# Pathogenic Specialization of Rice Blast Fungus in Japan

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Blast is the most destructive disease of rice crop in Japan, and lots of studies on the ecology and control of blast have been carried out from early times. The study on pathogenic specialization in the blast fungus, *Pyricularia oryzae*, was started first by Sasaki[8,9] as early as in 1922 in Japan. He described two blast strains, 'A' strain of narrow range of virulence against rice varieties and 'B' strain of wide range in Ehime Prefecture.

Since 1954, the collaborative team with Dr. K. Goto as a leader had carried out extensive inoculation tests with lots of blast isolates and rice varieties, and according to the results a differentiating system of blast races with 12 differential varieties was established.[3,4,7] By the system, 3 race groups and 18 races of *P. oryzae* were differentiated, and registered up to 1966. This system was utilized widely and usefully, pathogenic specialization of blast fungus in Japan became clear, and genetic analysis of blast vertical resistance of rice varieties advanced remarkably. Then, it became clear that genetic background of some of Goto's differentials was so complex that they were unsuitable for differential varieties, and some new vertical resistance genes which had not been included in the differentials were also introduced into Japanese commercial varieties from exotic origins one after another. The Goto's differentials, therefore, became gradually useless, and a new system was proposed.

In the system, proposed by Yamada et al.[11] in 1976, 9 differential varieties are used as shown in Table 1, and every differential variety represents each of main vertical resistance genes, identified by Yamasaki, Kiyosawa, and others,[6] effective to Japanese blast fungus. Out of 9 resistance genes, *Pi-k^s*, *Pi-a* and *Pi-i* are included in Japanese native rice varieties, and all other genes are of exotic origin. Code number by Gilmour's octal notation[2] is given to each differential variety, in other words, to each corresponding resistance gene. Each race is called with the sum of the code number of differential variety, to which the race is virulent, as shown in Table 1. For example, the race virulent to Shin 2, Aichi-asahi, Ishikari-shiroke, Kanto 51, Tsuyuake, and Yashiromochi is 1+2+4+10+20+100=137. Conversely, in the case of race 137, the number can be decomposed into 1, 2, 4, 10, 20 and 100, so we can understand that the race is virulent to those differential varieties, and to those resistance genes having the code numbers. We, therefore, can recognize the virulence of a certain race to vertical resistance genes of rice varieties directly from the number of the race.

By this new differentiating system, distribution of blast races was examined 2 times, i.e., in 1976 and 1980, on a nationwide scale. In 1976, Yamada et al.[12] conducted the examination at Central Agr. Exp. Sta., with 2,245 blast isolates. In 1980, Yamada (Hokkaido, a part of Kanto, Kinki, Chugoku, Shikoku and Kyushu districts), Koizumi (a part of Kanto district), Shindo et al.[10] (Tohoku district), Iwano[5] (Hokuriku district), Terasawa et al. (Tosan, Tokai districts except Aichi Pref.), and Nakagami (Aichi Pref.) examined with allotment of districts on 2,376 blast isolates, and some of those results were published. Results of race identification of all tested isolates were also reported

Table 1. Differentiating system of blast races in Japan, and the reaction of some races on the differentials

| Differential varieties | Shin 2 | Aichi-asahi | Ishikari shiroke | Kanto 51 | Tsuyu-ake | Fuku-nishiki | Yashiro-mochi | Pi No. 4 | Toride 1 |
|---|---|---|---|---|---|---|---|---|---|
| Resistance gene | *pi-k*$^{s}$ | *pi-a* | *pi-i* | *pi-k* | *pi-k*$^{m}$ | *pi-z* | *pi-ta* | *pi-ta*$^{2}$ | *pi-z*$^{t}$ |
| Code No. | 1 | 2 | 4 | 10 | 20 | 40 | 100 | 200 | 400 |
| Race | | | | | | | | | |
| 001 | S | — | — | — | — | — | — | — | — |
| 003 | S | S | — | — | — | — | — | — | — |
| 007 | S | S | S | — | — | — | — | — | — |
| 017 | S | S | S | S | — | — | — | — | — |
| 031 | S | — | — | S | S | — | — | — | — |
| 033 | S | S | — | S | S | — | — | — | — |
| 037 | S | S | S | S | S | — | — | — | — |
| 101 | S | — | — | — | — | — | S | — | — |
| 102 | — | S | — | — | — | — | S | — | — |
| 103 | S | S | — | — | — | — | S | — | — |
| 107 | S | S | S | — | — | — | S | — | — |
| 137 | S | S | S | S | S | — | S | — | — |
| 303 | S | S | — | — | — | — | S | S | — |
| 333 | S | S | — | S | S | — | S | S | — |

S : Susceptible reaction, — : Resistant reaction

promptly.[1] In the present paper, all the results are rearranged, the whole aspects of blast races in Japan are shown, and effects of planted rice varieties on blast race distribution are also described.

## Methods and results of examination of blast race distribution

The results of blast race examination in 1976 and 1980 are shown in Tables 2 and 3 respectively by districts. Our standard sampling procedure is to isolate one monospore culture per paddy field of about 1,000 ha. with randomized systematic sampling, but sampling of specimen was not always conducted as previously arranged. In Tables 2 and 3, isolation frequencies of the respective races are shown in the respective districts. A sign+ shows the race of frequency less than 1%.

Races are classified into 3 group races, namely I group races of race number of 1 figure, II group races of race number of 2 figures, and III group races of race number of 3 figures. The Gilmour's notation system for races is characterized by triplets of differential varieties, that is, of resistance genes. The I group races are virulent to only vertical blast resistance genes, *Pi-k*$^{s}$, *Pi-a*, and *Pi-i*, viz., virulent to Japanese native rice varieties. The II group races are virulent to *Pi-k* and *Pi-k*$^{m}$ introduced from Chinese varieties, and *Pi-z* of US variety, Zenith. The III group races are virulent to varieties of *Pi-ta*, *Pi-ta*$^{2}$, and *Pi-z*$^{t}$, which are introduced from *indica* rice varieties. Such grouping of races presents rough information of virulence of races, so that it is convenient for Japanese plant pathologists and breeders. In both years, 1976 and 1980, the I group races were most prevalent, and the isolation frequencies were 77 and 82%, respectively. The II and III group races followed, and their prevalence was far less than the I group races. There was a similar tendency in respective districts, but in Hokkaido, the II group races were ranked first with the frequency of about 90% in both years, and the III group races were never isolated. In Kyushu district, the III group races with frequen-

Table 2. Rice blast races identified in 1976, expressed by percentage to total isolates

| District | Number of isolates | I-group races | | | | | II-group races | | | | | | | III-group races | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 001 | 003 | 005 | 007 | Total | 013 | 017 | 031 | 033 | 035 | 037 | Total | 101 | 102 | 103 | 107 | 113 | 131 | 137 | 303 | 307 | 331 | 333 | 401 | 403 | Total |
| Hokkaido | 81 | 2* | 5 | | 5 | 12 | | | 5 | 81 | | 1 | 88 | | | | | | | | | | | | | | |
| Tohoku | 547 | +** | 69 | | 16 | 85 | | | + | 9 | | + | 10 | | | 3 | + | | | | 2 | + | | + | | | 6 |
| Kanto, Tosan | 377 | 3 | 70 | | 14 | 87 | 1 | 1 | 3 | 5 | | 1 | 10 | 1 | | 2 | + | | + | | 1 | | | | | + | 3 |
| Hokuriku | 292 | 12 | 27 | | 34 | 73 | + | | 1 | 13 | + | 8 | 22 | 1 | | 1 | 2 | | | + | | + | + | | + | | 5 |
| Tokai, Kinki | 342 | + | 73 | | 12 | 86 | + | 1 | 1 | 6 | 1 | 2 | 10 | | | 3 | | | + | | 1 | | | | | | 4 |
| Chugoku | 185 | 4 | 66 | 1 | 14 | 84 | | | | 6 | | 1 | 8 | | | 2 | | | | | 6 | | | | | | 8 |
| Shikoku | 104 | 10 | 71 | | 9 | 89 | | 1 | | 4 | | | 5 | 1 | | 5 | | | | | | | | | | | 6 |
| Kyushu | 317 | 5 | 46 | | 3 | 55 | + | | | 12 | | + | 12 | 2 | + | 28 | | + | | | 2 | | | | | | 33 |
| All Japan | 2,245 | 4 | 59 | + | 15 | 77 | + | + | 1 | 11 | + | 2 | 14 | 1 | + | 6 | + | + | + | + | 1 | + | + | + | + | + | 9 |

* Number in the table shows the isolation frequency (%) of each race in each district or in the whole country.
** + : less than 1%

Table 3. Rice blast races identified in 1980, expressed by percentage to total isolates

| District | Number of isolates | I-group races | | | | | | II-group races | | | | | | | | | III-group races | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 001 | 002 | 003 | 005 | 007 | Total | 017 | 031 | 033 | 037 | 041 | 043 | 047 | 073 | Total | 101 | 102 | 103 | 107 | 133 | 137 | 303 | 333 | 337 | Total |
| Hokkaido | 67 | 1* | | | | 7 | 9 | | 7 | 82 | 1 | | | | | 91 | | | | | | | | | | |
| Tohoku | 637 | | | 73 | +** | 9 | 83 | | | 7 | 1 | | 1 | 1 | + | 10 | | | 4 | + | 1 | + | 1 | + | | 7 |
| Kanto, Tosan | 432 | 3 | | 52 | | 38 | 93 | | 2 | 3 | + | | | | | 6 | + | | 1 | | | | + | | | 2 |
| Hokuriku | 324 | 35 | | 25 | | 23 | 82 | + | 1 | 6 | 11 | + | | | | 18 | | | | | | | | | | |
| Tokai, Kinki | 420 | 4 | 1 | 75 | | 6 | 86 | | + | 7 | 2 | | | | | 10 | | + | 4 | | | | + | | + | 5 |
| Chugoku | 195 | 3 | 11 | 61 | | 6 | 80 | | | 5 | 1 | | | | 3 | 9 | 1 | 2 | 5 | | | | 4 | | | 11 |
| Shikoku | 90 | 12 | 8 | 51 | | 2 | 73 | | | 21 | | | | | | 21 | | 2 | 3 | | | | | | | 6 |
| Kyushu | 211 | 6 | 12 | 56 | | 1 | 75 | | + | 10 | | | | | | 10 | | 7 | 7 | | | | 1 | | | 15 |
| All Japan | 2,376 | 7 | 2 | 58 | + | 14 | 82 | + | 1 | 9 | 2 | + | + | + | + | 13 | + | 1 | 3 | + | + | + | 1 | + | + | 5 |

* Number in the table shows the isolation frequency (%) of each race in each district or in the whole country.
** + : less than 1%

cy of 33% was next to the I group races of 55% in 1976, and there was a similar tendency in 1980.

On the distribution of respective races, 23 pathogenic races were isolated in 1976, 9 races were considered as the major races in Japan. Among them, race 003 was decisively prevalent and the frequency was 59%, the next was race 007 of 15%. The rest were 033 (11%), 103 (6%), 001 (4%), 037 (2%), 303 (1%), 031 (1%), and 101 (1%). In 1980, 22 races were isolated, and 10 races were considered as the major races. The most prevalent race was 003 (58%), the next was 007 (14%), and the third was 033 (9%), and the 3 races of top rank were same to those in 1976. The rest were 001 (7%), 103 (3%), 002 (2%), 037 (2%), 102 (1%), 031 (1%), and 303 (1%). The order of the races 103 and 001 reversed as compared with the result in 1976. The race 002 newly appeared, and its frequency reached 2%. The race 102 also increased showing the frequency of 1%, while race 101 decreased.

There were some big regional characters of race prevalency. The race 033 was especially prevalent in Hokkaido, and the frequency was 81% iu 1976, and 82% in 1980. In Hokuriku district, race 007 was more prevalent than race 003, and the frequency reached 34%, and in 1980 race 001 was the most prevalent. In Kyushu district, race 103 was isolated in 1976 with the frequency of 28%. The race 003 was isolated with frequency of 5% in Hokkaido district in 1976, so the race was isolated from all districts of Japan, but in 1980 there was no isolation in Hokkaido. The race 002 was not isolated in 1976, but in 1980 it was isolated from west of Kinki district with rather high frequency, as above mentioned.

## Relation of race prevalence and planted rice varieties

Regional race prevalence seemed to be influenced by rice varieties planted in the area.

In general, in case of cultivation of some vertical blast resistant varieties, only the races virulent to such varieties are increased selectively on the varieties. If planted area of the varieties will be increased, frequency of sampling of the varieties will also be increased, and isolation frequency of the races virulent to the varieties will also be remarkably increased. According to van der Plank, on some varieties in general, races of the least necessary virulence for survival on the varieties, survive best and increase. In Japan, each prefecture selects and recommends certain rice varieties for its farmers independently, so that quite different varieties are often cultivated even in the neighboring prefectures. The difference of race distribution as influenced by rice varieties, therefore, appears according to each prefecture. Some remarkable regional characteristics of race distribution by prefectures are cited as follows, and their causes are considered.

In Hokkaido, isolation frequency of race 033 was so high as 81% in 1976, and 82% in 1980. In the prefecture, planted area of *Pi-a*, *-k* varieties is very large. In 1976 4 *Pi-a*, *-k* varieties, Ishikari, Yunami, Kitahikari, and Yukara, occupied 67% of paddy fields of Hokkaido, and sampling frequency of the *Pi-a*, *-k* varieties was 69% in that year. Under such a situation, race 033 of the least virulence against *Pi-a*, *-k* varieties seemed to be increased remarkably. In 1980 two more varieties, Tomoyutaka and Hayakogane, joined, and then planting ratio of *Pi-a*, *-k* varieties increased up to 83%, with their sampling frequency of 78%.

In Hokuriku district, isolation frequency of race 007 was higher than race 003 in 1976. It was different from the tendency of the whole country (Table 4). There are 4 prefectures, Niigata, Toyama, Ishikawa, and Fukui, in Hokuriku district. Niigata Prefecture has the largest paddy field area, so that the largest number of blast isolates was tested in the prefecture. Thus the race prevalance in the Hokuriku district was mainly influenced by the situation in the Niigata Prefecture. In Niigata Prefecture, Tokorokiwase and other *Pi-i* varieties were planted to 33% of the total paddy area. This seemed to be the cause of high frequency of race 007. In Ishi-

Table 4. Rice blast races identified in 1976 in 4 prefectures of Hokuriku district, expressed by percentage to total isolates

| Prefecture | Number of isolates | Pathogenic race | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 001 | 003 | 007 | 013 | 031 | 033 | 035 | 037 | 101 | 103 | 107 | 137 | 307 | 331 | 401 |
| Niigata Pref. | 142 | 8 | 18 | 60 | | 1 | 5 | 1 | 1 | 1 | | 4 | | 1 | 1 | |
| Toyama Pref. | 68 | 25 | 40 | 10 | | | 18 | | 1 | 1 | 3 | | | | | 1 |
| Ishikawa Pref. | 43 | 16 | 23 | 2 | | | 7 | | 49 | | | | 2 | | | |
| Fukui Pref. | 39 | 3 | 44 | 13 | 3 | | 38 | | | | | | | | | |
| All area | 292 | 12 | 27 | 34 | + | 1 | 13 | + | 8 | 1 | 1 | 2 | + | + | + | + |

Table 5. Rice blast races identified in 1980 in 4 prefectures of Hokuriku district, expressed by percentage to total isolates

| Prefecture | Number of isolates | Pathogenic race | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 001 | 003 | 007 | 017 | 031 | 033 | 037 | 041 |
| Niigata Pref. | 133 | 23 | 28 | 48 | 1 | 1 | | | |
| Toyama Pref. | 67 | 81 | 12 | 1 | | | 1 | 4 | |
| Ishikawa Pref. | 58 | 38 | | | | 3 | 3 | 55 | |
| Fukui Pref. | 66 | 9 | 53 | 12 | | | 23 | 2 | 2 |
| All area | 324 | 35 | 25 | 23 | + | 1 | 6 | 11 | + |

kawa Prefecture, frequency of race 037 was so high as 49%. It was a very unique situation compared with the other prefectures. In the prefecture, Kagahikari (*Pi-i, -k*) was planted to 22% of paddy fields, so that the race 037 virulent to the variety seemed to have increased in the prefecture. In the examination of 1980 (Table 5), situation of race 007 in Niigata and 037 in Ishikawa were similar to those in 1976, but in Toyama Prefecture frequency of race 001 increased from 25% in 1976 to 81% in 1980. The race 001 shows the most narrow range of virulence in Japan. In Toyama Prefecture, almost all rice varieties have no vertical resistance in 1980. It seemed to give rise to the increase of the race 001. In Kochi Prefecture of Shikoku district, another example of scarce vertical resistant varieties was observed. Frequency of the race 001 was so high as 42% in 1980, as expected.

In Kyushu district, in 1976 the race 103 with its average frequency of 6% for all Japan, was isolated at a high frequency of 28%, but it decreased to 7% in 1980. Of all 8 prefectures in Kyushu district, the frequency of race 103 was highest (51%) in Fukuoka Prefecture, and lowest (2%) in Miyazaki Prefecture (except Okinawa Prefecture with very few samples) in 1976. In Fukuoka Prefecture in that year, Reiho was planted with frequency of 38% anlike in prefectures in other districts, and sampling frequency of Reiho reached 58%. In Miyazaki Prefecture, meanwhile, planting ratio of Reiho was only 4%, the number of samples of Reiho was only 8, and the ratio was 17% in the examination in 1976. From the fact, the high prevalence of race 103 in Fukuoka Prefecture seemed to be due to much planting of Reiho. Reiho is described to have resistance gene $Pi\text{-}ta^2$, and if it is true, race 103 avirulent to $Pi\text{-}ta^2$ should be avirulent to Reiho. Reiho, however, is highly susceptible to the isolate identified as race 103. On this problem, it needs more studies. In 1980, the frequency of planting of Reiho was 18% in Fukuoka Prefecture, the sampling frequency was 21%, and the isolation frequency of race 103 was 4%.

As shown by the above mentioned examples, distribution of blast races is controlled by vertical resistance genes of main rice varieties planted widely in given areas, and prevalent races alter with change of planted varieties, or change of planted area of special vertical blast resistant varieties.

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