race 3 doesn't help to explain why race 4 is more virulent than race 3.

ATGAAGTTGTACGACCTTCTTGTTTTCACTACTGCTGCCAGTGGGGCTCTCGTCCCGGTCCAGAACGGCGAGCTGCT
AGAAGGAACGAGTCTGAGCAGAAGAGCTTCCTGCGATGTTTGTGTGTAAGTTCAGACAGAAAATCAGCAGACAGTTT
CTGATTTATTAATCCTGTTAGAACTACTGTTAAGGGTCAATCGACAACGACTTGGGGCCCCTTCCCAATTCCTTATG
ACCAGGGAGGCCAGACGTCACGAGGGATATACGTGGGCTGCGACGTTCACATCGATCGCAAACGGACAACAAACTGT
CAACAATGGAGTGTTTGGACGTCCGGTACCTGTGGACAGGTTACAAAGCAACAGACCTGT**TAA**

Fig. 9. The DNA sequence of *Foa* race 3 PGN.19912. We postulated that this gene model encodes for an avirulence gene, but experimental evaluation by replacement of the DNA with a gene for hygromycin resistance did not indicate that the DNA has a role in pathogenesis.

Objective 3. *To identify the DNA sequence of the Fu1 gene from celeriac that confers tolerance to Foa race 2 in cv. Challenger, to develop and test a molecular marker for it, and to determine whether expression of the gene is suppressed by Foa race 4.*

Although we were expecting that the Challenger genome would be completed by this time, it is not yet done; parenthetically, good progress is being made. Regardless, objective 3 cannot be completed until the UCD Challenger genome project is completed. Consequently, we only report here completion of some analyses that are relevant to this objective. Challenger is resistant to *Foa* race 2, and highly susceptible to *Foa* race 4. Based on full-genome DNA sequences, *Foa* races 3 and 4 are closely related (Henry et al. 2020), but race 3 causes little if any disease. Here, we show that in Challenger, the concentration of *Foa* race 2 DNA in the crown declines between one and three weeks (Fig. 10); consequently, Challenger is immune, rather than tolerant, to *Foa* race 2. However, in celery in soil infested with *Foa* race 4, the *Foa* race 4 concentration increases ca. 100 X between one and two weeks. By three weeks after transplantation in *Foa* race 4-infested soil, plants were dying.

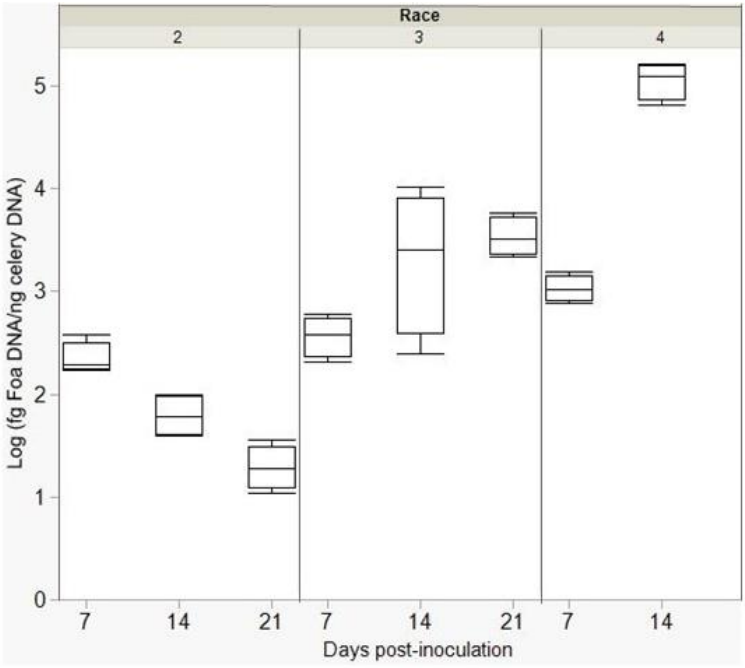

Fig. 10. A comparison of the amount on a log scale of *Foa* race 2, race 3 and race 4 DNA in celery cv. Challenger crowns 7, 14 and 21 days after transplantation. Each replicate was a pool of 8 plants and the boxes show the median and interquartile range of 4 replicates. Challenger is resistant to *Foa* race 2; data here show that the concentration of *Foa* race 2 DNA declines over the 21 days.

Song et al. (2021) published a full genome (but unfortunately not a publicly-available annotation, which makes it far less useful) of celery cv. Ventura. Regardless, once we have the *Foa* race 2-resistant Challenger genome, we can look for differences with the Ventura genome. However, to understand whether any differences in the DNA might be associated with *Foa* race 2-resistance, we wanted to understand more about the Ventura-*Foa* race 2 interaction. Originally, cv. Ventura was released in 1983 as having "field tolerance to *Fusarium.*" Here, we compared cv. Ventura to Tall Utah 52-70R Improved as a susceptible control and to Challenger as a resistant control (Fig. 11).

The data show that *Foa* race 2 colonizes the crowns of Ventura, and while it probably has less severe symptoms in the field, *Foa* race 2 had statistically indistinguishable concentrations of DNA in Ventura as in Tall Utah. That is, it is reasonable to consider Ventura to be genetically susceptible. In contrast, the *Foa* race 2-resistant Challenger had a significantly lower *Foa* race 2 DNA concentration in Challenger than in either Ventura or Tall Utah 52-70R Improved. We note that in Fig. 11B, log 3 on the y axis means that based on DNA concentration, the crown has 1 part fungal DNA: 1000 parts celery DNA. But if we adjust for the difference in DNA content between a *Foa* race 2 and a celery cell, log 3 means that there is approximately one (comparatively small) *Foa* race 2 cell for every 10 (comparatively large) celery cells.

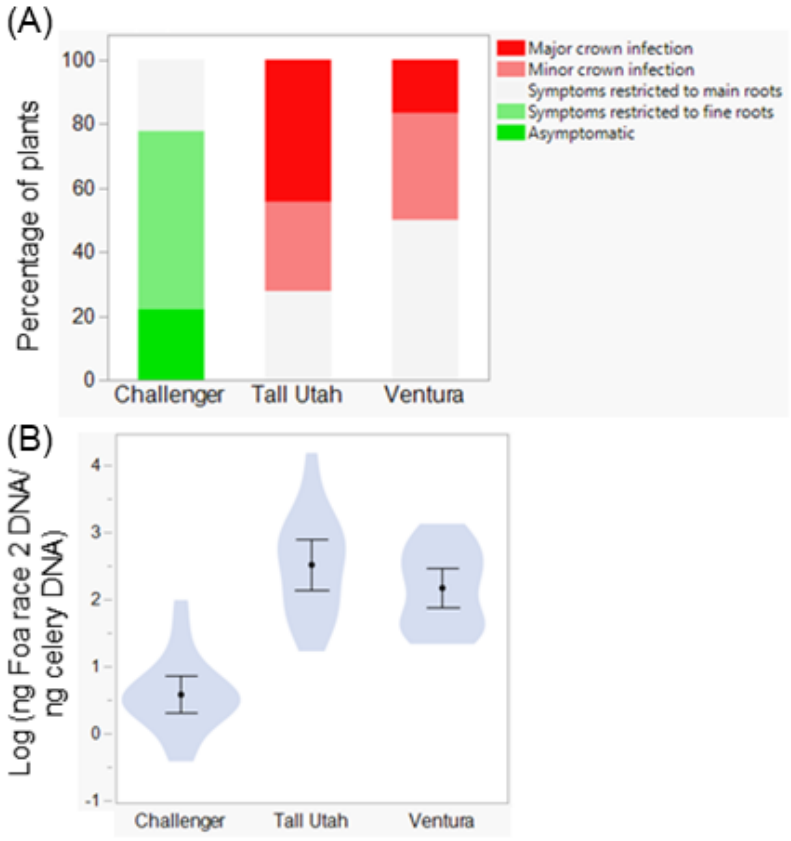

Fig. 11. The effect of *F. oxysporum* f. sp. *apii* (*Foa*) race 2 on three celery cultivars. Two-month-old celery was transplanted in the greenhouse into either unfested soil or soil infested with *Foa* race 2. Plants were evaluated after 58 days. There were 18 and 8 replicates for the infested and uninfested plants/cultivar, respectively. (A) Percentage of plants in infested pots with each of the indicated vascular discoloration-based ratings. None of the uninfested plants were symptomatic (data not shown). (B) The concentration of *Foa* race 2 DNA in celery crowns, expressed on a logarithmic scale as femtograms of *Foa* race 2 DNA/ng of celery DNA. The points indicate the means and the error bars show the 95% confidence intervals. Only four of each of the cultivars from uninfested pots were sampled for DNA; none of those had any detectable *Foa* race 2 DNA (data not shown).

Based on just symptoms, we also compared cv. Ventura to several other cultivars (Fig. 12); not surprisingly, it appears to be on the susceptibility continuum similar to Sonora.

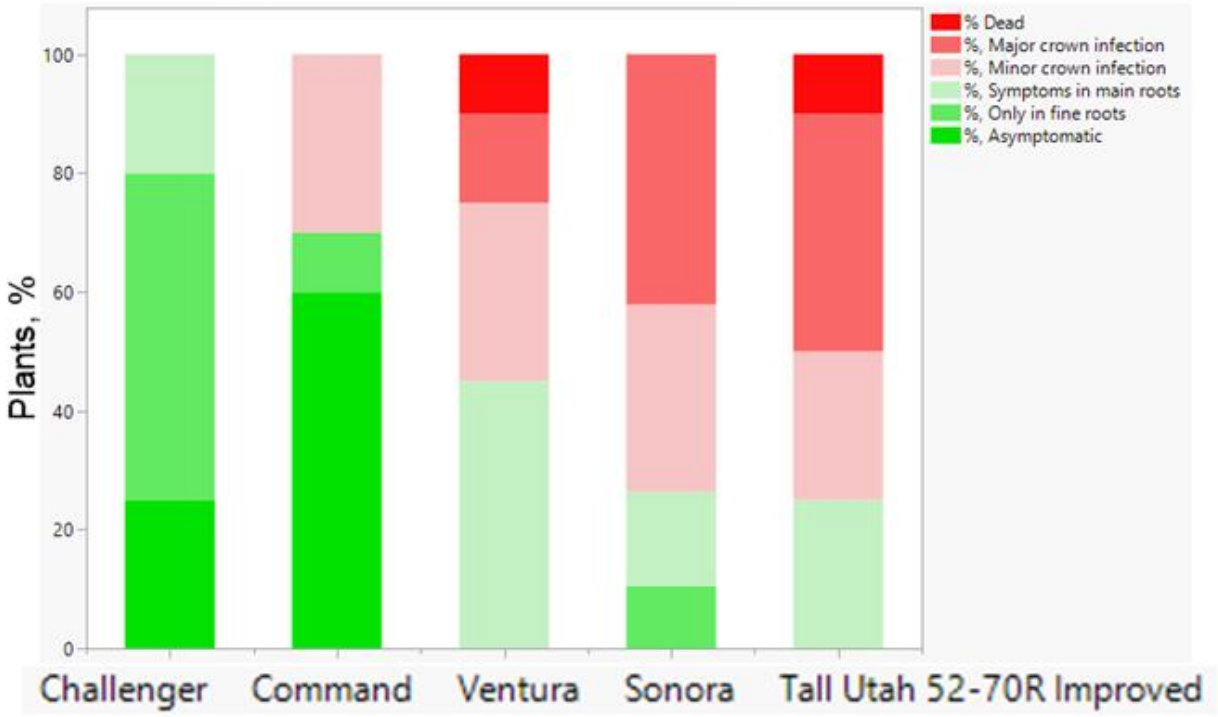

Fig. 12. The effect of *F. oxysporum* f. sp. *apii* (*Foa*) race 2 on five celery cultivars. There were 20 and 8 plants/cultivar in infested and uninfested pots, respectively. None of the plants in uninfested pots were symptomatic (data not shown).

Objective 4*. To write-up our protocols for Foa pathogen-testing, and screening for resistance*. All protocols that were written for this objective will be available on the PIs www site, https://epstein.faculty.ucdavis.edu/ As part of this objective, we quantified the inoculum in our pathogenicity assay in the greenhouse and growth chamber; those data are in Kaur et al. (2022). In addition, our current protocol for quantification of *Foa* race 2 and race 4 in celery crowns is published in Kaur et al. (2022).

Objective 5. *To continue to monitor any spread of the new Foa race 4 in celery fields in California*. As far as we know, *Foa* race 4 is only in Ventura and Monterey counties and only in California. Our current protocols for specific identification of *Foa* races 4 and 2 were published in Henry et al. (2020).

Objective 6. *To investigate the possibility of the expansion of the UCD germplasm collection with additional accessions from the Mediterranean in Europe of the progenitor of celery, Apium graveolens ssp. graveolens, i.e., truly wild Apium graveolens, preferably that is more adapted to higher temperatures.*
We proposed to develop a time-sensitive plan to arrange to obtain collections of *A. graveolens ssp. graveolens* from the Mediterranean region in 2022, However, given 1) the CCRAB decision in Jan. 2021 to transfer the UCD program to the USDA and 2) limitations due to the Covid-19 pandemic,

we concluded that this was not a feasible plan. However, based on our experience of screening the overlapping UCD and USDA collections for resistance to *Foa* race 4, we are convinced that the current collections do NOT have sufficient diversity for selecting germplasm for future CCRAB needs for disease and pest resistance and abiotic stresses such as high temperature. Both collections have a majority of celery accessions; the larger and more genetically diverse UCD germplasm collection (with ca. 322 accessions) has primarily domesticated *A. graveolens* with 53% celery (var. dulce), 24% celeriac (var. *rapaceum*), and 12% smallage.(var. *secalinum*). Only seven percent of the UCD accessions are either in other species in the genus *Apium* or are in related genera; few if any are authentic *A. graveolens ssp. graveolens.* Celery cultivars have extremely little diversity (Wang et al. 2011, Fu et al. 2014), i.e., there is comparatively little chance that untapped genetic potential will be identified in this population. While we previously demonstrated that are many accessions in var. *rapaceum* with resistance to *Foa* race 2, very few accessions in all the collection had resistance to *Foa* race 4, and indeed although there is more genetic diversity between the three domesticated populations, the wild progenitor of all three domesticated populations (*A. graveolens ssp. graveolens)* should have the largest pool of genes of potential value for celery production (Frese et al. 2018). Consequently, we encourage the CCRAB to try to expand the collection of the wild progenitor of celery, *A. graveolens* ssp. *graveolens*, from the warmest locations in the Mediterranean region.

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Grower Summary

Celery Cultivar and Germplasm Evaluations and Field Demonstrations for Observations of Fusarium Yellows Resistance and Crop Performance.

Richard Hurstak, Crop Science Services LLC, Private consultant

Introduction: Fusarium yellows, caused by *Fusarium oxysporum f. sp. apii* can induce stunting and yield reductions based on the level of tolerance or resistance within the individual celery varieties. The soil born disease enters the plant through the root system, damaging the vascular tissue of the host plant. Once damaged, the plant becomes more vulnerable to environmental stresses that often causes the commodity to fail in meeting market quality parameters. Currently, the only viable non-chemical means of controlling losses caused by Fusarium infection is by the use of resistant varieties.

We continued to evaluate several advanced lines, new entries, and current commercially available varieties in the 2021 testing program, with entries from Bejo Seeds Inc., Syngenta Seeds, Rijk Zwaan, Cal Grow, Tozer Seeds Ltd, and UC Davis. Newer hybrid varieties along with open pollinated varieties were planted into a historically Fusarium infested sites in the Santa Maria (race 2) and Oxnard /Ventura (race 4) growing district for evaluation of disease resistance and general crop characteristics observations. A field day was scheduled at each of the trial locations and direct observations were made by growers, celery plant breeders, and other allied celery production personnel.

Celery Research Board Annual Report 2021

Title: Celery Cultivar and Germplasm Evaluations and Field Demonstration for Observations of Fusarium Yellows Resistance and Crop Performance.

Principal Investigator: Richard Hurstak
Crop Science Services LLC
710 River Oaks Dr.
Paso Robles, CA. 93446
(805) 459-6400
Cropscienceservices@gmail.com

Objective: Evaluate current celery cultivars and newly developed germplasm for resistance to Fusarium Yellows caused by *Fusarium oxysporum f. sp. apii* and evaluate crop characteristics important to California celery growers in the Santa Maria Valley and Oxnard / Ventura production regions of California. Establish research trials in one FOA "race 2" and one "race 4" infested fields, schedule field days at each location for direct observations by growers, celery plant breeders, and other allied celery production personnel.

Background: After a greenhouse screening process, the Epstein lab identified one celeriac accession (A0134) with resistance to *Foa* race 4; the accession was also tested in race 4 infested soil in two field trials. To produce F1s, Challenger was crossed with A0134. After the F1 progeny were selected in the greenhouse for resistance to race 4, and selected F1s were selfed to produce F2s, the F2 lines were screened in a Dole-UC field trial in race 4-infested soil. The two best lines in terms of disease resistance, field performance, and potential for celery (rather than celeriac)-type were selected, and then in the field, individuals that appeared to have the best potential for celery-type were selected, and returned to the lab. In the lab, the plants were again assessed for Fusarium and celery-type, and used to produce clones. Not unexpectantly, some of the F2s were resistant and some were not, i.e., resistance was not "fixed." After the clones were tested for race 4 resistance in the greenhouse, individual plants were selected for another round of selfing to produce F3's (Epstein, personal communication 2020).

Establishment Procedures: Seed of varieties in or near market release were requested from cooperating celery plant breeders and private seed companies. Varieties were seeded into transplant trays by Plantel Nursery and grown under commercial production practices until ready for field transplanting. The experimental design at the Santa Maria field location consisted of a randomized complete block with three replications of each variety. Test plots were planted by a commercial crew using a tractor mounted transplanter, in single rows with two plant rows per bed at 7-7.5-inch plant spacing, measuring 40" x 30'. The Oxnard / Ventura field location consisted of a completely randomized design with four replications of each variety. Three individual trials were placed side by side in the field based on breeding developmental stages; CV trial (commercial or near commercial availability), F2 lines, and F3+ lines. Test plots were planted by a hand crew in single rows with two plant rows per bed at 7-7.5-inch plant spacing, measuring 40" x 25'. The trials were planted within the grower's field and managed with the same inputs and growing systems as typical of commercial celery for the region.

Table 1. Santa Maria study details:

Location: Betteravia Farms Ranch 12 Plot 04	
Activity	***Santa Maria***
Seeded	09-Apr
Transplant	10-Jun
Harvest Evaluation	13 thru 16-Sep
Fusarium Pressure	High
Irrigation Type	Sprinkler/Furrow
Transplant Operator	Plantel Nursery Santa Maria
Transplant Grower	Mike Leedom
Field Grower	Tom Minetti
Cooperator	Betteravia Farms

Table 2. List of celery varieties and breeders planted at the Sant Maria trial location.

Variety	**Breeder**	**Variety**	**Breeder**
TZA1	Tozer	76-8-36	UCD
TZA2	Tozer	76-8-15	UCD
TZA3	Tozer	76-8-10	UCD
TZA4	Tozer	76-8-4	UCD
TZA5	Tozer	CG390	Cal Grow
TZA6	Tozer	Sequoia	Cal Grow
E1	Bejo	Enterprise	Cal Grow
E2	Bejo	1001	Rijk Zwaan
E3	Bejo	1002	Rijk Zwaan
E4	Bejo	1003	Rijk Zwaan
E5	Bejo	1004	Rijk Zwaan
E6	Bejo	1005	Rijk Zwaan
E7	Bejo	1006	Rijk Zwaan
E8	Bejo	1007	Rijk Zwaan
E9	Bejo	1008	Rijk Zwaan
Tall Utah 52-70I		Conquistador	

Table 3. Oxnard / Ventura study details all trials.

Location: Rio Farms TJ Ranch	
Activity	***Ventura / Oxnard***
Seeded	17-Jun
Transplant	18-Aug
Harvest Evaluation	15 thru 17-Nov
Fusarium Pressure	Moderate
Irrigation Type	Drip
Transplant Operator	Plantel Nursery Santa Maria
Transplant Grower	Mike Leedom
Field Grower	Danny Pereira
Cooperator	Rio Farms

Table 4. List of celery varieties and breeders for CV Oxnard /Ventura trial location.

Variety	Breeder	Variety	Breeder
TZ7633	Tozer	RF6075	Rijk Zwann
TZ8540	Tozer	49-14RZ	Rijk Zwann
B11	Bejo	Earthrace	Rijk Zwann
B12	Bejo	Lipika RZ	Rijk Zwann
Command			

Table 5. List of celery varieties and breeders for F2 Oxnard /Ventura trial location.

Variety	Breeder	Variety	Breeder
77-41	UCD	76-6	UCD
76-2	UCD	Command	
76-21	UCD	76-8	UCD

Table 6. List of celery varieties and breeders for F3+ Oxnard /Ventura trial location.

Variety	Breeder	Variety	Breeder
76-8-4	UCD	A0134	UCD
76-8-19	UCD	76-8-36	UCD
76-21-6	UCD	76-8-110	UCD
76-8-28	UCD	76-8-27	UCD
Challenger		76-8-15	UCD
Command			

Evaluation Procedures

Celery harvest was conducted as close to commercial harvest timing as scheduling demands allowed. At that time, 10 adjoining plants from the center of each plot were harvested for evaluation (Santa Maria site and CV trial Oxnard / Ventura Site). Plants were dug from the soil with roots intact, soil covering the roots was removed and the roots were trans-sectioned multiple times to determine where Fusarium infection began to affect root color. Plants were

then trimmed, and plant height, weight, color, and ribbiness were evaluated and recorded. The F2 and F3+ Oxnard / Ventura trial location was limited to only evaluating Fusarium scoring on 5 adjoining plants at the ends of each plot. This was a requested change by CCRAB Officers to facilitate a larger selection population for breeding purposes.

Fusarium: The level of Fusarium infection was quantified using the common diagnostic discoloration seen in the vascular tissues of the roots and crown of infected plants. The following rating scale was used based on root discoloration; 0: asymptomatic, 1: visible in fine roots, 2: visible in several roots, 3: visible in most roots slightly affecting crown, 4: clearly visible in crown, 5: crown rotting /dead.

Stalk Weight: Average weight for 10 plants in pounds, commercially trimmed to 14 inches.

Ribbiness: This is a fairly arbitrary rating estimation of the celery petiole texture or smoothness rated from 1 to 3 at harvest. Plants given a rating of 1 are very smooth relative to the current varieties, 2: noticeable ribs, 3: prominent ribs. Fusarium infected plants tend to have a high degree of ribbiness, due to stunted growth.

Color: This scale is based on the relative shade of green coloring exhibited by the celery variety with a rating scale as follows; 1: light green, 2: medium green, 3: dark green.

Height: Plant height in inches from the plant butt to approximately 1 inch above the average length to the first petiole node.

Results

Data analysis was conducted using Gyllings Agricultural Research Management version 9. Mean comparisons were made using Duncan's New MRT at a 5 percent significance level. It must be kept in mind that the trial has a mix of hybrid and open-pollinated varieties that mature at different rates. While data collection occurs on the same dates for all varieties, it generally is not optimum for either of the variety types.

Fusarium Yellows pressure at the Santa Maria Valley trial was once again very high. There was a higher degree of variability in Fusarium scores within the same varieties by replicate than has been generally observed in past trials. Varieties 76-8-36 and TZA1 statistically had the lowest field Fusarium scores. The Ventura /Oxnard trial had moderate Fusarium Yellows pressure, presumably race 4. Fusarium scores were more uniform between replications than was seen in the Santa Maria site. Within the CV trial TZ8540 statistically had the lowest fusarium score. Within the F2 trial 76-21 statistically had the lowest fusarium score. Within the F3+ statistically A0134, 76-8-110, 76-8-19, and 76-8-27 shared the lowest fusarium scores.

Acknowledgments

I'd like to thank the California Celery Research Advisory Board for the financial funding to continue this long-term study and the following individuals and their companies for their assistance during the course of the trial: Mike Leedom and Plantel in Santa Maria; Tom Minetti and Betteravia Farms in Santa Maria, Danny Pereira and Rio Farms, Lynn Epstein and all the

participating seed companies. Without their cooperation and donation of time and space this study would not have been possible.

Figure 1. Celery trial field layout Santa Maria Valley District.

Figure 2. Celery trial field layout Ventura / Oxnard District.

Figure 3. Ventura /Oxnard CV Trial.

Figure 4. Ventura /Oxnard F2 Trial.

Figure 5. Ventura /Oxnard F3+ Trial.

Figure 6. Vascular discoloration caused by Fusarium yellows.

Figure 7. Healthy root system of resistant host plant.

Figure 8. Ventura /Oxnard trial individual variety display.

Table 7. Santa Maria 2021 trial summary of all data:

2021 CCRAB Summer Sant Maria Trial Data Summary

Variety	Fusarium (0-5)		Height (in)		Weight (lbs/10 plant)		Ribbiness(1-3)		Color (1-3)	
76-8-36	0.8	n	15.7	a	9.3	fg	2	cde	3	a
TZA-1	0.9	n	15	ab	22.5	a	1.7	cde	2	ef
76-8-4	1	mn	13.7	a-d	12	efg	2	cde	2.3	cde
76-8-10	1.1	lmn	14.9	abc	9.7	fg	2	cde	3	a
TZA-2	1.3	k-n	15.4	ab	21.7	ab	1.3	ef	2.3	cde
E3	1.4	j-n	12.3	de	21.3	abc	1.3	ef	2.5	bcd
E2	1.4	k-n	12	de	18.5	a-d	1	f	1.8	f
TZA-4	1.9	i-n	11.6	de	16.3	b-e	1.5	def	1.8	f
E5	2	h-m	11.7	de	16.3	b-e	1	f	2	ef
1001	2.1	h-l	13	bcd	18.7	a-d	1.8	cde	3	a
E4	2.1	h-m	12.1	de	19	a-d	1	f	2.2	def
TZA-6	2.2	g-k	12.4	cde	20.8	abc	1.8	cde	2.7	abc
76-8-15	2.2	h-l	11.2	de	8.7	gh	2	cde	3	a
1006	2.3	f-k	14.9	abc	17	a-e	3	a	3	a
TZA-5	2.5	e-j	13.3	a-d	20.2	abc	1.7	cde	1.8	f
E7	2.6	d-i	13	bcd	20.7	abc	2.7	ab	2.3	cde
TZA-3	2.8	d-i	13.6	a-d	19.8	abc	1.5	def	2.2	def
CG390	2.9	c-i	11.8	de	17.3	a-e	2.2	bcd	2.2	def
E1	3	c-h	11.2	de	16	cde	1.5	def	2.8	ab
E6	3.3	b-f	12.3	cde	12.3	efg	1.7	cde	3	a
E9	3.3	b-g	10.3	ef	14	d-g	2.3	bc	2.2	def
Sequoia	3.4	b-f	15.2	ab	21.7	ab	2	cde	3	a
E8	3.5	b-e	12.8	b-e	16.2	b-e	2	cde	2.8	ab
1003	3.6	bcd	11.8	de	14	d-g	2.3	bc	3	a
1004	3.9	abc	13.1	bcd	14.2	def	1.8	cde	3	a
Enterprise	4.3	ab	8.6	f	9.7	fg	3	a	3	a
1002	4.6	a	5.6	g	4.3	hi	3	a	3	a
Conquistador	4.9	a	1.2	h	1.3	i	3	a	3	a
T.U. 52-70-I	5	a	1.7	h	1	i	3	a	3	a
1005	5	a	0	h	0	i	3	a	3	a
1007	5	a	0	h	0	i	3	a	3	a
1008	5	a	0	h	0	i	3	a	3	a

Means followed by same letter or symbol do not significantly differ (P=.05, Duncan's New MRT).

Table 8. Ventura Oxnard 2021 CV trial summary of all data:

2021 CCRAB Fall CV Camarillo Trial Data Summary

Variety	Fusarium (0-5)		Height (in)		Weight (lbs/10 plant)		Ribbiness(1-3)		Color (1-3)	
TZ8540	1.2	g	12.9	bc	14.3	a	1.8	de	2.3	b
Earthrace	1.9	f	16	a	14.5	a	1.3	ef	3	a
TZ7633	2.5	ef	13.6	abc	11.1	bc	2.5	ab	3	a
RF6075	3.1	de	11.5	c	10	bcd	1.1	f	3	a
49-14RZ	3.5	cd	12.8	bc	12	ab	1.9	cd	2.8	a
B12	4	bc	15	ab	8.3	cd	1.8	de	1.9	c
Lipika RZ	4.3	ab	7.5	d	7	d	2.4	bc	3	a
B11	4.8	a	3.1	e	0.8	e	3	a	3	a
Command	4.9	a	2	e	2	e	3	a	2	c

Means followed by same letter or symbol do not significantly differ (P=.05, Duncan's New MRT).

Table 9. Ventura Oxnard 2021 F2 trial summary of all data:

2021 CCRAB Fall F3+ Camarillo Trial Data Summary

Variety	Fusarium (0-5)	
76-21	1.1	c
76-8	2	b
76-2	2.2	b
76-6	2.4	b
77-41	2.7	b
Command	4.8	a

Means followed by same letter or symbol do not significantly differ (P=.05, Duncan's New MRT).

Table 10. Ventura Oxnard 2021 F3+ trial summary of all data:

2021 CCRAB Fall F3+ Camarillo Trial Data Summary

Variety	Fusarium (0-5)	
A0134	0.5	d
76-8-110	0.7	cd
76-8-19	0.8	cd
76-8-27	0.8	cd
76-8-4	1.1	bc
76-8-36	1.2	bc
76-8-15	1.4	b
76-21-6	1.6	b
76-8-28	1.6	b
Challenger	4.3	a
Command	4.5	a

Means followed by same letter or symbol do not significantly differ (P=.05, Duncan's New MRT).

California Celery Research Advisory Board
Annual Report for 2020-2021
Management and Economics of Insect Pests on Celery

Principal Investigator: Dr. Thomas Perring, Department of Entomology
University of California, Riverside, CA 92521
thomas.perring@ucr.edu

Cooperating Personnel: Greg Kund, Department of Entomology
University of California, Riverside, CA 92521
gregory.kund@ucr.edu

Immediate Objectives:

I. Studies to minimize the negative effects of FQPA: Identifying control 'gaps' and finding solutions. Immediate goals are to screen new insecticides for insect control and resistance management programs on celery.

II. Continue economic analyses of IPM approaches developed through the support of the CCRAB using new insecticide chemistries. A comparison between the IPM and a "standardized" chemical approach has been evaluated.

Objective I. Screen new insecticides for insect control

Celery, variety "Command" was transplanted on 3 Nov 2020 at the Agricultural Operations, University of California, Riverside, California (Figure 1A). The plots were three beds wide (two rows per bed on 60" centers) by 40 feet, and were drip irrigated. Four replicates of each treatment were organized in a randomized complete block design. In addition to a non-treated control, a low input treatment had four applications using Exirel® 100SE, Beleaf® 50 SG, Radiant® 1.0 SC, Sequoia® 1.0 SC, and Dipel® DF (Table 1). The next treatment was a rate of Spear®-Lep plus Leprotec® DF, applied six times as a foliar spray with LI-700® used as a surfactant. Next was a rotation of Leprotec® DF, Spea®r-Lep, Radiant® 1.0 SC, Beleaf® 50 SG, Sequoia® 1.0 SC, and Dipel® DF using LI-700® as a surfactant. The 5th treatment Exirel® 100SE plus Beleaf® 50 SG, Spear®-Lep plus Leprotec® DF and Beleaf® 50 SG, Exirel® 100SE plus Sequoia® SC, and Spear®-Lep™ plus Leprotec® DF. The 6th treatment was Minecto® Pro applied three times as an individual treatment. The 7th treatment was an organic rotation of Entrust® SC, Pyganic® 1.4 EC plus Trilogy® EC, and Dipel® DF. The final treatment was the chemical standard of Asana® XL, which was applied six times as a foliar spray. Treatments and spray dates are listed in Table 1.

Figure 1. A is celery field plot at UCR Agricultural Operations in 2020-2021. B is the tractor setup for commercial scale application.

Table 1. IPM Materials Evaluated:

Compound [b]	Formulation	Rate/Ac	MoA [a]	Supplier
1- Control-Non-treated	--	--	--	--
2- Low Input				
a-Exirel	100 SE	13.5 oz	28	Dupont
+ Beleaf	50 SG	2.8 oz	9C	FMC
b-Radiant	1.0 SC	8.0 oz	5	Corteva
+ Beleaf	50 SG	2.8 oz	9C	FMC
c-Exirel	100 SE	13.5 oz	28	Dupont
+ Sequoia	1.0 SC	5.0 oz	4	Corteva
d-Dipel	DF	1 lb	11	Valent
LI-700		0.125%		Loveland
(a=2/11,b=3/4, c=3/19,d=4/2)				
3- Spear-Lep +	--	32 fl oz	32	Vestaron
Leprotec	Btk	16 fl oz	11	AEF Global
LI-700		0.125%		Loveland
(2/11, 3/4, 3/19,4/2)				
4- a-Spear-Lep +	--	32 oz	32	Vestaron
Leprotec	Btk	16 oz	11	AEF Global
b-Radiant 1.0 SC	--	8.0 oz	5	Corteva
+ Beleaf	50 SG	2.8 oz	9C	FMC
c- Spear-Lep +	--	32 oz	32	Vestaron
Leprotec+	Btk	16 oz	11	AEF Global
Sequoia	1.0 SC	5.0 oz	4	Corteva
d-Dipel	DF	1 lb	11	Valent
LI-700		0.125%		Loveland
(a=2/11, b=3/4, c=3/19, d=4/2)				
5- a-Exirel	100 SE	13.5 oz	28	Dupont
+ Beleaf	50 SG	2.8 oz	9C	FMC
b- Spear-Lep +	--	32 oz	32	Vestaron
Leprotec+	Btk	16 oz	11	AEF Global
Beleaf	50 SG	2.8 oz	9C	FMC
c-Exirel	100SE	13.5 oz	28	Dupont
+ Sequoia	SC	5.0 oz	4	Corteva
d- Spear-Lep +	--	32 oz	32	Vestaron
Leprotec	Btk	16 oz	11	AEF Global
LI-700		0.125%		Loveland
(2/11, b=3/4, c=3/19, d=4/2)				
6- Minecto Pro	SC	10.0 oz	28,6	Syngenta
Dyne-amic		0.125%		Loveland
(2/11, 3/4, 4/2)				
7- Organic IPM				
a-Entrust	1.0 SC	8.0 oz	5	Corteva
b-Pyganic +	1.4EC	32.0 oz	4	Valent
Trilogy	EC	64.0 oz		Certis

c-Dipel (a=2/11) (b=2/19, 3/4, 4/2) (c=2/26, 3/19)	DF	1 lb	11	Valent
8- Asana (2/11, 2/19, 2/26, 3/4, 3/19, 4/2)	XL	9.0 oz	1	Dupont

[a] MoA – Mode of Action for insecticide resistance management
[b] Spray dates are included.

IRAC

Using the guidelines established by the Insecticide Resistance Action Committee (IRAC) we are classifying the compounds used in the field trial based on their mode of action (MoA) (see Table 1). The purpose is to assist growers in the development of insecticide resistance management (IRM) strategies. These strategies will improve the effectiveness of IPM programs, slow resistance development, and extend the life of the pesticides. The following language is from the IRAC; additional information and MoA classifications can be found in the IRAC handout or online at www.irac-online.org.

> "Resistance to insecticides may be defined as '*a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species*' (IRAC). This definition differs slightly from others in the literature, but IRAC believes it represents the most accurate, practical definition of relevance to farmers and growers. Resistance arises through the over-use or mis-use of an insecticide or acaricide against a pest species and results in the selection of resistant forms of the pest and the consequent evolution of populations that are resistant to that insecticide or acaricide.
>
> In the majority of cases, not only does resistance render the selecting compound ineffective but it often also confers cross-resistance to other chemically related compounds. This is because compounds within a specific chemical group usually share a common target site within the pest, and thus share a common mode of action (MoA). It is common for resistance to develop that is based on a genetic modification of this target site. When this happens, the interaction of the selecting compound with its target site is impaired and the compound loses its pesticidal efficacy. Because all compounds within the chemical sub-group share a common MoA, there is a high risk that the resistance that has developed will automatically confer cross-resistance to all the compounds in the same sub-group. It is this concept of cross-resistance within chemically related insecticides or acaricides that is the basis of the IRAC mode of action classification".

In our studies, all chemicals were applied by tractor using a tractor-mounted boom sprayer operated at 100 PSI and 100 gal/Ac except the VST treatments, which were applied at 50 gal/Ac (Figure 1B). Four, disc-type cone nozzles per bed incorporated D3 orifice disks, #25 cores, and 50 mesh screens.

Field Counts:

The field was surveyed on 18 March and 13 April for Lepidopteran pests (primarily beet armyworm, (*Spodoptera exigua* (Hübner)) and cabbage looper (*Trichoplusia ni* (Hübner)), leafminer (*Liromyza trifolii*) (Burgess), cabbage aphid (*Brevicoryne brassicae*)(Linnaeus), lygus bug (*Lygus hesperus*)(Knight), greenhouse whitefly (*Trialeurodes vaporariorum*)(Westwood), and earwigs (*Forficula auricularia*) (De Geer) (Figure 2). Five plants from each plot were counted for a total of twenty plants per treatment. In addition to insect presence, insect damage was also assessed.

Of the insects listed we found aphids, Lygus bug, beet armyworm, and earwigs in numbers sufficient to analyze (Figure 3). Statistical differences between treatments were seen for aphids and lepidopterans on 18 March (Figure 4). Field assessments on 13 April showed statistical differences for lepidopterans only.

Figure 2. Insects and damage seen in the Celery IPM Trials at the UCR Agricultural Operations research study. A. Aphids; B. Lygus bug damage; C. Beet armyworm damage; D. Earwig damage.

Figure 3. Field counts level of infestation on 18 March (insects plus damage)

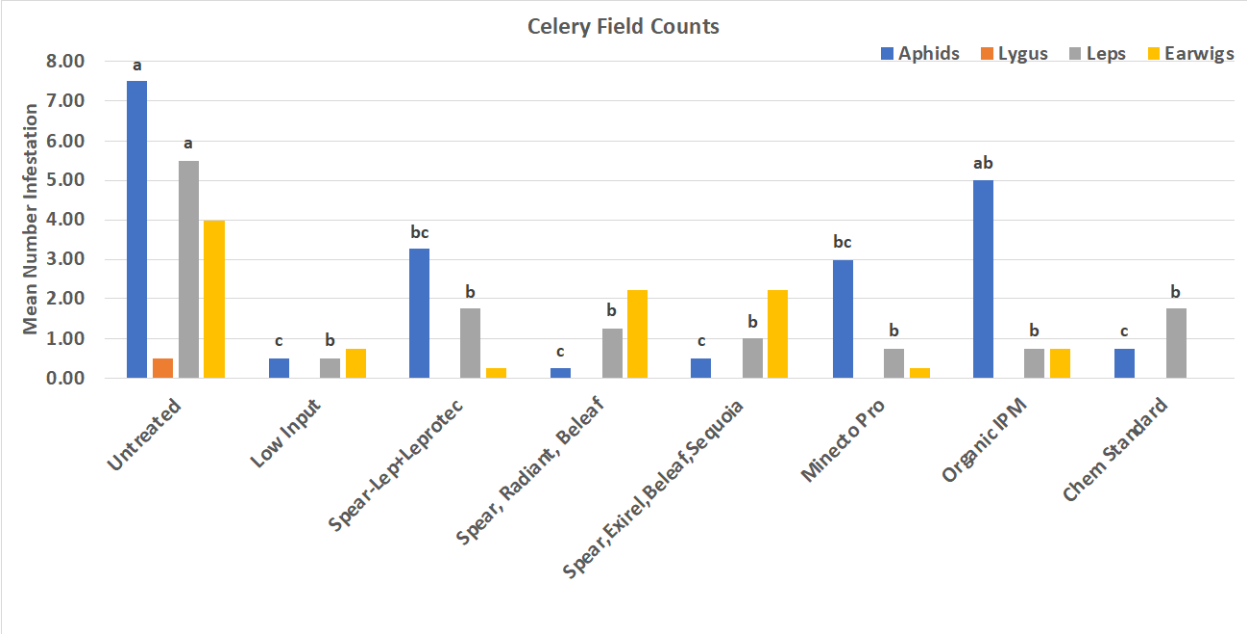
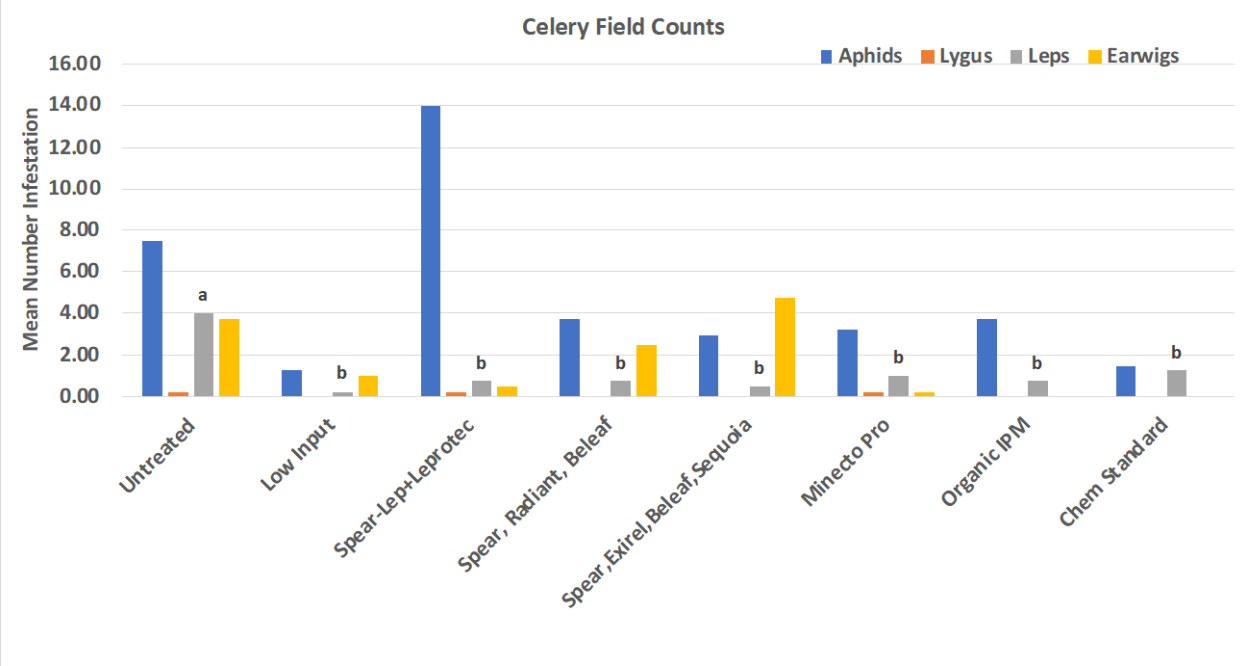


Figure 4. Field counts level of infestation on 13 April (insects plus damage)



Harvest Evaluations:

The field was evaluated at harvest on 16 April. The number of damaged plants found in 25 plants per replicate (4 replicates/treatment) from the center rows of each replicate were counted and recorded. Beet armyworm densities were high in the study; the control suffered 21% (5.24/25plants) damage (Table 2). However due to variability there was no statistical separation of beet armyworm between the treatments. The field trials had high levels of pressure for Lygus bugs and aphids, and the harvest assessment results provided statistical separation between the treatments. Spear®-Lep has been tested in our chemical trials for several years and is a biological product that was tested in IPM rotations as a substitute for Radiant® or Exirel®. Spear®-Lep performed well within the two IPM rotations, which may provide another product to use in rotations to reduce potential pesticide resistance of industry standard products. We also evaluated Minecto® Pro as a stand-alone product to see how it would perform against celery insect pests. Minecto® Pro is a broad-spectrum combination product composed of cyantraniliprole and abamectin. Results showed good efficacy against lepidopterans and lygus pests, but it did not perform as well on aphids. Sequoia® and Beleaf® were used within rotations to target sucking insects such as aphids and Lygus bugs. Both products performed well within their respective IPM rotations against lygus, but they were not effective against aphids. The organic IPM rotation performed well against lygus bugs but was not significantly better than the untreated control for aphid control. The Asana treatment sprayed weekly caused a significant increase in aphid populations; assessments measuring 45% (11.25/25 plants) damage. This situation may occur when aphids become resistant to a product or if beneficial parasitoids and predators are inadvertently killed due to weekly spray applications. Pyrethroid products should be used sparingly within IPM rotations to avoid this situation. Leafminers have not been included because of low pest pressure. Whitefly pressure also was very low. Adults were seen in the field, but nymphal densities were very low. No phytotoxicity was observed in any of the treatments.

TABLE 2. HARVEST MEAN NUMBER OF PLANTS DAMAGED

		Mean Number of Plants Damaged by [a]		
Treatment	**Rate**	**Aphids**	**Beet Armyworm**	**Lygus Bug**
1- Control-Non-treated	--	3.00 c	5.25	6.50 a
2- Low Input		4.75 bc	3.50	3.50 bc
a-Exirel	13.5 oz			
+ Beleaf	2.8 oz			
b-Radiant	8.0 oz			
+ Beleaf	2.8 oz			
c-Exirel	13.5 oz			
+ Sequoia	5.0 oz			
d-Dipel	1 lb			
LI-700	0.125%			
(a=2/11,b=3/4, c=3/19,d=4/2)				
3- Spear-Lep +	32 fl oz	8.00 ab	4.75	4.25 ab
Leprotec	16 fl oz			
LI-700	0.125%			
(2/11, 3/4, 3/19,4/2)				
4- a-Spear-Lep +	32 oz	3.25 c	4.25	2.25 bc
Leprotec	16 oz			
b-Radiant	8.0 oz			
+ Beleaf	2.8 oz			
c- Spear-Lep +	32 oz			
Leprotec+	16 oz			
Sequoia	5.0 oz			
d-Dipel	1 lb			
LI-700	0.125%			
(a=2/11, b=3/4, c=3/19, d=4/2)				
5- a-Exirel	13.5 oz	5.50 bc	3.50	1.50 c
+ Beleaf	2.8 oz			
b- Spear-Lep +	32 oz			
Leprotec+	16 oz			
Beleaf	2.8 oz			
c-Exirel	13.5 oz			
+ Sequoia	5.0 oz			
d- Spear-Lep +	32 oz			
Leprotec	16 oz			
LI-700	0.125%			
(2/11, b=3/4, c=3/19, d=4/2)				
6- Minecto Pro	10.0 oz	6.50 bc	2.75	2.50 bc
Dyne-amic	0.125%			
(2/11, 3/4, 4/2)				
7- Organic IPM		5.50 bc	3.25	2.25 bc
a-Entrust	8.0 oz			
b-Pyganic +	32.0 oz			
Trilogy	64.0 oz			

c-Dipel (a=2/11) (b=2/19, 3/4, 4/2) (c=2/26, 3/19)	1 lb			
8- Asana (2/11, 2/19, 2/26, 3/4, 3/19, 4/2)	9.0 oz	11.25 a	2.25	1.00 c
ANOVA F_{value}		2.965	1.239	4.115
ANOVA P value		0.022	0.321	0.004

[a] Means in columns followed by the same letter are not significantly different ($P < 0.05$, Fisher's Protected LSD).

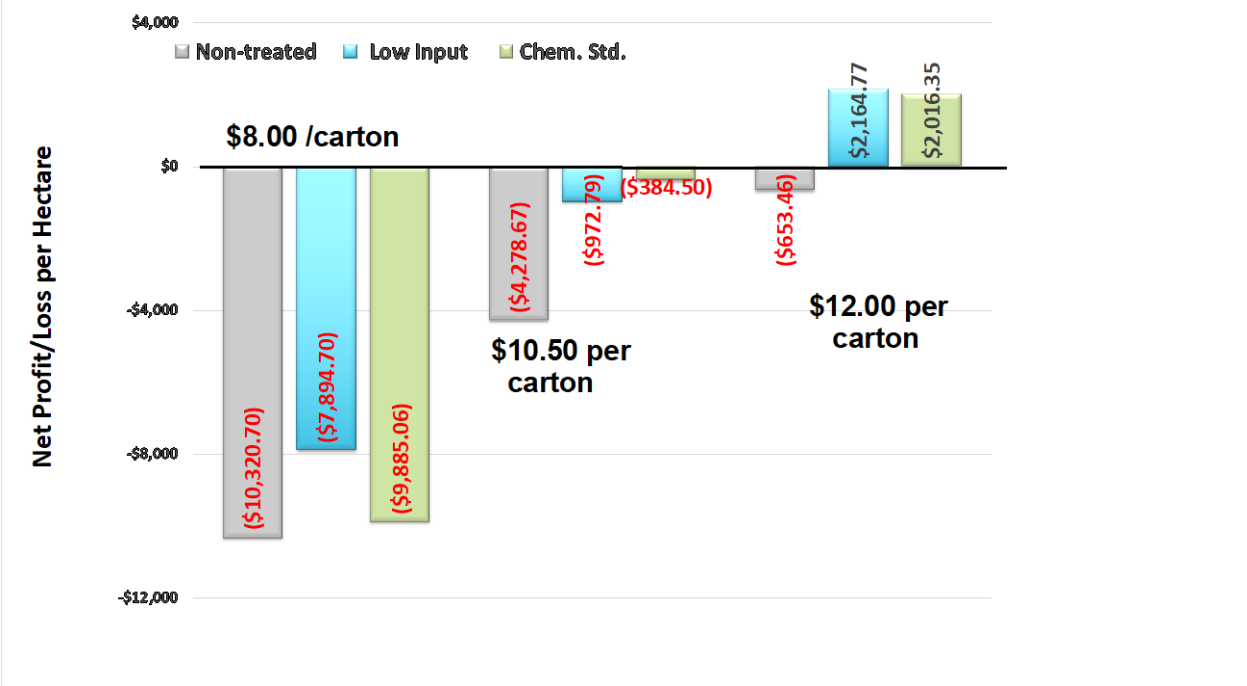
Objective II. Economic Analyses of an IPM and Chemical Standard Trial.

An economic analysis was prepared to compare harvest yields between treatments. Damage to the celery, costs of applications, and material costs were factored into the calculations. Figure 5 shows that the "Low Input" treatment performed the best at $12.00 per carton. The breakeven point for most growers is $10.50 per carton. An adjustment to the economic analysis was done to account for the high level of aphid damage that would have impacted the quality of the celery produced.

For this study, we tested new combinations of products designed to 1) reduce costs, 2) manage insecticide resistance, 3) increase harvest/yield, and 4) provide critical information to regulatory agencies on how products fit within an IPM program. The program consisted of a low input rotation of 1) Exirel®, Beleaf®, Radiant®, Sequoia® and Dipel® versus 2) Asana®. In the IPM plots chemicals were applied 4 times over the course of an 18 week season. In the 'chemical standard' treatment the materials were applied 6 times.

We used very progressive chemical treatments with fewer applications for the low input program. In spite of using chemicals that target specific insects, which in most cases have higher costs per application, we were able to increase net profits for the Low Input IPM program. Other benefits such as environmental effects and worker health and safety aspects are improved in the IPM programs and are necessary to conform with the FQPA. As reported to the Cal EPA, without some pesticidal control, celery damage by insects will be extensive, and losses would not allow a reasonable profit to be made. Thus, some pesticides must continue to be registered for celery for the crop to remain viable in California.

Figure 5. Net profit or loss in IPM, chemical standard, and control treatments in 2020. Numbers associated with each bar are net profits (if numbers are red and in parentheses, they represent net losses).



Celery Residue Concerns

We continued to address the concerns of celery being classified in a consumer advocates publication as part of the dirty dozen regarding pesticide residues. The amount of pesticides used in crop protection in California declined from 1997-2009. Examination of the "Pesticide Use Report" (PUR) from 2018 (web: https://www.cdpr.ca.gov/) shows a trend for the use of more biopesticides, which are generally safer for the environment, workers, and consumers. The goal of current pest management programs is to reduce the amount of pesticide applied, which minimizes environmental, occupational, and consumer exposures.

Future Research

In our 2021 celery field trials we will be utilizing promising compounds that may be included in an IPM program. We will be testing IPM programs against a chemical standard program to continue to identify the most effective and economical pest control strategies. VST-006340 is now registered in California for use on celery as Spear®-Lep and Spear®-T. Spear®-Lep targets lepidopteran control and must be tank mixed with *Bacillus thuringiensis* (Bt) products or another product that assists in moving the active ingredient to the site of activity. Some new insecticide materials are being developed in the industry and some are being tested in laboratory and IR-4 trials. As these products prove to be effective, we will continue to support the registration of these new products for celery use, which will continue to support the goals of the FQPA. We will test Minecto® Pro to determine how it will fit into an IPM program after it showed promising results this past season. Additionally, we will continue to pursue organic treatments that could fit into an IPM program for organic growers.