Pathogenic Specialization in *Uromyces phaseoli* in the United States and Rust Resistance in Beans

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ABSTRACT

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Twenty races were identified from single-uredinial isolates of *Uromyces phaseoli* by using 19 differential bean cultivars. Although these races did not include all of those occurring on beans in the United States, a few major races were included. At least 18 of these races differ from any previously described races of this fungus. A major objective of this research was to obtain races that were virulent on bean cultivars with broad rust resistance. Among such cultivars, Aurora, NEP-2, Olathe, and Mexico 309 are susceptible, respectively, to 9, 6, 6, and 3 of these 20 races. A high degree of variability and great potential for races that break host resistance exist in *U. phaseoli*. The most resistant cultivar of more than 400 tested was Compuesto Negro Chimaltenango, which was resistant to all 20 races.

Rust caused by *Uromyces phaseoli* (Reben) Wint. has been among the most destructive diseases of common bean, *Phaseolus vulgaris* L., in the United States in recent years (23). Pathogenic races were first reported for this autoecious, macrocyclic member of the family Pucciniaceae in 1935 (12,22).

Harter and Zaumeyer (13) identified 20 races of *U. phaseoli* in 1941 by using seven differential bean cultivars. Fisher (9) identified 10 additional races in 1952, using the same seven and two additional differentials. Since then, five more races have been identified in the United States (2,25) and about 150 races have been identified from other countries, principally Brazil (2,3), Australia (1), Mexico (7), Colombia (25), and other Latin American countries (5,23). Only 37 of these races are in the series initiated by Harter and Zaumeyer (2,9,13,14,25). The Brazilian races have been assigned numbers with capital letter prefixes designating the geographic area from which they were collected and identified. Most identifications have included the Harter and Zaumeyer (13) differential cultivars with additions, but in two cases, different cultivars were employed in the descriptions (1,7). In one of these two cases (1), races were assigned letter designations to correspond to virulence genes theoretically possessed by the pathogen for each differential cultivar.

The grading scale used to score host reaction has changed over time. Harter and Zaumeyer (13) used a scale of 0–10 for immunity through highest susceptibility. Their grades 3–10 were based on the size of the uredinium. Davison and Vaughan (8) simplified this scale to grades 1, 2, 3, 4, and 5, respectively, for immunity, necrotic lesions, uredinia smaller than 300 μm, uredinia 301–499 μm, and uredinia larger than 500 μm in diameter. They published a grading scale with printed dots about 300 and 500 μm in diameter for use in estimating uredinial diameters. Most subsequent researchers have used Davison and Vaughan's scale, some with modifications. The Harter and Zaumeyer (13) grades of 0–10 for the 35 U.S. races have been converted to the Davison and Vaughan (8) grades of 1–5 (2,25). As a result of her intensive study of bean rust, Ballantyne (1) recommended limiting grade 5 to 500–800 μm and assigning a sixth grade for uredinia larger than 800 μm. Using pure races, she often obtained host-pathogen combinations in which uredinial size fell into two grades. Harter and Zaumeyer (13) indicated that from test to test, "too close agreement must not always be expected, inasmuch as environmental conditions are known to influence the degree of infection."

At the Bean Rust Workshop in Mayaguez, PR, in 1983 (21), a standard grading scale was adopted that included that of Davison and Vaughan (8) plus grade 6 proposed by Ballantyne (1) (Table 1). It was suggested that when several uredinial grades are present, they all be recorded in order of predominance. At the same workshop, participants also adopted a uniform set of 20 differential cultivars to be used in race descriptions.

In spite of the high degree of well-documented variability in *U. phaseoli*, resistance has been an effective control measure. In 1979, Wood and Keenan (24) released pinto cultivar Olathe, which has gained considerable popularity in many pinto production areas because of its rust resistance. In 1975, the International Bean Rust Nursery (IBRN) program was initiated, coordinated by the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia (4). Snap and dry bean rust nurseries are also tested each year at several U.S. locations (20). As a result of these programs, considerable rust-resistant germ plasm has been identified.

All genetic data on rust resistance in beans obtained to date have indicated an oligogenic mode of inheritance (1,16), but it has been theorized that considerable horizontal resistance might be available in already identified germ plasm (15).

The purpose of this paper is to describe 20 races of *U. phaseoli* from the United States. These include the important races of the mid-Atlantic states as well as many with newly identified virulence, which is significant for future resistance breeding efforts.

MATERIALS AND METHODS

Urediniospore collections and single-uredinial isolations. Urediniospore collections were made in bean fields during midsummer to late summer. They came from several locations in Maryland and New Jersey, upper New York State, near Crossville, TN, Petersburg, VA, Belle Glade and Boynton Beach, FL, Arenac, Bay, and Sanilac counties of Michigan, near Northwood and Portland, ND, North Platte and Scottsbluff, NE, and Valentine, TX. Leaves with numerous uredinia were collected and shaken over a large sheet of paper. Urediniospores thus obtained were assigned a number indicating date, location, and sequence of collection (19). Spores were placed in a screw-cap bottle and stored at −18 C until used for inoculations.

These field collections of urediniospores

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were used to inoculate certain differential and other bean cultivars that had broad resistance. Although four races described in this paper often occurred in field collections, the others were minor components in field collections that contained more than one race. These minor component races produced isolated moderate- to large-diameter uredinia on cultivars resistant to the major component in the collection. The frequent occurrence of more than one race in collections of *U. phaseoli* is well documented (1,2,13). Urediniospores were transferred from widely separated, single uredinia with a small artist's brush moistened in 0.1% Tween 20 in sterile water. The brush was repeatedly touched to the uredinium, then painted over freshly opened unifoliolate leaves of rustfree plants of the same cultivar. The resultant first increase from a single uredinium produced enough urediniospores to inoculate five plants in each of 40 or more pots. Whenever inoculum of the single-uredinial isolates was increased, it was done on a cultivar susceptible to only a few races and in greenhouses isolated from other rust-infected plants. Some single-uredinial isolations had to be repeated two or three times before a uniformly virulent, apparently homozygous population of urediniospores was obtained. Uniformity was not assumed until leaves of all inoculated cultivars developed only one reaction type.

Bean cultivars, plant propagation, and inoculation method. Seed of the differential cultivars used by Harter and Zaumeyer (13) and Fisher's (9) Golden Gate Wax were available. Seed of the differentials used by Ballantyne (1) was received from her. Seed of Olathe, Aurora, and other U.S. cultivars was obtained from the appropriate breeder or commercial seed company. Seed of Early Gallatin was obtained from J. V. Groth and the appropriate seed company. Compuesto Negro Chimaltenango (CNC) was obtained from the authors (5) who originally reported its resistance. The remaining cultivars were obtained from the 1979–1980 IBRN.

Five seeds of a single cultivar were germinated in each pot as described earlier (19). All were kept in a rustfree greenhouse until after inoculation and incubation.

Both surfaces of all unifoliolate leaves were inoculated with an unmodified, hand-held spray device described earlier (19). Leaves were inoculated 6–8 days after seeding, when they were 35–65% expanded. Eight single-uredinial isolates were tested on 30 cultivars per trial. One pot of plants per cultivar was inoculated with each isolate. Inoculum was prepared as previously (19) and the concentration adjusted to about 15,000 or 20,000 viable urediniospores per milliliter. All tests were repeated at least three times, including at least one test with each concentration. Inoculated plants were placed in a large greenhouse mist chamber overnight at about 19 C, then moved (after the leaves had dried) to a single greenhouse with the thermostat set at 23 C. All results in this report are from tests conducted in late winter and early spring, when greenhouse temperatures rarely exceeded 27 C and usually remained close to the thermostatic setting.

Rust ratings and selection in differential cultivars. Rust reaction grades were recorded for both surfaces of the leaves of each cultivar on the 15th day after inoculation. The recently adopted grading scale (21) was used with the aid of printed cards similar to those of Davison and Vaughan (8) but to which dots about 0.8 mm in diameter had been added. These cards are available from the author on request. Leaves were tapped to remove excess urediniospores before making the readings. A hand lens was used to aid in determining reactions. Before assigning grades, all leaves were inspected to determine if the host cultivar was segregating, some plants giving one reaction and others giving a different reaction to a particular isolate.

In cases where differential cultivars were segregating for reaction to a particular isolate of the fungus, single plants were selected for at least two generations to obtain homozygosity. At least 20 plants were each inoculated (19) with eight isolates, including those to which the cultivar was segregating. A single plant with the predominant reaction type to all isolates was selected, repotted, and kept until maturity to obtain seed. Results in this report were taken from uniform selections from the cultivars that were originally segregating.

RESULTS

Races identified and their origins and distribution. On the basic set of differentials adopted at the recent Bean Rust Workshop (21), 20 races were identified (Tables 1 and 2). Reactions of only 19 of the 20 recommended differential cultivars are included because the 20th (Mountaineer White Half

Table 1. Reactions of differential bean cultivars to races 38 through 47 of *Uromyces phaseoli*

Differential cultivar[a]	Reaction[b] to pathogenic race									
	38	39	40	41	42	43	44	45	46	47
a. U.S. 3	2^+,2,3/3	2^+,2,3/3	5,6,4	5,4,6	5,4,6	5,4,6	5,4,6	4,5/2^{++c}	5,4,6	4,5/4,3
b. C.S.W. 643	2	2	5,4	3,2/3,4,2^+	3/3,4	3	3/3,4	3,4	3,4	3
c. Pinto 650	2,3/3,4	3,2	6,5	6,5	5,6	6,5/5,6,4	5,6/6,5	5,6	5,6,4	5,6,4
d. K.W. 765	2,2^+	2,2^+	5,4	2^+,2,3	5,4	2^+,2	3,4	3,4/3,2^+	3,4	3/2^+,3
e. K.W. 780	2^+,2^{++},2^c	2^+,2^{++},2^c	2^+,2^{++c}	5,4,6	5,4,6	5,4,6	2^+,2^{++c}	5,6/6,5	5,6/6,5	5,6/6,5
f. K.W. 814	2	2	5,6,4	5,4/4,5	4,3,5	3	4,5,3	3/2,3	3,4	3
g. Golden Gate Wax	2^+/3,4^c	6,5	2^+,2^c	2^+,2^{++c}	2^+,2^{++c}	2^+,2^{++c}	2^+,2	1	4,5/5,4	2,2^+
h. Early Gallatin	6	6	2^+,2	4,5	4	4,5	2^+,2	4,5	4,3,5	4,3
i. Redlands Pioneer	2	2	2^+,2	4,3	3	3,4	2^+,2	4	4,3	4,5,3
j. Ecuador 299	1	1	2	2	2	3/3,4	4,5/5,6	3	3	3
k. Mexico 235	1	1	2	2/2,3	2	2^+,3/3,2^+	5,6,4	3,2/3	3,2/3	3,2/3,4
l. Mexico 309	2	2	3,2/3	3,2/3	3,2/3	3,2/3	3,2/3	3,2/3	3,2/3	3,2/3,4
m. Brown Beauty	6,5	6,5	5,4	4,5	4	4/4,5	2^+,2	4,3,5	4,3,5	4,3,5
n. Olathe	2,2^+	2,2^+	2^+,2	2,2^+	3,4	2,2^+	2,2^+	2/2,3	3,2/2,3	2
o. A × S 37	2	2	2/2,3	2,2^{+c}	2/2,3	2^+,2^c	3,4/4,3	2,2^+/3	4,5/5,4,6	2,3/3
p. NEP-2	2	2	2	2	2	2	3,2/3,4	4,5/5,4,6	5,4,6	4,5/5,4
q. Aurora	2^+,2	2^+,2	2,2^+	2,2^+	2	4,5/5,4,6	4,5/5,4,6	4,5/5,4,6	4,5/5,4,6	4,5/5,6
r. 51051	2	2	2,2^+	2,2^+	2	5,6,4	4,5/5,4	3/3,4	3	3/3,4
s. CNC	1	1	2,3/3,2	2,3/3	3,2/3	3,2/3	3,2/3,4	2,3/3	2/3	1

[a] U.S. = United States, C.S.W = California Small White, K.W. = Kentucky Wonder, A × S 37 = Actopan × Sanilac Selection 37, CNC = Compuesto Negro Chimaltenango.

[b] Reaction grades: 1 = immune, 2 = necrotic spots without sporulation, 2^+ = necrotic spots 0.3–1 mm diameter, 2^{++} = necrotic spots 1–3 mm diameter, 3 = uredinia less than 0.3 mm diameter, 4 = uredinia 0.3–0.5 mm diameter, 5 = uredinia 0.5–0.8 mm diameter, and 6 = uredinia larger than 0.8 mm diameter. Where a slash is given, the numerator is for the adaxial leaf surface and the denominator is for the abaxial leaf surface. Where several figures are given, they are listed in order of predominance, from most to least.

[c] Some of the larger necrotic spots contained a small uredinium.

Runner) reacted to all races identically to Kentucky Wonder No. 780.

Race 38 was the most frequently isolated race from snap beans. It has been isolated during the past 10 yr from collections from Maryland, New Jersey, New York, Virginia, Tennessee, Michigan, and Florida. Race 39 was found together with race 38 in collections from snap beans in Maryland, Virginia, and Florida. These two races are readily distinguished on Brown Beauty and Golden Gate Wax (Table 1); the latter was used as a source for single uredinia to separate them. Races 38 and 39 were first collected together by J. P. Meiners in 1973 and have previously been referred to as collection 73-16 (17). Many snap bean cultivars react the same as Early Gallatin (Fig. 1A) to these and most other races (17). Races 38 and 39 also differ from the other races described in that teliospores do not develop when infected plants are kept in the greenhouse for three or more weeks after inoculation.

Races 40 and 41, isolated from collections 73-23 and 73-32, respectively, were occasionally found in Maryland and New Jersey. Race 40 has also been found in collections from Michigan, North Dakota, and Nebraska. Race 41 has been isolated from collections from Virginia, New York, and South Carolina. These races are easily distinguished from one another and the other races by the reactions of the differential cultivars (Tables 1 and 2).

Race 42 has only been isolated from collection 79-4 from Belle Glade, FL. It produced small uredinia on Olathe but not on Ecuador 299, which distinguished it from the other races producing small uredinia on Olathe. It produced large uredinia on Dade but was easily differentiated from McMillans race 35 (14) on C.S.W. 643.

All remaining races described produced large uredinia on one or more of cultivars Aurora, NEP-2, Olathe, and Mexico 309, which have been resistant in U.S. rust nurseries (20). These cultivars have been recognized as being among the most rust-

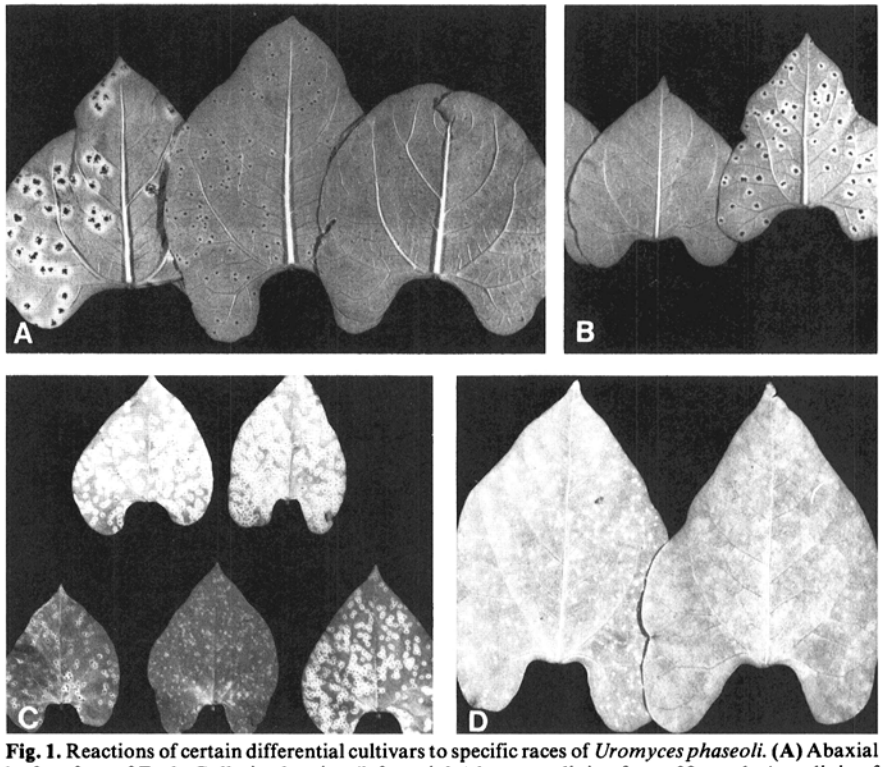

Fig. 1. Reactions of certain differential cultivars to specific races of *Uromyces phaseoli*. **(A)** Abaxial leaf surface of Early Gallatin showing (left to right) large uredinia of race 38, grade 4 uredinia of race 53, and necrotic reaction to race 50. **(B)** Abaxial surface of Ecuador 299 with (left) barely visible grade 3 uredinia of race 50 and (right) grade 5 uredinia of race 51. **(C)** Adaxial surface of Olathe showing (clockwise from upper left) large uredinia with distinct halo of races 53 and 52, nearly same size uredinia with faint halo of race 55, slightly smaller uredinia with faint halo of race 54, and large uredinia with distinct halo of race 56. **(D)** Adaxial surface of Mexico 309 showing (left) grade 3 uredinia and chlorotic spots of race 52 and (right) tiny necrotic spots from race 56.

Table 2. Reactions of differential bean cultivars to races 48 through 57 of *Uromyces phaseoli*

Differential Cultivar[a]	Reaction[b] to pathogenic race									
	48	49	50[c]	51	52	53[c]	54	55	56	57
a. U.S. 3	5,6	5,6	5,4,6	2^{++},2^{+d}	5,6,4/6,5,4	5,6,4/6,5,4	6,5,4	6,5,4	5,6,4/6,5	6,5
b. C.S.W. 643	3,4	3	3,4	5,6,4	3,4,2^{+}	6,5	3,4,2^{+}	4,3,2^{+}/4,5,3	3,2^{+}/3,4,2^{+}	5,4
c. Pinto 650	5,6/6,5	6,5	5,6	5,6/6,5	6,5/5,6	6,5	6,5	6,5/5,6	5,6	6,5
d. K.W. 765	4,3	3/3,2	3,4	4,5,3/2^{+d}	4,5,3/5,4	4,5/5,4	4,5,3/5,4	5,4,6	4,5,3/5,4	5,4
e. K.W. 780	2^{+},2^{++d}	2^{+},2^{++d}	2^{+},2^{++d}	2^{+},2^{++d}	5,6,4/6,5,4	5,6,4/6,5,4	2^{++},2^{+d}	5,6,4/6,5	5,6,4/6,5	5,6
f. K.W. 814	4,5,3	4,5,3	4,5,3	3	5,4	5,4,6	5,6	5,4	4,5/5,4	4,5/5,4
g. Golden Gate Wax	4,5/5,4	4,5/5,4	5,6,4	2	4,5	4,5/5,4	5,4/5,6	4,5	4,5/5,4	4,5/5,4
h. Early Gallatin	2^{+},2	2^{+},2	2^{+},2	2^{+},2	4,3/4	4/4,5	2^{+},2	4/4,5	4,3/4	4,5
i. Redlands Pioneer	4,5	4,5	4,3	2^{+},2	3,4	4,3/4	3,2	3,4	3,2	4,5
j. Ecuador 299	3	3,4	3	4,5/5,6	2	2	2	2	2	2
k. Mexico 235	3	2	2	5,6,4	2	2	2	2	2	2
l. Mexico 309	3,2/3	5,6,4	4,5/5,6,4	4,5/5,6,4	3,2/3	3,2/3	3,2/3	3,2/3	2/2,3	3,2/3
m. Brown Beauty	4,3,5	4,5	2^{+},2	2^{+},2	4,3	4,3	2^{+}	4,3	4,3	4/4,5
n. Olathe	3,4	3,2/3,4	3,4	2	6,5,4	6,5	5,4,6	5,6,4	6,5,4	5,6
o. A × S 37	5,4/5,6	2,2^{+}/2,2^{+},3	2,2^{+}/3,2,2^{+}	2,2^{+}/3,2	2,3	2,3/3,2	2,2^{+},3/2^{+},3	2,3/3,2	2/2,2^{+},3	2,2^{+}/3,2
p. NEP-2	4,5/5,4,6	5,4/5,4,6	4,5/5,4,6	3	2	2	2	2,2^{+}	2	2,2^{+}
q. Aurora	4,5/5,6	5,4/5,6	5,4,6	5,4/5,4,6	2,2^{+}	2,2^{+}	2,2^{+}	2,2^{+}	2,2^{+}	2,2^{+}
r. 51051	3/3,4	5,4,6	4,5/5,4	4,5/5,4,6	2,2^{+}	2,2^{+}	2,2^{+}	2,2^{+}	3,2	2^{+},2
s. CNC	1	3	3	3	3,2/3,4	3,2/3	3,2/3	3,2/3	3,2/3	2,3

[a] U.S. = United States, C.S.W. = California Small White, K.W. = Kentucky Wonder, A × S 37 = Actopan × Sanilac Selection 37, CNC = Compuesto Negro Chimaltenango.

[b] Reaction grades: 1 = immune, 2 = necrotic spots without sporulation, 2^{+} = necrotic spots 0.3–1 mm diameter, 2^{++} = necrotic spots 1–3 mm diameter, 3 = uredinia less than 0.3 mm diameter, 4 = uredinia 0.3–0.5 mm diameter, 5 = uredinia 0.5–0.8 mm diameter, and 6 = uredinia larger than 0.8 mm diameter. Where a slash is given, the numerator is for the adaxial leaf surface and the denominator is for the abaxial leaf surface. Where several figures are given, they are listed in order of predominance, from most to least.

[c] On differential cultivars a through f, race 50 is the same as Harter and Zaumeyer's (16) race 3 and race 53 as their race 13.

[d] Some of the larger necrotic spots contain a small uredinium.

resistant beans (1,4,15,17). These races were minor components in mixed collections of urediniospores.

Races 43 through 51 are virulent on Aurora (Tables 1 and 2). Race 43, obtained from collection 75-22 from Arenac County, MI, was the first isolate with virulence on Aurora. It was also obtained from a New Jersey collection. It is the only one of these nine races that did not produce uredinia larger than 0.5 mm on Ecuador 299 (Fig. 1B), Mexico 235, Mexico 309, or NEP-2. Race 44 produced large uredinia on Mexico 235. It was distinguished from race 51, which was also virulent on Mexico 235, by the reactions of many of the differential cultivars. Races 45 through 50 were virulent on NEP-2. Of this group, individual races were most clearly distinguished by the reactions of 780, 814, Golden Gate Wax, Early Gallatin, Mexico 309, Brown Beauty, A × S 37, and CNC. The reactions of Brown Beauty and U.S. 3 distinguished races 49, 50, and 51, which were the only races virulent on Mexico 309.

Races 52 through 57 were virulent on Olathe, a recently released U.S. pinto cultivar (24) (Fig. 1C). Olathe is still resistant in most bean-growing areas, although there have been a few unpublished reports of its rusting in the field. Race 53 was clearly separated from the other six races on C.S.W. 643. The reactions of 780, Early Gallatin, and Brown Beauty could be interpreted as an indication that race 54 is the most distantly related among the races virulent on Olathe. The differences among races 52, 55, 56, and 57 were less striking. Race 55 produced slightly smaller uredinia than races 52 and 56 and no halo on Olathe (Fig. 1C) but uredinia larger than 0.5 mm on the abaxial leaf surfaces of C.S.W. 643. Race 55 also differed from the others on pinto cultivar Scout, on which it produced predominantly grade 4, some grade 5, and a few grade 3 uredinia. Race 53 produced (from most to least) grades 6, 5, and 4 and the other races produced grades 3 and 4 on Scout. Race 56 was distinguished from the other Olathe races on Mexico 309 (Fig. 1D). The necrotic reaction predominated on Mexico 309 with race 56, but small uredinia predominated with the other races. Race 56 also differed from races 52, 55, and 57 by producing small uredinia on 51051. Race 57 produced somewhat larger uredinia than the other Olathe races on Redlands Pioneer. Race 57 produced a reaction like races 50 and 51 on A × S 37. This reaction differed in the relative proportion of small uredinia to necrotic spots from that produced by the other Olathe races.

Races 44, 50, 51, 52, 54, and 55 were all obtained from a single collection from Pinto 111 made at Portland, ND, in 1979. Races 45, 46, and 47 all came from a single collection from Aurora made in Belle Glade, FL, in 1979. Races 48 and 49 are from a 1982 collection from North Platte, NE. Race 54, which was also present in the Portland, ND, collection, and race 57 were obtained from a 1981 collection from cultivars San Juan Select and Pinto 111 made in Valentine, TX. All of these races occurred as minor components in the indicated collections. Race 56 was a larger component (about 50%) of a 1982 collection from White Seeded Blue Lake snap bean made near Crossville, TN. Race 52 was also identified in single-uredinial isolates from a 1975 collection from Sanilac County, MI, and a 1981 collection from Forest River, ND. Race 51 also occurred in a 1982 collection made near Hatton, ND.

Comparisons with previously reported races. When races 38 through 57 were tested on Ballantyne's (1) differentials, only races 38 and 39 gave reactions corresponding to those of any of her races, being similar to her respective races h and ch. Races 38 and 39 also resemble her h and ch in not producing teliospores. She reported, however, that cultivar Sanilac was susceptible to all of her races, including h and ch. Sanilac is susceptible to most of the races in this report but immune to races 38 and 39.

When races 38 through 57 were compared with the 31 Mexican races (8), the major problem encountered was segregation for reaction in the tested populations of Guerrero 9, Mexico 6, Mexico 12, and Veracruz 10. Nevertheless, reactions of the remaining Mexican differentials were uniform and these were sufficient to distinguish races 38 through 57 from all of the Mexican races.

Included with the differentials used were Cuva 168N, Canario 101, Bountiful 181, Pinto 111, and Mulatinho A, which have been used as differentials in certain other race descriptions (3,13,25). All were tested with races 38 through 57. Among these, Canario 101 reacted identically to Early Gallatin and Pinto 111 reacted identically to Pinto 650 with all 20 races. Bountiful 181 was not a good differential for these races, giving 4,5 or 5,4 infection grades with all but 38 and 39, to which it gave 5,6/6,5. Cuva 168N and Mulatinho A varied from immune to susceptible, depending on the race.

The closest resemblance among any of the 20 races in this report and any of the South American races occurred with certain Brazilian Viçosa races (2,3). Their races V-13 and V-29 have considerable resemblance to races 48 and 41, respectively. However, V-13 appeared distinctly less virulent than race 48 on C.S.W. 643 , and V-29 was more virulent than race 41 on Golden Gate Wax. The closest similarity was between V-21 and race 56; the only difference between them was production of small uredinia on the adaxial surfaces of leaves of C.S.W. 643 by 56 but not by V-21.

None of the races described here correspond to the six isolates from Minnesota and Wisconsin described by Groth and Shrum (11) in 1977. Groth's Early Gallatin accession reacted identically to those from commercial companies to each race.

Two races in this report are similar to two of the first 35 U.S. races. Without the original races 3 and 13 for comparison, my respective races 50 and 53 cannot be positively distinguished from them by Harter and Zaumeyer's (13) differentials. Race 50 seemed to produce somewhat smaller uredinia than race 3 did on 814. For Harter and Zaumeyer (13), race 13 produced a reaction graded 9 on a scale of 10 on C.S.W 643, but race 53 produced a highly susceptible (probable 10) reaction on this cultivar. Harter and Zaumeyer (13) also tested the first 14 of their races on a large number of commercial cultivars, some of which are still available. Races 50 and 53 differed from races 3 and 13 on a few of these cultivars. Race 50 produced necrotic spots and no sporulation on Stringless Green Pod, in contrast to the reported grade 8 uredinia of race 3. Race 53 produced uredinia that were smaller on Perry Marrow and larger on Swedish Brown than those reported for race 13. Race 50 was virulent on Mexico 309 and Aurora and produced small uredinia on Olathe (Table 2). Race 53 was virulent on Olathe. Races 50 and 53 are considered new races in this report on the assumption that they are different from races 3 and 13 in their virulence on Mexico 309, Aurora, Olathe, or some of the other new differentials used here and that they may be different on 814 and C.S.W. 643. Race 50 is also likely to be a new race because only a few years ago, Mexico 309 (to which it is virulent) was considered resistant to all races (1,15).

Resistance to races 38 through 57. More than 400 cultivars and breeding lines of *P. vulgaris* have been tested for reaction to races 38 through 57. These included all of those listed as having broad resistance by several previous authors (1,3,4,5,15) as well as all of the most resistant entries in the various rust nurseries (4,20). Only CNC is resistant to all of these races. A breeding line from CIAT, V3249-13-1C, was nearly as resistant as CNC. It was slightly less resistant than CNC to race 44, developing predominantly grade 4 uredinia. Pinto Serrano produced predominantly grade 4 uredinia with many of these races but none larger than 0.5 mm.

Several cultivars or lines were resistant to most of the 20 races in this report. IAN 5091 was immune to most races but developed grades 5,4 uredinia with race 50. Parana developed a grade 3,4 reaction with many of the races, but 4,5,3 with race 53. Zamorano 2 and S-434 developed large uredinia only with races 44 and 47. Several cultivars or lines had reactions to these races identical to those of Mexico 309. These included B-190 and BGF 1458,

Agrorrico Ag 495, and Rajado Ag 496 from Brazil.

Selected differential cultivars. When U.S. 3, C.S.W. 643, and Brown Beauty, as well as several of the Australian differentials, were originally tested with some of the races described in this report, segregation was found for their reactions to certain pure races in the host populations. After two generations of single-plant selection, the reactions of these cultivars were apparently homozygous. Results in this report were obtained on these selected strains of the original cultivars.

DISCUSSION

There is an acute need for rust resistance of both snap and dry beans in the United States. Pathogenic specialization in *U. phaseoli* is well recognized; additional evidence of the high degree of this variability is reported. Breeding procedures involving gene pyramiding, multilines, or horizontal resistance have been suggested for obtaining stable rust resistance in beans (6). Although all resistance investigated so far has proven to be oligogenic (16), several cultivars tested here were previously thought to have broad, perhaps horizontal and polygenic, resistance. Recently (18), however, resistance of Mexico 309 and its derivative, B-190, was found to be controlled by a series of linked monogenic dominant factors, one per race. If additional independent series of linked resistance genes could be identified, it may be possible to combine them to give the resultant cultivars more than one gene for resistance to most races. Bean rust may be adaptable to such an approach because of the range of reactions by which resistance is expressed and that can be detected in segregating populations. These include immunity, several distinct and constant types of hypersensitive necrotic reactions, and small uredinia. For definitive studies of resistance to such a variable pathogen, the homozygous pathogen races described in this paper are very useful. Such well-defined races, available to breeders and geneticists on a continuing basis, are needed to establish the relationships among resistance genes identified in various cultivars. Urediniospores of each of the races described in this paper have been stored in liquid nitrogen.

Several of these races have already been used in studies of the genetics of resistance. Grafton et al (10) used races 44 and 52 and I used races 39, 40, 41, 42, 43, 44, 45, 46, 50, and 52 (18).

Virulence of certain of these new races on Ecuador 299, Mexico 235, Mexico 309, Olathe, A × S 37, NEP-2, Aurora, and 51051 indicates that these cultivars have vertical, and thus probably monogenic, resistance to the numerous races to which they are resistant. The bean rust fungus has great potential to overcome such resistance because of the occurrence of genetic recombination through completion of the life cycle on a single host and the high populations of urediniospores available for mutation (22). The frequent occurrence of mixed collections indicates a high degree of natural diversity. Many such collections have been obtained from Pinto 111, a cultivar susceptible to all of these races except 38 and 39. The number of new races obtained that broke relatively broad resistances was relatively large, indicating that races breaking newly identified sources of resistance can be readily identified by continual monitoring and testing of field collections.

Only a few of these new races have been found frequently enough to be considered major components of current bean rust epidemics. In fact, the reactions of Aurora, NEP-2, Olathe, and Mexico 309 and its derivative B-190 in U.S. rust nurseries (20) indicate that most of these races are minor at this time. I have not attempted to identify the major races in rust collections from the Midwest. This can best be done within each state.

In identification of these new races, the full range of host reactions has been reported (Tables 1 and 2). In most previous reports of races of *U. phaseoli*, a single reaction grade has been assigned to each differential for each race. However, the variation that can occur at different times of the year has been recognized since the first definitive report of races (13). Temperature is a major factor in this variation (J. R. Stavely and R. W. Goth, *unpublished*). Some of the Harter and Zaumeyer (13) differentials developed larger uredinia at temperatures higher than 28–30 C. Therefore, these results were obtained at a time of year when extremes of temperature variation could be avoided. Few grade 1 immune reactions were obtained. Use of more concentrated inoculum for at least one test sometimes resulted in grade 2 reactions being detected when only apparent immunity was detected with the more dilute inoculum.

In this paper, arbitrary numbers have been used to name the races. In other recent work (1), letters were used. Letters have been assigned to the differentials so that this can be done. Therefore, race 38 could also be called race hm. The greatest problem with the letter system is that for these differentials and races, an arbitrary rule must be made for dealing with intermediate responses. Until more is known about the genetics of host reaction, the numbering system appears to be adequate.

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