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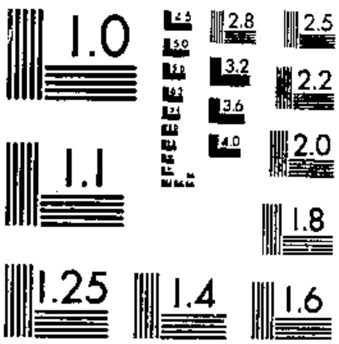
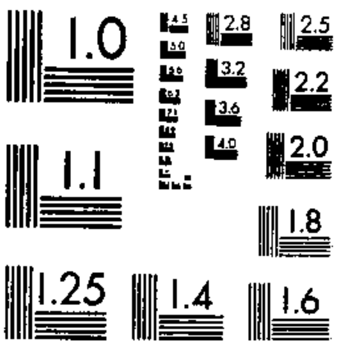


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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Studies on Dwarf Leaf Rust of Barley[1]

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INTRODUCTION

The dwarf leaf rust of barley (*Puccinia hordei* Otth.)[3] has had a relatively short history thus far as an agricultural problem in the

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[3] Less than a century ago this rust had not been distinguished taxonomically from leaf rust on wheat, rye, and many wild grasses. Of several names applied to it, *Puccinia rubigo-vera* (DC.) Wint. was the one used most generally. While still considering the leaf rust on *Hordeum* spp. an integral part of *P. rubigo-vera* (DC.), Winter (*25, p. 218*) classified it as var. *simplex* Körnicke. In view of statements in the standard work just referred to and others, Bisby (*1, p. 44*) concluded that the name "simplex" had "validity only as a variety" until Eriksson and Henning raised it to specific rank "in 1894, by which time it had become a later homonym * * * of *P. simplex* Peck, 1881." Meanwhile, in 1878, the binomial *P. anomala* Rostr. had been published; and, according to Bisby (*1, p. 44*), "its epithet is to be accepted * * * unless and until an earlier epithet might be found to have priority." Stevenson and Johnson (*21, p. 372*) reported in 1946 that such an epithet had been found by Buchwald—the name *Puccinia hordei* Otth. had been published in 1871. This binomial is used in the present paper tentatively and as a matter of expediency.

United States and Canada. In the United States, although it may have been present as early as 1899 (*5, p. 10*) [4] and by 1911 had made its appearance in Iowa, California, Minnesota, Virginia, and Maryland (*8, p. 11*), it did not begin to cause serious losses until about 1935 (*11, p. 21*). That year a severe epidemic of this rust occurred in Minnesota, with intensities on Minsturdi (C. I. 1556) [5] estimated as high as 55 percent at St. Paul and 85 percent at Waseca. In Canada, first collection of this rust was made in 1922. The disease was not found again in the Dominion until 1927, when collections were made throughout southern Manitoba and southeastern Saskatchewan (*4, p. 83*). In 1947 Dickson (*7, p. 57*) reported that "leaf rust of barley occurs extensively in both the winter and spring barley areas of the Eastern and Central United States. In this area the rust is found almost every season, and in some seasons it develops in epiphytotic form, especially in the southern spring-barley area."

Owing to intensified epidemics of dwarf leaf rust on barley, plant breeders in both the United States and Canada began work on development of resistant varieties. This resulted in a pressing need for further studies of physiologic races of the rust and their distribution in North America. A review of the literature on the subject forcefully indicated to the writers the urgent need for reinterpretation and codification of the accumulated data on this rust, which, in some cases, were confusing if not conflicting. Studies designed to meet this need were undertaken at the Federal Cereal Rust Research Laboratory, St. Paul, Minn., and the Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba. Laboratory work involved in the project was carried out during the period 1940–49 at St. Paul and during the period 1930–49 at Winnipeg. Most, if not all, of the barley varieties that at one time or another had been used—either in North America, in Europe, or in Australia—as differential hosts for determination of physiological specialization in this rust were assembled and were subjected to inoculation with hundreds of collections of dwarf leaf rust received from various parts of the United States and Canada. On the basis of results of this work and of published and unpublished findings of other investigators, the writers have prepared dichotomous keys for the identification of physiologic races of the rust. This publication presents these keys and also data on the frequency of occurrence of the races isolated in the United States and Canada during the study years and on mutations that occurred in the course of the laboratory work.

EARLIER WORK ON PHYSIOLOGIC SPECIALIZATION

Evidently sensing the latent threat of dwarf leaf rust to the barley crop in the United States, Mains (*13*) undertook the study of possible physiologic specialization in this fungus a quarter century ago. On the basis of the reactions of Oderbrucker (C. I. 940) and other barley varieties, he demonstrated the existence of at least two physiologic races of *Puccinia hordei* in this country. In 1927, Waterhouse (*23*)

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[4] Italic numbers in parentheses refer to Literature Cited, p. 16.

[5] "C. I." refers to accession numbers of the Division of Cereal Crops and Diseases.

reported his results of testing an Australian culture of dwarf leaf rust on a number of barley varieties and hybrids. Analyzing these results, Mains (*14*) later suggested that the Australian culture constituted a third physiologic race. Independently of the aforementioned researchers, Brown and Newton (*4*) reported in 1929 the isolation of two barley leaf rust races in Canada. In 1931 Brown (*2*, *3*) reported identification of a third and a fourth race of *hordei* in Canada. Also in 1931 Hey (*9*) published on the identification of eight different physiologic races of barley leaf rust in Germany. The barley varieties he used as differential hosts included none of those theretofore used by investigators. In 1932 Mains and Martini (*15*) reported on the reactions of a great many barley varieties in both greenhouse and field. In 1933 Hirschhorn (*10*) published an account of a barley leaf rust race in Argentina seemingly different from the previously known races.

In awareness of the pioneering endeavors of her predecessors, Ronsdorf (*18*), in 1934, published results from tests she had made with Hey's differential hosts plus 1 additional barley variety. She had succeeded in isolating a ninth race from German collections. Stakman and coworkers (*20*) pointed out the following year that, owing to the use of different test varieties for the determination of physiologic races of leaf rust of barley, comparisons of races isolated in different countries were extremely difficult if not altogether impossible. In the same year, Ronsdorf (*19*) reported on the reactions of 15 barley varieties obtained from Mains to 5 German physiologic races of leaf rust. She found these barleys inadequate for differentiating the races she was studying, although some of them had served as adequate differentials in Mains' tests. Ronsdorf then made 3 single-spore isolations from a barley leaf rust collection she had obtained from Mains. Subjecting the 3 monosporous cultures to a test on 11 German test varieties, she found them to be of 2 physiologic races. On the basis of these results she concluded that the barley varieties Hey and she had selected as differential hosts for the dwarf leaf rust were superior for that purpose to those used by Mains.

After testing a number of dwarf leaf rust collections on the set of differentials used by Hey and Ronsdorf, Straib (*23*) concluded in 1936 that of the 11 varieties thus used only 5 were essential. Adding to these 1 South American variety and 4 varieties previously used by Mains and Martini, and using this set of 10 as differentials, Straib succeeded in isolating 14 different races from 124 collections. Only 4 of the 14 races resembled races previously found in Germany.

Straib's further endeavors to identify dwarf leaf rust races in Europe by use of barley varieties so used in the United States were no more successful than those of Ronsdorf. Using 14 varieties of barley previously used by Mains, Straib differentiated only a few of the 13 physiologic races tested. Brown, at the Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba, used the same 14 barley varieties in testing 8 Canadian leaf rust races. His unpublished results indicate that these races were, in certain respects, differentiable by some of the varieties he used. Brown also tested 4 of the Canadian races on 10 barley varieties used by Straib and succeeded in determining only 3 of the races. Waterhouse (*24*) reported in 1938 that the Kinver barley variety possessed differentiating properties for dwarf leaf rust in

Australia, and that by use of this variety he had ascertained the existence of at least 2 physiologic races of *Puccinia hordei* in that country. Waterhouse made tests with a number of the varieties used by Mains, but found them of no value as differential hosts in Australia. The differential varieties used by German workers had not been available to Waterhouse. D'Oliveira (*16*) isolated 11 new physiologic races from dwarf leaf rust collections obtained in Great Britain, Portugal, and Spain. He used as differential varieties 7 of the 10 hosts chosen by Hey, the 1 added by Ronsdorf, and 2 of those used by Mains. Johnson and Newton (*12, p. 358*) concluded in 1946 that because "different groups of differential hosts were used by North American and European workers, it is not possible to make any comparison between the races present in the two continents." This observation, corroborating the one by Stakman et al. quoted above, might well have included Australia.

Evidence was found in earlier research that physiologic races of *Puccinia hordei* originate through hybridization in the aecial stage and through mutation in the uredial stage. D'Oliveira (*16*) selfed two known races of leaf rust of barley on *Ornithogalum umbellatum* and obtained six new physiologic races through this operation. When he crossed two known races an additional new race resulted. So far these seem to be the only instances on record of production of new *P. hordei* races through selfing and artificial hybridization.

In the earlier works on physiologic specialization of the dwarf leaf rust pathogen, it was assumed that the parasitic behavior of races in the uredial stage remained constant except for minor fluctuations caused by environmental changes. However, when Ronsdorf (*18*) made tests with two races obtained from Hey the behavior of these races was very different from what it was in Hey's tests, under similar cultural conditions. She offered no explanation for the differences. Straib (*22*) doubted that Ronsdorf had the same cultures Hey had worked with. D'Oliveira (*16*) was the first to recognize and report a mutation in a race of dwarf leaf rust of barley. The mutation he found, in a race collected in England which he designated race 14, was a radical change in color and also a change in parasitism. D'Oliveira gave the resultant race the number 23. Mutation may explain the Ronsdorf results just mentioned and may account for certain discrepancies in the pathogenic behavior of physiologic races of the dwarf leaf rust reported by Mains and Martini (*15*) and others.

COORDINATION AND CONSOLIDATION OF PHYSIOLOGIC RACES

Much of the difficulty encountered in identifying physiologic races of *Puccinia hordei* stems from the sensitivity of the organism to the biotic and physical environment in which it is cultured. Moderate and relatively constant temperature and good light are important. The writers have found that a temperature fluctuating around 20° C. is almost ideal for normal development of barley leaf rust, and that in the Manitoba-Minnesota area early spring and fall provide optimum light conditions. Thrifty seedlings 1 to 1½ weeks old were found to be a most desirable medium for clearly defining different infection types, and spring barleys were preferred as differential hosts. Homozygous differential hosts, manifesting homogeneous infection types and reacting consistently under a reasonable variety of conditions, are essential. Essential also are lucid description and classification of the various infection types, so that the types may be discerned and differentiated readily.

Through inoculation tests with all barley varieties previously reported as differentials, it was found that some of these varieties were not entirely adequate as such, some could be used interchangeably, some were essential and some critical, and others possessed auxiliary differential properties. Varieties found essential to keying out all authentic races of barley leaf rust thus far recorded in the literature or otherwise reported numbered 16. Of these 16 varieties, 9 were found to be critical for identification of outstandingly important races consolidated with races of lesser importance. The 16 varieties required for the identification of all authentic races are as follows:

Speciale, C. I. 7536 (Hey's "*Hordeum vulgare speciale*").
Reka 1, C. I. 5051 (Waterhouse's "Reka 1" and Hey's "Australische Recka").
Sudan, C. I. 6489 (Hey's "Sudan" or "Aegyptische Sudan").
Cruzat, C. I. 6482 (Straib's "*Hordeum hexastichum pyramidatum* Kcke.").
Chilean D, C. I. 1433 (Mains' "Chilean D, C. I, No. 1433").
Bolivia, C. I. 1257 (Mains' "Bolivia, C. I. No. 1257").
Oderbrucker, C. I. 940 (Mains' "Oderbrucker, C. I. No. 940").
Quinn, C. I. 1024 (Mains' "Quinn, C. I. No. 1024").
Egypt 4, C. I. 6481 (Ronsdorf's "Aegyptische 4 zeilige").
Club Mariout, C. I. 261 (Mains' "Club Mariout, C. I. No. 261").
Samaria, C. I. 6493 (Hey's "Samaria 4 zlg.").
Berg, C. I. 6486 (Hey's "Friedrichswerther Berg W.-G.").
Gold, C. I. 1145 (Mains', also Brown's, "Gold, C. I. No. 1145").
Lechtaler, C. I. 6488 (Hey's "Lichtis Lechtaler").
Austral, C. I. 6483 (Straib's "Australische 2-zeilige").
Kinver, C. I. 2361 (Waterhouse's "Kinver").

The 9 differential varieties found to be critical in the identification of the racial complexes into which the ingredient races of barley leaf rust were consolidated are Speciale (C. I. 7536), Reka 1 (C. I. 5051), Sudan (C. I. 6489), Bolivia (C. I. 1257), Oderbrucker (C. I. 940), Quinn (C. I. 1024), Egypt 4 (C. I. 6481), Gold (C. I. 1145), and Lechtaler (C. I. 6488). All 9 varieties possess the spring growth habit. For this reason they are most suitable for studies conducted in the North Central region of the United States and in the Western Provinces of Canada. Their usefulness as biological reagents in other parts of the world remains to be proved.

It became necessary to redefine the various infection types and to reconstitute the existing reaction classes, in order to facilitate ready and certain recognition of different physiologic races. Thus, infection types 0, 1, and 2 were incorporated into the resistant class (R), and infection types X, 3, and 4 into the susceptible class (S). The mesothetic class (M), as such, was abolished. The new definitions follow: 0, practically immune—no uredia visible, pronounced necrotic lesions or flecks may or may not be present; 1, extremely resistant—minute uredia clearly visible, pustules embedded in well-defined necrotic areas; 2, moderately resistant—small uredia abundant, necrotic lesions clearly defined but less extensive, green islands surrounded by necrotic halos may be present; X, variably mesothetic—conglomeration of uredia of diverse sizes and types tending to integrate, both necrotic lesions and chlorosis usually present; 3, moderately susceptible—uredia of medium size, usually slight chlorosis but no necrosis at infection centers; 4, extremely susceptible—uredia predominantly large, necrotic lesions absent, chlorosis may be present.

Plus, double-plus, minus, and double-minus (equality) signs are used in connection with Arabic numerals to express gradations in severity of infection produced by a given race; the sign ± indicates a range from plus to minus. In the absence of pustules, necrotic flecks are represented by a semicolon, following a zero (0;); necrotic lesions by a period, following a zero (0.); and green islands by a colon, following a zero (0:). The exponent ^{c} stands for chlorosis; the exponent ^{n}, for necrosis.

The 16 barley varieties found to be essential as differential hosts were all used in the current study. Despite this, 3 pairs of very closely related races were automatically consolidated. A comprehensive master key, presented as key 1, was constructed after the tests and after examination of all available published or otherwise reported infection records. In each case only the initial recording, unaffected by later developments, was taken into account in the preparation of the master key. Because this key is presented here as of historical rather than practical value, it is not accompanied by an infection record of all the races involved in its make-up. A detailed infection record of the consolidated races on the 9 critical differential varieties is presented as table 1. The key for the identification of the known consolidated races is key 2.

Numerical designations of the antecedent races in both keys are preceded by authors' initials; the numerical designations of the consolidated races are prefixed by the symbol UN (unified numeration). The sequence of UN numbers is harmonized with the order of dates of publication or discovery of the physiologic races under consideration.

KEY 1.—*Key for identification of all physiologic races of Puccinia hordei Otth. thus far described by investigators*

REACTIONS OF DIFFERENTIAL VARIETIES: (*Race number or numbers*[1])

- Speciale resistant
  - Reka 1 resistant
    - Sudan resistant
      - Cruzat resistant
        - Chilean D resistant
          - Egypt 4 resistant
            - Gold resistant C10, L20
            - Gold susceptible C11
          - Egypt 4 susceptible
            - Club Mariout resistant
              - Austral resistant C16, L7
              - Austral susceptible B1, L5
            - Club Mariout susceptible
              - Gold resistant C9, L18
              - Gold susceptible B2, L8, M1
        - Chilean D susceptible B4
      - Cruzat susceptible
        - Chilean D resistant C15
        - Chilean D susceptible
          - Oderbrucker resistant
            - Lechtaler resistant L13
            - Lechtaler susceptible L4
          - Oderbrucker susceptible L1

[1] See footnote at end of key.

Key 1.—*Key for identification of all physiologic races of Puccinia hordei Otth. thus far described by investigators*—Continued

Reactions of Differential Varieties—Continued — *Race number or numbers* [1]

- Speciale resistant—Continued
  - Reka 1 resistant—Continued
    - Sudan susceptible
      - Cruzat resistant
        - Bolivia resistant
          - Lechtaler resistant — H7, L3
          - Lechtaler susceptible — H1, S1
        - Bolivia susceptible
          - Quinn resistant — D14, D17
          - Quinn susceptible — D16
      - Cruzat susceptible — L14
  - Reka 1 susceptible
    - Sudan resistant
      - Cruzat resistant — L2
      - Cruzat susceptible
        - Bolivia resistant
          - Lechtaler resistant — B6
          - Lechtaler susceptible — L15, S11
        - Bolivia susceptible — B5
    - Sudan susceptible
      - Bolivia resistant
        - Egypt 4 resistant — D21
        - Egypt 4 susceptible — D23, S10
      - Bolivia susceptible
        - Quinn resistant
          - Egypt 4 resistant — D30
          - Egypt 4 susceptible
            - Lechtaler resistant — D26
            - Lechtaler susceptible
              - Samaria resistant — D22
              - Samaria susceptible — D15
        - Quinn susceptible
          - Lechtaler resistant — D20, H8, R10
          - Lechtaler susceptible
            - Berg resistant — D18
            - Berg susceptible — D19

- Speciale susceptible
  - Reka 1 resistant
    - Sudan resistant
      - Cruzat resistant
        - Bolivia resistant
          - Oderbrucker resistant — L9
          - Oderbrucker susceptible — L6
        - Bolivia susceptible — H2, S2
      - Cruzat susceptible
        - Bolivia resistant — L19
        - Bolivia susceptible
          - Quinn resistant — D29, S16
          - Quinn susceptible — H6, S12
    - Sudan susceptible
      - Cruzat resistant
        - Bolivia resistant
          - Egypt 4 resistant
            - Gold resistant — C19
            - Gold susceptible
              - Lechtaler resistant — C17
              - Lechtaler susceptible
                - Samaria resistant — H4, H5, R4
                - Samaria susceptible — R5

See footnote at end of key.

KEY 1.—*Key for identification of all physiologic races of Puccinia hordei Otth. thus far described by investigators*—Continued

REACTIONS OF DIFFERENTIAL VARIETIES—Continued

Race number or numbers[1]

- Speciale susceptible—Continued
  - Reka 1 resistant—Continued
    - Sudan susceptible—Continued
      - Cruzat resistant—Continued
        - Bolivia resistant—Continued
          - Egypt 4 susceptible
            - Club Mariout resistant
              - Gold resistant
                - Austral resistant C13
                - Austral susceptible C18
              - Gold susceptible H3, R3, S3
            - Club Mariout susceptible C12, L16, M2
        - Bolivia susceptible D13, S13
      - Cruzat susceptible
        - Bolivia resistant
          - Egypt 4 resistant C14
          - Egypt 4 susceptible B20
        - Bolivia susceptible
          - Lechtaler resistant D27, L10
          - Lechtaler susceptible S15
  - Reka 1 susceptible
    - Sudan resistant
      - Cruzat resistant
        - Lechtaler resistant L17
        - Lechtaler susceptible B21
      - Cruzat susceptible
        - Bolivia resistant B3, L11
        - Bolivia susceptible
          - Gold resistant B7
          - Gold susceptible
            - Kinver resistant W2
            - Kinver susceptible B8, L12, W1
    - Sudan susceptible
      - Bolivia resistant
        - Quinn resistant
          - Egypt 4 resistant
            - Lechtaler resistant S14
            - Lechtaler susceptible R2, S19
          - Egypt 4 susceptible R9, R11, S9
        - Quinn susceptible S17
      - Bolivia susceptible
        - Quinn resistant
          - Egypt 4 resistant S18
          - Egypt 4 susceptible D25
        - Quinn susceptible
          - Egypt 4 resistant D24
          - Egypt 4 susceptible
            - Berg resistant D28
            - Berg susceptible D12

[1] Capital letters prefixed to numbers signify authorities as follows: B=Brown et al. (*2*, *3*, *4*, and unpublished results); C=Cherewick (unpublished results); D=D'Oliveira (*16*); H=Hey (*9*); L=Levine (unpublished results); M=Mains (*13*, *14*), and Mains and Martini (*15*); R=Ronsdorf (*18*, *19*); S=Straib (*22*); W=Waterhouse (*23*, *24*).

Table 1.—*Infection record of consolidated races of Puccinia hordei Otth.*

Unified-numeration race	Mean infection types [1] on specified differentials [2]								
	Spc	Rka	Sdn	Bol	Odr	Qin	Egp	Gld	Lec
1	1++	1±	1	1++	1+	0;	4+	4=	0;
2	3	1	3+	0;	3++	1=	3	0:	1
3	3+	4=	1	4	3+	1++	3++	3	3++
4	1−	1	1=	1=	1	1=	4+	1	1−
5	3++	3+	0;	2−	1++	3	4	3++	3+
6	0	2+	3++	1	0	1++	1=	4	4
7	4	1++	1+	3++	4	3	0;	4	4−
8	4	1	3+	2±	4−	0	3	4−	4
9	4−	1=	4−	2	4	0	2	3	4=
10	3++	1++	1++	4−	4	4−	4	4	1−
11	1+	1+	4	0;	4	1=	4−	1±	1++
12	0	4−	4	3	2−	4	4−	-----	2
13	4=	3++	3	1	4	0	1=	-----	4−
14	4−	3	3++	1++	4	0;	3	4	4
15	1=	3++	4	2=	0	3	3++	-----	4
16	1++	3+	1−	0.	1=	1++	3+	3+	3++
17	4	2+	4	3++	4	4−	4	-----	3
18	4	3	4	1	-----	0;	0	-----	1=
19	4	1=	4	3	4	0	3+	-----	4
20	4	1++	2	3++	4	1++	4	-----	3++
21	4	4−	4	2	4	3	4=	-----	4
22	4	4−	4	3	4	1=	0.	-----	4
23	4	3+	4	4	4−	3	3++	-----	3+
24	1−	1+	3+	3+	1=	1	1±	-----	3++
25	0	3++	4	3++	1−	1	4−	-----	4
26	0	0	4	3±X	0	3	0	-----	3+
27	0	4	4	3++	1=	4	4	-----	3++
28	0	3++	4−	2	0	3++	2−	-----	4−
29	4	4	4	4	4	3−	0	-----	3
30	4−	4	4	4−	4−	1+	4	-----	3+
31	0	4	4	4	1	2	4	-----	2−
32	3+	1	3+	3+	3++	1+	3++	1+	1++
33	0	3++	4	4	0	1	0	-----	4
34	0;	3	1−	3	0;	0;	3	1	3
35	0;	3	1−	0;	0;	0;	3	3	0;
36	3	3	1	3	3	0;	3	1+	3
37	0;	1=	1±	0;	0;	0;	2±	0;	2−
38	1=	2	0;	0;	0;	0:	2+	3	3+
39	4−	2=	3+	1=	1=	0;	2±	1=	2−
40	0;	1+	0;	1=	0;	0;	X	3	3+
41	3	1−	3+	0;	3	0;	2±	3−	1+
42	3−	1+	3+	0;	3−	0;	2	1+	1
43	1++	1	1++	1++	3+	1−	4±	1++	1
44	1±	3	1−	1	2−	1	4	1−	1++
45	1+	1−	1+	1−	1+	1	3++	1++	3+
46	3++	1+	2	0:	4−	1+	3++	0:	1±
47	4=	1−	1++	0;	2	0;	4+	1	1
48	1++	0.	3+	0;	2	0;	3+	0;	0;
49	3	3	0;	1−	0:	0.	3	0;	1
50	3	0;	0.	0;	3	0;	3++	0;	3
51	3	1+	3	0;	2+	1+	3	2+	3
52	3	3+	0;	0:	1+	1	3	1+	3

[1] Symbols for infection types and for gradations in severity of infection are defined on pp. 5–6.

[2] Bol=Bolivia (C. I. 1257); Egp=Egypt 4 (C. I. 6481); Gld=Gold (C. I. 1145); Lec=Lechtaler (C. I. 6488); Odr=Oderbrucker (C. I. 940); Qin=Quinn (C. I. 1024); Rka=Reka 1 (C. I. 5051); Sdn=Sudan (C. I. 6489); Spc=Speciale (C. I. 7536). These abbreviations are used for convenience in recording rust readings.

986490—52——2

Key 2.—*Condensed standard key for identification of consolidated physiologic races of Puccinia hordei Otth., embracing all races thus far described by investigators* [1]

REACTIONS OF DIFFERENTIAL VARIETIES: (Unified-numeration race number)

- Speciale resistant
  - Reka 1 resistant
    - Sudan resistant
      - Oderbrucker resistant
        - Egypt 4 resistant
          - Gold resistant—C10, L20 …… 37
          - Gold susceptible—C11 …… 38
        - Egypt 4 susceptible
          - Gold resistant
            - Lechtaler resistant—B1, B4, C9, C16, L5, L7, L13, L18 …… 4
            - Lechtaler susceptible—L4 …… 45
          - Gold susceptible
            - Lechtaler resistant—B2, L8, M1 …… 1
            - Lechtaler susceptible—C15 …… 40
      - Oderbrucker susceptible—L1 …… 43
    - Sudan susceptible
      - Bolivia resistant
        - Oderbrucker resistant
          - Egypt 4 resistant—H1, S1 …… 6
          - Egypt 4 susceptible—L14 …… 48
        - Oderbrucker susceptible—H7, L3 …… 11
      - Bolivia susceptible
        - Quinn resistant—D14, D17 …… 24
        - Quinn susceptible—D16 …… 26
  - Reka 1 susceptible
    - Sudan resistant
      - Bolivia resistant
        - Gold resistant—L2 …… 44
        - Gold susceptible
          - Lechtaler resistant—B6 …… 35
          - Lechtaler susceptible—L15, S11 …… 16
      - Bolivia susceptible—B5 …… 34
    - Sudan susceptible
      - Bolivia resistant
        - Egypt 4 resistant—D21 …… 28
        - Egypt 4 susceptible—D23, S10 …… 15
      - Bolivia susceptible
        - Quinn resistant
          - Egypt 4 resistant—D30 …… 33
          - Egypt 4 susceptible
            - Lechtaler resistant—D26 …… 31
            - Lechtaler susceptible—D15, D22 …… 25
        - Quinn susceptible
          - Lechtaler resistant—D20, H8, R10 …… 12
          - Lechtaler susceptible—D18, D19 …… 27
- Speciale susceptible
  - Reka 1 resistant
    - Sudan resistant
      - Bolivia resistant
        - Oderbrucker resistant—L9 …… 47
        - Oderbrucker susceptible
          - Lechtaler resistant—L6 …… 46
          - Lechtaler susceptible—L19 …… 50
      - Bolivia susceptible
        - Quinn resistant—D29, S16 …… 20
        - Quinn susceptible
          - Egypt 4 resistant—H2, S2 …… 7
          - Egypt 4 susceptible—H6, S12 …… 10

See footnote at end of key.

Key 2.—*Condensed standard key for identification of consolidated physiologic races of Puccinia hordei Otth., embracing all races thus far described by investigators*[1]—Continued

Reactions of Differential Varieties—Continued (Unified-numeration race number at right)

- Speciale susceptible—Continued
  - Reka 1 resistant—Continued
    - Sudan susceptible
      - Bolivia resistant
        - Oderbrucker resistant
          - Egypt 4 resistant—C14 39
          - Egypt 4 susceptible—B20 51
        - Oderbrucker susceptible
          - Egypt 4 resistant
            - Gold resistant—C19 42
            - Gold susceptible
              - Lechtaler resistant—C17 41
              - Lechtaler susceptible—H4, H5, R4, R5 9
          - Egypt 4 susceptible
            - Gold resistant—C12, C13, C18, L16, M2 2
            - Gold susceptible—H3, R3, S3 8
      - Bolivia susceptible
        - Quinn resistant
          - Lechtaler resistant—D27, L10 32
          - Lechtaler susceptible—S15 19
        - Quinn susceptible—D13, S13 17
  - Reka 1 susceptible
    - Sudan resistant
      - Bolivia resistant
        - Quinn resistant
          - Lechtaler resistant—L17 49
          - Lechtaler susceptible—B21 52
        - Quinn susceptible—B3, L11 5
      - Bolivia susceptible
        - Gold resistant—B7 36
        - Gold susceptible—B8, L12, W1, W2 3
    - Sudan susceptible
      - Bolivia resistant
        - Quinn resistant
          - Egypt 4 resistant
            - Lechtaler resistant—S14 18
            - Lechtaler susceptible—R2, S19 13
          - Egypt 4 susceptible—R9, R11, S9 14
        - Quinn susceptible—S17 21
      - Bolivia susceptible
        - Quinn resistant
          - Egypt 4 resistant—S18 22
          - Egypt 4 susceptible—D25 30
        - Quinn susceptible
          - Egypt 4 resistant—D24 29
          - Egypt 4 susceptible—D12, D28 23

[1] Code numbers heretofore used as racial designations, which appear in the identification column of key 1, appear in the varietal-reaction column here. As in key 1, B=Brown et al. (*2, 3, 4*, and unpublished results); C=Cherewick (unpublished results); D=D'Oliveira (*16*); H=Hey (*9*); L=Levine (unpublished results); M=Mains (*13, 14*), and Mains and Martini (*15*); R=Ronsdorf (*18, 19*); S=Straib (*22*); W=Waterhouse (*23, 24*).

RACES ISOLATED FROM NORTH AMERICAN COLLECTIONS

Many hundreds of isolates were studied during 1930–49 at the Manitoba and during 1940–49 at the Minnesota rust research laboratory. Isolates that were fully identified totaled 357, including 115 of Canadian and 242 of United States origin. These isolates grouped themselves into 26 consolidated races bearing unified numerations. The frequency of occurrence of the races and the geographic origin of the collections from which they were isolated are shown in table 2. All these 26 races have been found in nature. In addition to them, race 50 appeared as a mutant in a greenhouse culture that had been stored for several months in a refrigerator. Most common and most widely distributed in each of the two countries was race 4, which constituted 28.9 percent of the isolates obtained from United States specimens, 31.3 percent of those from Canadian specimens, and 29.7 percent of the grand total. Second most common in the United States was race 37, isolates of which amounted to 21.9 percent of the total identified, and third place was held by race 47, with 21.5 percent of all U. S. isolates identified. In Canada, second place went to race 2, which made up 22.6 percent of the identified isolates, and third place to race 35, with 7.0 percent of the Canadian total.

Of the 26 consolidated races isolated in either Canada or the United States, 11 occurred, in various proportions, in both countries. These were UN races 1, 2, 3, 4, 5, 16, 37, 44, 46, 47, and 49. It appears that UN race 3 occurs also in Australia and UN race 16 in Europe. Furthermore UN race 11, which was isolated twice in the United States, was present also among the isolates identified in Germany. With the exceptions just mentioned, there is little in common between known North American and European races of dwarf leaf rust of barley. However, there are as many consolidated races on one continent as on the other.

TABLE 2.—*Physiologic races of Puccinia hordei Otth. isolated in Canada and the United States*

Place of origin	Frequency distribution of specified physiologic races																										Total	
	1	2	3	4	5	11	16	32	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	51	52	Units	Races
Canada:																												
British Columbia				3	1		1		1	4		1	1		2							1					15	9
Manitoba	5	19	1	13					1	1	1	1	1			2	1				1	1			1	1	50	15
Nova Scotia		1	1	2					2	3	1		1														11	7
Ontario		3		12								2			1				1								19	5
Quebec		3	1	5									3	2					1					1		1	17	8
Saskatchewan	2			1																							3	2
United States:																												
Arkansas												1							4								5	2
Delaware				1		1																					2	2
Florida				1								3									1	1					6	4
Georgia												5								1		4		1			11	4
Illinois				4															2	1		1					8	4
Iowa				9				1				3							1	1		1					16	6
Kansas			1	2								5										5					13	4
Kentucky				3								4										6					13	3
Maine				1															3								4	2
Maryland				1																1		1					3	3
Michigan	2			6								4						1	1	2		4	2				22	8
Minnesota	3	1		7								2							3	3	1	6					26	8
Mississippi				1																							1	1
Missouri				1																		2					3	2
New Jersey												1															1	1
New York												3										1					4	2
North Carolina			1	1	2			1				6							1			6					18	7
North Dakota		1																		1		1					3	3
Ohio				5																							5	1
Oklahoma				2								3										1					6	3
South Carolina		1		7	1							3						3				4					19	6
South Dakota				1		1																					2	2
Tennessee				2								1							1				1				5	4
Texas			1	7			1					1							2	1							13	6
Virginia				5								4						1				2	1				13	5
West Virginia												1										2	2				5	3
Wisconsin	1			3								3							2	1		4		1			15	7
Total	13	29	6	106	4	2	2	2	4	8	2	57	6	2	3	2	1	5	22	12	3	54	6	3	1	2	357	26

EVIDENCE OF PATHOGENIC MUTATIONS

In table 3 are recorded comparative reactions of 20 barley varieties to 2 isolates of *Puccinia hordei* before and after a period of approximately 2 years at the St. Paul laboratory. The isolates had undergone some drastic changes in their pathogenicity during the period 1942–45. Both isolate 1 and isolate 2 were cultured for 12 successive uredial generations in the greenhouse season 1942–43, for 8 more generations in 1943–44, and for 4 generations in 1944–45. Between greenhouse seasons, the cultures were stored for several months in a refrigerator at about 6° C. During the first 2 greenhouse seasons, or for 20 uredial generations, there was no discernible change in the parasitism of either isolate; but for each of the 4 successive generations of the third season, the behavior pattern of these isolates appeared quite different in several respects from what each was during the first 2 seasons of the experiment.

TABLE 3.—*Pathogenicity of two isolates of Puccinia hordei Otth. observed at the Federal Cereal Rust Laboratory, St. Paul, in 1944–45 in comparison with their consistent parasitic behavior during the two preceding greenhouse seasons*

Barley variety	C. I. number	Mean relative infection types [1]			
		Isolate 1		Isolate 2	
		1942–44	1944–45	1942–1944	1944–1945
Afghan 2	6366	3++	0.	0;	1
Austral	6483	3++	3+	2±	4
Bavaria	6395	1±	3++	1++	1±
Berg	6486	0;	3	1−	0;
Bolivia	1257	0;	0;	0;	0;
Coast	1430	3+	3+	2+	3++
Chilean D	1433	1++	3+	2−	3±
Cruzat	6482	1++	3+	1±	4±
Egypt 4	6481	4=	3++	3+	4
Flynn	1311	3+	3++	2++	4+
Gold	1145	1=	0;	0;	1=
Grossklappige	6485	4	3+	4+	4
Horsford	877	4=	3	1±	0;
Kuban	6480	1−	0;	1=	1=
Lechtaler	6488	1++	3	1=	0.
Oderbrucker	940	4±	4−	2=	1±
Quinn	1024	1=	0;	1±	0;
Reka 1	5051	2	0;	1−	1−
Schladener	6490	1±	3+	0;	0;
Sudan	6489	4±	0.	1±	1=

[1] Symbols for infection types and for gradations in severity of infection are defined on pp. 5–6.

Significant changes in the parasitic behavior of isolate 1 were very evident on the eight varieties Afghan 2, Bavaria, Berg, Chilean D, Cruzat, Lechtaler, Schladener, and Sudan. In the case of isolate 2, significant changes were observed on Austral, Coast, Chilean D, Cruzat, and Flynn. In general, the isolates had become more virulent on the varieties just listed; in the case of isolate 1, however, there was a shift in the opposite direction on Afghan 2 and Sudan. According to its original behavior, isolate 1 was identified as UN race 11; it became UN race 50 as a result of mutation. Because of consolidation, isolate 2 maintained its identity as UN race 4 even after it had undergone the radical changes in pathogenicity just discussed; nevertheless, these changes, too, can best be explained as results of mutation.

A number of mutations appeared also at the Winnipeg laboratory. Four isolates that underwent such changes are listed in table 4. The changes appeared in uredial material of purified cultures of certain physiologic races of *Puccinia hordei* that had been stored for several months between two greenhouse seasons in a refrigerator at approximately 3° to 6° C.

TABLE 4.—*Pathogenicity of four isolates of Puccinia hordei Otth. observed at the Dominion Laboratory of Plant Pathology, Winnipeg, in 1946–47 and in 1947–48 in comparison with their consistent parasitic behavior during the preceding greenhouse season*

Barley variety	C. I. number	Mean relative infection types [1]							
		Isolate 1		Isolate 2		Isolate 3		Isolate 4	
		1945–1946	1946–1947	1946–1947	1947–1948	1946–1947	1947–1948	1946–1947	1947–1948
Austral	6483	2+	2+[a]	3−[a]	2±[a]	2+	3−[a]	3−	3±[a]
Bolivia	1257	1=	0;	0;	0;	0;	0;	0;	0;
Chilean D	1433	2	2−	3−	1=	1=	2±	1+	2±
Club Mariout	261	0;	3	2−	3−	2	2+	1+	2±
Cruzat	6482	3	1+	2−	1	2+	1±	1+	2±
Egypt 4	6481	X	3	3	3+	3+	3+	3+	3+
Gold	1145	3	1=	1=	1=	1=	2±	1=	1=
Kuban	6450	2+	1−	1	1±	1−	2±	1−	1−
Lechtaler	6488	3+	1+	1−	1−	1−	2±	1−	1
Oderbrucker	940	0;	1=	0;	1=	0;	3±	0;	4
Quinn	1024	0;	0;	0;	1=	1=	1=	1=	1±
Reka 1	5051	1+	2++	1−	1±	1	1±	1+	1±
Speciale	7536	0;	1=	0;	1=	0;	3±	0;	3+
Sudan	6489	0;	1−	1=	1=	0;	3	1=	3+

[1] Symbols for infection types and for gradations in severity of infection are defined on pp. 5–6.

Isolate 1, after cold storage, showed a significant gain in virulence on Club Mariout and a significant loss on Cruzat, Gold, and Lechtaler; isolate 2 gained some virulence on Club Mariout and lost more on Chilean D; isolate 3 gained significantly in virulence on Oderbrucker, Speciale, and Sudan, and lost significantly on no variety; isolate 4 underwent in a more sharply defined fashion the changes that took place in isolate 3. Isolate 1 changed from UN race 40 to UN race 4; isolate 2 remained UN race 4 regardless of the changes; and isolates 3 and 4 changed from UN race 4 to UN race 2.

SUMMARY AND DISCUSSION

Most, if not all, varieties of barley that at one time or another had been used as differential hosts for determination of the existence of physiologic specialization in barley leaf rust (*Puccinia hordei* Otth.) were assembled and subjected to inoculation with 357 isolates of this rust, of which 115 originated in Canada and 242 in the United States. It was found that some of the varieties were not entirely adequate as differentials, some could be used interchangeably, some were essential and some critical, and others possessed auxiliary differential properties. Varieties found essential to keying out all authentic ingredient races of barley leaf rust thus far reported numbered 16; of these 16, 9 varieties were found to be critical for the identification of the consolidated races. The 9 critical differentials are: Speciale, Reka 1, Sudan, Bolivia, Oderbrucker, Quinn, Egypt 4, Gold, and Lechtaler.

On the basis of results of this work and a critical interpretation of previously recorded data, two dichotomous keys were constructed for the identification of physiologic races of the dwarf leaf rust of barley. One of these, the comprehensive master key, enables the tracing of all essential ingredient races described by investigators. The other, the condensed standard key, is designed for practical identification of present and future racial complexes. It is based upon the consolidation of ingredient races as determined by the reactions of the abovementioned set of 9 critical differentials. To avoid recurrence of confusion, numbers designating consolidated physiologic races have been given the prefix UN. The sequence of UN numbers is harmonized with the order of dates of publication or discovery of the physiologic races under consideration.

Physiologic races included in the condensed standard key number 52. Of these, 26 were found in the North American collections. Very few of the known physiologic races of *Puccinia hordei* have been found on more than one continent, and many have been found in only one country.

Pathogenic mutations occurred rather frequently in the course of the laboratory work of this study. Evidence suggests, also, that mutations occur under natural conditions. New physiologic races are uncovered each year in numbers that are strikingly large in proportion to the total numbers of isolates studied. Since observation of an aecial stage of the dwarf leaf rust of barley in North America has not been reported, it seems likely that the multiplicity of races existing on this continent stems from mutation.

Recent discovery of aecia of dwarf leaf rust of barley on *Ornithogalum pyrenaicum* in Britain by Dennis and Sandwith (*6*) and the finding by D'Oliveira (*17*) that many species of *Ornithogalum* contain strains congenial to *Puccinia hordei* indicate a need of further research in North America with reference to possible alternate hosts of this rust.

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