STUDIES ON THE DISEASE-RESISTANCE IN BARLEY
III. FURTHER STUDIES ON THE PHYSIOLOGIC RACES OF *ERYSIPHE GRAMINIS HORDEI* IN JAPAN. *

U. Hiura and H. Heta

Introduction

Five physiologic races of *Erysiphe graminis hordei* in Japan had been isolated by the writers during 1950—1952, and it was found that the six differential varieties of barley used by Cherewick in Canada were not adequate for differentiating the physiologic races of the fungus prevalent in Japan (2, 6). In 1953 and 1954, therefore, a new set of barley varieties, Goldfoil C. I. 928, Hanna C. I. 906, Heil's Hanna 3 C. I. 682, Kairyo-bozu-mugi, Nakaizumi-zairai and Nigrate C. I. 2444 were selected by the writers to differentiate the Japanese physiologic races of *Erysiphe graminis hordei*; and by so doing, five new races in 1953 and one new race in 1954 were isolated, making a total of eleven physiologic races of barley mildew in Japan. Of these eleven physiolgic races, some were rare in occurrence, and it seems for the present and the near future that they should not become a problem necessitating elaborate control measures. Nevertheless, for developing varieties of barley resistant to the disease, the occurrence and geographic distribution of even the rare physiologic races or biotypes must not be overlooked.

Results of a study on the relative resistance of barley varieties to the eleven physiologic races are also reported in this paper.

Materials and Methods

In the spring of 1953, 67 cultures of barley mildew were established from the materials from 40 prefectures of Japan. These cultures were preserved in a refrigerator till autumn and purified by means of single spore isolations. The methods of isolation, preservation and purification of the cultures were described in detail in the previous report (2). During the winter of 1953—1954, the selected 120 barley varieties, including the

* Investigation undertaken by the Subsidy in Aid for Fundamental Scientific Research from the Ministry of Education in 1953—1954.

Cherewick's differential hosts, were inoculated with 26 of the 67 pure cultures and the five races of powdery mildew identified during 1950—1952. The 26 cultures were isolated from materials that were collected at different districts or isolated from different varieties of barley. Tests were made in the glass-room where each variety could be studied for its reactions to individual cultures of mildew. From this test, the six barley varieties—Goldfoil C. I. 928, Hanna C. I. 906, Heil's Hanna 3 C. I. 682, Kairyo-bozumugi, Nakaizumi-zairai and Nigrate C. I. 2444—were selected as differential varieties for differentiating physiologic races of *Erysiphe graminis hordei* prevalent in Japan. By the use of these six and those of Cherewick's, the pathogenicity of the remaining 41 cultures were identified. In the spring of 1954, 213 cultures were established from the materials gathered from 17 prefectures. These cultures were identified in the spring by the reactions of the six differential varieties. The cultures employed in this experiment were all established from conidia.

Methods of inoculation were almost same as those taken in the previous experiment made from 1950 to 1952 (2). In the previous work, however, seedlings of the differential varieties were protected from stray mildew spores by a glass lamp chimney; but, a glass lamp chimney was not suitable for the purpose, as the temperature and humidity in the chimney became too high under direct sunlight. In this experiment an isolation box was used in place of a lamp chimney, thus obtaining satisfactory results. The boxes were enclosed with glass on two sides and white cotton cloth on the other two sides and top.

Five classes of reaction were distinguished, such as immune or highly resistant "0", resistant "1", moderately resistant "2", moderately susceptible "3", and susceptible "4". Although in previous report (2) immune type "i" was distinguished from highly resistant type "0", highly resistant varieties occasionally gave immune type under certain environmental conditions. Moreover, the difference of the two reaction types was not significant for differentiating the physiologic races of powdery mildew. In this paper, therefore, both the immune type and highly resistant type were together denoted as "0".

Experimental Results

Identification of physiologic races

In order to distinguish Japanese races from American and Canadian races, Japanese physiologic races of *Erysiphe graminis hordei* were designated by the Roman numerals. In 1953, nine physiologic races (races I, II, III, IV, VI, VII, VIII, IX and X) were isolated from 67 cultures. The five of the nine races (races VI, VII, VIII, IX and X) were first found in 1953. In 1954, eleven physiologic races (races I, II, III, IV, V, VI, VII, VIII, IX, X and XI) were isolated from 213 cultures. The race XI was first found in 1954. The races I, II, III, IV and V had already been isolated during 1950 to 1952, and were reported as races 13, 8B, 14, 8C and 15 respectively. The reaction types produced on seedling leaves of the six selected differential varieties by the eleven physiologic races are presented in Table 1. The

Table 1. *Infection types produced on seedling leaves of six differential varieties of barley by 11 physiologic races of Erysiphe graminis hordei.*

Varieties \ Races	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Goldfoil C. I. 928	0	0	2	0	0	0	2	0	0	0	2
Hanna C. I. 906	4	4	3—4	4	3—4	4	4	4	0—1	4	4
Heil's Hanna 3 C. I. 682	0	4	0	4	0	0	3—4	3—4	4	0	0
Kairyo-bozu-mugi	1	3—4	1	1	1	4	1	1	1—2	1	1
Nakaizumi-zairai	1	1	1	1	3—4	1	1	3—4	1—3	1	1
Nigrate C. I. 2444	0	0	0	0	0	0	0	0	0—1	4	4

0 ···Immune or highly resistant. No visible signs of infection, or necrotic spots present with no visible development of mycelium.

1 ···Resistant. Necrotic spots present with a slight development of mycelium.

2 ···Moderately resistant. Moderate development of mycelium with a slight conidia formation. Chlorotic or necrotic spots present.

3 ···Moderately susceptible. Moderate development of mycelium and sporulation. Chlorotic or necrotic spots may be present.

4 ···Susceptible. Abundant mycelium and conidia formation. No necrotic spots.

reaction type of Goldfoil to race III (race 14) had been represented as "2—4", but in this experiment it was moderately resistant type "2".

As shown in Table 1 and Plates 1, 2, 3 and 4, Heil's Hanna is highly resistant to races I, III, V, VI, X and XI, but susceptible to races II, IV, VII, VIII and IX. By these reactions, the eleven physiologic races can be easily divided into two groups. Within the group of races I, III, V, VI, X and XI, each is distinguished one another by the following reactions: race III—reaction of Goldfoil, race V—Nakaizumi-zairai, race VI—Kairyo-bozu-mugi, race X—Nigrate, and race XI—Goldfoil and Nigrate. And, similarly for race II—Kairyo-bozu-mugi, race VII—Goldfoil, race VIII—Nakaizumi-zairai, and race IX—Hanna.

In order to compare Japanese physiologic races with American and Canadian races, infection types produced on seedling leaves of Cherewick's differential varieties by Japanese physiologic races are given in Table 2. Race VIII and race IX resemble each other in the reactions of Cherewick's differential varieties. Only in reactions of Chevron C. I. 1111 a little difference is observed. It is impossible to differentiate races VIII and IX from race 3 isolated in America and Canada by using the reactions of Cherewick's differential varieties. Hanna C. I. 906, which is susceptible to race VIII and resistant to race 3, may be used for their distinction. So far, race IX can not be differentiated distinctly from race 3 by the reactions of varieties tested

Table 2. *Infection types produced on seedling leaves of Cherewick's differential varieties by Japanese physiologic races of Erysiphe graminis hordei.*

Races / Varieties	3		8		13			14		15	16
	VIII	IX	II	IV	I	VI	X	III	XI	V	VII
Black Hull-less C. I. 666 ···	3—4	3—4	4	4	4	4	4	4	4	4	4
Chevron C. I. 1111 ········	2	0	2	2	2	2	2	2	2	2—4	2
Goldfoil C. I. 928 ···········	0	0	0	0	0	0	0	2	2	0	2
Heil's Hanna 3 C. I. 682 ···	3—4	4	3—4	3—4	0	0	0	0	0	0	4
Nepal C. I. 595 ··············	3—4	3—4	4	4	4	4	4	4	4	4	4
Peruvian C. I. 935 ········	3—4	3—4	1	1	1	1	1—2	1	1	2	1

in this experiment (2, 4, 5, 6). It is also impossible to find differences between race II and race IV, race I and race VI and race X, race III and race XI by using only the reactions of Cherewick's differential varieties. Races II and IV resemble races 4 or 8 isolated in America and Canada respectively. As it was already discussed in our previous report, however, the race II and race IV may be distinguished from races 4 or 8 by the reactions of Duplex C. I. 2433 (2).

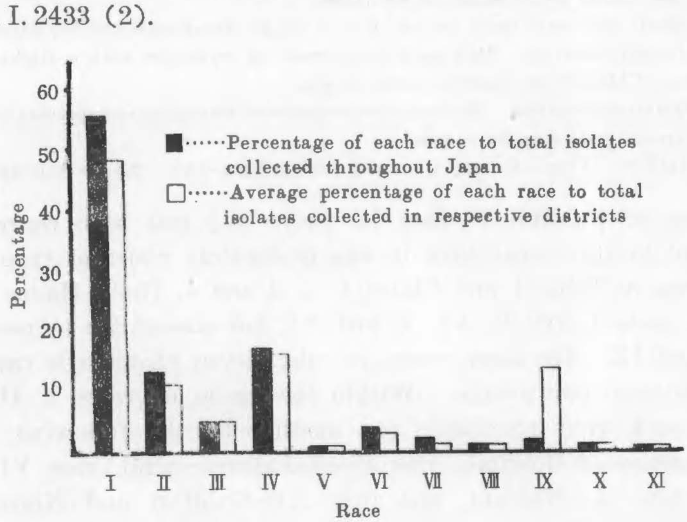


Fig. 1 Frequency of occurrence of physiologic races of *Erysiphe graminis hordei* in Japan during 1953—1954.

The percentage of each race to total isolates is diagramed in Figure 1. A black column represent the percentage of each race to total isolates (280 cultures), and a white column represent average percentage of each race to total isolates collected in respective districts. As will be seen in Figure 1, race I is very predominant, showing 56% of the total isolates. Races IV and II are next prevalent showing 17 and 13% of the total isolates respectively. The remaining races occur in very low proportions. Although only two cultures were established from Hokkaido, both were identified as race IX. The percentage of race IX to total isolates may be increased if more materials, as many as collections from other districts, are collected from Hokkaido.

Geographical distribution of physiologic races in Japan

Two hundred and eighty cultures of *Erysiphe graminis hordei* were established from the materials gathered from the entire Japan, and from them, eleven physiologic races were identified during the last two years, 1953—1954. Geographic distribution of the eleven physiologic races are presented in Table 3 and Figure 2.

Table 3. *Distribution by geographical areas of physiologic races of Erysiphe graminis hordei from 1953 to 1954. (Figures represent the number of times each race was collected in each geographical area).*

Races	I			II			VI			III			IV			VII			V			VIII			X			XI			IX			Total
Districts / Years	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	1953	1954	total	
Hokkaido																															1	1	2	2
Tohoku	2	26	28								6	6	1	3	4					1	1	1	2	3	1	1	2							44
Kanto-Tozan	8	11	19							4	1	5		2	2														1	1		2	2	29
Hokuriku	2	22	24		1	1		1	1		1	1	3	20	23	1	4	5																55
Tokai-Kinki	5	3	8							1		1	1	8	9																			18
Chugoku	13	24	37	3	3	6	1	2	3				2	3	5																			51
Shikoku	2	12	14	5	16	21	1	2	3																									38
Kyushu	6	20	26	1	8	9	2	2	4					4	4																			43
Total	38	118	156	9	28	37	4	7	11	5	8	13	7	40	47	1	4	5	0	1	1	1	2	3	1	1	2	0	1	1	1	3	4	280

Race I is very widespread present in almost over the whole of Japan except Hokkaido. The percentages of race I in each of the following districts were: 64% in Tohoku, 66% in Kanto-Tozan, 44% in Hokuriku, 44% in Tokai-Kinki, 73% in Chugoku, 37% in Shikoku, 60% in Kyushu. The results obtained in these two years (1953—1954) were in agreement with those of three years (1950—1952).

Races II and VI were isolated, with one exception each, from materials collected from only the western parts of Japan (Chugoku, Shikoku and Kyushu districts). The above exceptions were both from samples collected from the prefecture of Niigata (Hokuriku district). Race II was predominant in Shikoku district, consisted of 55% of isolates. This race was first isolated in 1951 from specimens received from prefectures of Niigata (Hokuriku dirtrict) and Nagano (Kanto-Tozan district). In 1952 it was isolated from materials collected from various districts of Japan. At the end of 1952, however, race IV was first isolated, where it was distinguished from race II by the reactions of Kairyo-bozu-mugi. A majority of cultures identified as race II in 1951 and 1952 were not tested on their pathogenicity on Kairyo-bozu-mugi, thus they were not distinguished from race IV. In this

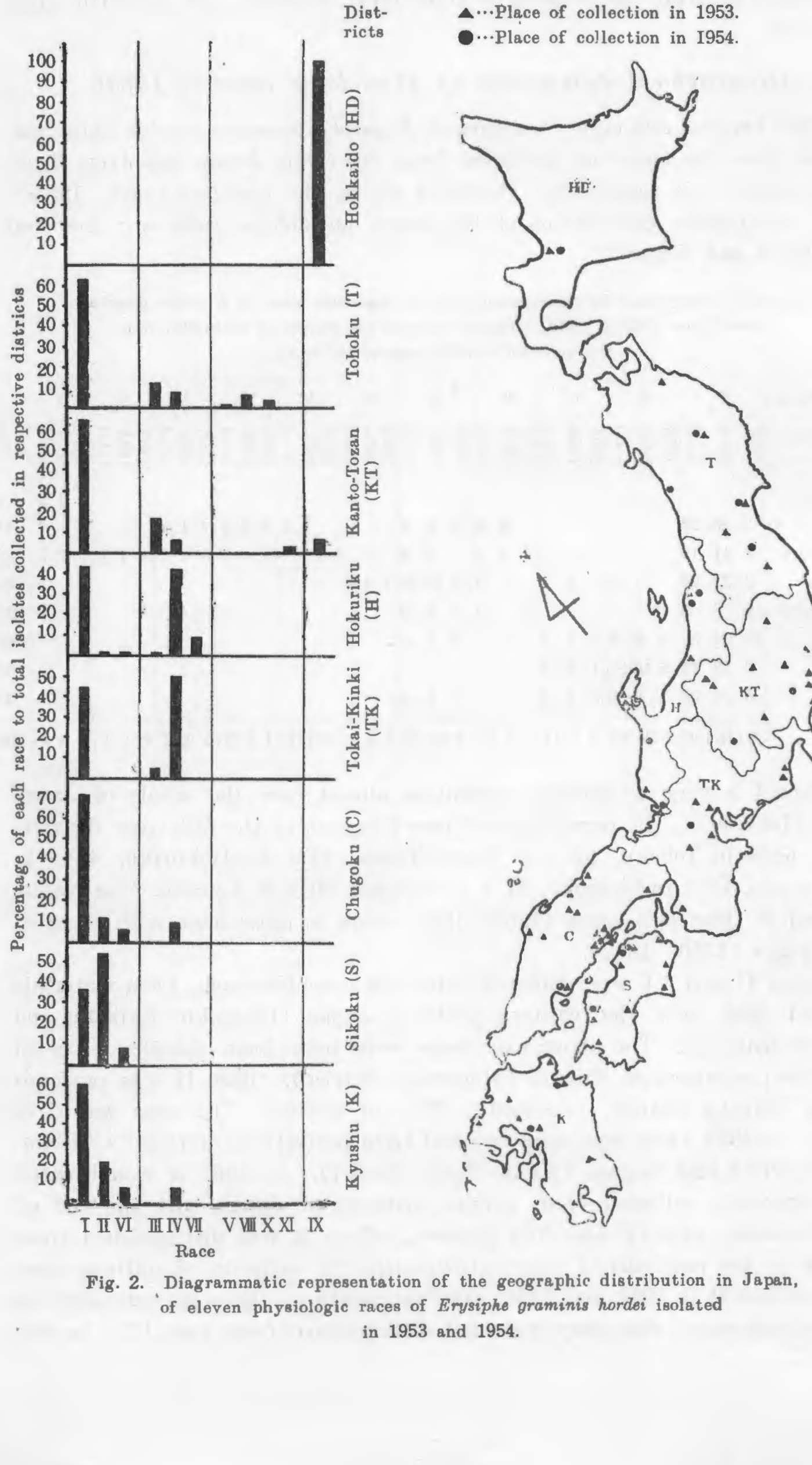


Fig. 2. Diagrammatic representation of the geographic distribution in Japan, of eleven physiologic races of *Erysiphe graminis hordei* isolated in 1953 and 1954.

experiment race II was hardly isolated from materials collected from districts other than western parts of Japan. It is presumed, therefore, that a majority of race II identified in 1951 and 1952 were race IV, except cultures collected from western parts of Japan.

Race III was isolated from materials collected from Tokai-Kinki, Hokuriku, Kanto-Tozan and Tohoku districts, and never found on samples collected from western parts of Japan. This race occurred mostly as a mixture with race I in low proportions. These results were in agreement with that of our previous work made in 1950 to 1952.

Race IV is widespread over the whole of Japan except Shikoku and Hokkaido districts, and next to race I in frequency of population, being 17% of the total isolates. This race was prevalent in Hokuriku and Tokai-Kinki districts, showing 42% and 50% of isolates in each district. However, concerning the geographic distribution of race IV in Hokuriku and Tokai-Kinki districts, more detailed consideration is required. In Hokuriku district, the percentages of race IV were, 50% in Fukui prefecture, 100% in Ishikawa prefecture and 0% in Niigata prefecture in 1953; and 80% in Fukui, 40% in Ishikawa and a very low proportion of 8% in Niigata prefectures in 1954. This is very interesting when we refer to the fact that races II and VI are found only in Niigata and western parts of Japan. The population of physiologic races of barley mildew in Niigata appears to resemble that of western parts of Japan. In Tokai-Kinki district, seven cultures were established in 1953 from materials gathered from prefectures of Wakayama, Mie, Shiga, Gifu, Aichi, and Shizuoka. Of the seven cultures, only one was identified as race IV, showing 14% of the total isolates. In 1954, eleven cultures were established from the samples collected at Maibara of Shiga prefecture. Of the eleven cultures, eight were race IV, showing 73% of the total isolates. The environmental conditions of Maibara rather resemble those of prefectures of Fukui and Ishikawa. Consequently, it may be concluded that the race IV is prevalent predominantly in Hokuriku district, except Niigata, and its adjacent areas.

Race VII was first isolated in 1953 from specimen collected from Hokuriku district, but was again collected in 1954. Races V, VIII and X were isolated only from materials collected from Tohoku district. Race XI was isolated only once from specimen collected in Tokyo (Kanto district) in 1954.

Race IX was first isolated in 1953 from specimen received from Hokkaido, and again in 1954. It was also collected in Tokyo in 1954. Although only two samples were collected from Hokkaido, both were identified as race IX. This race may be the principal in Hokkaido district.

From the view point of geographical distribution, physiologic races of *Erysiphe graminis hordei* in Japan are divided into five groups: race I distributed over the whole of Japan, races II and VI distributed mainly in western parts of Japan, races III, IV and VII distributed principally in

Hokuriku district and its neighbourhood, races V, VIII, X and XI distributed in only Kanto-Tozan and Tohoku districts, and race IX distributed principally in Hokkaido district (Table 3 and Figure 2).

Relative resistance of barley varieties to powdery mildew

A study of the relative resistance of 170 barley varieties to the eleven physiologic races of powdery mildew was undertaken in 1953—1955. The inoculation experiments on 120 varieties of the 170 varieties were made during the winter of 1953. The remaining 50 varieties and some of the former as indicators, were tested during the winter of 1954—1955. The seedlings to be tested were grown in a compartment of a glass-room free from any barley mildew. The inoculations were made on seedlings when they have developed their second leaf. The inoculated seedlings were immediately placed in a temperature-controlled glass-room, having a temperature approximately of 20 C. Three days after inoculation the seedlings were removed to greenhouse. Special precautions were taken to prevent the temperatures of glass-room and greenhouse from becoming above 25 C. In glass-room, however, the temperature occasionally fell as low as freezing point. The experimental results are given in Table 4.

Table 4. *Infection types on 170 barley varieties inoculated in the seedling stage with 11 physiologic races of Erysiphe graminis hordei.*

Barley Varieties	Infection types with physiologic races											Group numbers
	I	III	V	VI	X	XI	II	IV	VII	VIII	IX	
Algerian C. I. 1179	0	0	0	0	0	0	0	0	0	0	0	1
Atlas 46 C. I. 7323	0	0	0	0	0	0	0	0	0	0	0	
Black Russian C. I. 2202	0	0	0	0	0	0	0	0	0	0	0—1	
Engledow India D.I.V, 464	0	0	0	0	0	0	0	0	0	0	0	
Gopal C. I. 1901	0	0	0	0	0	0	0	0	0	0	0	
H. spont. nigrum	0	0	0	0	0	0	0	0	0	0	0	
H. spont. 6586	0	0	0	0	0	0	0	0	0	0	0	
J. 20	0	0	0	0	0	0	0	0	0	0	0	
Russian No. 68	0	0	0	0	0	0	0	0	0	0	0	
Do No. 81	0—1	0	0—1	0	0	0	0—1	0—1	0	0—1	0—1	
Weichenstephaner I	0	0	0	0	0	0	0	0	0	0	0	
Do II	0	0	0	0	0	0	0	0	0	0—1	0	
Arlington Awnless C. I. 702	1	1	1	1	1	1	1	1	1	1	1	2
H. E. S. 1	1—2	1—2	2	1—2	1—2	1—2	2	2	2	1—2	2	
Kwan C. I. 1016	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	2	
Marini	1—2	1—2	1—2	1—2	1	1	2	2	1	1—2	2	
Minn. 90—5	1—2	1—2	1	1—2	2	2	2	2	1—2	1—2	2—4	
Nigrinudum	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	2—3	
Akashinriki	4	4	4	4	4	4	4	4	4	2—3	2—3	

Table 4. *Continued.*

Barley varieties	Infection types with physiologic races											Group numbers
	I	III	V	VI	X	XI	II	IV	VII	VIII	IX	
Black Hull-less C. I. 666	4	4	4	4	4	4	4	4	4	4	3—4	
Black Shen Yong ········	4	4	4	4	4	4	4	4	4	1—3	3—4	
Cebada Negra D. I. V. 479	4	4	4	4	4	4	4	4	4	1—3	1—4	
Kobinkatagi ················	4	4	4	4	4	4	4	4	4	2—3	2—3	
Muyoji ······················	4	4	4	4	4	4	4	4	4	4	2—4	3
Nepal C. I. 595 ············	4	4	4	4	4	4	4	4	4	4	3—4	
No. 16—17 ················	4	3—4	4	4	4	4	4	4	4	4	2—4	
Shiroto ·····················	4	4	4	4	4	4	4	4	4	4	4	
West China D. I. V. 465···	4	3—4	4	4	4	3—4	4	4	4	3—4	0—3	
Yuhoshu ·····················	4	4	4	4	4	4	4	4	4	4	2—4	
Coast C. I. 276 ············	0	0	0	0	0	0	0	0	0	0	1—3	
Kleinwanzleben ··········	0	0	0	0	0	0	0	0	0	0	3—4	4
Manmuth ····················	0	0	0	0	0	0	0	0	0	0	2—3	
Russian No. 74 ············	0	0	0	0	0	0	0	0	0	0	4	
A. 222 ······················	1—2	1—2	2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	3—4	
Bolognes ····················	1—2	0—1	2	0—1	1	1	1—2	1—2	0—1	1—2	3—4	
Brome ························	1	0—1	2	1—2	1—2	1	2	1—2	1	2—3	4	
Hosomugi NO. 2 ··········	1—2	1—2	2	1—2	1—2	1—2	1—2	1—2	1—2	1—2	2—4	5
Vankuri ······················	1—2	0—1	1—2	1—2	1—2	0	1—3	2	0—1	1—2	3—4	
Victorie ······················	2	1—2	2	2	2	1—2	2	1—2	1	1—2	3—4	
ZZ Ist. C. I. 6298 ········	1	0—1	1—2	1	1	1	1	1	0—1	2	3—4	
Duplex C. I. 2433 ········	3—4	4	4	4	4	3—4	4	3—4	4	4	0	6
Hanna C. I. 906 ··········	4	3—4	3—4	4	4	4	4	4	4	4	0—1	
Aizu No. 2 ················	1	1	3—4	1	1	1	1—2	1—2	1	3—4	2—3	
Do No. 4 ················	1	1	3—4	1	1	1	1	1—2	1	3—4	3	
Do No. 5 ················	1	1	3—4	1	1	1	1	1	1	3—4	2—3	
Do No. 6 ················	1	1	3—4	1	1	1	1—2	1	1	3—4	3—4	
Akimaki-hokusei ··········	1	1	4	1	1	1	1	1—2	1	3—4	3	
Colsess C. A. 772 ··········	1	1	3—4	1	1—2	1	1	1—2	1	3—4	3—4	
Date No. 2 ················	0—1	0—1	3—4	0—2	0—1	0	1	0—2	0—1	3—4	3	
H. spont. 5060 ············	1	1	3—4	1—2	1—2	1	1—2	1	0—1	3—4	1—3	
Hosomugi C ················	1	0—1	3—4	1	0—1	0	1	1	1	3—4	1—3	7
Hosomugi No. 3 ··········	1	1	3—4	1	1	0—1	1—2	1—2	1	3—4	2—3	
Hosogara No. 1 ··········	1	1—2	3—4	1	1	1	1—2	1—2	1—2	3—4	3	
Kachidoki ····················	1	1	3—4	1	1	1	1	1—2	1	3—4	3	
Kenkichi No. 1 ············	1	1	3—4	1	1	0—1	1	1	1	3—4	3	
Do No. 3 ············	1	1	3—4	1	1	0—1	1—2	1—2	1	3—4	3—4	
Mensury C (Iwate)········	1	1	3—4	1	1	1	1	1	1	3—4	1—2	
Mukade-mugi ··············	1	1	3—4	1	1	1	1	1	1	3—4	2—3	
Murasaki-hadaka ··········	1	1	4	1	1	1	1	1—2	1	3—4	2—3	
Nakaizumi-zairai ··········	0—1	0—1	3—4	0—1	0—1	0—1	1	1	1	3—4	1—3	

Table 4. *Continued.*

Barley Varieties	Infection types with physiologic races											Group numbers
	I	III	V	VI	X	XI	II	IV	VII	VIII	IX	
Nihonsan	1—2	1—2	3—4	1—2	1—2	1	1—2	1—2	1—2	3—4	3—4	
Omugi No. 2	1	1	3—4	1	1	1	1	1	1	3—4	1—3	
Russian No. 12	1	1	3—4	1	1	1	1—2	1—2	1	3—4	4	7
Sangatsu	1	0—1	3—4	1	1	0—1	1—2	1—2	1	3—4	2—3	
Wase-hosogara	1	1	3—4	1	1	1	1—2	1—2	1	3—4	2—3	
Blackhull C. A. 813	0—1	0—1	2—3	1	1	1	1	1	0—1	3—4	4	8
Peruvian C. I. 935	1	1	2	1	1—2	1	1	1	1	3—4	4	
Abyssinia C. I. 2192	0—1	1	1—2	1	1	0—1	0—2	1	0—1	1—3	4	
Ackermann's Isaria	0—1	0—1	2—3	1	1—2	0—1	1	1	0	2—3	2—4	9
Arequipa C. I. 2329	0—1	0—1	1—2	1	1	0—1	1—2	1	0—1	1—3	4	
Aizu-hadaka No. 3	0—1	0	1—2	0	0	0	0—1	0—1	0—1	1—2	2	
Chevalier (Winter barley)	0—1	0	1—3	0—1	0	0	0—1	0—1	0	1—3	2—3	
Hokudai No. 4	0—1	0	1—2	0—1	0	0	0—1	0—1	0	1—3	2—3	
Do No. 9	0	0	1—2	0	0	0	0	0	0	1—2	1—2	
Maruchin No. 1	0—1	0	1—3	0	0—1	0	0—1	0—1	0—1	1—2	2—3	10
Psaknon C. I. 6305	0—1	0	1	0—1	0—1	0	0—1	0—1	0	1	1	
Sanjaku-honaga C	0	0	0—1	0	0	0	0	0	0	0—1	2—3	
Yuki-shirazu C	0	0	1	0	0	0	0	0	0	1	2—3	
Arivat C. I. 6573	0	0	0	0	0	0	3—4	3—4	3—4	4	4	
German summer barley	0	0	0	0	0	0	3—4	3—4	3	3—4	4	
German No. 58	0	0	0	0	0	0	4	4	4	4	4	
H. E. S. 4	0	0	0	0	0	0	4	4	4	3—4	4	
Hakata No. 2	0	0	0	0	0	0	3—4	3—4	4	4	4	
Heil's Hanna 3 C. I. 682	0	0	0	0	0	0	4	3—4	4	3—4	4	
Hokudai No. 1	0	0	0	0	0	0	3—4	3—4	3—4	4	4	
Hosogara C No. 2	0	0	0	0	0	0	4	4	4	4	4	
J. 135 K-36—964	0	0	0	0	0	0	4	4	4	4	4	
Kinai No. 42	0	0	0	0	0	0	4	4	4	4	4	11
Konosu No. 30	0	0	0	0	0	0	4	4	4	4	4	
Miyagi No. 123	0	0	0	0	0	0	4	4	4	3—4	1—3	
No. 22—1	0	0	0	0	0	0	4	4	4	2—3	2—3	
No. 35—1009	0	0	0	0	0	0	4	4	3—4	3—4	4	
Ōsomugi	0	0	0	0	0	0	4	4	4	4	3	
Russian No. 4	0	0	0	0	0	0	4	4	3—4	3—4	4	
Do No. 59	0	0	0	0	0	0	4	4	3—4	3—4	4	
Sultan	0	0	0	0	0	0	4	4	4	4	4	
Sydney	0	0	0	0	0	0	3—4	3—4	3—4	3—4	4	
Vaughn C. I. 1367	0	0	0	0	0	0	3—4	3—4	3—4	3—4	3—4	
Chevalier (Hokkaido)	0	0	0	0	0	0	2—3	2—3	1—2	2—4	3—4	
Do (6—rowed)	0	0	0	0	0	0	1—2	1—2	1	3—4	4	
Dajokan	0	0	0	0	0	0	1—2	1—2	1	3—4	4	

Table 4. *Continued.*

Barley varieties	Infection types with physiologic races											Group numbers
	I	III	V	VI	X	XI	II	IV	VII	VIII	IX	
Himalaya C. I. 620	0	0	0	0	0	0	1—2	1—2	1—2	3—4	4	
Hosomugi	0	0	0	0	0	0	1—2	1—2	1—2	4	3	
Irakian barley	0	0	0	0	0	0	2	2	2	3—4	4	
Kinai No. 43	0	0	0—1	0	0	0	1—2	1	1	3—4	2—4	12
Miyako C	0	0	0—1	0	0	0	1—2	1	1—2	4	2—4	
Russian No. 33	0	0	0	0	0	0	1—2	1—2	1	2—4	2—4	
Shirobo	0	0	0	0	0	0	1—3	1—2	1	4	4	
Binder	0	0	0	0	0	0	2—4	2—4	2—3	2	4	
Caucasus	0	0	0	0	0	0	1—2	1—2	1	2—3	2—3	
Chevalier	0	0	0	0	0	0	2—3	2—3	1—2	2—3	4	
Do (2—rowed)	0	0	0	0	0	0	2—3	2—3	1—2	2—3	4	
Ebis	0	0	0	0	0	0	2—3	1—2	0—1	1	4	
Frederikson	0	0	0	0	0	0	1	1	1	1—2	4	
German Golden	0	0	0	0	0	0	2—3	1	1	1—2	4	
German No. 11	0	0	0	0	0	0	2—3	1	0—1	0—1	4	
Do No. 59	0	0	0	0	0	0	1—2	2	1	2	4	
Do No. 61	0	0	0	0	0	0	3—4	1	1	0—1	4	
Golden Melon	0	0	0	0	0	0	3	0—1	0—1	1	4	
Do (Kagoshima)	0	0	0	0	0	0	3—4	1—2	1—2	1—2	4	
Do No. 1	0	0	0	0	0	0	3—4	1—2	1	1—2	4	
Golden No. 20	0	0	0	0	0	0	3	0—1	1	1	4	
Hu Lan	0	0	0	0	0	0	2—3	2	1—2	1—2	4	
Maja	0	0	0	0	0	0	2	2	0—1	1—2	4	
No. 1703—1	0	0	0	0	0	0	2—4	2—4	1—2	2	4	13
No. 1881—3	0	0	0	0	0	0	1—2	2	0—1	1—2	4	
No. 4790—10	0	0	0	0	0	0	2—3	1	1—2	0—1	4	
No. 4887—3	0	0	0	0	0	0	1—2	1—2	0—1	1—2	4	
Okla C. I. 7524	0	0	0	0	0	0	1—3	2	0—1	1	3—4	
Primus	0	0	0	0	0	0	2—3	2	1	0—1	3—4	
Russian No. 6	0	0	0	0	0	0	1—2	1—2	1	1—2	4	
Do No. 8	0	0	0	0	0	0	2—3	3	1	2	3—4	
Do No. 21	0	0	0	0	0	0	1—3	3	0—1	1—2	4	
Do No. 26	0	0	0	0	0	0	3—4	3	2	1—3	4	
Do No. 27	0	0	0	0	0	0	1—3	1—2	1	1—2	4	
Do No. 28	0	0	0	0	0	0	2—4	2—3	1—2	2	4	
Do No. 36	0	0	0	0	0	0	2	2	1—2	2—3	3—4	
Do No. 38	0	0	0	0	0	0	1—3	2—3	0—1	1—2	3—4	
Do No. 50	0	0	0	0	0	0	1—2	2	1	1	4	
Do No. 53	0	0	0	0	0	0	1—3	2	1	1—2	4	
Do No. 63	0	0	0	0	0	0	3—4	3	3	3	2—4	
Do No. 41118	0	0	0	0	0	0	2—3	2	1—2	1—2	4	
Sanalta C. I. 6087	0	0	0	0	0	0	3—4	2—3	1—2	1—2	4	
Svanhals	0	0	0	0	0	0	1—2	2	1	1—2	4	

Table 4. *Continued.*

Barley varieties	Infection types with physiologic races											Group numbers
	I	III	V	VI	X	XI	II	IV	VII	VIII	IX	
Trebi I	0	0	0	0	0	0	1–3	1–2	1	2	4	
Vaga	0	0	0	0	0	0	3–4	2–3	2	2	4	
Seksandel	0	0	0	0	0	0	2–3	2–3	1–2	2–3	4	
Luth C. I. 972	0	0	0	0	0	0	1	1	0	1–2	4	14
Moravia	0	0	0	0	0	0	1–2	1–2	0–1	1–3	4	
Opal	0	0	0	0	0	0	1–2	1–2	0–1	1–2	4	
Shidabum No. 1	0	0	0	0	0	0	1–2	1–2	0	1–3	3–4	
Russian No. 66	0	0	0	0	0	0	4	4	4	4	0–1	15
J. 5	0	0	0	0	0	0	0	0–1	0	0	0	16
Monte Cristo C. I. 1017	0	0	0	0	0	0	0	1–2	0	0	0	
Goldfoil C. I. 928	0	2	0	0	0	2	0	0	2	0	0	17
Nigrate C. I. 2444	0	0	0	0	4	3–4	0	0	0	0	0–1	18
Chevron C. I. 1111	2	2	2–4	2	2	2–4	2	2	2	2	0	19
H. Spont. 3325	1–2	1–2	4	1–2	1–2	1–2	1–2	1–2	1–2	2–3	0–1	
Ehime-hadaka No. 2	1–2	1–2	1–2	4	1–2	1–2	4	2	2–3	2	2–3	20
German No. 17	0–1	0–1	1	2–3	1–2	0–1	3–4	1–2	1	1–2	4	
Kairyo-bozu-mugi	1	1	1–2	4	1	1	3–4	1	1	1	1–2	
Kinai No. 5	1–2	1–2	1–2	4	1–2	2	3–4	1–2	1	1–2	4	
Chilian Chevalier	0	0	0	0	0	0	0–1	0–1	0	0–1	2	21
Hadostreng	0	0	0	0	0	0	0–1	0–1	0	1–2	3	
Irakian Black	2–3	0–1	1–2	1–2	3	0–1	2–3	2–3	0	1–2	1–2	
Kaikei No. 44	0–1	0	0–1	0–1	1–2	0–1	1–2	1–2	0	0–1	3	
Minsturdi C. I. 1556	0	0	0	0	0	0	1–2	1–2	1	1–2	2	
Russian No. 41	0	0	0	0	0	0	1–3	3	0–1	1–2	3	
Do No. 55	0	0	0	0	0	0	1–3	2	1–2	1–2	2–3	
Wong C. I. 6728	0	0	0	0	0	0	1–2	1–2	0	0–1	2–3	

As can be seen, the 170 varieties can be classified into twenty one groups by their reactions to the eleven physiologic races. In greenhouse, the reactions of varieties in the seedling stage may be determined quickly and accurately. Nevertheless, difficulties were encountered in grouping the varieties into the limited twenty one reaction types. Because, except in immune or highly susceptible varieties, it may be said that strictly speaking, there are scarcely any variety that will give consistent reaction type to any one race. Moreover, some variations in varietal reaction to powdery mildew were observed to be due to environmental conditions. In this paper, therefore, the varieties which gave characteristic reactions to selected physiologic races are grouped into same reaction type, even if they show some differences in the reactions to other races.

Group 1. Highly resistant to all races. Algerian C. I. 1179, Black Russian C. I. 2202 and Russian No. 81 give sometimes Type "1".

Group 2. Moderately resistant to all races.

Group 3. Susceptible to all races, but some varieties may be moderately susceptible or moderately resistant to races VIII and IX.

Group 4. Highly resistant to all races except race IX.

Group 5. Moderately resistant to all races except race IX.

Group 6. Susceptible to all races except race IX. Reaction of this group is opposite of Group 4.

Group 7. Susceptible to races V and VIII, and moderately resistant or moderately susceptible to race IX, and resistant or moderately resistant to the remaining eight races. Some varieties, however, may be susceptible to race IX.

Group 8. Susceptible to races VIII and IX, and moderately susceptible or moderately resistant to race V, and resistant to the remaining eight races.

Group 9. Susceptible to race IX, and moderately susceptible or moderately resistant to races V and VIII, and resistant or moderately resistant to the remaining eight races.

Group 10. Moderately resistant or moderately susceptible to races V, VIII and IX, and resistant to the remaining eight races.

Group 11. Highly resistant to races I, III, V, VI, X and XI, but susceptible to the remaining five races. Miyagi No. 123, unnamed No. 22—1 and Osomugi give moderately resistant or moderately susceptible types to race IX.

Group 12. Highly resistant to races I, III, V, VI, X and XI, and resistant or moderately resistant to races II, IV and VII, and susceptible or moderately susceptible to races VIII and IX.

Group 13. Highly resistant to races I, III, V, VI, X and XI, and resistant or moderately resistant to races II, IV, VII and VIII, and susceptible to only race IX. The varieties belonged to this group may be further divided into two types by the reactions to race II, one is susceptible and the other is moderately resistant to the race. However, they are mutually moderately resistant to race VIII, and by this reaction they are distinguished from varieties belonged to Group 11 and Group 12.

Group 14. This group resembles Group 13, but it is distinguished from Group 13 by the reactions to race VII.

Group 15. Susceptible to races II, IV, VII and VIII, but resistant to the remaining seven races. This group resembles Group 11 but is distinguished by the reactions to race IX.

Group 16. Highly resistant to all races except the race IV, which makes some development. The difference between Group 16 and Group 1 is not so great.

Group 17. Moderately resistant or moderately susceptible to races III, VII and XI, but highly resistant to the remaining eight races.

Group 18. Susceptible to races X and XI, but resistant to race IX and highly resistant to the remaining eight races.

Group 19. Susceptible to race V, and resistant to race IX, and moderately resistant to the remaining nine races.

Group 20. Susceptible to races II and VI, but resistant or moderately resistant to the remaining nine races. This Group may be further divided into two types by the reactions to race IX.

Group 21. Varieties of this group can not be placed in any of the 20 groups of reaction type. These varieties, therefore, do not necessarily give same reaction types with one another. However, except Irakian Black and Kaikei No. 44, they resemble in giving highly resistant type of reaction to races I, III, V, VI, X and XI, and resistant or moderately susceptible types to the remaining five races.

Of the 170 varieties, the Japanese varieties belong to the ten Groups of 3, 5, 7, 10, 11, 12, 13, 14, 20 and 21. Although in this experiment, only five Japanese varieties belonged to the Group 3, a majority of Japanese barley varieties may be classified into the Group 3. The varieties grown in the northern parts of Japan, showing resistance to the snow mold, are mostly classified into the Groups 7 or 10, and more susceptible to races V, VIII and IX than to the remaining eight races. The varieties classified into the Groups 11, 12 and 13 are highly resistant to races I, III, V, VI, X and XI, and more or less susceptible to the remaining five races. A majority of Japanese varieties belonged to these groups were introduced from Europe as brewing barleys or were developments from them. They presumably have at least one common factor for resistance to powdery mildew. Of the three Japanese varieties belonged to Group 20, two varieties Ehime-hadaka No. 2 and Kairyo-bozu-mugi are grown mainly in Shikoku. The varieties to be classified into this group may not be so many in Japan. Only one Japanese variety belonged to each of the Groups 5, 14 and 21. Concerning the resistance to powdery mildew, it is concluded that Japanese barley varieties may be grouped further into three great types: Japanese indigenous varieties (Group 3), varieties grown in northern parts of Japan (Groups 7 and 10), and brewing barley varieties (Groups 11, 12 and 13).

Discussion

Since *Erysiphe graminis hordei* is obligate parasitic, the physiologic races of the organism can not survive when susceptible host is absent. *Erysiphe graminis hordei* in Japan consists of physiologic races selected upon Japanese barley varieties under cultivation. There are notable differences in respect to resistance to powdery mildew of barley varieties grown in Japan and America and Canada. It is reasonable, therefore, that the differential varieties selected to differentiate American and Canadian physiologic races of barley mildew are inadequate to differentiate those of Japan. The six barley varieties were selected by the writers for differentiating physiologic races of *Erysiphe graminis hordei* prevalent in Japan, and by so doing eleven races were isolated during 1953—1954.

Physiologic race is identified by the reactions of a specially-provided set of varieties. This is not the ultimate limit of specialization, for these races may frequently be further subdivided into biotypes. They may be reformed if the differential varieties are replaced by other set of varieties. Thus, physiologic race does not always mean phylogenic system. Differential varieties, therefore, should be selected, as Johnson discussed (3), from practical point of view. No genetical studies on the factors for resistance to Japanese physiologic races of powdery mildew of the six differential varieties and barley varieties commonly grown in Japan has yet been undertaken. Further studies are necessary before conclusions may be reached regarding whether the six differential varieties are pertinent or not in Japan.

The physiologic races of *Erysiphe graminis hordei* prevalent in Japan were characterised into five groups by their geographic distribution. What are the factors by which brought about the differences in frequency of population of physiologic races of *Erysiphe graminis hordei*? Race II and race IV are predominant in Shikoku and Hokuriku districts respectively. In Shikoku, Kairyo-bozu-mugi and Ehime-hadaka are grown. These varieties are susceptible to races II and VI, but resistant to other races of powdery mildew. This appears to be one of the determining factors that race II is predominant in Shikoku. In Hokuriku, however, we can not find any variety which is susceptible to race IV and resistant to other races. As already pointed out, a principal race of barley mildew in a region may be varied by the barley varieties grown in that region. But from this point of view alone, it is difficult to explain why race I is so widespread and prevalent over the whole of Japan, or why race IV is predominant in Hokuriku. The varieties appears to be not always one of the determining factors in the occurrence of different frequency of physiologic race population.

The relative pathogenicity of the eleven physiologic races to barley varieties is diagramed in Figure 3. The pathogenicity of race I plus the pathogenicity which infect Group 11 is the pathogenicity of race IV. In the same way, the pathogenicity of race I plus the pathogenicity which infect Groups 20, 7, 17, and 18 are races VI, V, III and X respectively. Moreover race VI plus race IV is race II, race V plus race IV is race VIII, race III plus race IV is race VII, and race III plus race X is race XI. Therefore, the races marked by an arrow, for example races I, IV and II, or races I, VI and II etc., do not show opposite pathogenicity to one another. On the other hand the races which are not marked by an arrow show contrary

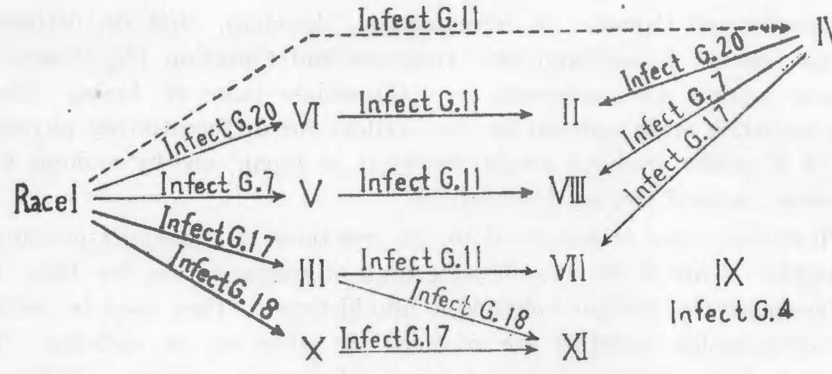


Fig. 3. Diagrammatic representation of the relative pathogenicity of eleven physiologic races of *Erysiphe graminis hordei*.

pathogenicity to one another. For example race VI infect Group 20 but not Group 7, on the contrary race V infect Group 7 but not Group 20 etc.

Race IX infect Group 4 which is resistant to all other races, but unable to infect Group 6. Group 6 is susceptible to all races except race IX. Race IX, therefore, always shows contrary pathogenicity compare to any other races.

Further interest is found when Figure 3 is compared with Figure 2. It is found that races encircled by arrows were isolated from the materials collected from the same district. For example races I, IV, II and VI were isolated from the materials collected from western parts of Japan, races I, IV, VIII and V from Tohoku district, and races I, IV, VII and III from Hokuriku district. From this fact it would be expected that there are phylogenic connection in the races kept in circle of arrows. On the other hand it is presumed that specialization of physiologic race of *Erysiphe graminis hordei* is due to mutation, and the physiologic races in a region had been selected by the barley varieties or by other environmental conditions of the region, and consequently races which resemble in their pathogenicity have survived in that region.

Cherewick (1) have explained that physiologic race of *Erysiphe graminis hordei* may be homothallic. On the other hand, new physiologic races were isolated by him from perithecia of the fungus. The new physiologic races were never isolated from conidia collected from the same field plots. From this results, he presumed that recombination and segregation of factors occurred in perithecia.

In any case, further genetical and cytological studies on the physiologic race of *Erysiphe graminis hordei* must be made to explain the mechanism of its specialization.

From our studies on the pathogenicity and population of physiologic races, it may be concluded that races I, IV and IX are fundamental and principal physiologic rsces of *Erysiphe graminis hordei* in Japan.

Summary

The six barley varieties—Goldfoil C. I. 928, Hanna C. I. 906, Heil's Hanna 3 C. I. 682, Kairyo-bozu-mugi, Nakaizumi-zairai, and Nigrate C. I. 2444—were selected by the writers for differentiating physiologic races of barley mildew, and by so doing five new races in 1953, and one new race in 1954 were isolated, making a total of eleven physiologic races of *Erysiphe graminis hordei* in Japan.

Race I was very predominant, showing 56% of the total isolates. Races IV and II were secondly prevalent, showing 17 and 13% of the total isolates respectively. The remaining eight races occurred in very low proportions. Race IX, however, showed 100% in Hokkaido.

From the view point of geographical distribution, physiologic races of *Erysiphe graminis hordei* in Japan were divided into five groups: races distributed over the whole of Japan, races distributed mainly in western parts of Japan, races distributed principally in Hokuriku district and its neighbourhood, races distributed in only Kanto-Tozan and Tohoku districts, and races distributed principally in Hokkaido district.

A study of the relative resistance of 170 barley varieties to the eleven physiologic races of powdery mildew was undertaken, and the 170 varieties were classified into 21 groups by their reactions. From this results, concerning the resistance to powdery mildew Japanese barley varieties were grouped further into three great types: Japanese indigenous varieties, varieties grown in northern parts of Japan, and varieties for brewing purpose.

From the pathogenicity and the frequency of population, it was concluded that races I, IV and IX might be fundamental and principal physiologic races of *Erysiphe graminis hordei* in Japan.

Acknowledgments

The writers wish to express their indebtedness to Dr. Y. Nishikado of the Ohara Institute for Agricultural Biology for valuable suggestions and criticism throughout the course of the investigation. They are also obliged to Mr. T. Nakayama for the preparations of the English text of this paper.

Literature Cited

(1) Cherewick, W. J. 1944. Studies on the biology of *Erysiphe graminis hordei* DC. Canad. Jour. Res., 22: C, 52—86.

(2) Hiura, U. and Heta, H. 1953. Studies on the disease-resistance in barley. II. Physiologic races of *Erysiphe graminis hordei* in Japan. Ber. Ohara Inst. landwirt. Forsch., 10: 17—28.

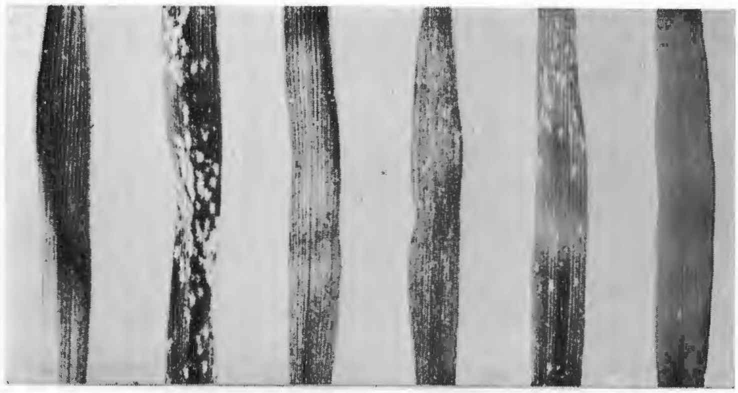
(3) Johnson, T. 1953. Variation in the rusts of cereals. Biol. Rev., 28: 105—157.

(4) Mains, E. B. and Dietz, S. M. 1930. Physiologic forms of barley mildew, *Erysiphe graminis hordei* Marchal. Phytopath., 20: 229—239.

(5) Mains, E. B. and Martini, M. L. 1932. Susceptibility of barley to leaf rust (*Puccinia anomala*) and to powdery mildew (*Erysiphe graminis hordei*). U. S. Dept. Agr. Tech. Bull., 295 : 1—33.

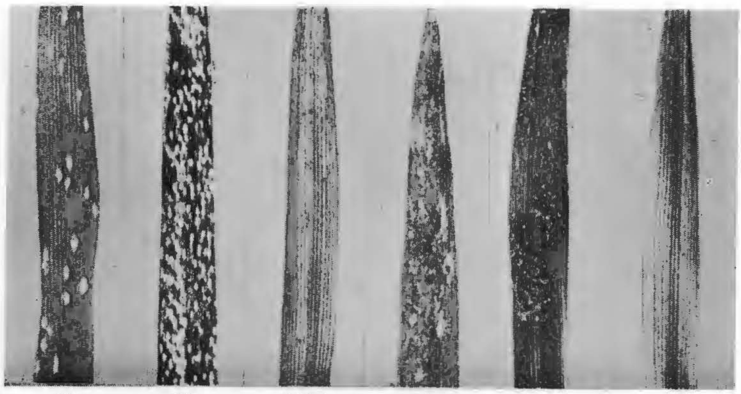
(6) Newton, Margaret and Cherewick, W. J. 1947. *Erysiphe graminis* in Canada. Canad. Jour. Res., C, 25 : 73—93.

Race I



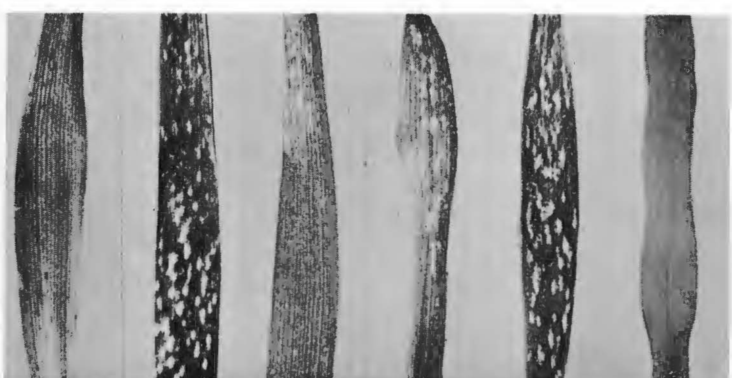
G H HH K NZ N

Race III



G H HH K NZ N

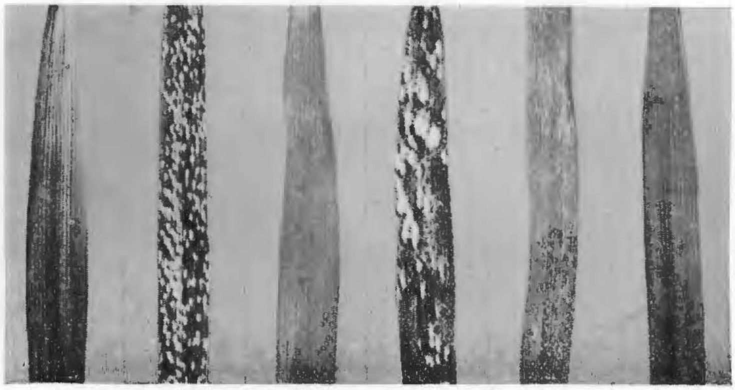
Race V



G H HH K NZ N

Plate 1

Race VI

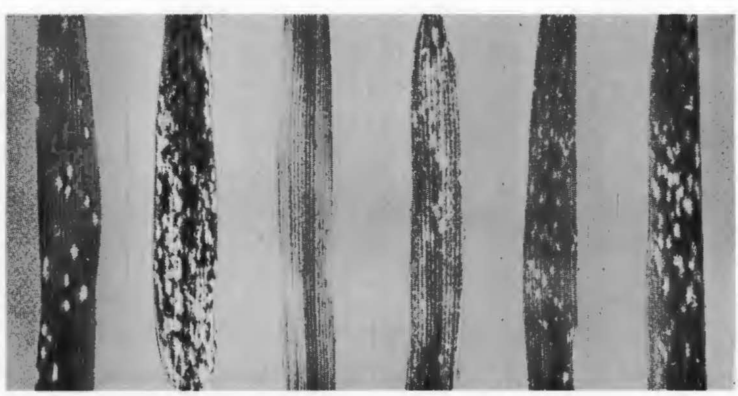


G H HH K NZ N

Race X

G H HH K NZ N

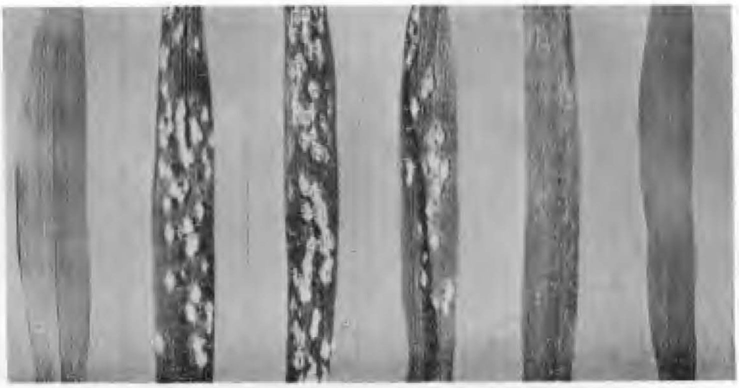
Race XI



G H HH K NZ N

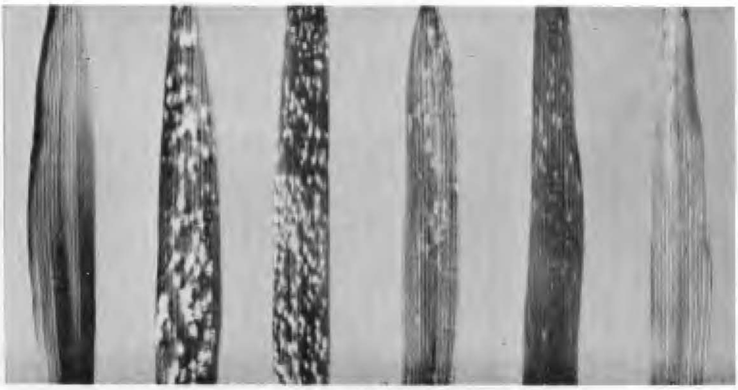
Plate 2

Race II



G H HH K NZ N

Race IV



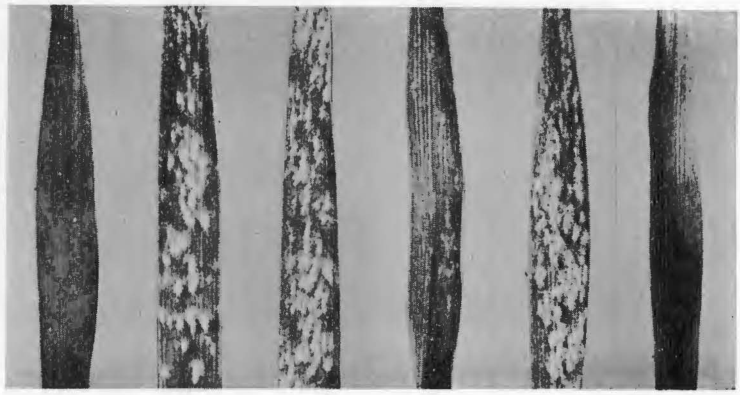
G H HH K NZ N

Race VII

G H HH K NZ N

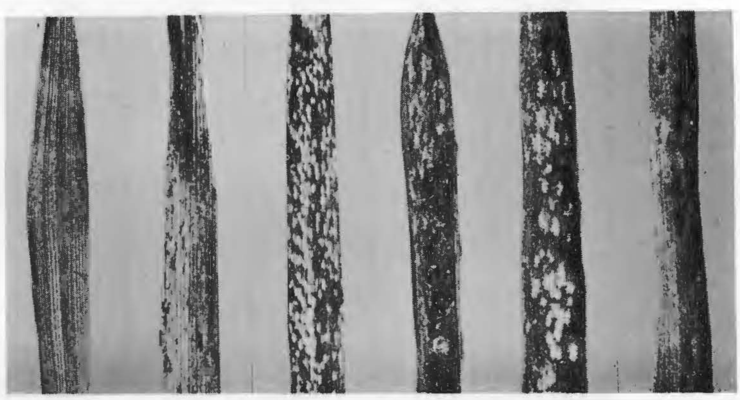
Plate 3

Race VIII



G H HH K NZ N

Race IX



G H HH K NZ N

G……Goldfoil C. I. 928
H……Hanna C. I. 906
HH…Heil's Hanna 3 C. I. 682
K……Kairyo-bozu-mugi
NZ….Nakaizumi-zairai
N……Nigrate C. I. 2444

Plate 4