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

In 2023-24, spinach downy mildew disease pressure remained relatively low and was similar to the three previous years. A total of 20 races have been described and the disease reactions of the 20 races on the standard set of spinach differentials was re-examined (Table 1). Efforts with the International Working Group Group on Peronospora led to the identifation and press release in conjunction of the UC Extension Service with Dr. Yu-Chen Wang of the formal nomination of race 20 this past year.. Several novel isolates are currently being examined and are being discussed by the IWGP for nomination as new races. However, the IWGP met in October of 2024 and discussed how to proceed with naming several novel isolates. These tests are currently underway. A sentinel field trial was conducted in Yuma Arizona in January-March, 2024 to evaluate naturally occurring disease on 70 varieties. The field trials allow for a real-world test of how varieties hold up to downy mildew.

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. In addition, our lab works closely with the International Working Group on Peronospora (IWGP) by sharing isolates and conducting collaborative ring tests to determine which isolates are nominated for race identification.
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:

Extensive efforts were conducted with a novel isolate of downy mildew that was observed in numberous locations in a collaborative ring-test. The ring test led to the nomination of the deviating isolate as race 20 and the data were released in a joint press release bt the UCCE system and NAKT in the E.U. (Table 1).

Press Release
Denomination of Pe: 20, a new race of downy mildew in spinach

Consistent, clear, and timely communication about new races of the spinach downy mildew pathogen is the common interest and aim of all members of the International Working Group for Peronospora effusa (Pe) (IWGP). The group fosters a uniform evaluation of Pe field isolates in different parts of the world and integrates and evaluates all information about Pe diversity continuously. Many Pe isolates with the same new virulence pattern have been reported from the USA and Europe in 2023, prompting IWGP to denominate race Pe: 20 today.

Race Pe: 20 poses a significant threat to the spinach industry in all parts of the world, and resistance to this new race is important. The stable performance of isolate RZ2331B, found in France, has been confirmed in validation tests by all IWGP members, and renamed as reference isolate Pe: 20. A new differential cultivar was added to the differential set to distinguish Pe: 20 from races Pe: 1 through Pe: 19. Race Pe: 20 is able to infect the differentials NIL 3, 4, 5, and the new differential host cultivar Yakalo.

The IWGP is continuously monitoring the appearance of strains of the pathogen that deviate in virulence from the known races. The virulence patterns of all races are published by the International Seed Federation (ISF) at https://www.worldseed.org/our-work/plant-health/differential-hosts/. In this way the IWGP aims to promote a consistent and clear communication between public and private entities, such as the seed industry, growers, scientists, and other interested parties, about all new races overcoming important resistant factors, that are persistent enough to survive over several years, occur in a wide area, and cause a significant economic impact.

The IWGP is operating internationally and is administered by Plantum located in The Netherlands. The IWGP consists of representatives from spinach seed companies (BASF, Bayer, Bejo, DeSeed, Enza, Pop Vriend Seeds / KWS, Rijk Zwaan, Sakata, Syngenta, Takii, and Vilmorin) and Naktuinbouw, and is supported by public research at the **University of Arkansas**. Spinach researchers over the world are invited to join the IWGP initiative and use the common host differential set to identify new isolates. All denominated isolates and seeds of the differential set are available at Naktuinbouw (The Netherlands).

Table 1. Reaction of the the 20 names races of the downy mildew pathogen, Peronospora effusa. Reaction phenotypes of isolates to IWGP differentials: Resistance is indicated by the symbols - or (-), and susceptibility by the symbol +.

	Viroflay	NIL 5	NIL 3	NIL 4	NIL 6	NIL 1	NIL 2	Pigeon	Caladonia	Meerkat	Hydrus	Yakalo
Pe: 1	+	-	-	-	-	-	-	-	-	-	-	-
Pe: 2	+	-	+	-	+	-	-	-	-	-	-	-
Pe: 3	+	+	-	-	-	-	-	-	-	-	-	-
Pe: 4	+	+	+	-	-	-	-	-	-	-	-	+
Pe: 5	+	+	-	+	-	-	-	-	-	-	-	-
Pe: 6	+	+	+	+	+	-	-	-	-	-	-	-
Pe: 7	+	+	+	+	-	-	-	-	-	-	-	-
Pe: 8	+	+	-	+	+	+	-	-	-	-	-	-
Pe: 9	+	+	-	+	+	-	-	-	-	-	-	-
Pe: 10	+	+	+	+	+	+	-	-	-	-	-	-
Pe: 11	+	+	-	+	-	-	+	-	-	-	-	-
Pe: 12	+	+	-	+	+	+	+	-	-	-	-	-
Pe: 13	+	+	+	+	-	(-)	+	-	-	-	-	-
Pe: 14	+	+	-	+	+	+	+	+	-	-	-	-
Pe: 15	+	+	+	-	-	-	-	-	+	-	-	-
Pe: 16	+	+	-	+	-	-	+	+	-	+	-	-
Pe: 17	+	+	+	+	+	+	+	+	+	(-)	-	-
Pe: 18	+	+	+	+	-	-	+	+	+	+	-	-
Pe: 19	+	+	-	+	+	+	+	+	-	+	+	-
Pe: 20	+	+	+	+	-	-	-	-	-	-	-	+

Additional work has been conducted to examine a collection of commercial spinach varieties to races 18 and 19 as well as a number of deviating isolates (Table 2). Some of these isolates are currently being discussed by the IWGP to determine if they would be nominated for a collaborative ring test and possible race nomination.

Table 2. Disease reactions of 70 lines to races Pe 18, Pe 19 and five novel strains of *Peronospora effusa.*

Genotype	UA202047 (Pe 18)	UA202001E (Pe 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.

A large replicated field trial was conducted in Yuma, Z in 2024 to evaluate downy mildew reactions on 70 spinach varieties from naturally occurring downy mildew inoculum in the region (Figure 1). Disease incidence was evaluated on the 70 varieties and compared for statistical differences in disease incidence (Table 3).

Figure 1. Field trial in Yuma Arizona in 2024.

Evaluation of spinach cultivars for downy mildew resistance in Yuma, AZ, 2024.
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. Disease symptoms initially develop on leaves as marginally yellow, chlorotic lesions, that can become curled and distorted under severe infections. Low levels of disease incidence can lead to unmarketable spinach. Downy mildew is successfully managed with fungicides and resistant cultivars in conventional fields. However, the 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 20 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 70 commercial spinach cultivars, which were rated at the University of Arizona, Yuma Agricultural Center, between 12 Jan–21 Feb 2024. Seed was sown on 10–11 Jan, sprayed with Dual Magnum herbicide on 13 Jan, and the 'wet date' was 12 Jan. The seed was planted at a density of 4 million seed/A. The field plots measured 15 ft by 6 ft, with spinach beds approximately 600 ft in length, across three separate plots or replications. Each replication consisted of even rows with 10 cultivars per row. The plots were set up as a completely randomized block design. Maximum air temperature ranged from 63˚-83˚F and minimum from 32˚-57˚F, cumulative rainfall was 0.02 in., and the maximum wind peak was 36 mph. Throughout the experiment, plants were irrigated with overhead sprinklers 2–3 times per week.

Downy mildew disease pressure for this trial originated from naturally occurring inoculum and was first observed 5 Feb. Disease incidence (DI) was evaluated on 21 Feb when plants were 40 days old. Downy mildew DI was assessed by visually estimating the percentage of plants showing downy mildew symptoms in each of the three

replicate plots per cultivar. 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. 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%.

Table 3. Field evaluation of downy mildew resistance in Yuma, AZ in 2024.

Cultivar	Mean disease incidence (DI)*		Cultivar	Mean DI		Cultivar	Mean DI	
Red Kitten	96.7	a	Cocopah	0.0	h	Onyx 2	0.0	h
SV2157	81.7	ab	Colusa	0.0	h	Opal 1	0.0	h
Racoon	75.0	bc	Corvus	0.0	h	Opal 2	0.0	h
Responder	65.0	cd	Crosstrek	0.0	h	Pathfinder	0.0	h
Revere	58.3	de	Disko	0.0	h	Patton	0.0	h
SV2146VB	53.3	de	Dracus	0.0	h	Prosper	0.0	h
Basson	46.7	e	Escape	0.0	h	PV1452	0.0	h
Kona	20.0	f	Escape 2	0.0	h	PV1514	0.0	h
PV1703	18.3	fg	Evoque	0.0	h	PV-1526	0.0	h
Avengers	16.7	fg	Fantail	0.0	h	PV-1610	0.0	h
Reward	15.0	fgh	Frontier	0.0	h	PV-1664	0.0	h
Viroflay 1	15.0	fgh	GTO	0.0	h	PV1719	0.0	h
Galah	13.3	fgh	Highcountry	0.0	h	Quartz	0.0	h
Trailboss	13.3	fgh	Houston	0.0	h	Skarne/PV-1656	0.0	h
Viroflay 2	10.0	fgh	Jeep	0.0	h	SV1714	0.0	h
Mykonos	8.3	fgh	Kingranch	0.0	h	Tabit	0.0	h
Tasman	8.3	fgh	Kiowa	0.0	h	Thanos	0.0	h
Carmel	6.7	fgh	Larado	0.0	h	Traverse	0.0	h
Kodiak	6.7	fgh	Laredo	0.0	h	Whale	0.0	h
ED1103	5.0	fgh	Magnetic	0.0	h	Wombat	0.0	h
Platypus	3.3	gh	Minkar	0.0	h	Woodpecker	0.0	h
Baboon	0.0	h	Nembus	0.0	h	Yuma	0.0	h
Bandera	0.0	h	Nevada	0.0	h			
Califlay	0.0	h	Onyx 1	0.0	h			

* Downy mildew incidence was rated by visually estimating the percentage of plants showing symptoms in each of the three replicate plots per cultivar. Mean disease incidence (DI) was calculated by averaging the three replications, and DI scores with the same letter are not significantly different, as determined by Fisher's least significant difference (LSD) test ($P \leq 0.05$).