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Screening of Rice Cultivars for Adult-Plant Resistance to *Pyricularia oryzae*

Young Jin Koh, Byung Kook Hwang* and Hoo Sup Chung

Department of Agricultural Biology, College of Agriculture, Seoul National University, Suweon 170, Korea
**Department of Plant Protection, College of Agriculture, Korea University, Seoul 132, Korea*

稻熱病에 對해 成體植物 抵抗性을 지닌 벼 品種의 選拔

高榮珍·黃炳國*·鄭厚燮

서울大學校 農科大學 農生物學科
*高麗大學校 農科大學 植物保護學科

ABSTRACT

Thirty two rice cultivars which have been cultivated or used as breeding materials in Korea were tested for screening rice cultivars resistant to leaf blast at adult-plant stages in the blast nursery hill plots. When compared on the basis of disease severities in individual leaves at different growth stages of rice plants under natural field infection, the 16 indica-japonica hybrids tested were highly resistant but the 16 japonica cultivars tested showed various degrees of resistance to leaf blast. With aging of rice plants, the quantitative levels of resistance to leaf blast increased in all the cultivars, although the levels of resistance to leaf blast varied according to rice genotypes. The leaf position of rice plants in which changed from susceptible to resistant reactions varied also with rice genotypes. The susceptible reactions of the rice cultivars to *Pyricularia oryzae* were distinctly changed to a resistant reaction on upper leaves of rice plants. The rice cultivars, in which the quantitative level of resistance to leaf blast was higher, were resistant on the lower leaves of rice plants. The cultivars Akibare, Palkeum, Jinheung, Olchal, Dobong and Ginga which drastically decreased blast infection at late growth stage were evaluated as adult-plant-resistant to leaf blast in the field. The adult-plant-resistant cultivars became resistant to leaf blast, both qualitatively and quantitatively, as rice plants matured.

Key words: Pyricularia oryzae, rice, adult-plant resistance.

要　　約

成體植物期에 잎稻熱病에 對해 抵抗性인 벼 品種 選拔을 위해 韓國에서 栽培되거나 育種材料로 쓰이고 있는 32個의 벼 品種을 稻熱病檢定 못자리에 供試하였다. 生育時期가 다른 각 잎에 自然感染된 發病率을 土壤로 比較할 때, 16個의 統一型 品種들은 모두 高度 抵抗性이었으나 16個의 日本型 品種들은 잎稻熱病에 對해 多樣한 抵抗性程度를 나타내었다. 잎稻熱病에 對한 抵抗性程度는 品種에 따라 다르지만, 植物體가

成熟해 갈수록 量的抵抗性程度는 모든 品種에서 增加하였다. 感受性에서 抵抗性으로 바뀌는 葉位는 品種에 따라 달랐다. 稻熱病菌에 對한 벼 品種의 感受性反應이 上位葉에서 抵抗性反應으로 뚜렷하게 바뀌었다. 稻熱病에 對한 量的 抵抗性程度가 큰 品種일수록 下位葉에서 抵抗性反應을 나타내었다. 生育後期에 稻熱病 感染을 急激히 感少시키는 品種인 아끼바레, 八錦, 振興, 올찰, 道峰 및 銀河는 圃場에서 잎稻熱病에 對한 成體植物抵抗性을 보였다. 成體植物抵抗性品種들은 植物體가 成熟해감에 따라 量的, 質的으로 잎稻熱病에 對해 抵抗性을 나타내었다.

INTRODUCTION

The rice blast disease caused by *Pyricularia oryzae* Cavara is one of the major limiting factors against stable rice production in most rice growing countries. The use of resistant rice cultivars has been known to be the most economical and effective measure for controlling rice blast (4, 12). However, intensive cultivation of highly resistant cultivars eventually led to the break-down of resistance due to shifting race of the pathogen (7). Since the indica-japonica hybrids including Tongil have been widely cultivated in farmer's fields in 1971, no blast occurred until 1976, but the great loss of rice production in 1978 resulted from the drastic epidemic on the indica-japonica hybrids, probably due to the shift of race population of *P. oryzae* (3). Recently, stable and durable resistance to *P. oryzae* has received increased attention by rice breeders and plant pathologists in Korea.

Adult-plant resistance found in various crops is evaluated as one of the most effective type of resistance for the control of plant diseases. Until now, there is no information about adult-plant resistance of rice cultivars to blast, expressed at later growth stage of rice plants in fields. Recently, adult-plant resistance of rice plants to bacterial blight was reported (13). Rate-reducing resistance to rice blast has been intensively studied only at a particular growth stage of rice plants in terms of quantitative resistance (1 2, 11), dilatory resistance (8, 9), slow blasting resistance (16, 17) and field resistance (4). However, cultivation of adult-plant-resistant cultivars which are fully susceptible at the seedling stage in the nursery but reduce rice blast progress to negligible level at later growth stage in the paddy field after transplanting may be efficient for blast control in temperate countries such as Korea where rice blast epidemic occurs late in the rice growing season.

In present study, the reactions of rice cultivars which are cultivated or used as breeding material in Korea to leaf blast were evaluated by examining disease development on various leaves of rice plant at different growth stages in terms of infection type and disease severity of leaf blast in blast nursery hill plots.

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MATERIALS AND METHODS

The thirty two rice (*Oryza sativa* L.) cultivars which have been cultivated or used as breeding materials in Korea were tested for screening adult plant-resistant cultivars in the blast nursery sown on 11 May 1983. Twenty out of 32 rice cultivars were re-evaluated for adult-plant resistance to blast in rice plants at the two growth stages, sown on 1 May and 25 June, 1984.

Twenty rice seeds of each cultivar per hill were sown on hill plots in the blast nursery. The hill plots (20x15 cm), spaced 30 cm apart, were arranged in the randomized complete block design with five replicates. The mixed seeds of the tested cultivars were sown around the nursery beds to increase the natural occurrence of rice blast. No artificial inoculation was necessary as natural infection occurred all around the blast nursery hill plots. The nursery fertilizer was treated at the rate of 30 10-15 kg of actual N-P-K per 10a before plantin

and additional nitrogen of 15 kg a.i. N per 10a was applied. The weeds in the blast nursery were removed by hands sometimes. The nursery beds were kept wet by flood-irrigation periodically.

To evaluate blast reactions on individual leaves or whole plants of rice, five plants per hill plot were randomly selected and the positions of leaves on the main culms of five rice plants were marked by small plastic clips to permit disease assessments on the same leaves each time. Leaf blast development on the marked leaves of five rice plants at different stages of growth was rated each day Monday through Friday per week after the first appearance of blast lesions. Disease ratings were simultaneously done at different plantings of rice for 30 days (15 July - 14 August 1983 and 30 July - 29 August 1984). Because various types of lesions appeared on a leaf, the percent diseased leaf area (DLA) and the proportion of DLA based on lesion types were recorded to permit more accurate evaluation of the reactions of rice cultivars to leaf blast. The disease severity on different leaves or whole plants was determined using the following equation (10):

Disease severity (%) =

$$\sum_{i=1}^{3} \{[\text{DLA}(\%)] \times [\text{DLA proportion based on lesion type (\%)}] \times [\text{Lesion type (i)}]\} / (100 \times 3)$$

, in which resistant type lesion = 1 (pinpoint or larger pinhead), intermediate type lesion = 2 (round to slightly elongated, necrotic grey spots with a brown margin) and susceptible type lesion = 3 (elliptical lesion with a greyish center and brown margin). The disease severity of whole plants was calculated from the blast severity data of individual leaves. Blast severity data obtained in individual leaves and whole plants were converted to areas under disease progress curves (AUDPC) to compare the relative levels of resistance of rice cultivars to leaf blast. The area under the disease progress curve was calculated as described by Shaner and Finney (13):

$$\text{AUDPC} = \sum_{i=1}^{n} [(X_{i+1} + X_i)/20] [t_{i+1} - t_i]$$

, where X_i = blast severity at the *ith* observation, t = time (days) at the *ith* observation, and n = total number of observations.

Korean differential rice cultivars were used to examine the distribution of pathogenic races of *P. oryzae* in the blast nursery in rice blast rating periods of 1983 and 1984. Ten seeds of each differential cultivar treated with the fungicide Busan 30 were sown on plastic pots (8x16x7 cm) every 10 days from 30 June to 30 July 1983. The sterilized soil used was fertilized with N-P-K (9-6-6 g/m^3) in the forms of $(NH_4)_2SO_4$, P_2O_5, and K_2O before seeding, and additional nitrogen of 6 g/m^3 was applied five days before natural infection.

The rice plants were incubated in the greenhouse at 25 - 35°C for 15 - 20 days. The plants of each differential cultivar at five-leaf stage were exposed to natural field infection for one day in the blast nursery hill plots at the 10 days intervals and then incubated in the greenhouse. Reactions of differential rice cultivars to *P. oryzae* were rated in terms of disease severity calculated by the above mentioned equation at seven days after natural infection.

The eight Korean differential rice cultivars were also planted around the nursery beds with about 50 seeds per row on 16 July, 1984. Reactions of the differential cultivars to *P. oryzae* were determined 45 days after sowing.

RESULTS

The AUDPCs and percent disease severities for whole plants of all the rice cultivars sown on 11 May 1983 are shown in Table 1. The rankings of entries by AUDPC and percent disease severity values were similar. Of the 16 indica-japonica hybrids, only Palkwang showed hypersensitive reaction but the other cultivars showed no reaction to leaf blast. Japonica cultivars Norin 6, Norin 8, Palkweng, Paltal, Nakdong, Jinju, Akibare and Palkeum were highly susceptible to leaf blast. Jinheung, Olchal, Dobong and Ginga were moderately susceptible to leaf blast. The other japonica

Table 1. Percent disease severities and area under disease progress curves (AUDPC) of 32 rice cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast nursery hill plots sown on 11 May 1983 at Suweon, Korea

Cultivar	Country of origin	Percent disease severity (days after sowing)			AUDPC	Rank
		75	85	95		
Japonica cultivars						
Norin 6	Japan	34.7 a [z]	65.7 a	62.9 b	134.5 a	1
Norin 8	Japan	24.3 b	57.4 b	66.8 a	115.2 b	2
Palkweng	Korea	19.5 c	57.9 b	61.0 c	110.4 c	3
Paltal	Korea	21.3 bc	42.8 d	59.7 cd	98.3 d	4
Nakdong	Korea	19.1 c	49.1 c	58.3 d	95.6 de	5
Jinju	Korea	6.4 d	36.5 e	55.5 e	70.0 e	6
Akibare	Japan	3.8 de	25.1 f	44.8 f	52.6 f	7
Palkeum	Korea	2.3 de	18.9 g	27.6 g	37.0 g	8
Jinheung	Korea	1.5 e	2.6 h	7.9 h	8.9 h	9
Olchal	Japan	0.3 e	1.9 h	6.2 h	5.0 hi	10
Dobong	Korea	0.7 e	1.5 h	2.4 i	3.8 ij	11
Ginga	Japan	0.4 e	0.4 h	1.2 ij	1.5 ij	12
Kwanak	Korea	0.1 e	0.2 h	0.7 ij	0.5 j	13
Dongjin	Korea	0.1 e	0.2 h	0.3 j	0.5 j	13
Nongbaek[y]	Korea	0.1 e	0.1 h	0.3 j	0.3 j	14
Sangpung[y]	Korea	0.1 e	0.1 h	0.1 j	0.3 j	14
Indica-japonica hybrids						
Palkwang[y]	Korea	0.1	0.1	0.1	0.2	15
Baekyang	Korea	0	0	0	0	16
Early Tongil	Korea	0	0	0	0	16
Keumkang	Korea	0	0	0	0	16
Mansok	Korea	0	0	0	0	16
Milyang 23	Korea	0	0	0	0	16
Milyang 30	Korea	0	0	0	0	16
Nampung	Korea	0	0	0	0	16
Nopung	Korea	0	0	0	0	16
Raekyung	Korea	0	0	0	0	16
Samsung	Korea	0	0	0	0	16
Seokwang	Korea	0	0	0	0	16
Sujung	Korea	0	0	0	0	16
Taebaek	Korea	0	0	0	0	16
Tongil	Korea	0	0	0	0	16
Yushin	Korea	0	0	0	0	16

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column followed by the same letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.

cultivars were highly resistant or resistant to leaf blast.

The two plantings in 1984 showed the results similar to the 1983 planting, although slightly lower disease severity than that from the 1983 planting was observed in all cultivars (Tables 2 and 3). In general, rice plants at late stages of development became more resistant to leaf blast than those at early stages and their levels of resistance varied according to rice genotypes. Nakdong, Jinju, Akibare and Palkeum were ranked as more susceptible cultivars at early stages than at late stages, but the other cultivars showed similar rankings at the two plantings in 1984.

Table 2. Percent disease severities and area under disease progress curves (AUDPC) of selected 20 rice cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast nursery hill plots sown on 25 June 1984 at Suweon, Korea

Cultivar	Country of origin	Percent disease severity (days after sowing)			AUDPC	Rank
		45	55	65		
Japonica cultivars						
Norin 6	Japan	22.0 c [z]	44.0 c	61.0 ab	95.5 c	4
Norin 8	Japan	20.2 cd	38.9 ef	61.1 ab	86.4 e	6
Palkweng	Korea	10.9 e	44.6 c	61.5 ab	84.9 e	7
Paltal	Korea	16.7 d	32.5 g	54.6 c	73.0 f	8
Nakdong	Korea	31.4 a	55.7 a	62.0 a	117.1 a	1
Jinju	Korea	23.6 bc	42.0 cd	59.4 b	100.3 b	2
Akibare	Japan	27.6 ab	47.4 b	54.3 c	99.2 b	3
Palkeum	Korea	28.0 ab	40.1 de	52.6 c	91.5 d	5
Jinheung	Korea	15.3 d	33.2 g	44.8 d	70.7 f	9
Olchal	Japan	0.5 f	1.6 j	9.7 ef	6.7 i	12
Dobong	Korea	1.3 f	3.2 j	11.3 e	11.1 h	11
Ginga	Japan	5.2 f	8.6 i	8.7 f	17.2 g	10
Kwanak	Korea	0.2 f	0.5 j	1.4 g	1.3 j	13
Dongjin	Korea	0.1 f	0.3 j	0.6 g	0.6 j	14
Nongbaek [y]	Korea	0.1 f	0.1 j	0.2 g	0.3 j	15
Sangpung [y]	Korea	0.0 f	0.1 j	0.2 g	0.3 j	15
Indica-japonica hybrids						
Milyang 23 [y]	Korea	0	0.1	0.2	0.2	16
Milyang 30	Korea	0	0	0	0	17
Nampung	Korea	0	0	0	0	17
Tabaek	Korea	0	0	0	0	17

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column followed by the same letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.

Table 3. Percent disease severities and area under disease progress curves (AUDPC) of selected 20 rice cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast nursery hill plots sown on 11 May 1984 at Suweon, Korea

Cultivar	Country of origin	Percent disease severity (days after sowing)			AUDPC	Rank
		90	100	110		
Japonica cultivars						
Norin 6	Japan	16.5 b [z]	30.5 b	38.9 b	66.5 b	2
Norin 8	Japan	14.5 c	27.4 c	39.5 a	60.8 c	3
Palkweng	Korea	23.3 a	36.0 a	35.4 d	76.9 a	1
Paltal	Korea	11.2 d	32.5 b	36.9 c	60.6 c	4
Nakdong	Korea	12.0 cd	26.6 c	35.4 d	57.8 d	5
Jinju	Korea	8.4 e	20.4 d	34.0 c	46.8 e	6
Akibare	Japan	6.0 f	11.4 e	24.4 f	31.0 f	7
Palkeum	Korea	3.9 g	10.7 e	23.4 f	26.8 g	8
Jinheung	Korea	2.8 gh	7.7 f	15.3 g	17.6 h	9
Olchal	Japan	0.8 hi	4.1 g	9.7 h	9.5 i	10
Dobong	Korea	0.5 i	1.8 h	4.4 i	4.7 j	11

Cultivar	Country of origin	Percent disease severity (days after sowing)			AUDPC	Rank
		90	100	110		
Ginga	Japan	0.9 hi	1.2 h	1.7 j	3.4 j	12
Kwanak	Korea	0.2 i	0.5 h	1.2 jk	1.4 k	13
Dongjin	Korea	0.1 i	0.2 h	0.3 k	0.4 k	14
Nongbaek[y]	Korea	0.1 i	0.1 h	0.1 k	0.3 k	15
Sangpung[y]	Korea	0.0 i	0.1 h	0.1 k	0.2 k	16
Indica-japonica hybrids						
Milyang 23	Korea	0	0	0	0	17
Milyang 30	Korea	0	0	0	0	17
Nampung	Korea	0	0	0	0	17
Taebaek	Korea	0	0	0	0	17

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column ofllowed by the same letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.

Table 4. Reactions of individual leaves of 16 japonica cultivars to *Pyricularia oryzae* in blast nursery hill plots sown on 11 May 1983 at Suweon, Korea

Cultivar	Blast reaction[a]					
	Seventh leaf	Eighth leaf	Ninth leaf	Tenth leaf	Eleventh leaf	Flag[b] leaf
Norin 6	S[c]	S	S	S	S	S
Norin 8	S	S	S	S	S	S
Palkweng	S	S	S	S	S	S
Paltal	S	S	S	S	S	S
Nakdong	S	S	S	S	S	S
Jinju	S	S	S	S	S	S
Akibare	S	S	S	S	S	R
Palkeum	S	S	S	S	S	R
Jinheung	S	S	S	S	R	R
Olchal	S	S	S	S	R	R
Dobong	S	S	S	S	R	R
Ginga	S	S	S	R	R	R
Kwanak	S	S	R	R	R	R
Dongjin	S	S	R	R	R	R
Nongbaek	R	R	R	R	R	R
Sangpung	R	R	R	R	R	R

[a] Evaluated on 14 August 1983.

[b] Twelfth or thirteenth leaf.

[c] S : susceptible, R : resistant.

As compared by the infection types on individual leaves to *P. oryzae*, cultivars Nongbaek and Sangpung out of the 16 japonica cultivars and all the 16 indica-japonica hybrids tested showed resistant reactions on all the leaves in the 1983 and 1984 plantings. Japonica cultivars Norin 6, Norin 8, Palkweng, Paltal, Nakdong and Jinju were susceptible to leaf blast at all the growth stages of rice plants in both years. However, the infection types of the other japonica cultivars were changed at a certain leaf stage depending on the rice genotypes (Tables 4, 5 and 6). The cultivars with lower disease

Table 5. Reactions of individual leaves of 16 japonica cultivars to *Pyricularia oryzae* in blast nursery hill plots sown on 25 June 1984 at Suweon, Korea

Cultivar	Blast reaction[a]					
	Fourth leaf	Sixth leaf	Eighth leaf	Tenth leaf	Eleventh leaf	Flag[b] leaf
Norin 6	S[c]	S	S	S	S	S
Norin 8	S	S	S	S	S	S
Palkweng	S	S	S	S	S	S
Paltal	S	S	S	S	S	S
Nakdong	S	S	S	S	S	S
Jinju	S	S	S	S	S	S
Akibare	S	S	S	S	S	S
Palkeum	S	S	S	S	S	R
Jinheung	S	S	S	S	S	R
Olchal	S	S	S	S	R	R
Dobong	S	S	S	S	R	R
Ginga	S	S	S	S	R	R
Kwanak	S	S	R	R	R	R
Dongjin	S	S	R	R	R	R
Nongbaek	R	R	R	R	R	R
Sangpung	R	R	R	R	R	R

[a] Evaluated on 29 August 1984.

[b] Twelfth or thirteenth leaf.

[c] S : susceptible, R : resistant.

Table 6. Reactions of individual leaves of 16 japonica cultivars to *Pyricularia oryzae* in blast nursery hill plots sown on 11 May 1984 at Suweon, Korea

Cultivar	Blast reaction[a]					
	Seventh leaf	Eighth leaf	Ninth leaf	Tenth leaf	Eleventh leaf	Flag[b] leaf
Norin 6	S[c]	S	S	S	S	S
Norin 8	S	S	S	S	S	S
Palkweng	S	S	S	S	S	S
Paltal	S	S	S	S	S	S
Nakdong	S	S	S	S	S	S
Jinju	S	S	S	S	S	S
Akibare	S	S	S	S	S	R
Palkeum	S	S	S	S	S	R
Jinheung	S	S	S	S	S	R
Olchal	S	S	S	S	R	R
Dobong	S	S	S	S	R	R
Ginga	S	S	S	S	R	R
Kwanak	S	R	R	R	R	R
Dongjin	S	R	R	R	R	R
Nongbaek	R	R	R	R	R	R
Sangpung	R	R	R	R	R	R

[a] Evaluated on 29 August 1984.

[b] Thirteenth or fourteenth leaf.

[c] S : susceptible, R : resistant.

Table 7. Area under disease progress curves (AUDPC) for various leaves of 16 japonica cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast nursery hill plots sown on 11 May 1983 at Suweon, Korea

Cultivar	AUDPC[w]			
	Seventh leaf	Ninth leaf	Eleventh leaf	Flag[x] leaf
Norin 6	216.5 a[z]	126.5 a	72.4 a	0.4 c
Norin 8	190.7 b	114.6 b	72.3 a	12.4 a
Palkweng	169.3 c	119.4 b	65.3 b	0.3 c
Paltal	171.6 c	91.1 c	42.8 d	3.4 b
Nakdong	150.2 d	94.8 c	51.0 c	10.5 a
Jinju	142.0 e	64.2 d	35.9 e	10.7 a
Akibare	141.0 e	39.7 e	19.8 f	2.5 bc
Palkeum	122.5 f	29.1 f	2.3 g	0 c
Jinheung	23.4 g	7.7 g	0.3 g	0 c
Olchal	12.5 h	4.3 gh	0.2 g	0 c
Dobong	9.4 hi	4.6 gh	0.1 g	0 c
Ginga	3.0 ij	0.8 h	0.1 g	0 c
Kwanak	1.6 j	0.2 h	0.0 g	0 c
Dongjin	0.8 j	0.3 h	0.0 g	0 c
Nongbaek[y]	0.9 j	0.3 h	0.0 g	0 c
Sangpung[y]	0.5 j	0.1 h	0.0 g	0 c

[w] Rated from 15 July to 14 August 1983.

[x] Twelfth or thirteenth leaf.

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column followed by the same letter are not statistically different (P=0.05) according to Duncan's multiple range test.

severities showed resistant reactions in the earlier leaf stages. Cultivars Kwanak and Dongjin were resistant from the eight- or nine-leaf stages, whereas cultivars Akibare and Palkeum were resistant at the flag leaf stage.

The AUDPCs for various leaves of the 16 japonica cultivars are presented in Tables 7, 8 and 9. The lower six leaves of rice plants sown on 11 May 1983 and 1984 and the lower three leaves sown on 25 June 1984 were naturally killed already at the first disease rating. In general, lower leaves of rice plants were more severely infected than upper leaves. With aging of leaves, blast infection on upper leaves gradually decreased in all the cultivars tested. In particular, more conspicuous change in susceptibility to blast was observed in the cultivars showing

Table 8. Area under disease progress curves (AUDPC) for various leaves of 16 japonica cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast nursery hill plots sown on 25 June 1984 at Suweon, Korea

Cultivar	AUDPC[w]			
	Fourth leaf	Seventh leaf	Tenth leaf	Flag[x] leaf
Norin 6	191.3 c[z]	98.2 d	46.2 c	0.1 bc
Norin 8	177.7 e	83.0 e	56.4 a	0.3 ab
Palkweng	154.5 g	101.1 c	49.3 b	0.2 abc
Paltal	161.3 f	83.5 e	36.8 e	0.3 ab

Cultivar	AUDPC[w]			
	Fourth leaf	Seventh leaf	Tenth leaf	Flag[x] leaf
Nakdong	209.9 a	131.2 a	41.8 d	0.4 a
Jinju	184.0 e	107.6 b	27.0 f	0.1 bc
Akibare	197.9 b	129.8 a	19.5 g	0.1 bc
Palkeum	191.3 c	106.5 b	35.7 e	0 c
Jinheung	181.4 de	80.0 e	12.8 h	0 c
Olchal	26.6 j	4.0 h	0.1 i	0 c
Dobong	45.0 i	8.2 g	0.3 i	0 c
Ginga	50.4 h	19.9 f	2.0 i	0 c
Kwanak	3.3 k	1.6 h	0.3 i	0 c
Dongjin	1.5 k	1.2 h	0 i	0 c
Nongbaek[y]	0.6 k	0.3 h	0 i	0 c
Sangpung[y]	0.9 k	0.3 h	0 i	0 c

[w] Rated from 30 July to 29 August 1984.

[x] Twelfth or thirteenth leaf.

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column followed by the same letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.

Table 9. Area under disease progress curves (AUDPC) for various leaves of 16 japonica cultivars in an evaluation of adult-plant resistance to *Pyricularia oryzae* in blast hursery hill plots sown on 11 May 1984 at Suweon, Korea

Cultivar	AUDPC[w]			
	Seventh leaf	Ninth leaf	Eleventh leaf	Flag[x] leaf
Norin 6	156.6 c[z]	86.2 a	50.7 b	1.2 a
Norin 8	143.0 e	87.7 a	20.1 d	0.5 b
Palkweng	163.3 b	79.3 b	53.8 a	0.3 c
Paltal	126.2 f	86.8 a	42.3 c	0.2 cd
Nakdong	169.6 a	65.5 c	17.5 e	0.1 d
Jinju	148.1 d	64.6 c	15.7 f	0.1 d
Akibare	98.5 g	36.2 d	5.1 g	0 d
Palkeum	96.0 g	28.5 e	3.1 h	0 d
Jinheung	53.3 h	19.2 f	2.5 h	0 d
Olchal	31.4 i	10.9 g	0.3 i	0 d
Dobong	17.5 j	5.2 h	0.2 i	0 d
Ginga	8.9 k	3.9 h	0.3 i	0 d
Kwanak	3.4 l	1.5 i	0.1 i	0 d
Dongjin	1.7 l	0.5 i	0 i	0 d
Nongbaek[y]	1.0	0.3 i	0 i	0 d
Sangpung[y]	0.5 l	0.2 i	0 i	0 d

[w] Rated from 30 July to 29 August 1984.

[x] Thirteenth or fourteenth leaf.

[y] These cultivars showed only hypersensitive reactions.

[z] Values in the same column followed by the same letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.

moderate resistance to leaf blast such as Akibare, Palkeum, Jinheung, Olchal, Dobong and Ginga, which showed only a negligible level of blast infection on upper leaves. Therefore, these cultivars were evaluated as resistant to leaf blast at adult-plant stages.

Table 10 showes the reactions of eight Korean differential rice cultivars to *P. oryzae* at the blast nursery in 1983. Cultivars Tetep, Taebaek, Tongil and Yushin showed no reaction to blast and cultivar Nongbaek showed only hypersensitive reaction. Cultivars Nakdong, Jinheung and Kanto 51 showed susceptible reactions but there were no significant differences among the leaf blast severities of the cultivars infected by the virulent races of *P. oryzae* at the blast nursery during the disease rating periods

Table 10. Reactions of eight Korean differential rice cultivars exposed to *Pyricualria oryzae* for one day in blast nursery hill plots during the disease rating periods in 1983 at Suweon, Korea

Differential cultivar	Percent disease severity			
	July 15 [x]	July 25	August 5	August 15
Nakdong	25.6 NS	27.5	32.1	27.0
Jinheung	16.1 NS	14.4	15.8	17.5
Nongbaek [y]	0.3 NS	0.3	0.2	0.2
Kanto 51	23.5 NS	25.0	21.7	21.6
Yushin [z]	0	0	0	0
Tongil [z]	0	0	0	0
Taebaek [z]	0	0	0	0
Tetep [z]	0	0	0	0

[x] Rice plants at five-leaf stages were exposed to natural blast infection on different dates in the field.

[y] These cultivars showed only hypersensitive reactions.

[z] These cultivars showed no disease

NS : Non-significant

Table 11. Reactions of eight Korean differential rice cultivars to *Pyricularia oryzae* in blast nursery hill plots during the disease rating periods in 1983 and 1984 at Suweon, Korea

Differential cultivars	Blast reaction [z]	
	1983	1984
Nakdong	HS	HS
Jinheung	HS	HS
Nongbaek	HR	HR
Kanto 51	HS	HS
Yushin	NR	MS
Tongil	NR	NR
Taebaek	NR	NR
Tetep	NR	NR

[z] HS : highly susceptible reaction,
HR : highly resistant reaction,
MS : moderately susceptible reaction,
NR : no reaction.

of 1983. The qualitative reactions of eight Korean differential rice cultivars at the blast nursery in 1983 and 1984 are given in Table 11. Cultivar Yushin showed no reaction to blast in 1983 but moderate resistance in 1984. The other cultivars showed the consistent reactions in the two years.

DISCUSSION

When compared on the basis of disease severities by natural field infection, all the indica-japonica hybrids tested in 1983 showed nearly immune type resistance to leaf blast but the 16 japonica cultivars tested showed various degrees of resistance to leaf blast. Similar results were obtained in the two plantings in 1984. Therefore, the indica-japonica hybrids were less valuable for screening rice cultivars resist

ant to leaf blast at adult-plant stages in the two years.

With aging of rice plants, the quantitative levels of resistance to leaf blast gradually increased in all the japonica cultivars tested, although the levels of resistance varied according to rice genotypes. This indicates that all rice plants, both resistant and susceptible, become increasingly resistant to leaf blast as plants mature. Similar phenomenon was reported on the barley cultivars to powdery mildew by Hwang and Heitefuss (5, 6). In particular, more conspicuous change in susceptibility of rice plants to leaf blast was observed in moderately susceptible cultivars than highly susceptible ones. Therefore, the moderately susceptible cultivars Akibare, Palkeum, Jinheung, Olchal, Dobong and Ginga, of which disease severity drastically decreased in upper leaves, were evaluated as resistant to leaf blast at adult-plant stages in the blast nursery.

The actual leaf position in which qualitative resistance to leaf blast was expressed at later growth stages of rice plants varied among rice genotypes. Out of the 16 japonica cultivars, highly susceptible cultivars Norin 6, Norin 8, Palkweng, Paltal, Nakdong and Jinju showed only susceptible reactions at all growth stages. Highly resistant cultivars Nongbaek and Sangpung showed hypersensitive reaction in the three plantings in 1983 and 1984. However, the dramatic change in blast reaction from susceptible to resistant was observed in the other cultivars which quantitatively decreased the disease severity in upper leaves. The growth stages in which the susceptible reactions were changed to resistant ones varied according to rice genotypes. The cultivars, in which the quantitative level of resistance to leaf blast was higher, showed qualitatively resistant reaction on the lower leaves of rice plants. The changes in blast reaction in the cultivars resistant to leaf blast at late growth stages of rice plants occurred in eight- or nine-leaf stages in the three plantings, their resistance being consistently expressed on the flag leaves. Qi and Mew (13) also resported that all the adult-plant-resistant cultivars were resistant to bacterial blight consistently on the flag leaves of the cultivars. Our results suggest that the cultivars resistant to leaf blast at adult-plant stages may express resistance to leaf blast, both quantitatively and qualitatively, as rice plants mature.

Since 1978 when the nearly immune type of resistance of the indica-japonica hybrids to rice blast was broken down in Korea, the cultivation of japonica cultivars instead of the indica-japonica hybrids has been rapidly increased (3). The populations of indica races of *P. oryzae* virulent to the hybrids markedly decreased with reduced cultivation of the hybrid rice. As a result, the conspicuous decrease in the populations of indica races in 1983 and 1984 may result in resistance to leaf blast in the indica-japonica hybrids tested in our study. The changes of the virulence frequencies of races have been known to be one of the most important factors to greatly influence the degree of disease severity in screening resistant cultivars in fields (18, 19, 20). Quamaruzzaman and Ou (14) demonstrated that some rice cultivars showed different reactions to rice blast at various stages of development by the changes of the races of *P. oryzae* in fields. Therefore, the comparison of resistance of indica-japonica hybrids with that of japonica cultivars may lead some difficulties in evaluating resistance to leaf blast in the two experiment years. However, the changes in susceptibility to leaf blast at upper leaves of the cultivars tested did not seem to be due to the shifts of races of *P. oryzae*, because any significant changes of the pathogenic races of the blast fungus were not observed in the blast nursery during the disease rating period in the first planting.

Usually, rice blast epidemics in Korea occur in July after transplanting in the paddy field. Rice plants of seedling stage grown in the nursery beds before transplanting can be escaped from rice blast due to climatic conditions unfavorable for occurrence of seedling blast. Seedling blast in the nursery beds can be controlled by fungicides more efficient-

ly and economically than in the paddy field. Therefore, cultivation of adult-plant-resistant cultivars, which were fully susceptible at seedling stages in the nursery but resistant to blast at adult-plant stages in the paddy field, could be recommended for efficient control of rice blast in the temperate countries such as Korea. Adult-plant resistance of rice cultivars to leaf blast may be characterized more precisely by further studying specificity to races of *P. oryzae* and yield potentials of these cultivars.

REFERENCES

1. AHN, S. W. & OU, S. H. (1982). Quantitative resistance of rice to blast disease. *Phytopathology* 72: 279-282.
2. AHN, S. W. & OU, S. H. (1982). Epidemiological implications of the spectrum of resistance to rice blast. *Phytopathology* 72: 282-284.
3. CHUNG, H. S. (1979). The shifting races of *Pyricularia oryzae* and some problems on the blast epidemics of IR varieties in Korea. Lecture Meeting on Rice Blast Disease. 24-28 July 1979, pp. 41-71, ASPAC/FFTC & ORD, Suweon, Korea.
4. EZUKA, A. (1979). Breeding for and genetics of blast resistance in Japan. Proceedings of the Rice Blast Workshop. 22-24 February 1977, pp 27-48, International Rice Reseasrch Institute, Los Banos, Laguna, Philippines.
5. HWANG, B. K. & HEITEFUSS, R. (1982). Characterization of adult plant resistance of spring barley to powdery mildew (*Erysiphe graminis* f.sp. *hordei*). I. Race specificity and expression of resistance. *Phytopathol. Z.* 104: 168-178.
6. HWANG, B. K. & HEITEFUSS, R. (1982). Characterization of adult plant resistance of spring barley to powdery mildew (*Erysiphe graminis* f.sp. *hordei*). II. Infection process at different leaf stages. *Phytopathol. Z.* 104: 179-190.
7. KIYOSAWA, S. (1982). Genetics and epidemiological modeling of breakdown of plant disease resistance. *Ann. Rev. Phytopathol.* 20: 93-117.
8. MARCHETTI, M. A. (1983). Dilatory resistance to rice blast in USA rice. *Phytopathology* 73: 645-649.
9. MARCHETTI, M. A. (1983). Dilatory blast resistance in rice lines exotic to the southern United States. *Plant Disease* 67: 1362-1364.
10. ORDÓNEZ, M. T. (1981). Epidemiologische und cytologische-histochemische Untersuchungen zum Verhalten von Sommergerste gegenüber Mehltau (*Erysiphe graminis* f.sp. *hordei*) unter besonderer Berücksichtigung der Altersresistenz. *Dissertation Göttingen University, Germany.*
11. OU, S. H., NUQUE, E. L. & BANDONG, J. M. (1975). Relation between qualitative and quantitative resistance to rice blast. *Phytopathology* 65: 1315-1316.
12. ROSERO, M. J. (1979). Breeding for blast resistance in rice at CIAT. Proceedings of the Rice Blast Workshop. 22-24 February 1977, pp 63-68, International Rice Research Institute, Los Banos, Laguna, Philippines.
13. QI, Z. & MEW, T. W. (1985). Adult-plant resistance of rice cultivars to bacterial blight. *Plant Disease* 69: 896-898.
14. QUAMARUZZAMAN, MD. & OU, S. H. (1970). Monthly changes of pathogenic races of *Pyricularia oryzae* in a blast nursery. *Phytopathology* 60: 1266-1269.
15. SHANER, G. & FINNEY, R. E. (1977). The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knot wheat. *Phytopathology* 67: 1051-1056.
16. VILLAREAL, R. L., MACKENZIE, D. R., NELSON, R. R. & COFFMANN, W. R. (1980). Apparent infection rates of *Pyricularia oryzae* on different rice cultivars. *Phytopathology* 70: 1224-1226.
17. VILLAREAL, R. L., NELSON, R. R., MA-

CKENZIE, D. R. & COFFMANN, W. R. (1981). Some components of slow-blasting resistance in rice. *Phytopathology* 71: 608-611.

18. WATSON, I. S. (1970). Changes in virulence and population shifts in plant pathogens. *Ann. Rev. Phytopathol.* 8: 209-230.
19. WOLFE, M. S. (1973). Changes and diversity in populations of fungal pathogens. *Ann. appl. Biol.* 75: 132-135.
20. YAMADA, M. (1979). Changes in population of *Pyricularia oryzae* races and varietal resistance to blast disease in Japan. Lecture Meeting on Rice Blast Disease. 24-28 July 1979, pp 75-108, ASPAC/FFTC & ORD, Suweon, Korea.