Project Title: Race diversity and the biology of the spinach downy mildew pathogen
CLGRB Annual Report
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Abstract:

In 2021, spinach downy mildew disease pressure remained relatively low and was similar to the three previous years. A total of 19 races have been described and the disease reactions of the 19 races on the standard set of spinach differentials is included (Table 1). A comprehensive list of isolates, races and novel strains that have been recovered and tested was also included (Tables 2, 3, and 4). In addition, a large collection of commercial spinach cultivars was screened against the contemporary races 18 and 19 and four novel strains (UA202043A, UA202046, UA202048, and UA202105C) of the downy mildew pathogen (Table 5). Results of the disease development in the January-March, 2022 Yuma Spinach Field Trial are also included. The Spinach Field Trial for September-October 2022 is planned and a tentative Spinach Field Day is planned for October 21, 2022.

Objectives

1. We have worked closely with growers, seed company personnel, and PCA's to maintain a service to identify and characterize races of the downy mildew pathogen as they appear throughout the year. This effort is exceptionally labor intensive, but believe it is critical for the industry.
2. Evaluate advanced breeding lines, and newer commercially released material for resistance to new races and novel strains of downy mildew.
3. Establish sentinel plots in Yuma, AZ, to evaluate variety performance based on naturally occurring downy mildew pressure.

Results

Objective 1 and 2

Table 1. Disease reactions of differentials to the 19 races of *P. effusa*.

Race	Viroflay	NIL1	NIL2	NIL3	NIL4	NIL5	NIL6	Pigeon	Caladonia	Meerkat	Hydrus
Pfs 1	+	-	-	-	-	-	-	-	-	-	-
Pfs 2	+	-	-	+	-	-	-	-	-	-	-
Pfs 3	+	-	-	-	-	+	-	-	-	-	-
Pfs 4	+	-	-	+	-	+	-	-	-	-	-
Pfs 5	+	-	-	-	+	+	-	-	-	-	-
Pfs 6	+	-	-	+	+	+	+	-	-	-	-
Pfs 7	+	-	-	+	+	+	-	-	-	-	-
Pfs 8	+	+	-	-	+	+	+	-	-	-	-
Pfs 9	+	-	-	-	+	+	+	-	-	-	-
Pfs 10	+	+	-	+	+	+	+	-	-	-	-
Pfs 11	+	-	+	-	+	+	-	-	-	-	-
Pfs 12	+	+	+	-	+	+	+	-	-	-	-
Pfs 13	+	-	+	+	+	+	+	-	-	-	-
Pfs 14	+	+	+	-	+	+	+	+	-	-	-
Pfs 15	+	-	-	+	-	+	-	-	+	-	-
Pfs 16	+	-	+	-	+	+	-	+	-	+	-
Pfs 17	+	+	+	+	+	+	+	+	+	(+)	-
Pfs 18	+	-	+	+	+	+	-	+	+	+	-
Pfs 19	+	+	+	-	+	+	+	+	-	+	+

* +: >85% plants were susceptible, -: >85% plants were resistant; (+): sporulation was found on cotyledons, but not on true leaves.

Table 2. Isolates tested from January 2020 to May 2021.

Isolate	Host Cultivar	Origin	Date Received	Race ID
UA201951	SVB3719	Winslow, ME	12/18/2019	Pfs 19
UA202001A	172	El Centro, CA	12/30/2019	Pfs 19
UA202001B	El Rio	El Centro, CA	12/30/2019	Pfs 19
UA202001E	Dallas	El Centro, CA	1/3/2020	Pfs 19
UA202003B	El Giga 997	Yuma, AZ	1/16/2020	Pfs 19
UA202004A	Dallas	Yuma, AZ	1/21/2020	Pfs 19
UA202004C	Nevada	Yuma, AZ	1/21/2020	Pfs 19
UA202004D	Cocopah	Yuma, AZ	1/23/2020	not viable
UA202006	El Giga	Yuma, AZ	2/6/2020	Pfs 19
UA202006B	El Giga	Imperial Valley, CA	2/7/2020	Pfs 19
UA202006C	Nevada	Yuma, AZ	2/7/2020	novel
UA202007A	51-367	Yuma, AZ	2/13/2020	Pfs 19
UA202007C	El Giga	Yuma, AZ	2/13/2020	Pfs 19
UA202008A	Cocopah	Yuma, AZ	2/20/2020	Pfs 19
UA202008D	Trailboss	Yuma, AZ	2/22/2020	Pfs17
UA202009E	Trailboss	Yuma, AZ	2/27/2020	Pfs14
UA202009F	Viroflay	Yuma, AZ	2/27/2020	Pfs17
UA202010B	Bandera	Yuma, AZ	3/5/2020	UA202006C
UA202025A	Space/kookaburrra	Falmouth, ME	6/19/2020	UA202025A
UA202027	Nun07542	Salinas, CA	7/1/2020	Pfs14
UA202028	Viroflay	Salinas, CA	7/7/2020	mixture
UA202041B	Kookaburra	Burlington, VT	10/9/2020	not viable
UA202041C	Plymouth	Le Roy, NY	10/9/2020	not viable
UA202041D	SV1714 (SV1)	Le Roy, NY	10/9/2020	not viable
UA202043A	Corvair	Union Bridge, MD	10/21/2020	UA202043A
UA202044A	Auroch	Amherst, MA	10/26/2020	UA202044A
UA202044B	Kookaburra	Gilford, NH	10/28/2020	UA202044B
UA202045	Corvair	Amherst, MA	11/4/2020	Pfs14
UA202046A	Crater	King city, CA	11/13/2020	UA202044B
UA202047		Netherlands	11/18/2020	Pfs 18
UA202048	Kookaburra	Ipswich, MA	11/25/2020	UA202044A
UA202051	Lacerta	Yuma, AZ	12/15/2020	Pfs 19
UA202052	Crater	Yuma, AZ	12/30/2020	UA202044B
UA202004	Crater	Yuma, AZ	1/25/2021	Pfs 19
UA202105B	Nevada	Yuma, AZ	2/2/2021	Pfs 19
UA202105C	Tabit	Yuma, AZ	2/2/2021	Pfs 19
UA202107A	3592	Yuma, AZ	2/24/2021	UA202044A
UA202111A	Trailboss	Yuma, AZ	3/15/2021	Pfs 7
UA202111C	Minkar	Yuma, AZ	3/18/2021	Pfs 4
UA202114A	Lacerta	Yuma, AZ	3/29/2021	Pfs 19
UA202114B	Lacerta	Yuma, AZ	3/31/2021	Pfs 19
UA202117A	Spiro	Salinas, CA	4/20/2021	mixture
UA202117B	Gazelle	Sackets Harbor, NY	4/23/2021	UA202044A
UA202119	Racoon	Santa Barbara	5/5/2021	not viable
UA202119B	Aries	Salinas,CA	5/7/2021	testing

UA202120	Tundra+Sioux	North Easton, MA	5/14/2021	testing

Table 3. Isolates of *P. effusa* evaluated for race phenotype on spinach differentials

Isolate	Host Cultivar	Geographical origin	Race identification	Date Received
UA201723	SV2146 VB	Pasco, WA	Pfs 10	6/9/2017
UA201731B	Mission (262)	King City, CA	Pfs17	8/2/2017
UA201737A	Finwhale	Salinas, CA	UA201621A	9/15/2017
UA201741B	Escalade	Belleville, WI	UA201741B	10/13/2017
UA201741C	Gazelle	Amherst, MA	UA201720B	10/13/2017
UA201746A	El Rio	Buckeye, AZ	Pfs 8	11/15/2017
UA201801A	SV5821VC	Yuma, AZ	UA201801A	1/2/2018
UA201805	Blutto	Uvalde,TX	Pfs 17	1/30/2018
UA201811C	Space	Riverhead, NY	UA201811C	3/13/2018
UA201812B	El Prado	Yuma, AZ	UA201707A	3/22/2018
UA201816	Corvair	Bridgeton, NY	UA201720B	4/17/2018
UA201818B	Serpens	Hollister, CA	Pfs 18	5/2/2018
UA201820A	Tasman	Othello, WA	UA201820A	5/14/2018
UA201820B	Gazelle	Easton, NY	UA201720B	5/17/2018
UA201821A	SV3580 VC	Bowdoinham, ME	Pfs 8	5/21/2018
UA201834	Spoonbill	Salinas, CA	UA201820A	8/21/2018
UA201834B	Bandicoot	Salinas, CA	UA201834B	8/24/2018
UA201838B	Breezer	Salinas, CA	UA201834B	9/18/2018
UA201841A	Shelby	San Juan Bautista, CA	UA201820A	10/11/2018
UA201841B	Viroflay	San Juan Bautista, CA	UA201820A	10/11/2018
UA201843A	PV1525	Salinas, CA	UA201621A	10/24/2018
UA201843BB	PV1501	Salinas, CA	Pfs 14	10/26/2018
UA201847A	Acadia	Windsor, VT	Pfs 12	11/21/2018
UA201847B	Corvair	Windsor, VT	Pfs 12	11/21/2018
UA201843D	El Prado – SP967	Salinas, CA	UA201843D	10/26/2018
UA201843AV	Shelby	Salinas, CA	UA201843D	10/26/2018
UA201851B	Corvair	Amherst, MA	UA201851B	12/14/2018
UA201904	RZ51-359	Bard, CA	UA201904	1/23/2019
UA201908E	Silverwhale	Yuma, AZ	UA201720B	2/21/2019
UA201908L	51-169	Yuma, AZ	Pfs 17	2/21/2019
UA201908M	Shelby	Yuma, AZ	Pfs 17	2/21/2019
UA201913	Escalade	Belle Glade, FL	UA201913	3/25/2019
UA201915	Meerkat	Oxnard, CA	UA201915	4/9/2019
UA201932B	Finwhale	King city, CA	UA201932B	8/8/2019
UA201938A	Fantail	King city, CA	Pfs 17	8/18/2019
UA201938B	Kodiak	King city, CA	Pfs 17	8/18/2019
UA201941A	Cocopah	Salinas, CA	UA201941	10/9/2019

UA201941B	Bonobo	San Juan Bautista, CA	Pfs 14	10/10/2019
UA201941C	Melville	San Juan Bautista, CA	Pfs 14	10/10/2019
UA201946	Viroflay	Salinas, CA	Pfs 16	11/14/2019
UA201951	SVB3719	Winslow, ME	Pfs 19	12/18/2019
UA202001A	172	El Centro, CA	Pfs 19	12/30/2019
UA202001B	El Rio	El Centro, CA	Pfs 19	12/30/2019
UA202001E	Dallas	El Centro, CA	Pfs 19	1/3/2020
UA202003B	El Giga 997	Yuma, AZ	Pfs 19	1/16/2020
UA202004A	Dallas	Yuma, AZ	Pfs 19	1/21/2020
UA202004C	Nevada	Yuma, AZ	Pfs 19	1/21/2020
UA202004D	Cocopah	Yuma, AZ	UA201834B	1/23/2020
UA202006	El Giga	Yuma, AZ	Pfs 19	2/6/2020
UA202006B	El Giga	Imperial Valley, CA	Pfs 19	2/7/2020
UA202006C	Nevada	Yuma, AZ	UA202006C	2/7/2020
UA202007A	51-367	Yuma, AZ	Pfs 19	2/13/2020
UA202007C	El Giga	Yuma, AZ	Pfs 19	2/13/2020
UA202008A	Cocopah	Yuma, AZ	Pfs 19	2/20/2020
UA202008D	Trailboss	Yuma, AZ	Pfs 17	2/22/2020
UA202009E	Trailboss	Yuma, AZ	Pfs 14	2/27/2020
UA202009F	Viroflay	Yuma, AZ	Pfs 17	2/27/2020
UA202010B	Bandera	Yuma, AZ	UA202006C	3/5/2020
UA202025A	Space/kookaburrra	Falmouth, ME	UA202025A	6/19/2020
UA202027	Nun07542	Salinas, CA	Pfs14	7/1/2020
UA202028	Viroflay	Salinas, CA	mixture	7/7/2020
UA202043A	Corvair	Union Bridge, MD	UA202043A	10/21/2020
UA202044A	Auroch	Amherst, MA	UA202044A	10/26/2020
UA202044B	Kookaburra	Gilford, NH	UA202044B	10/28/2020
UA202045	Corvair	Amherst, MA	Pfs 14	11/4/2020
UA202046A	Crater	King city, CA	UA202044B	11/13/2020
UA202047		Spain	Pfs 18	11/18/2020
UA202048	Kookaburra	Ipswich, MA	UA202044A	11/25/2020
UA202051	Lacerta	Yuma, AZ	Pfs 19	12/15/2020
UA202052	Crater	Yuma, AZ	UA202044B	12/30/2020
UA202004		Yuma, AZ	Pfs 19	1/25/2021
UA202105B	Nevada	Yuma, AZ	Pfs 19	2/2/2021
UA202105C	Tabit	Yuma, AZ	Pfs 19 ?	2/2/2021
UA202107A		Yuma, AZ	UA202044A	2/24/2021

Table 4. Disease reactions of differentials to novel strains of *P. effusa*.

Isolate	Viroflay	NIL1	NIL2	NIL3	NIL4	NIL5	NIL6	Pigeon	Caladonia	Meerkat	Hydrus
UA201741B	+	-	+	-	+	-	+	+	-	-	-
201801	+	+	+	+	-	-	+	+	+	-	-
201811C	+	-	+	+	+	+	-	-	-	-	-
201816	+	+	+	-	+	-	+	+	-	-	-
201820A	+	+	+	+	+	+	+	+	+	-	-
UA201843D	+	+	+	+	+	+	+	+	+	-	(+)
UA201851B	+	+	+	-	+	+	+	+	-	(+)	-
UA201904	+	+	-	+	+	+	+	-	-	-	(+)
UA201908E	+	+	+	+	+	-	+	+	+	-	-
UA201913	+	+	+	+	-	+	+	+	+	-	-
UA201915	+	-	+	-	+	+	-	+	-	+	-
UA201946	+	-	+	+	-	+	-	+	+	(+)	-
UA202006C	+	+	+	-	-	+	+	-	-	-	(+)
UA202025A	+	-	+	-	+	-	+	+	-	(+)	-
UA202043A	+	+	+	-	-	-	+	+	-	(+)	(+)
UA202044A	+	+	+	+	+	+	+	+	+	(+)	(+)
UA202044B	+	+	+	+	+	-	+	+	+	(+)	(+)

* +: >85% plants were susceptible, -: >85% plants were resistant; (+): sporulation was found on cotyledons, but not on true leaves.

Table 5. Disease reactions of 70 lines to races Pfs 18, Pfs 19 and five novel strains of *Peronospora effusa.*

Genotype	UA202047 (Pfs 18)	UA202001E (Pfs 19)	UA202043A	UA202046	UA202048	UA202105C
Formax	+	+	-	-	(+)	(+)
Califlay	+	-	-	+/-	+	-
Sculptur	-	+	(+)/-	-	(+)	(+)
Red Kitten	+	+	+	+	+	+
Whale	+	-	-	-	+	-
Riverside	+	-	-	+	+	-
Lakeside	+	-	-	+	+	-
Seaside	+	-	-	+	+	-
Oceanside	-	-	-	+	+	-
C2-606	-	-	-	+	+	-
Houston	-	+	(+)	-	(+)/-	(+)
Arlington	-	+	(+)	+/-	(+)/-	(+)
Cocopah	-	+	(+)	+/-	(+)	(+)
PV1506	-	+	(+)	+/-	(+)	(+)
Viroflay	+	+	+	+	+	+
SP997	-	+	(+)	-	(+)	+
SP999	-	-	-	-	-	-
El Lucio	-	-	-	-	-	-
El Prado	-	+	(+)	(+)	(+)	+
El Rio	-	+	(+)	(+)	(+)	+
Magnetic	+	+	(+)	(+)	(+)	+
5998	+	+	(+)	+/-	(+)	+
Java	+	+	(+)	(+)	(+)	+
Midway	+	+	(+)	(+)	(+)	+
Melville	+	+	+	(+)	(+)	+
SV2146VB	-	+	+	+	+	+
SV2157VB	-	+	+	+	+	+
SV3580VB	-	+	+	+	+	+
SV1864VB	+	-	-	+	+	-
Bylot	-	+	(+)	(+)	(+)	+
Tacoma	+	-	-	-	(+)	-
Kodiak	-	+	+	(+)	(+)	+
Sunangel	-	-	-	+/-	+/-	+
Fantail	+	+	-	(+)	(+)	+
Silverwhale	-	-	-	(+)	+	-
Bonobo	-	+	(+)	(+)	(+)	+
Cabezon	(+)	-	-	(+)	(+)/-	-

Spoonbill	(+)	-	-	(+)	(+)	-
Bandicoot	+/-	+	-	(+)	(+)	+
Finwhale	(+)	+	-	-	(+)	+
Virgo	-	+	-	+/-	(+)	(+)
Volans	-	+	-	(+)	(+)	(+)
Alcor	-	+	(+)	+/-	(+)	+
Regor	+	-	-	-	-	-
Minkar	-	-	-	-	-	-
Nembus	-	-	-	-	-	-
Tabit	-	-	+	-	-	+
Corvus	-	+	(+)	+/-	(+)	(+)
Crater	-	-	-	+	(+)	-
Dracus	+/-	-	-	-	(+)	-
Viroflay	+	+	+	+	+	+
Pawnee	+	-	-	-	-	-
Tundra	-	+	+	+	+	(+)
Escalade	+	-	-	+	+	-
Acadia	-	+	+	+	+	+
Shelby	-	+	+	+	+	+
Yukon	+	-	+	+	+	-
PV1506	-	+	(+)	-	(+)	(+)
2636	+	+	(+)	+/-	(+)	+
Platybus	+	+	(+)	+/-	(+)	+
C7-613	+	-	-	+	+	+/-
Patton	+	+	(+)	+	(+)	+
Reflect	-	+	+	+	+	+
Responder	+	-	-	+	+	-
Trailboss	+	-	-	-	(+)	-
Nevada	-	+	(+)	+/-	(+)	(+)
Laredo	-	+	(+)	(+)	(+)	(+)
Colusa	-	+	(+)	+/-	(+)	(+)
Dallas	-	+	(+)	+/-	(+)	(+)
Bandera	-	+	(+)	+/-	(+)	+

* +: >85% plants were susceptible, -: >85% plants were resistant; (+): sporulation was found on cotyledons, but not on true leaves. +/-: more than 15%, less than 85 plants were susceptible; (+)/-: more than 15%, less than 85 plants had cotyledon infection, but no sporulation was found on true leaves.

Objective 3. Evaluation of spinach cultivars for downy mildew resistance in Yuma, AZ 2022.

Downy mildew (*Peronospora effusa*) is a major constraint to spinach production. The pathogen can produce wind-dispersed spores, and requires cool, wet conditions for infection. Increased canopy density and overhead irrigation create optimal conditions for the pathogen and subsequent spread of the disease. Low levels of disease incidence can lead to unmarketable spinach. Downy mildew is successfully managed with fungicides and resistant cultivars in conventional fields but use of resistant cultivars is the only effective management strategy for organic production, which represents about half of U.S. production. At present, there are 19 described races of *P. effusa*, as well as isolates with novel virulence patterns on spinach differentials. The purpose of this study was to assess resistance to *P. effusa* among commercial spinach cultivars, with a total of 70 cultivars that were rated at the University of Arizona, Yuma Agricultural Center between 11 Jan-16 Mar 2022. Seed was sown on 10-11 Jan, sprayed with Dual Magnum herbicide on 12 Jan. The "wet-date" was 13 Jan. The plots were 15 ft by 6 ft and seed was planted at a density of 4 million seed/A, and beds were about 600 ft in length with three separated replications. Each replication even rows with 10 cultivars per row. The plot was set up as a completely randomized block design. The trial was flanked by a single bed of the cultivar Woodpecker and single bed of a mixture of cultivars. Maximum air temperature ranged from 71-86˚F and minimum from 46˚-55˚F, cumulative rainfall was 0.02 in., and the maximum wind peak was 35 mph. Plants were watered with overhead sprinklers 2-3 times per week for the duration of the experiment. Downy mildew incidence was rated by visually estimating the percentage of plants showing downy mildew symptoms for each of the three replicate plots per cultivar. Mean disease incidence was calculated by averaging the three replications.

y Analysis of variance (ANOVA) was performed (P≤0.05) followed by Post Hoc analysis using Fisher's least significant difference (LSD) test. Mean DI scores with the same letter are not significantly different as determined by Fisher's LSD test (P≤0.05).

Downy mildew disease pressure for this trial originated from naturally occurring inoculum and was first observed on 8 Feb. Disease incidence (DI) was evaluated on 16 Mar when plants were 64 days old. Disease pressure was high as indicated by the DI detected on several cultivars and the overall range of DI was from 0.0 to 96.7%.

Cultivar	Mean disease incidence (DI)		Cultivar	Mean DI		Cultivar	Mean DI	
Red Kitten 1	96.7	a	Bylot	1.7	ij	Longhorn	0.0	j
Red Kitten 2	91.7	a	Tacoma	0.7	ij	Laredo	0.0	j
SV2157VB	86.7	a	Opal	0.0	j	Kona 2	0.0	j
SV2146	63.3	b	Patton	0.0	j	Kona 1	0.0	j
Lakeside	61.7	bc	Pheasant	0.0	j	Kodiak	0.0	j
Revere	51.7	bc	PV-1526	0.0	j	Kiowa	0.0	j
SV2146VB	48.3	bcd	PV-1610	0.0	j	Java 1	0.0	j
606	45.0	cde	PV-1656	0.0	j	Frontier	0.0	j
DS40001	33.3	def	PV-1702	0.0	j	Finwhale	0.0	j
Starfish	28.3	ef	PV-1716	0.0	j	Dracus	0.0	j
SV2157	26.7	f	Quartz	0.0	j	Denton	0.0	j
Avenger 2	26.7	f	3592	0.0	j	Dallas	0.0	j
Avenger 1	23.3	fg	SVVC5998	0.0	j	Crosstrek	0.0	j
Responder	21.7	fg	SVVC6091	0.0	j	Corvus	0.0	j
Viroflay 2	20.0	fgh	SV5883	0.0	j	Colusa	0.0	j
DS30199	18.3	fghi	Tabit	0.0	j	Cocopah	0.0	j
Magnetic 2	8.3	ghij	Thanos	0.0	j	Cabezon	0.0	j
Java 2	8.3	ghij	Traverse	0.0	j	Bandicoot	0.0	j
DS30159	8.3	ghij	Viroflay 1	0.0	j	Bandera	0.0	j
Woodpecker 2	3.3	hij	Woodpecker 1	0.0	j	Baboob	0.0	j
Minikar	3.3	hij	Onyx	0.0	j	7542	0.0	j
1038	3.3	hij	Nimbus	0.0	j	Regor	0.0	j
Magnetic 1	1.7	ij	Nevada	0.0	j			
El Rio	1.7	ij	Mykonos	0.0	j			

[z] Downy mildew incidence was rated by visually estimating the percentage of plants showing downy mildew symptoms for each of the three replicate plots per cultivar. Mean disease incidence was calculated by averaging the three replications.

[y] Analysis of variance (ANOVA) was performed ($P \leq 0.05$) followed by Post Hoc analysis using Fisher's least significant difference (LSD) test. Mean DI scores with the same letter are not significantly different as determined by Fisher's LSD test ($P \leq 0.05$).