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IDENTIFYING RACES OF PUCCINIA GRAMINIS F. SP. AVENAE A MODIFIED
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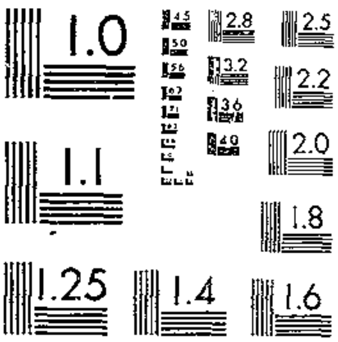

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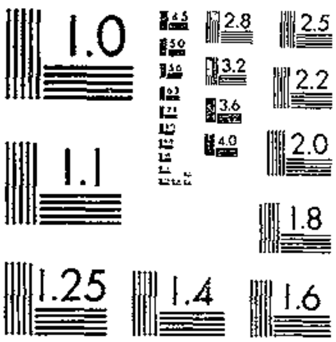

MICROCOPY RESOLUTION TEST CHART
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IDENTIFYING RACES OF PUCCINIA GRAMINIS F. SP. AVENAE

A Modified International System

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Contents

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IDENTIFYING RACES OF PUCCINIA GRAMINIS F. SP. AVENAE:

A Modified International System[1]

By D. M. STEWART, *research plant pathologist, Plant Protection Division,* and B. J. ROBERTS, *formerly plant pathologist, Crops Research Division, Agricultural Research Service*

In identifying and designating physiologic races of oat stem rust (*Puccinia graminis* Pers. f. sp. *avenae* (Eriks. & E. Henn.)), communication between investigators is becoming more difficult. This is due to lack of international uniformity in (1) the supplemental differential oat varieties (*Avena sativa* L.) used, (2) the environments in which races are identified, and (3) the systems of designating races. Confusion, therefore, has resulted in identifying what may be the same races; e.g., 6AF in the United States and Canada is equivalent to 6AB in Sweden, and 7A in Brazil is equivalent to 7D in Colombia. In this bulletin an attempt has been made to clarify the nomenclature and to establish an international system for race identification in this rust.

Identifying First 13 Races

In 1923 Stakman, Levine, and Bailey (*54*)[2] identified the first four biologic forms or races of oat stem rust by differentiation on three oat varieties—Victory (C.I. 1145),[3] White Tartar (Minnesota 339) (C.I. 1466), and Monarch (of Etheridge) (C.I. 1876). In 1925 Bailey (*1*) published an analytical key to physiologic forms 1–5 differentiated on three varieties—White Tartar (C.I. 551), synonymous with White Russian (*60*), Richland (C.I. 787), and Joanette Strain or Jostrain (C.I. 2660), similar or identical to Strain 703 (C.I. 2659) and known also as Sevnothree (C.I. 3251) (*18*). This trichotomous key employed three reaction classes for differentiating races—resistant, mesothetic, and susceptible. In 1937 Levine and Smith (*38*) added races 6–10 in a key that included the mean infection types of the 10 races on White Tartar, Richland, and Sevnothree. In 1944, using the same three differential varieties, Newton and Johnson (*44*) added races 11–13.

In 1938 Minrus (C.I. 2144) was substituted for White Tartar (White Russian) as a differential variety for identifying races in the United States, whereas workers in certain other countries continued to use White Tartar until 1944 or later (*35*). Sevnothree, equivalent to Jostrain, was used as a differential variety in Canada until 1964 (*21*), when Jostrain was substituted for Sevnothree.

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[1] Paper No. 6719, Scientific Journal Series, Minnesota Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 19.

[3] C.I. represents accession number in World Oat Collection maintained by U.S. Department of Agriculture at Beltsville, Md.

Races Versus Resistant Host Genes

In the 45 years since physiologic specialization was first demonstrated in oat stem rust (*54*), this pathogen has been extremely successful in adapting itself to new oat varieties with various combinations of genes conditioning resistance, as reflected by changing and shifting populations of new and virulent races. Between 1923 and 1942 the race population in the United States was stable, with race 2 and the closely related race 5 predominating (fig. 1). However, in 1942 there began a rapid increase in the North Central States[4] of rust-resistant oat varieties possessing the *A* (*Pg*–2) gene, such as Boone, Tama, Vicland, and others, mostly derived from Victoria × Richland crosses

[4] Iowa, Minnesota, Nebraska, North Dakota, South Dakota, and Wisconsin.

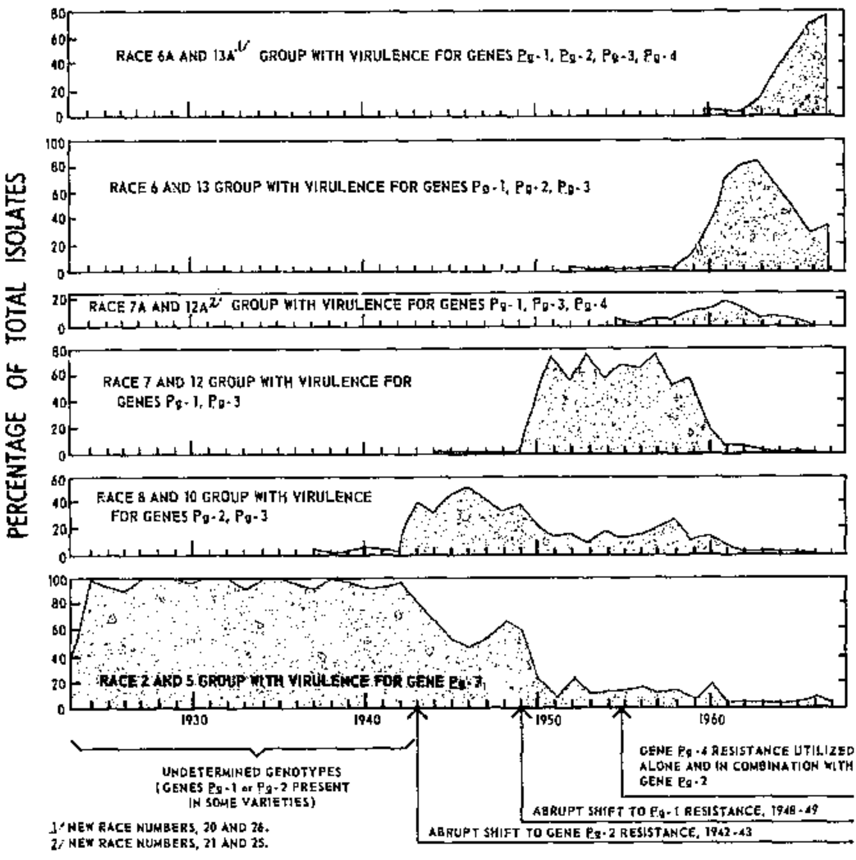

FIGURE 1.—Relationship of resistant genes in commercial oat acreage in North Central States and prevalence of races of *Puccinia graminis* f. sp. *avenae* in United States, 1923–67. (Data compiled from 13,939 uredial isolates.)

(*8, 48, 84*). However, since the new varieties were not resistant to race 8, this race became widespread in the United States for the first time in 1943 (*55*).

In about 1948 resistance of White Russian or White Tartar with gene *D* (*Pg*–1) (*13*) was utilized in breeding programs in the North Central States plus an increasing amount of the resistance of Richland with gene *A* (*Pg*–2). The varieties deriving resistance from White Russian were in turn susceptible to race 7, which became widespread and prevalent for the first time in 1950 (*56*).

The Hajira or "Canadian" type of resistance (gene *B* (*Pg*–4)) was incorporated into commercial varieties about 1956 and provided protection against races 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, and 13, but not 7A (*84*). This variant or subrace of 7, designated 7A, had become widespread in 1954 and attacked Rodney (C.I. 6661) and other varieties with the Hajira type of resistance (*59*).

From 1956 to about 1965 the principal sources of resistance in commercial varieties in the North Central States included gene *B* (*Pg*–4) supplemented by gene *A* (*Pg*–2) of Richland or gene *D* (*Pg*–1) of White Russian. In 1957 a subrace of 13, designated 13A, was identified from Rodney oats in a barberry-infested area in the Eastern States (*61, 64*), the first record of a race to attack oat varieties with resistant genes *A*, *B*, and *D*. Race 6, with virulence for the Richland and White Russian types of resistance, established itself in the Mississippi Valley (U.S.) for the first time in 1959. The following year subrace 6A, with virulence for varieties with genes *A*, *B*, *D*, and *E* (*Pg*–3), became a significant component of the rust population.

In 1958 Browning (*2*) and in 1959 Browning and Frey (*5*) reported a new source of resistance to race 6 and subrace 13A in varieties with a recessive gene designated as *F* by Welsh, Green, and McKenzie (*83*). Oat varieties with gene *F* presumably had resistance to races 1–13 and to races 4A, 5A, 6A, 7A, 8A, 10A, 12A, and 13A (*25*). In 1961 Green and Samborski (*26*) used a line of Eagle^2 × C.I. 4023[5] (C.I. 8111) with gene *F* to differentiate a variant of race 6, designated 6F, found in western Canada. Race 6F was identified in the United States in 1962 and increased to 70 percent of the isolates identified in 1963.

Reidentification of race 6 cultures stored at the Cooperative Rust Laboratory at St. Paul, Minn., in 1957 showed one culture of race 6 to be a mixture with 6F and certain other cultures stored in 1958, 1959, and 1960 to be pure cultures of 6F. Circumstantial evidence indicated that race 6 originated on or near barberry in the Northeastern States and that 6F probably was present but remained undetected until a specific tester variety with gene *F* (*pg*–8) was discovered (*66*). Our experience in going back to identify 6F is merely an example of undetected virulence in the rust pathogen that may occur in any collection of rust. Although varieties with gene *F* are susceptible to races 6F and 6AF, they are resistant to many other races at moderate temperatures of 20° to 23° C. (*29*).

Studies by McKenzie and Green (*40*) in 1965 showed that resistance of six oat varieties to races 6F and 6AF was conferred by a recessive

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[5] C.I. 4023 = Hajira × Joanette.

gene, which they designated gene *H* (*pg*–9). One of these varieties, Santa Fe Selection (C.I. 5844), equivalent or similar to Santa Fe Reselection[6] (C.I. 5844–1) (*21*), was useful as a differential variety for detecting races with virulence for gene *H*. Since gene *H* conditioned resistance to races 6F and 6AF, the most prevalent races in the United States and Canada since 1963, this type of resistance is currently important in breeding new varieties (*23*).

A new subrace, designated 6AFH, first reported and collected near barberries in Pennsylvania in 1965, attacks varieties having the *A*, *B*, *D*, *E*, *F*, and *H* genes for resistance (*50*). Six isolates of this race were found in three other States in 1966, but race 6AFH was not found in the United States in 1967.

Supplemental Differential Oat Varieties

For almost three decades three standard differential oat varieties—Minrus (C.I. 2144) (gene *D*), Richland (C.I. 787) (gene *A*), and Jostrain (C.I. 2660) (gene *E*) (*80, 82*)—or their equivalents, were used in identifying oat stem rust races in the United States and other countries (*6, 38, 44, 54*). The discovery of subrace 7A on Rodney (C.I. 6661) (gene *B*) by Johnson et al. in 1952 (*33, 34*) led to the use of this oat in the annual physiologic race survey in the United States. Welsh and Johnson (*84*) first reported a close linkage between genes *B* and *C* found in the varieties Rodney, Canuck (C.I. 4024), and certain selections of Hajira. Later Welsh, Green, and McKenzie (*83*) reported that the resistance of Hajira and its derivatives including Rodney was due to the single gene *B* instead of the linked genes *BC*.

In 1962, the year after Welsh et al. described gene *F* in Eagle^2 × C.I. 4023 (C.I. 8111), this oat was added as a supplemental differential variety in the race survey in the United States (*66*). It has been useful for differentiating 6AH and 6AF from 6AFH.

Santa Fe Selection (C.I. 5844) (gene *H*) has been used as a supplemental variety since 1966. At moderate temperatures (20° to 23° C.) it serves to distinguish races 2H, 7H, 6AH, 6AFH, 13AH, and others that attack varieties with gene *H*.

In 1961 Wahl et al. (*78, 79*) found a new source of resistance in Rosen's Mutant (C.I. 8159) conditioned by a gene later designated by Canadian workers (*39*) as gene *H*. This oat variety was resistant in the seedling stage to all races except 2 in Israel. In 1965 McKenzie and Green (*40*) reported that the resistance of Santa Fe Selection to races 6F and 6AF was conferred by recessive gene *H*. In comparative studies at St. Paul, Minn., Rosen's Mutant and Santa Fe Selection were tested with cultures identified in the 1967 race survey and were found to react similarly to most races. However, races 6F and 6AF consistently produced infection type 2= on Rosen's Mutant compared with type 2 on Santa Fe Selection.

The diploid oat Saia (*Avena strigosa* Schreb.) (C.I. 4639) was first used in 1954 as a test variety in the race survey in the United States

[6] Used in race survey in Canada as a differential variety.

(*59*). Although this undetermined genotype of *A. strigosa* was known to be susceptible to certain cultures of oat stem rust in South America (*10, 46*), it was resistant to all known races in the United States. In 1955, however, Stewart et al. (*69*) reported a new culture of race 5, designated 5A (synonymous with 5-US1), which was collected on Saia oats adjacent to barberry in Virginia. This was the first known Saia-attacking culture in North America (*70*). Since that time Saia has been used as a supplemental differential variety in the annual race survey in the United States.

Since 1957 Gopher (C.I. 2027) has been used at the Cooperative Rust Laboratory to increase oat rust inoculum. This oat variety is susceptible to all known races in the United States (*63*).

Infection Types

Infection types (table 1) produced on seedlings of differential oat varieties representing genes for resistance to oat stem rust can be considered characters that are distinctive for each race-variety combination. Since environmental factors, particularly temperature and light, can affect the behavior of the rust race, the differential variety, and the interaction between the two, they can markedly affect the phenotypic variability in infection types (pl. 1, *left*). This variability is especially evident in early investigations by Gordon (*15*), Johnson (*30*), and Welsh (*81*). Roberts[7] later showed that correct identification of nine of 16 races was dependent on a temperature range between 18° and 21° C. for expression of a resistant or mesothetic response of the standard differential variety Jostrain. Furthermore, the identification of 11 of 16 races required from 18° to 27° for development of a resistant response on the differential variety Rodney. Most infection types in table 1 were recorded at a mean temperature of 20°.

Precise effects of light on the infection type are not so well known as those of temperature, but light intensities of 1,500 ft.-c. or more are usually adequate for developing distinctive infection types of oat stem rust. Rust reaction of certain varieties may be affected more by light than others. Browning et al. (*3, 4*) reported that light affected the response of genes *D* and *F* in stem rust races in Colombia. Infection types on Minrus (C.I. 2144) and other varieties that possess gene *D* were 3± at high light intensity and 2± at medium and low light intensities. The identification of oat stem rust races at high light intensities in Colombia produced Minrus-virulent races almost exclusively. Controlling light intensity as well as temperature is essential for accurate determination of races of stem rust.

The inoculum load may affect rust development in certain race-host combinations. Infection types may be easily recognized when a few infection sites are uniformly distributed on rusted leaves, whereas many infection sites resulting from a medium or heavy inoculum load

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[7] ROBERTS, B. J. THE EFFECT OF TEMPERATURE ON SEEDLING REACTION OF OATS TO *PUCCINIA GRAMINIS VAR. AVENAE*. 1962. [Unpublished doctor's thesis. Copy on file Dept. Plant Path., Univ. Minn., St. Paul.]

TABLE 1.—*Seedling mean infection types on 7 differential oat hosts representing genes for resistance to oat stem rust*[1]

[Most readings recorded at mean temperature of 20° C.]

New race No.[2]	Former race or subrace No.	Mean infection types on differential hosts[3]							References
		Minrus[4] (*Pg*–1) (*D*)	Richland (*Pg*–2) (*A*)	Jostrain (*Pg*–3) (*E*)[5]	Rodney (*Pg*–4) (*B*)[6]	Eagle[2] × C.I. 4023 (*pg*–8) (*F*)[7]	Santa Fe Selection (*pg*–9) (*H*)[7]	Saia (undetermined) (?)	
1	Same	2	1	1–	------	------	------	------	*1, 12, 32, 54, 63*
2	do	2	2=	4	------	------	------	------	*1, 32, 38, 41, 54*
3	do	4–	1	1–	------	------	------	------	*1, 32, 38, 44, 54*
4	do	3+	3±	0;	------	------	------	------	*1, 32, 54, 72, 76*
5	do	2	2=	×±	------	------	------	------	*1, 32, 38*
6	do	4	4	4	------	------	------	------	*14, 16, 17, 32, 38*
7	do	4	1	4	------	------	------	------	*16, 32, 41, 44, 58*
8	do	2	4	4	------	------	------	------	*21, 32, 45, 53, 55*
9	do	2±	×+	4	------	------	------	------	*32, 38, 44*
10	do	2	4	×	------	------	------	------	*7, 31, 32, 38*
11	do	2	4	1±	------	------	------	------	*28, 31, 32, 44, 80*
12	do	3	1++	×+	------	------	------	------	*22, 32, 44, 45*
13	do	4–	4–	×	------	------	------	------	*44, 45, 57, 83, 84*
14	1A	2	1	0;	4	2–	------	0	*37*
15	2A	2–	1	3+	3	2–	3+	0;	*37, 62*
16	3A	4	1	0	4	2	([8])	0	*27, 36, 37*
17	4A	4	4	1–	4	2	------	0;	*27, 36, 37, 46*
18	4A	3+	3+	0;, 1	3+	2	2++	0;, 1	*68, 72*
19	5B	2	1	×–	3+	2–	3+	0;, 1	([9]), *62*
20	C14 (6A)	4	4	4	4	2	1–	0;	*27, 36, 41, 46, 48*
21	C3 (7A)	4	2–	3+	3+	2	------	0;	*27, 33, 36, 46, 59*
22	C11 (8A)	2	4	3+	4	2	------	0;	*19, 21, 24, 37, 65*
23	10A	2	3+	×	3+	2++	2+	0;	*26, 65*
24	C22 (11A)	2	4	1–	4	2	2	0	*37, 49, 67*
25	12A	4	2–	×±	4	2	2++	0;	*46, 65, 66*
26	13A	3+	3+	×	3+	2	------	0;	*19, 24, 46, 61, 64*
27	1AB	1–	1–	0	4	4	------	0	*37*

28	2AB	2	1	3+	4	4	----	0	*37*
29	3AB	4	1	2=	4	4	([10])	0	*37*
30	4AB	4	4	2=	4	4	([8])	1−	*37*
31	C10 (6AF)	3+	3+	3	3+	3	1	1	([9]), *20*, *21*, *37*, *66*
32	7AF	4	1−	4	4	4	----	0	*37*, *66*
33	C12 (8AF)	2	4	4	3	3	2	1	*21*, *41*
34	13AF	4	4	×	3+	3+	2	0;	([9]), *23*
35	1AD	2	1	0	4	2	----	4	*37*
36	2B	2	2−	3+*cn*	2−	----	----	3+	*65*, *66*
37	5A (5-US1)	2	2=	×−	2−	3	3+	3+	([9]), *69*, *70*
38	3BD	4	1	0	1−	3+	----	3+	*37*
39	4BD	4	4	0	1	4	----	4	*37*
40	6E	3++	3+	3++	1	3+	2	3+	*73*, *74*, *77*, *78*
41	Same	3++	3+	3++	3++	3++	1+	3+	*73*
42	3A	4+	2+	1=	0;, 1=	----	----	4+	*10*, *11*, *75*
43	4A	4	4+	1−	0;, 1	----	----	4	*10*, *11*
44	7A	4	2	4	0;, 1	----	----	4	*11*, *46*
45	2B[11]	1, 2	1	4	1	----	----	4	([12])
46	3B	3	1	1	4	----	----	4	*46*
47	3C-1	3	1	1	4	----	----	×	*46*
47	3C-2	4	2	1	4	----	----	×	*46*
48	3E	3	1	1	1	----	----	×	([12])
49	3G-1	3	1	1	1	2	1	1	([12])
50	4B	3	4	1	4	2	1	×	([12])
51	4B-1	4	4	1	4	4	1++	×	([12])
52	4C	3	4	1	4	----	----	4	*46*
53	4D[13]	3	4	1	4	----	----	1	*46*
54	6B	3	4	4	4	2	1	×	([12])
54	6D[13]	3	4	4	4	----	----	×	([12])
55	6C	3	4	4	4	----	----	4	*46*, *47*
56	6E	3	4	4	1	2	1	×	([12])
57	7B	3	1	4	4	----	----	4	([12])
58	7C-1	3	1	4	4	----	----	×	([12])
58	7C-2	4	2	4	4	----	----	×	([12])
59	7E-1	3	1	4	1	----	----	×	([12])
59	7E-2	4	1	4	1	----	----	×	([12])
60	7F-1	3	1	4	1	2	1	1	([12])
61	7F-2	4	1	4	1	4	1	1	([12])

See footnotes at end of table.

TABLE 1.—*Seedling mean infection types on 7 differential oat hosts representing genes for resistance to oat stem rust* —Continued

New race No.[2]	Former race or subrace No.	Mean infection types on differential hosts[3]							References
		Minrus[4] (*Pg*–1) (*D*)	Richland (*Pg*–2) (*A*)	Jostrain (*Pg*–3) (*E*)[5]	Rodney (*Pg*–4) (*B*)[6]	Eagle[2] × C.I. 4023 (*pg*–8) (*F*)[7]	Santa Fe Selection (*pg*–9) (*H*)[7]	Saia (undetermined) (?)	
62	12A	3	1	×	4	----	----	×	(11)
63	12B	3	1	×	4	----	----	4	(12)
64	12D	3	1	×	1	----	----	×	(12)
65	12E	3	1	×	1	----	----	4	(12)
66	13B	3	4	×	4	2	1	×	(12)
66	13B-1[14]	4	4	×	4	2	1	×	(12)
66	13D[13]	3	4	×	4	----	----	×	(12)
67	13C	3	4	×	4	----	----	4	(12)
68	1B	2	1–	1–	1–	4	(15)	0	*37*, *78*
69	2B	2	1	4	1–	4	----	0;	*37*, *71*
70	3B	4	1–	2=	2=	4	(8)	2=	*37*, *71*
71	4B	4	3+	2=	2=	3+	----	2=	*37*
72	6F	3+	3+	3+	1	3+	2–	0;, 1	(9), *21*, *26*, *37*, *73*
73	11B	2	4	0	1	4	----	0	*37*
74	13F	3+	3+	×	0;, 1	3+	×–	0;, 1	(9)
75	7B	3+	1–	4	2=	3+	----	1–	*37*, *78*
76	C1 (1)	2	1	1	1	2	3+	1	(9), *21*, *29*, *41*
77	C2 (2)	2–	0;	3+	1	2–	3+	1	(9), *21*, *29*, *41*, *78*
78	5H	2	1	×–	1	2–	3+	1	(9), *29*
79	C13 (6)	3+	3+	3	1–	2	3+	0;	*41*
80	7H	3+	2–	3+	2–	2++	3+	1	(9), *29*, *41*
81	8H	2	3+	3+	1	2	3+	0;	(9), *29*, *41*
82	10H	2	3+	×–	0;, 1	2	3+	0;, 1	(9)
83	11H	2–	3+	0;, 1	1	1	3+	1	(9)
84	12H	3+	0;	×–	0;	2++	3+	0;, 1	(9)
85	13H	3+	3+	×	0;, 1	2–	3+	0;, 1	(9)
86	C8 (4A)	3	3	1–	3	2=	3+	1–	*21*, *41*

87	C9 (6A)	3+	3+	3+	3+	1	3+	0;, 1	(9), *21*, *41*
88	C3 (7A)	3+	1	3+	3+	2	3+	0;, 1	(9), *21*, *41*
89	C6 (8A)	2	3+	3+	3+	2	3+	0;, 1	(9), *41*
90	C6 (10A)	2	3+	×−	3+	2	3+	0;, 1	(9), *41*
91	C17 (11A)	2	3+	0;	2+	2	3+	0;	(9), *21*, *41*
92	C3 (12A)	3+	2	×−	3+	2	3	0;	(9), *21*, *41*
93	C9 (13A)	3+	3+	×	3+	2	3+	1±	(9), *21*, *41*
94	6AFH	3+	3+	3+	3+	3+	3+	1	(9), *29*, *50*
95	7AFH	3	1−	3+	3+	3+	3+	0;	(9)
96	C7 (8AF)	2	4	4	3+	3+	3+	1	(9), *21*, *41*
97	C20 13AFH	3+	3+	×	4	3	4−	0;, 1	(9), *23*

1 Infection types and other data for races in Colombia, Israel, and Sweden were furnished through personal correspondence, respectively, with Juan Orjuela N. and Elkin Bustamante, Instituto Colombiano Agropecuario, Bogotá; A. Sztejnberg and I. Wahl, Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot; and Bengt Leijerstam, Statens Växtskyddsanstalt, Svalöv.

2 Races 98–101 similar to races 14, 30, 61, and 25, respectively; first three produce type 4 on Santa Fe Selection and race 101 produces type 4 on Eagle² × C.I. 4023. (98–101 assigned to cultures identified at Coop. Rust Lab. after submittal of manuscript for publication.)

3 Based on gene nomenclature proposed by Simons et al. (*52*), new (*Pg*–1) and original (*D*) gene designations follow each host name. 0 = immune; 0; = nearly immune; 1 = very resistant; 2 = moderately resistant; 3 = moderately susceptible; 4 = very susceptible; × = heterogeneous; + and − signs = variation within given infection type; ++ and = signs = upper and lower limits, respectively, of each type; ± signs = variation between + and − for type; *c* = pronounced chlorosis; *n* = tendency toward necrosis; ×− = predominance of types 0; and 1 with occasional type 3-*cn*; ×+ = predominance of types 2, 3, and 4 with fewer types 0; and 1.

4 Differentiation made in Colombia between infection type 3 and 4 on Minrus (C.I. 2144).

5 Sevnothree (C.I. 3251) used in Sweden for host gene *Pg*–3 (*E*).

6 Canuck (C.I. 4024) used in Brazil for host gene *Pg*–4 (*B*).

7 Eagle² × C.I. 7438 (C.I. 8112) used in Sweden for host gene *pg*–8 (*F*), (C.I. 7438 = Hajira × Banner); no data available for host gene 8 (*F*) and 9 (*H*) in Brazil and gene *pg*–9 (*H*) in Sweden.

8 Colombia race 3D-1 produces infection types 1, 2 =; 3D-2 and 3-G produce type 1 on Santa Fe Selection (C.I. 5844) (gene *pg*–9).

9 HULLUKA, M. THE REACTION OF 45 VARIETIES OF OATS TO 28 PHYSIOLOGIC RACES OF PUCCINIA GRAMINIS VAR. AVENAE. 1966. [Unpublished master's thesis. Copy on file Dept. Plant Path., Univ. Minn., St. Paul.]

10 Former race 3D-2 (Colombia) produces infection type 1 on Santa Fe Selection and type 4 on Colombia variety ICA-Bacata.

11 Produces type × on Bond (C.I. 2733) and Gopher (C.I. 2027).

12 Data furnished by personal correspondence only.

13 Infection type 1 on Garry (C.I. 6662).

14 Type 4 on ICA-Bacata.

15 Israel race 1 produces infection type 1+ on Israel Selection of Rosen's Mutant (C.I. 8159) (gene *pg*–9).

produce coalescence of pustules and thus make it difficult or impossible to characterize the true infection type for identifying a race (pl. 1, *right*).

The following data on infection types, reaction classes, and host reactions were first used by Stakman, Levine, and Bailey (*54*) for the three original standard differential varieties—Minrus, Richland, and Jostrain—and apply also to four additional standard differential varieties—Rodney, Eagle[2] × C.I. 4023, Santa Fe Selection, and Saia. (See pls. 2–5.)

Infection types	*Reaction classes and host reactions*
	RESISTANT
0	**immune**—no uredia or other indications of infection.
0;	**nearly immune**—hypersensitive flecks present, usually few and scattered with occasional very minute uredium surrounded by necrosis.
1	**very resistant**—uredia minute, surrounded by very sharply defined necrotic areas up to 2 mm. in diameter.
2	**moderately resistant**—uredia small to medium, surrounded by sharply defined necrosis, sometimes showing green islands surrounded by necrotic border ranging to pronounced chlorosis with only slight tendency toward green islands and often indistinguishable from small type 3 uredia, particularly when infection is heavy.
	SUSCEPTIBLE
3	**moderately susceptible**—uredia small to medium with tendency to coalesce; typical hypersensitiveness usually absent, but chlorotic areas almost always present.
4	**very susceptible**—uredia large and usually confluent; hypersensitiveness absent, but chlorosis may or may not be present.
	MESOTHETIC
×	**heterogeneous**—uredia extremely variable in size with interspersal of types 0;, 1, 2 (infrequent), 3, and 4 and surrounded with blotchlike areas of pronounced necrosis; infection types frequently intergrade into each other on same leaf; on reinoculation small uredia may produce large ones and large uredia, small, minute, or necrotic flecks.

An International System for Race Identification and Designation, With Specific Modifications

Not only the advantages but some of the difficulties are recognized in trying to solve problems dealing with race identification and designation for international acceptance. Problems of nomenclature raise certain questions. Should all newly identified genes in oats be included among international differential varieties? Should genes for resistance in diploids and tetraploids be included among the differential varieties? Who will determine when a variety should become an international differential variety? Perhaps these questions can be more easily answered after clarification of current race terminology. But mutual agreement on objectives and goals is essential for international control of the rust.

The identification of races has the following purposes: (1) To provide comparative data for evaluating performance of host genotypes tested to specific cultures of rust as a basis for producing better rust-resistant varieties; (2) to contribute to better understanding of the behavior of genes conditioning resistance in the host and their interaction with pathogenicity in the rust fungus; (3) to provide a method of genetic analysis of host and pathogen; and (4) to detect new or potentially dangerous races on new or widely grown host genotypes. In addition, data from surveys reflect long-term trends in race populations. The final objective, of course, is not to tabulate race distribution but to aid in controlling the disease. Therefore, to make communication more precise, the following specific modifications are made:

(1) These generally accepted varieties with their current gene designations have been established as standard differential varieties: Minrus (*Pg*-1), Richland (*Pg*-2), Jostrain (*Pg*-3), Rodney (*Pg*-4), Eagle[2] × C.I. 4023 (*pg*-8), Santa Fe Selection (*pg*-9), and Saia (undetermined).

Oat investigators were among the first to utilize monogenic varieties for identifying races. Among these seven standard differential varieties, diploid Saia is the only one of undetermined genotype. This variety is commercially important in certain countries, e.g., Brazil and Israel, where it is useful also for differentiating rust races (*10, 74, 77*). Although incorporation of stem rust resistance into a hexaploid oat derived from Saia has not been reported, resistance to crown rust (*Puccinia coronata* (Cda.) f. sp. *avenae* Fraser & Led.) has been transferred from Saia into hexaploid oats (*9, 85*).

(2) Races are recorded by country and race equivalents.

Literature is often difficult to evaluate because of diverse race nomenclature. Kernkamp (*35*) alluded to the confused terminology of oat stem rust races and to the need for clarification. An international register of races by country and race equivalents should make race information more understandable.

Race equivalents in table 2 were determined according to similarities among infection types (table 1) produced by races on several standard differential varieties. Information from some countries is incomplete, since data were not available or certain host genotypes had not yet been tested.

(3) New race numbers are assigned beginning with race 14, leaving races 1–13 unchanged, which now are meaningless but have historical value.

To avoid duplication of race numbers in identifying crown rust of oats, Simons and Murphy (*51*) began a new series of races in 1955 starting with 201, based on a revised set of 10 standard differential varieties. Similarly in this bulletin the original 13 races are left unchanged as a link with the past and numbering new races begins with 14 based on seven standard differential varieties described in tables 1–3. In 1944 a culture collected on Big Bluegrass (*Poa ampla* Merr.) by Fischer and Claassen (*12*) was provisionally designated as race 14, but subsequently the culture was reclassified as a variant of race 1 at the Cooperative Rust Laboratory.

TABLE 2.—*Physiologic races of oat stem rust and pathogenicity on host genes for 6 hexaploid oats and diploid oat Saia*

New race No.	Former race or subrace No. [1]	Country of original collection	Equivalent or similar to race—	Pathogenicity on host genes: Virulence index [2]	Pathogenicity on host genes: Avirulence index [2]
1	Same	United States	14 (U.S.)[3] provisional		1, 2, 3
2	do	do	C19 (Canada)	3	1, 2
3	do	South Africa		1	2, 3
4	do	Sweden		1, 2	3
5	do	Canada		[4] *3*	1, 2
6	do	do	6Y (Canada)	1, 2, 3	
7	do	do	(C18) 7Y (Canada), 7B (U.S.)	1, 3	2
8	do	do	C4 (Canada)	2, 3	1
9	do	do		*2*, 3	1
10	do	United States		2, *3*	1
11	do	Germany	10a (Canada)	2	1, 3
12	do	do		1, *3*	2
13	do	Canada		1, 2, *3*	
14	1A	Sweden		4	1, 2, 3, 8, Sa
15	2A	United States	2A (Sweden)	3, 4, 9	1, 2, 8, Sa
16	3A	Sweden	3D-1 and 3D-3 (Colombia)[5]	1, 4	2, 3, 8, Sa
17	4A	do	4A (Colombia)	1, 2, 4	3, 8, Sa
18	4A	United States		1, 2, 4	3, 8, 9, Sa
19	5B	do		*3*, 4, 9	1, 2, 8, Sa
20	C14 (6A)	Canada	6A (Colombia, Sweden, U.S.)	1, 2, 3, 4	8, 9, Sa
21	C3 (7A)	do	7A-1 (Colombia), 7A (Sweden, U.S.)	1, 3, 4	2, 8, Sa
22	C11 (8A)	do	8A (Sweden, U.S.)	2, 3, 4	1, 8, Sa
23	10A	United States	10A (Canada)	2, *3*, 4	1, 8, 9, Sa
24	C22 (11A)	Canada	11A (Sweden, U.S.)	2, 4	1, 3, 8, 9, Sa
25	12A	United States	C3 (12A) (Canada), 12C (Colombia)	1, *3*, 4	2, 8, 9, Sa
26	13A	do	C9 (13A) (Canada), 13A (Colombia)	1, 2, *3*, 4	8, Sa
27	1AB	Sweden		4, 8	1, 2, 3, Sa
28	2AB	do		3, 4, 8	1, 2, Sa
29	3AB	do	3D-2 (Colombia)[5]	1, 4, 8	2, 3, Sa

30	4AB	do		1, 2, 4, 8	3, Sa
31	C10 (6AF)	Canada	6AB (Sweden), 6AF (U.S.)	1, 2, 3, 4, 8	9, Sa
32	7AF	United States	7AB (Sweden), 7A (Colombia)	1, 3, 4, 8	2, Sa
33	C12 (8AF)	Canada		2, 3, 4, 8	1, 9, Sa
34	13AF	United States		1, 2, 3, 4, 8	9, Sa
35	1AD	Sweden		4, Sa	1, 2, 3, 8
36	2B	United States		3, Sa	1, 2, 4
37	5A (5-US1)	do	5-US1 (U.S.)	3, 8, 9, Sa	1, 2, 4
38	3BD	Sweden		1, 8, Sa	2, 3, 4
39	4BD	do		1, 2, 8, Sa	3, 4
40	6E	Israel		1, 2, 3, 8, Sa	4, 9
41	Same	do		1, 2, 3, 4, 8, Sa	9
42	3A	Brazil	3A (Argentina), 3F (Colombia)	1, Sa	2, 3, 4
43	4A	do		1, 2, Sa	3, 4
44	7A	do	7D (Colombia)	1, 3, Sa	2, 4
45	2B	Colombia		3, Sa	1, 2, 4
46	3B	do		1, 4, Sa	2, 3
47	3C-1	do		1, 4, *Sa*[4]	2, 3
47	3C-2	do		1, 4, *Sa*	2, 3
48	3E	do		1, *Sa*	2, 3, 4
49	3G-1	do		1	2, 3, 4, 8, 9, Sa
50	4B	do		1, 2, 4, *Sa*	3, 8, 9
51	4B-1	do		1, 2, 4, 8, *Sa*	3, 9
52	4C	do		1, 2, 4, Sa	3
53	4D	do		1, 2, 4	3, Sa
54	6B	do		1, 2, 3, 4, *Sa*	8, 9
54	6D	do		1, 2, 3, 4, *Sa*	
55	6C	do		1, 2, 3, 4, Sa	
56	6E	do		1, 2, 3, *Sa*	4, 8, 9
57	7B	do		1, 3, 4, Sa	2
58	7C-1	do		1, 3, 4, *Sa*	2
58	7C-2	do		1, 3, 4, *Sa*	2
59	7E-1	do		1, 3, *Sa*	2, 4
59	7E-2	do		1, 3, *Sa*	2, 4
60	7F-1	do		1, 3	2, 4, 8, 9, Sa
61	7F-2	do		1, 3, 8	2, 4, 9, Sa
62	12A	do		1, 3, 4, *Sa*	2
63	12B	do		1, 3, 4, Sa	2

See footnotes at end of table.

TABLE 2.—*Physiologic races of oat stem rust and pathogenicity on host genes for 6 hexaploid oats and diploid oat Saia*—Continued

New race No.	Former race or subrace No. [1]	Country of original collection	Equivalent or similar to race—	Pathogenicity on host genes	
				Virulence index[2]	Avirulence index[2]
64	12D	do	Biotype of 12 (Canada)	1, *3*, *Sa*	2, 4
65	12E	do		1, *3*, Sa	2, 4
66	13B	do		1, 2, *3*, 4, *Sa*	8, 9
66	13B-1	do		1, 2, *3*, 4, *Sa*	8, 9
66	13D	do		1, 2, *3*, 4, *Sa*	
67	13C	do		1, 2, *3*, 4, Sa	
68	1B	Sweden	1 (Israel)[6]	8	1, 2, 3, 4, Sa
69	2B	do	2F (U.S.)	3, 8	1, 2, 4, Sa
70	3B	do	3 (Israel), 3G (Colombia)[5]	1, 8	2, 3, 4, Sa
71	4B	do		1, 2, 8	3, 4, Sa
72	6F	United States	C5 (6F) (Canada), 6B (Sweden), 6 (Israel)	1, 2, 3, 8	4, 9, Sa
73	11B	Sweden		2, 8	1, 3, 4, Sa
74	13F	United States		1, 2, *3*, 8, *9*	4, Sa
75	7B	Sweden	7 (Israel)	1, 3, 8	2, 4, Sa
76	C1 (1)	Canada	1H (U.S.)	[7] 9	1, 2, 3, 4, 8, Sa
77	C2 (2)	do	2H (U.S.), 2 (Israel)	3, 9	1, 2, 4, 8, Sa
78	5H	United States		*3*, 9	1, 2, 4, 8, Sa
79	C13 (6)	Canada	6H (U.S.)	1, 2, 3, 9	4, 8, Sa
80	7H	United States	C16 (7) (Canada)	1, 3, 9	2, 4, 8, Sa
81	8H	do	C15 (8) (Canada)	2, 3, 9	1, 4, 8, Sa
82	10H	do		2, *3*, 9	1, 4, 8, Sa
83	11H	do		2, 9	1, 3, 4, 8, Sa
84	12H	do		1, *3*, 9	2, 4, 8, Sa
85	13H	do		1, 2, *3*, 9	4, 8, Sa
86	C8 (4A)	Canada	4AH (U.S.)	1, 2, 4, 9	3, 8, Sa
87	C9 (6A)	do	6AH (U.S.)	1, 2, 3, 4, 9	8, Sa
88	C3 (7A)	do	7AH (U.S.)	1, 3, 4, 9	2, 8, Sa
89	C6 (8A)	do	8AH (U.S.)	2, 3, 4, 9	1, 8, Sa
90	C6 (10A)	do	10AH (U.S.)	2, *3*, 4, 9	1, 8, Sa

91	C17 (11A)	do	11AH (U.S.)	2, 4, 9	1, 3, 8, Sa
92	C3 (12A)	do	12AH (U.S.)	1, *3*, 4, 9	2, 8, Sa
93	C9 (13A)	do	13AH (U.S.)	1, 2, *3*, 4, 9	8, Sa
94	6AFH	United States	C20 (6AFH) (Canada)	1, 2, 3, 4, 8, 9	Sa
95	7AFH	do		1, 3, 4, 8, 9	2, Sa
96	C7 (8AF)	Canada	8AFH (U.S.)	2, 3, 4, 8, 9	1, Sa
97	C20 13AFH	do	13AFH (U.S.)	1, 2, *3*, 4, 8, 9	Sa

[1] A culture similar to one of original 13 races on Minrus, Richland, and Jostrain and avirulent on Rodney, Eagle[2] × C.I.4023, Santa Fe Selection, and Saia is designated by original race numbers 1–13.

[2] 1 = Minrus (*Pg*–1) (*D*), 2 = Richland (*Pg*–2) (*A*), 3 = Jostrain (*Pg*–3) (*E*), 4 = Rodney (*Pg*–4) (*B*), 8 = Eagle[2] × C.I. 4023 (*pg*–8) (*F*), 9 = Santa Fe Selection (*pg*–9) (*H*), Sa = Saia (undetermined). New (*Pg*–1) and original (*D*) gene designations follow each host name; gene nomenclature proposed by Simons et al. (*52*).

[3] Race 14 was provisionally assigned to culture collected on grass (*Poa ampla* Merr.) but later classified as variant of race 1 (*12*).

[4] Numbers and Sa in italic = mesothetic response.

[5] Santa Fe Selection (C.I. 5844) (gene *pg*–9) is resistant to Colombia races 3D-1, 3D-2, and 3-G (data furnished by E. Bustamante, Bogotá).

[6] Israel Selection of Rosen's Mutant (C.I. 8159) (gene *pg*–9) is resistant to Israel race 1 (*73*).

[7] Santa Fe Reselection (C.I. 5844-1) used in Canada as differential variety (*21*).

TABLE 3.—*Key for determining oat stem rust races based on reactions of 7 differential oat hosts*

New race No. [1]	Rust reaction of differential hosts [2]						
	Minrus (*Pg*-1) (*D*)	Richland (*Pg*-2) (*A*)	Jostrain (*Pg*-3) (*E*)	Rodney (*Pg*-4) (*B*)	Eagle[2] × C.I. 4023 (*pg*-8) (*F*)	Santa Fe Selection (*pg*-9) (*H*)	Saia (undetermined) (?)
94	S	S	S	S	S	S	R
31	S	S	S	S	S	R	R
41	S	S	S	S	S	R	S
20	S	S	S	S	R	R	R
87	S	S	S	S	R	S	R
54	S	S	S	S	R	R	X
55	S	S	S	S	----	----	S
40	S	S	S	R	S	R	S
72	S	S	S	R	S	R	R
79	S	S	S	R	R	S	R
56	S	S	S	R	R	R	X
97	S	S	X	S	S	S	R
34	S	S	X	S	S	R	R
93	S	S	X	S	R	S	R
66	S	S	X	S	R	R	X
67	S	S	X	S	----	----	S
74	S	S	X	R	S	X	R
85	S	S	X	R	R	S	R
26	S	S	X	S	R	----	R
51	S	S	R	S	S	R	X
30	S	S	R	S	S	----	R
52	S	S	R	S	----	----	S
86	S	S	R	S	R	S	R
50	S	S	R	S	R	R	X
53	S	S	R	S	----	----	R
18	S	S	R	S	R	R	R
17	S	S	R	S	R	----	R
39	S	S	R	R	S	----	S
71	S	S	R	R	S	----	R
43	S	S	R	R	----	----	S
95	S	R	S	S	S	S	R
32	S	R	S	S	S	----	R
88	S	R	S	S	R	S	R
21	S	R	S	S	R	----	R
57	S	R	S	S	----	----	S
58	S	R	S	S	----	----	X
61	S	R	S	R	S	R	R
75	S	R	S	R	S	----	R
80	S	R	S	R	R	S	R
44	S	R	S	R	----	----	S
59	S	R	S	R	----	----	X
60	S	R	S	R	R	R	R
92	S	R	X	S	R	S	R
25	S	R	X	S	R	R	R
63	S	R	X	S	----	----	S
62	S	R	X	S	----	----	X
65	S	R	X	R	----	----	S
64	S	R	X	R	----	----	X
84	S	R	X	R	R	S	R
29	S	R	R	S	S	([3])	R
16	S	R	R	S	R	([3])	R
46	S	R	R	S	----	----	S
47	S	R	R	S	----	----	X
38	S	R	R	R	S	----	S

See footnotes at end of table.

TABLE 3.—*Key for determining oat stem rust races based on reactions of 7 differential oat hosts*—Continued

New race No.[1]	Rust reaction of differential hosts[2]						
	Minrus (*Pg*-1) (*D*)	Richland (*Pg*-2) (*A*)	Jostrain (*Pg*-3) (*E*)	Rodney (*Pg*-4) (*B*)	Eagle[2] × C.I. 4023 (*pg*-8) (*F*)	Santa Fe Selection (*pg*-9) (*H*)	Saia (undetermined) (?)
70	S	R	R	R	S	([3])	R
42	S	R	R	R	--------	--------	S
48	S	R	R	R	--------	--------	X
49	S	R	R	R	R	R	R
96	R	S	S	S	S	S	R
33	R	S	S	S	S	R	R
89	R	S	S	S	R	S	R
22	R	S	S	S	R	--------	R
81	R	S	S	R	R	S	R
90	R	S	X	S	R	S	R
23	R	S	X	S	R	R	R
82	R	S	X	R	R	S	R
91	R	S	R	S	R	S	R
24	R	S	R	S	R	R	R
73	R	S	R	R	S	--------	R
83	R	S	R	R	R	S	R
28	R	R	S	S	S	--------	R
15	R	R	S	S	R	S	R
69	R	R	S	R	S	--------	R
77	R	R	S	R	R	S	R
36	R	R	S	R	--------	--------	S
45[4]	R	R	S	R	--------	--------	S
19	R	R	X	S	R	S	R
37	R	R	X	R	S	S	S
78	R	R	X	R	R	S	R
27	R	R	R	S	S	--------	R
35	R	R	R	S	R	--------	S
14	R	R	R	S	R	--------	R
68	R	R	R	R	S	([5])	R
76	R	R	R	R	R	S	R

[1] Newly assigned numbers beginning with 14.

[2] Based on gene nomenclature proposed by Simons et al. (*52*), new (*Pg*–1) and original (*D*) gene designations follow each host name. S = susceptible, R = resistant, X = heterogeneous. Most reactions recorded at mean temperature of 20° C.

[3] Resistant to Colombia races 3D-1, 3D-2, and 3-G.

[4] Produces infection type X on Bond (C.I. 2733) and Gopher (C.I. 2027).

[5] Israel Selection of Rosen's Mutant (C.I. 8159) (gene *pg*–9) is resistant to Israel race 1 (*73*).

(4) A host-gene defined formula is adopted, hereinafter referred to as virulence-avirulence indices, using numerals in lieu of letters to conform with the practice of oat workers in the United States (*52*).

Descriptive formulas for physiologic races in cereal rusts were first used in 1935 by Murphy (*42*) for 11 standard differential varieties of oat crown rust. In 1963 Green (*20*) used a host-gene defined system in a virulence formula for stem rust races by indicating effective and ineffective host genes. These races were assigned numbers preceded by the letter "C" (Canada). For example, C1 was equivalent to "standard race" 1, C2 (2), and C3 (7A, 12A).

In the modified system of identifying and designating races, the dominant genes, as shown in tables 1–3, are *Pg*–1 (formerly gene *D*), *Pg*–2 (*A*), *Pg*–3 (*E*), *Pg*–4 (*B*); recessive genes are *pg*–8 (*F*), *pg*–9 (*H*); and Saia is an undetermined genotype (*52*). In this system, "standard race" 6AF (new No. 31) is designated by virulence index 1, 2, 3, 4, 8 and by avirulence index 9 and Sa; race 13AF (new No. 34) has a virulence index of 1, 2, *3*,[8] 4, 8 and an avirulence index of 9 and Sa (table 2).

(5) A number is assigned to a race differentiated on a new variety only after the host-gene and virulence-avirulence indices are determined and workers in various countries have tested it to their rust cultures.

It is self-evident that plant breeders in different regions and countries will use different sources of resistance in their breeding programs and that pathologists will use these sources as supplemental differential varieties for identifying races. It seems likely also that some of these differential varieties will be useful and should be elevated to the rank of standard differential varieties. However, it is important that a number be assigned to a race differentiated on a new variety only after the host-gene and virulence-avirulence indices are determined. Assignment of new race numbers will be made at the request of workers through a central register maintained at the Cooperative Rust Laboratory at St. Paul, Minn. Furthermore, this "clearing house" for rust races will provide pure seed of differential varieties in coordinating oat stem rust work internationally.

(6) A key of rust reaction is devised for determining oat stem rust races.

A key for determining races, based on the reactions of differential oat varieties to known races, is given in table 3. Races listed in descending order of virulence are grouped by host reaction on seven standard differential varieties. Reactions of the original 13 standard races are not included.

Conclusion

In identifying physiologic races of oat stem rust, a taxonomic system should be internationally understandable insofar as possible. Although the hosts for this rust pathogen in certain countries may be entirely different from those in other parts of the world, it is necessary to be able to communicate about pathogen populations as well as about host genes. While man is exchanging rust-resistant oat materials, it is evident that nature is changing and creating virulent rust biotypes just as rapidly.

The pathogen deserves as much work as the genotypes of the host. Judgment involving interactions of the pathogen, host, and environment may be as difficult as mapping the chromosomes in the oat plant. No single factor contributing to rust reactions can be disregarded if precise expression of the relationship is to be determined. In general, the problems involve dynamic factors rather than static ones and utilitarian judgments are needed for perspective.

[8] *3* = mesothetic reaction on differential variety Jostrain (*Pg*–3).

The final aim is to construct a taxonomic system that represents genetic relationships. Although it is most essential to utilize resistant host genes for race identification in cereal rusts, it is also important to direct investigations toward gene-for-gene relationships between the rust pathogen and the host and toward behavior of genes in given genotypes. All these objectives have not yet been attained, but adoption of the modified international system presented here should contribute toward a practical approach to current and future problems.

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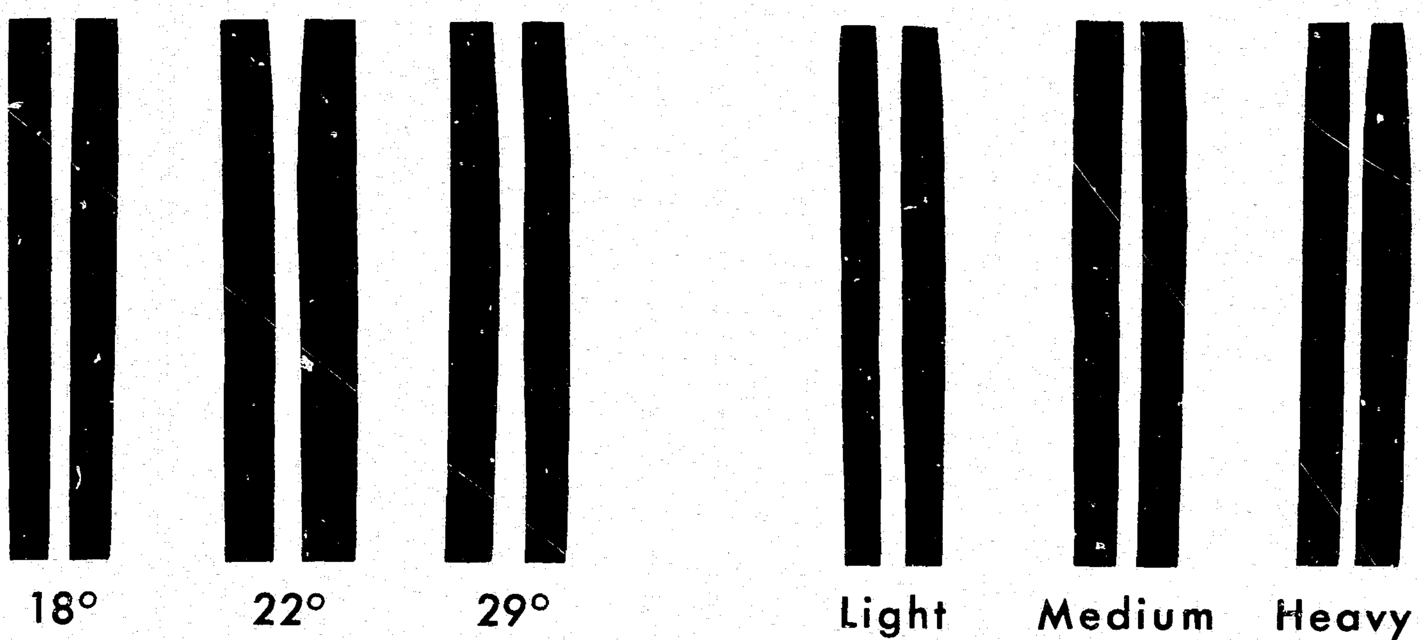
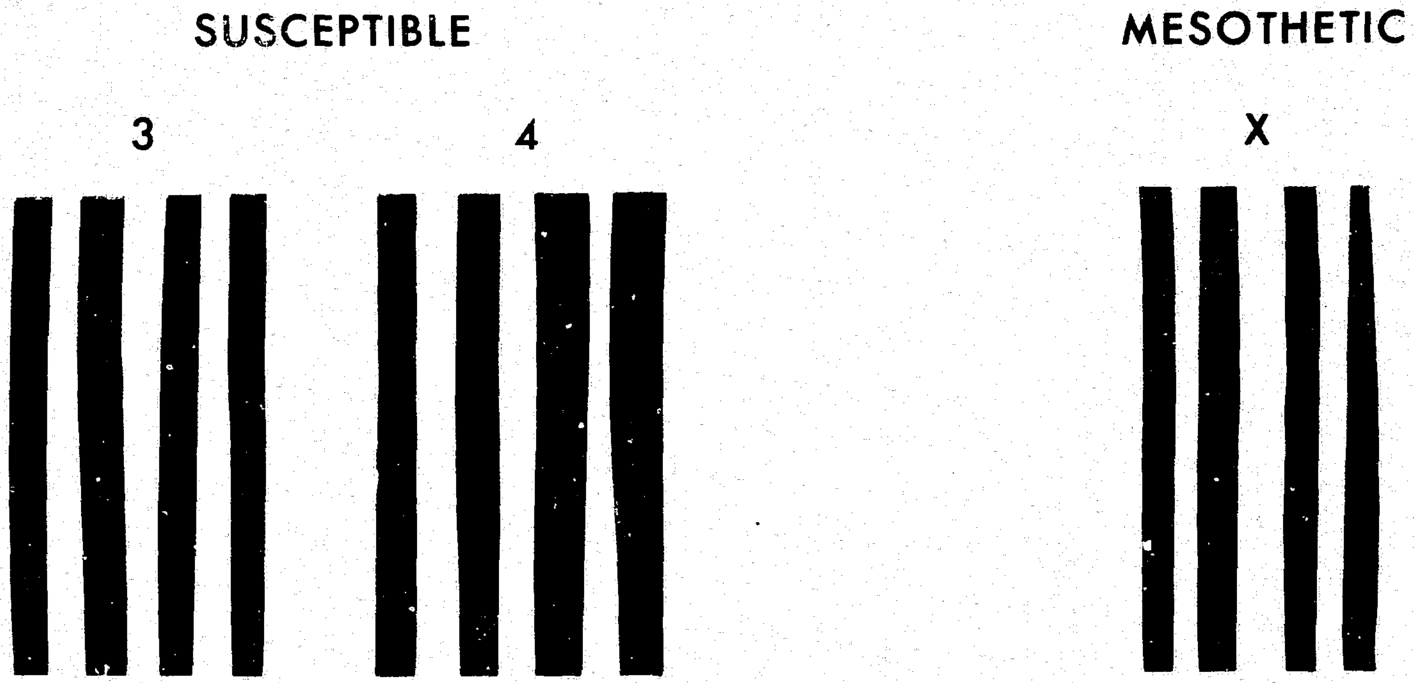


Left, effect of temperature on rust development on Rodney oats inoculated with race 80 of oat stem rust at various temperatures (° C.). *Right*, effect of amount of inoculum load on rust development, showing infection type 2 on Santa Fe Selection inoculated with race 31 of oat stem rust. Note heavy inoculum load obscures necrotic rings.

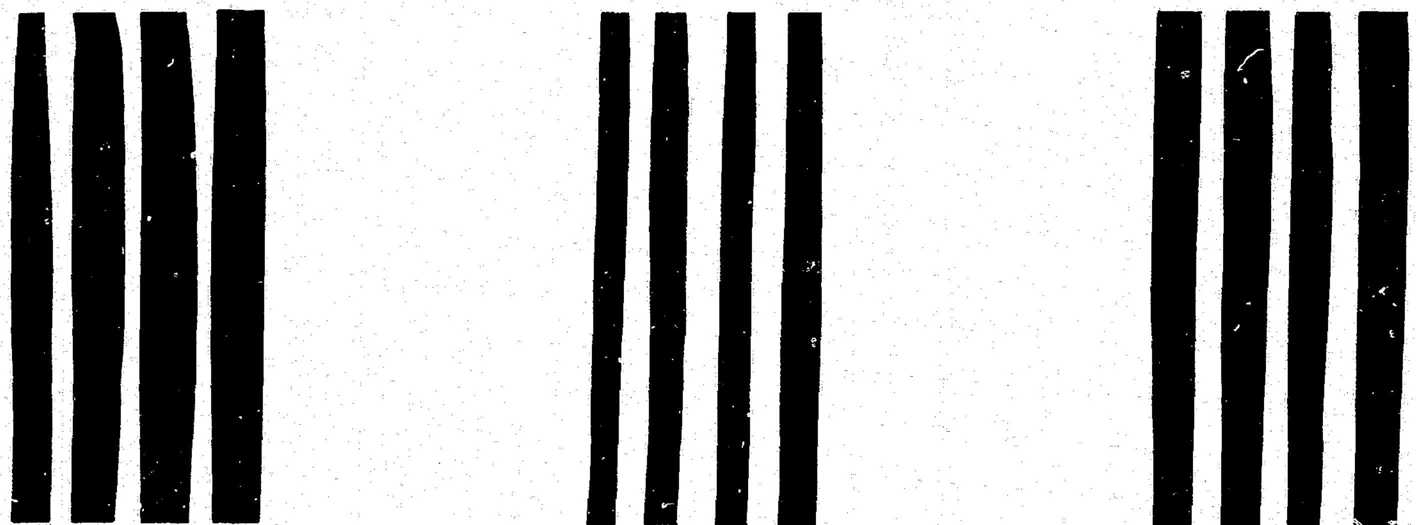
PLATE 1



Reaction classes and infection types within each class used to identify physiologic races. (See table 1.)

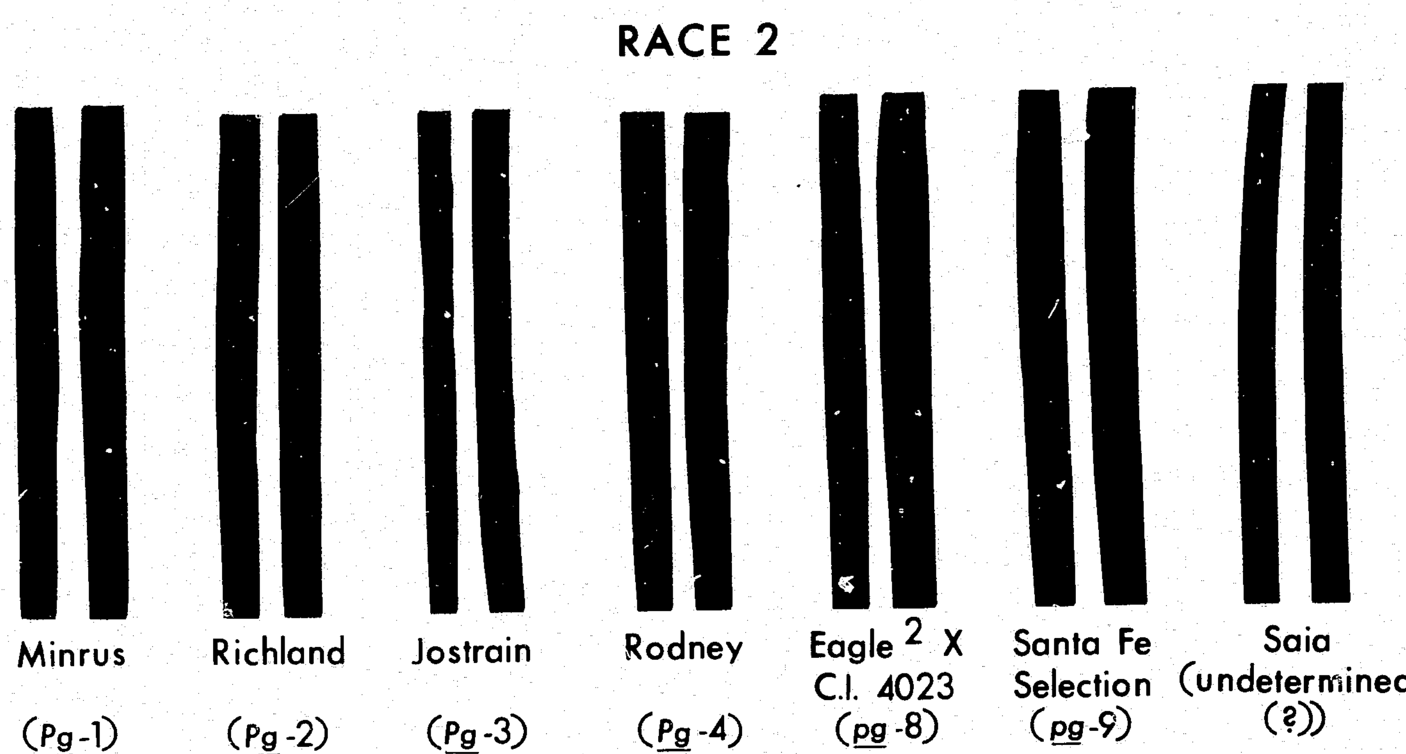
RESISTANT

0; 1 2



Reaction classes and infection types within each class used to identify physiologic races. (See table 1.)

PLATE 4



Infection types produced by race 2 of oat stem rust on seven standard differential varieties at 20° C.

RACE 31

Minrus	Richland	Jostrain	Rodney	Eagle[2] X C.I. 4023	Santa Fe Selection	Saia
(Pg-1)	(Pg-2)	(Pg-3)	(Pg-4)	(pg-8)	(pg-9)	(undetermined (?))

Infection types produced by race 31 of oat stem rust on seven standard differential varieties at 20° C.

END