6. RECENT STATUS OF RICE BREEDING FOR BLAST RESISTANCE IN TAIWAN, WITH SPECIAL REGARD TO RACES OF THE BLAST FUNGUS

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Introduction

Blast is the most destructive disease of rice in Taiwan, particularly in the first crop-season. The annual loss is estimated to be not less than 5% of the total production. Application of mercuric and antibiotic fungicides is not a satisfactory method of control, as application at the correct time, phytotoxicity to native varieties (*indica* type) and the high cost of application are difficult problems. The breeding of resistant varieties would provide the best solution of the problems. In Taiwan, the Ponlai varieties (*japonica* type), predominantly grown, are generally more susceptible to blast than native (*indica*) varieties. Breeding of resistant Ponlai varieties is then important in Taiwan.

Systematic breeding work for blast resistance was initiated in 1950. Crosses in various combinations of parental stocks, back-crosses, selection and regional test of varietal resistance have then been made. Since the occurrence of various physiological races of the fungus was found in 1961, test of breeding materials with different races, and genetic studies of the reaction to different races have been conducted, in order to obtain information of basic importance for the resistance breeding. This paper summarizes these work in the past few years and point out problems that have arisen during the work.

Breeding of Blast Resistant Varieties by Hybridization

1. Breeding Materials

In the past years, for the improvement of Ponlai varieties, crosses were made mostly between Ponlai and Japanese varieties. The new varieties selected from Ponlai×Ponlai were generally susceptible to the blast disease. In recent years, rice breeders are widening their choice of parental varieties to include Taiwanese native varieties of the *indica* type, native ones of the mountain region of Taiwan and strains introduced from other Asian countries. In the Taiwan Agricultural Research Institute (TARI), we also crossed Ponlai varieties with Magnolia, Zenith and other U. S. varieties. The District Agricultural Improvement Stations (DAIS) at Taichung, Tainan and Kaohsiung have successfully employed *japonica*×*indica* crosses in their breeding programs. The Taichung DAIS has introduced into their selections, blast resistance genes of a Japanese variety, Kanto 55. As the result, Taichung 181, 184 and 186 were developed. The Kaohsiung DAIS has crossed a Philippines variety Milfor with their Ponlai selection Kaohsiung 64 and 68.

2. Breeding Procedure

The procedure of breeding Ponlai rice in Taiwan has been reviewed by Dr. T. T. Chang (1960) at the meetings of the Breeding Committee of Rice Improvement Conference in 1960.

The major improvement recently adopted in the breeding procedure is to incorporate tests for blast resistance as mandatory part of the breeding program. In some experimental

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stations (Taichung and Kaohsiung DAIS's, TARI-Chiayi) which have a special test field for the disease resistance, the test is begun in the F_2 and is continued until the last yield trial of progeny selections. In those stations which do not have the facilities, selected lines from the preliminary yield trials are sent to the TARI for greenhouse testing of the seedlings. Entries in advanced yield trials are tested in the test field of a neighboring station for at least one year (two crops). New varieties are released after being evaluated in the test fields at five locations, namely, Taipei (Ilan), Taichung (Tunshu), Chiayi (TARI-Chiayi) and Pingtung (Wanluan) and Taitung (Kuansan). In the test fields, a uniform set of strains is always tested in the same seasons.

3. Method of Testing Disease Resistance

Each strain is planted in a two-row plot, a row consisting of 7 hills, each of three plants, spaced at 22.7×22.7 cm. A susceptible Italian variety Lomello is planted between the plots to induce a heavy epidemic of the disease. Randomized block design is used with three replications. Fertilizers are applied at the rate of 1200 kg (N: 240 kg/ha) of ammonium sulfate, 300 kg (P: 54 kg/ha) of calcium superphosphate and 100 kg (K: 60 kg/ha) of potassium sulfate per ha. P and K are applied as the basic dressing while N is splited into four dressings. The degree of natural infection obtained in the test fields is generally satisfactory. This is achieved by a high level of nitogen fertilizer and frequent drainings of the field for soil aeration.

The degree of infection of the leaves is classified into 12 grades basing upon the percentage of lesion ared and the number of leaves killed in different stages. It is then grouped into six classes i. e. highly resistant (HR), resistant (R) moderately resistant (MR) moderately susceptible (MS), susceptible (S) and highly susceptible (HS), as follows:

% of lesion area	0	0.5	0.5	1	2	5	11	25	55	80	100	Complete killing
Disease index number	0	1	2	3	4	5	6	7	8	8.5	8.8	9
	(Hr)	(R)		(Mr)		(Ms)		(S)		(Hs)		

In addition to this, legion types classified into Inmune (I) Resistant (R) Moderattely resistant (M) susceptible (S) are also recorded in each line.

Regardinng the neck blast, the percentage of infected panicles in a hill is observed and classified into six classes as follows:

% of diseased neck	0–10	11–30	31–50	51–70	71–90	91–100
Classes	Hr	R	Mr	Ms	S	Hs

4. Results

The number and kinds of strains to be tested for blast resistance are decided by the Breeding Committee Meeting held once a year. The varieties so far tested may be grouped into the following categories:

1956–1959: Commercial Ponlai, native, upland and Japanese varieties, in addition to a few newly selected ones.

1960–1961: Selected lines from advanced yield trials, in addition to a few commercial varieties.

1962–1967: Lines selected from primary and advanced yield trials.

All strains to be tested are supplied by TARI, TARI–Chiayi, and DIAS's at Taipei, Hsinshu, Taichung, Tainan, Kaohsiung, and Hualien. The number of strains tested during 1956–1967 is as follows:

Year	No. of Strains	Year	No. of Strains
1956	40	1961	36
1957	20	1962	46
1958	21	1963	46
1959	25	1964	47
1960	34	1965	44

1966	54	1967	49
		Total:	412

(1) Variations in leaf and neck blast resistances

As shown in table 1, varietal resistances to the leaf blast differed according to years, crop seasons and locations. Differences on environment as well as the occurrence of different races of the blast fungus may give rise to such variations.

Table 1. Leaf blast reactions of rice strains at five locations in 1965–1966.

Strain name	Taipei		Taichung		Chiayi		Kaohsiung		Taitung	
	1965	1966	1965	1966	1965	1966	1965	1966	1965	1966
Taipei-yu 380	Mr	S	S	S		S	Ms	Hs	Ms	Hs
Taipei-yu 399		S		Hs		Hs		Hs		Hs
Taipei-yu 404		S		S		S		Hs		Hs
Hsinchu-yu 169	Mr	Hs	S	Hs	Hs	Hs	Ms	Hs	Hs	Hs
Hsinchu-yu 254	Hs	Hs	Hs	Hs	Hs	S	S	Hs	S	Hs
Hsinchu 56	S	S	S	Hs	Hs	Hs	S	Hs	Hs	Hs
Taichung-shi 97	R	R	R	R	S	R	Mr	R	R	R
Taichung-shi 99	Mr	S	S	S	Hs	S	Ms	S	Hs	S
Taichung-shi 100	R	Ms	Ms	Ms	Hs	Ms	Mr	Ms	Mr	R
Taichung-shi 101	Ms	Ms	S	S	S	S	S	Ms	Ms	Ms
Taichung-shi 102	Hr	R	Ms	Mr	Hs	Ms	Mr	R	Mr	R
Taichung-shi 103	Mr	Ms	S	S	Hs	S	Ms	S	Hs	S
Taichung native 1	R	R	R	R	S	R	Ms	Mr	Mr	R
Taichung 65	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs
C–216		S		Hs		Hs		Hs		Hs
C–217		Hs		Hs		Hs		Hs		Hs
C–218		Mr		Mr		Mr		R		R
Chianung 242	Mr	Ms	S	S	Hs	S	Ms	S	Hs	S
Nan-kai-yu 37	Mr	S	S	S	Hs	S	Ms	Hs	R	Ms
Nan-kai-yu 38	Mr	S	S	S	Hs	Hs	Hs	S	R	S
Nan-kai-yu 40	Hs	Hs	Hs	Hs	Hs	Hs	S	Hs	S	Hs
Chianan 8	S	S	S	Hs	Hs	Hs	S	Hs	Hs	Hs
Tainan 3	Hs	Hs	Hs	Hs	Hs	S	S	Hs	Ms	Hs
Kaohsiung-yu 197		S		S		S		S		S
Kaohsiung-yu 198		S		S		S		S		S
Kaohsiung-yu 200		S		S		S		S		Ms
Taitung-yu 138	Hr	R	Mr	R	Hs	R	Mr	R	Mr	R
Taitung-yu 140	Hr	R	Ms	R	Hs	Ms	Mr	Mr	R	R
Taitung-yu 162	Mr	Mr	S	S	Hs	Ms	Ms	Mr	Mr	Mr
Hua-yu 74	R	Ms	Ms	S	S	S	S	Mr	Ms	Mr
Hua-yu 77		Hs		Hs		Hs		Hs		Hs
Hua-yu 78		S		S		S		Hs		Hs

The records of neck blast resistance also differed according to varieties, years and locations, as shown in Table 2.

Table 2. Neck blast reactions of rice strains at five locations in 1965–1966.

Strain name	Taipei		Taichung		Chiayi		Kaohsiung		Taitung	
	1965	1966	1965	1966	1965	1966	1965	1966	1965	1966
Taipei-yu 380	R	Mr	Hs	Ms	R	Ms	Hs	Hs	Hs	Hs
Taipei-yu 399		Ms		Hs		Ms		Hs		Hs
Taipei-yu 404		Mr		Hs		S		Hs		Hs
Hsinchu-yu 169	Mr	Hs	Hs	Hs	R	Mr	Mr	Hs	Hs	Hs
Hsinchu-yu 254	Hs	Hs	Hs	Hs	R	R	Hs	Hs	S	Hs
Hsinchu 56	Hs	S	Hs	Hs	Mr	Ms	S	Hs	Hs	Hs
Taichung-shi 97	R	R	Hr	Hr	R	Hr	Hr	Hr	R	R
Taichung-shi 99	R	Mr	Hs	Hr	R	Ms	R	Ms	Hs	S
Taichung-shi 100	Ms	Mr	Hs	S	R	Hr	S	Hs	S	Ms
Taichung-shi 101	Mr	Ms	S	S	Mr	Mr	Mr	R	R	Hs
Taichung-shi 102	R	R	S	R	Hr	Ms	Mr	Mr	Ms	R
Taichung-shi 103	Ms	Mr	S	Mr	R	Mr	Mr	S	Hs	Hs
Taichung native 1	Ms	Mr	R	R	Hr	Mr	S	S	Hr	R
Taichung 65	Hs	Hs	Hs	Hs	Ms	Hs	Hs	Hs	Hs	Hs
C–216		Ms		Hs		Ms	Hs	Hs		Hs
C–217		Hs		Hs		R		Hs		Hs
C–218		R		Hr		Hr		Hr		Mr
Chianung 242	Mr	Mr	Hs	R	Mr	Mr	R	S	Hs	Ms
Nan-kai-yu 37	Mr	S	Hs	S	R	Mr	Mr	Hs	R	Hs
Nan-kai-yu 38	Mr	Ms	Hs	Ms	R	Mr	Mr	S	R	S
Nan-kai-yu 40	Hs	Hs	Hs	Hs	Mr	Mr	S	Hs	Hs	Hs
Chianan 8	S	S	S	Hs	Mr	Mr	S	Hs	Hs	Hs
Tainan 3	S	Hs	Hs	Hs	R	Ms	S	Hs	Hs	Ms
Kaohsiung-yu 197		Mr		Mr		S		S		Ms
Kaohsiung-yu 198		R		Mr		Ms		Hs		Ms
Kaohsiung-yu 200		Ms		Ms		S		Ms		Ms
Taitung-yu 138	Ms	Ms	Hs	Ms	Mr	Hr	R	S	R	R
Taitung-yu 140	Mr	Ms	Hs	Mr	R	Mr	Mr	S	Hs	R
Taitung-yu 162	Mr	Ms	Hs	Mr	R	R	R	R	R	Ms
Hua-yu 74	R	Mr	Ms	S	Hr	Mr	Mr	R	Ms	R
Hua-yu 77		Ms		Hs		Mr		Hs		Hs
Hua-yu 78		S		Hs		Hs		Hs		Hs

Table 3. Comparison of blast susceptibility between 1st and 2nd crops at Taichung in 1965–1966.

	Strain name	Leaf blast		Neck blast	
		1st crop	2nd crop	1st crop	2nd crop
1	Taipei-yu 380	S	Ms	Ms	S
2	Taipei-yu 399	Hs	S	Hs	Ms
3	Taipei-yu 404	S	S	Hs	Mr
4	Hsinchu-yu 169	Hs	Ms	Hs	Hs
5	Hsinchu-yu 254	Hs	Ms	Hs	Hs
6	Hsinchu 56	Hs	S	Hs	Ms
7	Taichung-shi 97	R	R	Hr	Hr
8	Taichung-shi 99	S	Ms	Hr	Mr
9	Taichung-shi 100	Ms	R	S	R
10	Taichung-shi 101	S	Ms	S	Mr
11	Taichung-shi 102	Mr	R	R	Mr
12	Taichung-shi 103	S	Ms	Mr	Ms
13	Taichung 65	Hs	S	Hs	Ms
14	Taichung native 1	R	R	R	R
15	C–216	Hs	S	Hs	S
16	C–217	Hs	R	Hs	Hr
17	C–218	Mr	Mr	Hr	R
18	Chianung 242	S	S	R	Hs
19	Nan-kai-yu 37	S	Ms	S	S
20	Nan-kai-yu 38	S	Ms	Ms	S
21	Nan-kai-yu 40	Hs	S	Hs	Hs
22	Chianan 8	Hs	S	Hs	Hs
23	Tainan 3	Hs	Ms	Hs	Hs
24	Kaohsiung-yu 197	S	Ms	Hs	Hs
25	Kaohsiung-yu 198	S	Ms	Mr	Mr
26	Kaohsiung-yu 200	S	Ms	Ms	Mr
27	Taitung-yu 138	R	R	Ms	Mr
28	Taitung-yu 140	R	R	Mr	Ms
29	Taitung-yu 162	S	Mr	Ms	R
30	Hua-yu 74	S	Mr	S	Hr
31	Hua-yu 77	Hs	S	Hs	S
32	Hua-yu 78	S	S	Hs	Ms

(2) Relation between leaf-and neck-blast resistances

How the resistance of leaf and that of panicle neck are correlated has been a problem of general interest. As shown in table 4, 81% of strains tested showed positive correlations between leaf and neck blast resistances, while the remaining 19% showed no corretations. Question then arieses as to whether or not the leaf and neck blast resistances are controlled by the same genes. Hashioka (1950) reported that some varieties, the number of the infected ears, has no correlation with the susceptibility of the leaves. The writer (Hsieh 1965) estimated phnotypic and genetic correlations between leaf and neck blast resistances in F_2 populations. He found that though phenotypic correlations differed according to crosses, genetic correlations were in most crosses high (rg=0.3–0.9). This suggests that the same genes control both leaf and neck resistances. The reason for the absence of the correlation in certain crosses seems to need further investigations.

Table 4. Number of strains classified according to leaf-and neck-blast resistances

Relation between leaf and neck blast resistances	Locations						
	Taipei	Taichung	Chiayi	Kaohsiung	Taitung	Total	%
L. N.	65	29	60	73	39	265	43.5 } 81
l. n.	38	68	37	35	50	228	37.5
L. n.	9	28	4	10	10	61	10.0 } 19
l. N.	12	–	23	6	14	55	9.0
Total	124	125	124	124	112	609	100

Note: L. N. Resistant to both leaf and neck blasts
l. n. Susceptible to both leaf and neck blasts
L. n. Resistant to leaf blast but susceptible to neck blast
l. N. Susceptible to leaf blast but resistant to neck blast

(3) Development of resistant varieties

Through selection in the test fields for resistance, the Taichung and Kaohsiung DAIS's, and TARI-Chiayi, have developed a number of new varieties and strains shown resistance under heavy fertilization. Some of them are listed in table 5.

Table 5. Resistant varieties recently developed

Originating station	Variety or line	Parents	Reaction to blast		Other characters
			leaf	neck	
Taipei DAIS	Taipei 309	Kwanfu 401 × Taipei 177	R	Hr	Medium maturity; highly responsive to heavy manuring tolerant to draught
TARI-Chiayi	Chianung 242	(Hsinchu 4 × Taichung 150) × (Taipei 7 × Tainung 45)	R	Mr	Highly responsive to heavy nitrogen fertilizer; medium maturity; high yield.
	Chianung-yu 280	(K2 × Tainung 45) × (Taichung-yu 12 × Ju-wee-tze)	R	R	Stiff straw; late maturity; high yield.
Taichung DAIS	Taichung native 1	Ti-chio-wu-chien × Tsai-yuan-tsun	R	Hr	Short statured: highy responsive to heavy manuring; tolerant to lodging
	Taichung-sen 2	Ti-chio-wu-chien × Pai-mi-fen	R	S	Stiff straw; eary maturity; medium grain; good grain quality.
	Taichung 179	Kwangfu 401 × Kwanglu	Mr	Ms	Medium maturity; tolerant to heavy manuring.
	Taichung 181	Taichung 65 × Kanto 55	R	R	Madium maturity; tolerant to heavy manuring.
	Taichung 184	Taichung 65 × Kanto 55	R	R	Highly responsive to heavy nitrogen fertilizer; medium maturity; good grain quality.
	Taichung 186	Taichung 65 × Kanto 55	R	Hr	Highly resposive to nitrogen fertilizer; good grain quality.
Tainan DAIS	Tainan 5	Kaohsiung 18 × Chianan 8	R	Mr	Medium maturity; highly responsive to nitrogen fertilizer.
Kaohsiung DAIS	Kaohsiung 137	Kaohsiung 53 × Chianung 242	R	Mr	Highly responsive to heavy nitrogen fertilizer; resistant to lodging; high yield.

Physiologic Races of Blast Fungus and Their Distribution

The occurrence of physiologic races of the blast fungus in Taiwan was first reported by Li (1957). Hung *et al.* (1961) then, tested six isolates of the blast fungus collected by Li from various rice growing areas, and classified them into five pathogenic groups. Using the same set of differential hosts, Chien *et al.* (1963) distinguished 27 races from 743 isolates tested in 1960–1966.

The distribution and frequency of the 27 races of *P. oryzae* so far identified are presented in table 6. Fig. 1 shows their distribution in 1960–1966.

As shown in table 6, races 1, 17 and 24 dominated in 1960–1966. They were obtained fro all six locations where the test fields were located. Race 13, another prevalent one occurred mainly in Taichung and Chiayi areas.

The number of races occurring at the six locations in 1960–1966 were as follows; Taipei, 21 (nos. 1, 2, 14, 17 and 24 dominating), Tunshu, 24, Chiayi, 25 (nos. 1 and 13 dominating), Pintung, 23 (nos. 1, 2, 17 and 24 dominating) and Taitung, 25 (nos. 17 dominating) and Hualien, 11 races.

Table 6. The variation in the frequency of occurrence of physiologic races of *P. oryzae* in Taiwan due to locations and years

Location	Year	Race 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Total No. of isolate	Total No. of races
Taipei	1960	1	1										1	1	2			1		1									8	7
	1961	2	1		4						1			2	12			1	1										24	8
	1962	10	2	1			2	2		2		1		1				1	3										25	10
	1963	1	3		1													5	1			1	1		1				14	8
	1964	4	4	2														3				1			9				23	6
	1965		1							1								1				1			1		1		6	6
	1966	1	4	4														2			1		2	1	3				18	8
	Total	19	16	7	5		2	2		3	1	1	1	4	14			14	5	1	1	3	3	1	14		1		118	21
Taichung	1960	3	1		2				2	3	2		4	11		1		1											30	10
	1961	1	1		2					9	5		3	6	5			1	7										40	10
	1962				1		1	1		2	1		1	1					2										10	8
	1963	7		1										3			1	1			1	2	1	1		2			20	10
	1964	5	1										2				1	2	1	1		3	1		1		1		19	11
	1965		1	2																			1	1	3		1		9	6
	1966	1		4										1				3			2				2	1			14	7
	Total	17	4	7	5		1	1	2	14	8		10	22	5	1	2	8	10	1	3	5	3	2	6	3	2		142	24
Chiayi	1960										2		2	3	1	1													9	5
	1961	3	1										2	8	3			3	1										21	17
	1962	4	6		2	1		1			1		2	6		1	6	3	5										38	12
	1963	8	3	1				1		1			4	2		1		6	1	2	4	1	6	1	1	1			44	17
	1964	8	4	1								1						4			3		1		7		12	1	42	10
	1965	1											1									1	2		1			1	7	6
	1966	2	2	1														1		1	1	2	1		1			1	13	10
	Total	26	16	3	2	1		2		1	3	1	11	19	4	3	6	17	7	3	8	4	10	1	10	1	12	3	174	25
Pintung	1960			1									2			3													6	3
	1961	3	2							2	5		1	4	1	4		3		2									27	10
	1962	6	5	1		3	1	2			4	2		1	2		1	8	2										78	13
	1963	4	1															2		2					1	1			11	6
	1964	4	6	1														4		2					12	1	1		31	8
	1965		2							2			2					2			1	1			4		2		16	8
	1966	2	3	1																	3	4	1		5				19	7
	Total	19	19	4		3	1	2		4	9	2	5	5	3	7	1	19	2	6	4	5	1		22	2	3		148	23
Taitung	1960								2				2			1		8		1									14	5
	1961	1	5							2	2		1	6	2			9	2										30	9
	1962	3	2	1	3	2	1	1					4		2	4	4	5	2	5									34	13
	1963	3	2															1							1				7	4
	1964	1		1														5				1	1		3		4	3	24	9
	1965	1	1															1				1			1				6	6
	1966	1		2														1			1	3	1	1	5			3	18	9
	Total	10	10	4	3	2	1	1	2	2	2		7	6	4	5	4	30	4	6	1	5	2	2	10		4	6	133	25
Hualien	1964	2	1															2		1					4	2			12	6
	1965		1																		1	1			1		1		5	5
	1966	2	2	1														1				1	1		1		2		11	8
	Total	4	4	1														3		1	1	2	1		6	2	3		28	11
Grand total		95	69	26	15	6	5	8	4	24	23	4	34	56	30	16	13	91	28	18	18	24	20	6	68	8	25	9	743	27

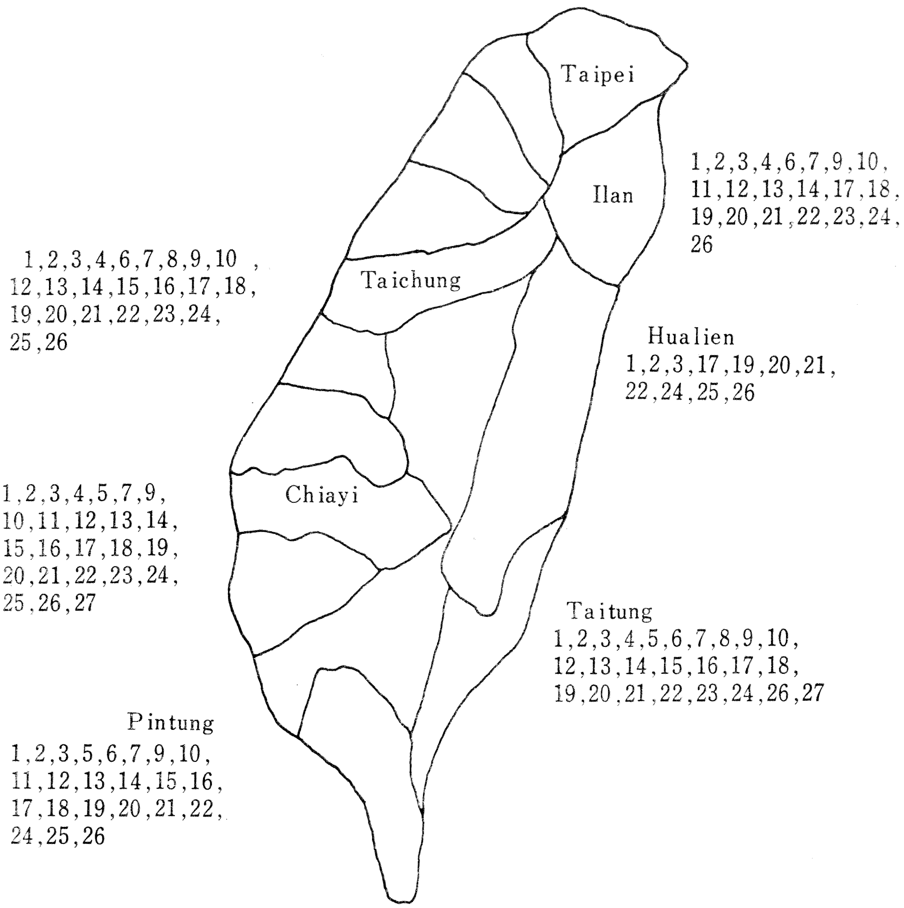

Fig. 1. Distribution of *Piricularia oryzae* races in Taiwan during 1960–66.

It is noticed from table 6, that the presence of blast races at a locality is varied from years. For instance, in Taipei (Ilan) area, races 6, 7, 10, 11, 12, 13 and 14 which occurred during 1960–1962 have disappeared since 1963. Instead, races 20, 21, 22, 23, 24 and 26 have occurred in 1963–1966. In Taituug, races 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15 and 16 which occurred in 1960–1962 have disapeared since 1963; instead, races 19, 20, 21, 22, 23, 24, 26 and 27 were added in 1963–1966. The presence and abscence of races may give rise to the variation of blast resistance to a variety at a location.

Genetics of the Resistances to Different Races

Recent genetic studies on the resistances to identified fungus races proved that the resistance to a race was controlled by a dominant gene (Atkins 1965; Kiyosawa 1966). The results we obtained in this study are consistent with this. We found four resistance genes, Pi_4, Pi_{14}, Pi_{22} and Pi_{25}, which appeared to be independent of one another. The above cited workers also reported the independency of resistance genes. Genes controlling the resistances to different fungus races might be distributed in different chromosomes. The genotypes for resistance genes of the strains used as parents were assumes as follows:

Pai-kan-tao ·············· Pi; Pi_{13}; Pi_{22}; Pi_{25}
Sensho ···················· Pi_{13}; Pi_{22}
Chianung 280 ··········· Pi_4; Pi_{22}; Pi_{25}

IG-65-2 .... Pi_4; Pi_{22}
IG-65-3 .... Pi_4; Pi_{22}
H106 .... Pi_4

Varieties identified to carry blast resistance genes Pi_4, Pi_{13}, Pi_{22} and Pi_{25} are given in table 7.

Table 7. Varieties identified to carry blast resistance genes Pi_4, Pi_{13}, Pi_{22} and Pi_{25}

Blast resistance genes	Variety name
Pi_4	Taichung 65, Thichung 171, Taichung lines 33, Kwanfu 1, Kwanfu 401, Chianan 8, Chianung 242, Kaohsiung 27, Nakamura, Shinriki, Pai-kan-tao, C-2180.
Pi_{13}	Taichung 171, Taichung 184, Taichung 186, Pai-kan-tao, IG-62-2, Tamanishiki, Sensho, Kanto 51, Norin 21, H-106, C-2180.
Pi_{22}	Pai-kan-tao, Kanto 51, Norin 21.
Pi_{25}	Taichung 171, Taichung 184, Taichung 186, Taichung line 33, Kwanfu 1, Chianung 280, Kanto 51.

It seems that when a particular fungus race is used in an experimental condition, the "gene-to-gene" hypothesis by Flor (1955) generally applies. Segregation of two or more genes reported by earier workers (Nakamori 1936; Hashioka 1950; Hsieh *et al.* 1961, 1965) might be due to mix infection of different races. However, breeders experience "field resistance" can not always be explained well by the results of controlled experiments. How the resistance genes work in different genetic backgrounds and in different environments needs further investigation.

Test of Breeding Materials with Different Races of the Blast Fungus

In the light of recent findings on pathogenic races of the blast fungus, breeders in Taiwan are realizing the importance to take this problems into consideration. Test of the breeding materials with races of the fungus were made as the first step in this direction. 50 strains from Taiwan, Japan, U. S. A., India and Philippines were tested with 27 races of the blast fungus. The results are given in table 8. Races 12, 13 and 16 are of the most pathogenic ones among the 27. There was a trend for most introduced varieties, either *japonica* or *indica* type, to show resistant reaction to a majority of the races tested. In contrast, varieties which have long been grown in Taiwan showed a wide range of variation in the susceptibility to Taiwanese races. This may be of interest to notice.

In table 9, further, the varieties were classified according to the number of races to which they showed resistance.

As shown in table 9, Taipei 306, Taipei 308 and Kaohsiung 24 were resistant to only one of eight races tested. The U. S. variety Coloro was also resistant to only two of ten races. Japanese varieties Pi no. 1, Ginga, Homare-nishiki showed resistances to 9 races, while Chokoto, Yakeiko, Ishikarishiroke were resistant to all the 10 races tested. Zenith, Rexaro (from U. S. A.), Tadudan, Dular (from India), wag-wag (from Philippines) also showed resistances to all the 10 races tested. Taichung 65 a representative of Ponlai variety in Taiwan was resistant to 10 races but was susceptible to 17 races. Taichung native 1 (*indica*), showed resistance to 7 of 8 races tested.

Taichung line 33, Chiaung-yu 280, Norin 21 and Kanto 51 were the most resistant ones showing resistances to 18 of 27 races tested. The more resistant genes a variety carries, the more it would be desirable. Such varieties may be obtained by combining many resistance

Table 8. Reaction of Breeding materials of rice to Taiwan races of *P. oryzae*

Variety	Race 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Source
Taipei 177	R				S							S	S			S	S							R		S		
Taipei 306	R				S							S	S			S	S							S		S		
Taipei 308	R				S							S	S			S	S							S		S		
Hsinchu 56	Rs				R							S	S			S	S							S		S		
Hsinchu 61	R				R							S	S			S	R							R		R		
Taichung 65	R	R	R	R	Sm	S	R	R	R	R	R	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	
Taichung 171	R	R	R	R	R	R	R	R	R	R	R	S	S	S	S	S	R	R	S	R	R	S	S	R	R	S	S	
Taichung 187	R				S							S	S			S	Rm							S		Rs		
Taichung-yu 184	R				R							R	R			R	R							R		R		
Taichung 185	R				R							R	R			R	R							R		R		Taiwan (Ponlai rice)
Taichung-line 33	R	R	R	R	R	R	R	R	R	R	R	S	S	S	S	S	R	R	R	R	S	S	S	R	R	R	S	
Chianung 242	R	R	R	R	R	S	R	S	R	R	R	S	S	S	S	S	R	R	S	R	R	S	S	S	R	S	S	
Chianung-yu 280	R	R	R	R	R	R	R	R	R	R	R	S	S	S	S	S	R	R	R	R	R	S	S	R	R	S	S	
Kwang-fu 1	R	R	R	R	R	S	R	S	R	R	R	S	S	S	S	S	R	R	S	R	R	S	S	R	R	S	S	
Tainad 1	R				R							S	S			S	S							S		S		
Tainan 3	R				R							S	S			S	S							R		R		
Shianan 8	Rs				R							S	S			S	S							S		S		
Kaohsiung 10	Rs				R							S	S			S	S							S		S		
Kaohsiung 24	Rs				S							S	S			S	S							S		S		
Kaohsiung 27	R				R							S	S			S	S							S		S		
Kaohsiung 64	Rs				R							S	S			S	S							S		S		
Kaohsiung 122	R				S							Sr	S			S	Mr							S		Rm		
Pai-kan-tao	R	R	R	R	Mr	S	R	R	Rs	R	S	S	S	Sm	Sr	S	R	S	R	R	R	R	R	R	S	R	R	
Taichung native 1	R				Rs							R	R			S	R							Rm		R		
Kung-shan-wu-shen-ken	R	S	R	S	S	S	S	R	R	R	R	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	
Kao-chio-liu-chao	R	R	R	R	Sm	S	Sm	S	Sr	S	S	S	S	S	R	R	R	R	R	S	S	S	S	R	R	R	R	
Kaohsiung-ta-li-chen-yu	R	R	R	R	M	S	Sm	S	S	S	S	S	S	Sr	R	R	R	R	R	S	S	S	S	R	R	R	R	Taiwan (Native rice)
Taichung-ti-chio-wu-chien	R	R	R	Sm	R	Sm	Sm	S	S	S	S	S	S	M	R	R	R	S	R	S	S	S	S	R	R	R	R	
Ai-chueh-chien	R				S							Rs	S			S	Rs							R		R		
Cutsugucul	R	R	R	Sm	S	S	S	R	R	R	S	Sm	S	Sr	R	S	R	R	R	R	S	S	S	R	R	R	S	Taiwan (Native rice in mountain region)
Natala	R	R	S	S	S	S	S	Sm	S	S	R	Sm	Sm	S	S	S	R	Sm	Sm	R	S	S	S	S	S	S	S	
Pi no. 1	R		Rs		R						R		Rs	R		Sr	R					R				R		
Norin 20	R		R		R						R					R	Rs					S				S		
Norin 21	R	R	R	S	M	S	S	S	R	R	R	S	R	S	R	S	R	R	R	R	R	R	S	R	R	R	R	
Norin 22	R		R		R						R		R	S		R	R					S				R		
Norin 51	R	R	R	S	M	S	S	R	R	R	R	S	R	Sr	R	S	R	R	S	R	R	R	S	R	R	R	R	
Sensho	R	R	R	S	M	S	S	S	R	S	S	S	R	Sm	M	S	R	R	R	R	R	R	R	R	R	R	R	Japan
Chokoto	R		R		R						R		R	R		R	R					R				R		
Yakeiko	R		R		R						R		R	R		R	R					R				R		
Ishikari shiroke	R		R		R						R		R	R		R	R					R				R		
Ginga	R		R		Rs						Rs		R	Rs		R	R					Sr				R		
Aichi-asahi	R		Sr		R						R		S	S		R	R					S				R		
Homare-nishiki	R		R		Rs						R		R	Rs		R	R					S				R		
Zenith	R		R		R						R		R	R		R	R					R				R		
Rexaro	R		R		R						R		R	R		R	R					R				R		
Lacrosse	R		R		R						R		Rs	R		S	R					Sr				R		U. S. A.
Caloro	R		Sr		Sr						S		S	S		S	S					S				S		
Dular	R		R		R						R		R	R		R	R					R				R		India
Tadukan	R		R		R						R		R	R		R	R					R				R		Philippines
Wag-Nag	R		R		R						R		R	R		R	R					R				R		

genes by hybridization. Varieties carrying many blast resistance genes, such as Taichung lines 33, Kanto 51, Norin 21, Chianung-yu 280 and Pai-kan-tao, may be used as the cross parents.

Even though gathering of all resistant genes in a variety is not possible, it is not difficult to combine in a variety, genes controlling the resistances to two or three races predominating in a region.

Table 9. Varieties grouped according to the resistance to different races of the blast fungus

Number of races to which resistance is found	Variety name
1	Taipei 306*, Taipei 308*, Kaohsiung 24*
2	Taipei 177*, Hsinchu 56*, Tainan 1*, Chianan 8*, Kaohsiung 10*, Kaohsiung 27*, Kaohsiung 64*, Caloro**, Kaohsiung 122*, Tainan 1*
3	Taichung 178*
4	Tainan 3*
5	Hsinxhu 61*, Ai-chio-chien*, Natala
6	Norin 20*, Aichi-asahi*
7	Taichung native 1*, Kung-shan-wu-shen-ken
8	Taichung 184*, Taichung 185*, Norin 22*, Lacrose**
9	Pi no. 1**, Ginga,** Homare-nishiki**
10	Taichung 65, Chokoto**, Yakeiko**, Ishikari-shiroke**, Zenith**, Rexaro**, Tadukan**, Wag-wag**, Dular**, Raminad Str. 3**, CI 5309**
11	Taichung-ti-chio-wu-chien
12	Kao-chio-liu-chao, Kaohsiung-ta-li-chen-yu
13	Chianung 242, Cutsugucul
14	Kwang-fu 1
15	Sensho
16	Taichung 171, Pai-kan-tao
17	Taichung line 33, Chianuug-yu 280, Norin 51, kanto 51

Note: 1. * … Tested with eight races i. e. nos. 1, 5, 12, 13, 16, 17, 24 and 26.
2. **… Tested with ten races i. e. nos. 3, 5, 11, 13, 14, 16, 17, 22 and 26.
3. …… Unmarked ones were tested with all 27 races.

Future Plan of Breeding for Resistant Varieties

1. Breeding of Varieties Having More Than Two Major Resistant Genes

As given in table 9, Taipei 306, Taipei 308, and Kaohsiung 24 are resistant only to race 1. They are presumed to carry one resistant gene, *Pi*. 1. If other races than no. 1 predominat, these varieties may lose their resistance. Varieties with two or more resistant genes, may not lose resistance so easily. Such varieties must be established. In practice, however, the more the resistance genes to be combined, the more difficult would be the work, and some resistant genes may be linked with other genes controlling undesirable characters. Cross parents may be selected from varieties listed in tables 7 and 8.

2. Breeding of Isogenic Lines Each Carrying a Major Resistance Gene

Breeding of varieties carrying a major gene is relatively easy. Varieties adaptive to different regions may be used as the recurrent parents of back-crosses for obtaining isogenic lines with certain resistant genes. Tsai and Oka (1965) developed isogenic lines of Taichung 65 carrying genes for early maturity, Positive phenol reaction, glutinous endosperm etc. by back-crossing. Since the degree of blast resistance of a strain widely varies due to locations and years, environmental modifications must be carefully observed for performing this work. If many isogenic lines become available, a few selections of them may be grown according to the fungus races predominating in a given region. Recording and forcasting of prevalent races should be made every year in each locality. Pathogenic mutations of the races if frequency, may make this effort fruitless, however.

3. Mixture of Various Isogenic Lines to Make up a Variety

Various isogenic lines of the same variety may be mixed to form a "multi-line". The variety, kind and number of isogenic lines to be mixed must be determined according to the prevalent races in a given region. Such a "multi-line" variety may be usefull especially when various races spontaneously occurred in a region. Though the breeding of many isogenic lines needs a long time and much labour, this may be attempted in the future.

4. Application of Field Resistance

Varieties truly resistant to a race or races are not always completely resistant in the field where the given race or races prevail. The mechanism of "field resistance" seems to remain unknown. Minor genes may possibly be concerned. It is important to select field resistance together with true resistance. It seems that a breeding program should be conducted under both controlled and natural conditions.

Conclusion

1. Systematic breeding work for blast resistance in Taiwan has started in 1950. Crosses of various conbinations of parental stocks, back crosses, selection and regional test of varietal resistance have been made. To obtain resistant varieties, hybridization between *japonica* and *indica* types has been emphasized.
2. The resistances to leaf and neck blast widely varied due to variety, year, crop season and location. In 81% of strains so far tested, leaf and neck resistances were correlated, and appeared to be controlled by the same genes. In the remaining 19%, the leaf and neck resistance, were not correlated. Whether or not this is due to the occurrence of different races remains unknown.
3. 27 reces of *P. oryzae* were identified from among 743 isolates so far tested in Taiwan during the period 1960–1966. The distribution and frequency of the 27 races were studied. Races 1, 17 and 24 were dominating ones. The numbers of races found in different localities were as follows: Taipei (Ilan) 21, Taichung (Tunshu) 24, Chiayi 25, Kaohsiung (Pintung) 23, Taitung 25 and Hualien 11.
4. From genetic studies of the resistance using identified fungus races, it was proved that the resistance to a race was controlled by a dominant gene. The genotypes for resistance genes of some parental strains were assumed from the result of genic analysis. It seemed that when a particular fungus race was used for inoculation in an experimental condition, the "gene-to-gene" hypothesis by Flor (1955) generally applies.
5. 50 rice strains from Taiwan, Japan, U. S. A., India and Philippines were tested the 27 races of blast fungus. Races 12, 13 and 16 are the most pathogenic ones among them. Newly introduced varieties, either *japonica* or *indica* type, tended to be resistant to a majority of the races tested. Taichung line 33, Chianung-yu 280, Norin 21 and Kanto 51 were the most resistant ones, showing resistances to 18 of the 27 races tested. These varieties were considered to be desirable materials for the blast-resistance breeding program in Taiwan.
6. Breeding of varieties having more than two major resistant genes and isogenic lines each carrying a major resistant gene was planned. An Application of both true resistance to races and field resistance in the breeding program was emphasized.

Discussion

S. Okabe, Japan: Could you recommend any Taiwanese varieties which seems to have so-called "field resistance"? and could you distinguish the varietal difference regarding "field resistance" among the Taiwanese varieties?

Answer: I would like to recommend you first Chianung 242. This medium-maturity variety is highly resistant to both leaf and neck blasts and also highly responsive to heavy nitrogen fertlizer. Next, I like to recommend you Tainan 5. This variety has been released only three years ago; however, owing to its degree of blast resistance which is comparable to that of Chianung 242, together with its high response to nitrogen fertilizer, the acreage of cultivation has since been very much increased, especially in the Southern part of Taiwan. Taichung 181 is also medium-maturity variety with high tillering, tolerant to heavy manuring and resistant or moderately resistant to blast disease under the field condition. Chianung 280 which is late in maturity and stiff strawed is another variety showing high degree of resistance to both leaf and neck blasts. Taichung native 1 (*indica* type) which is short statured, highly responsive to heavy manuring, tolerant to lodging is also highly resistant to both leaf and neck blast. Other blast resistant varieties include Taichung 184, Taichung 186 and Kaohsiung 137 etc. Chianan 8 and Kaohsiung 24 usually show the moderate degree of field resistance.

To the second question, I would say "yes" practically, all of these varieties I have just named were selected after the repeated trial in the disease nurseries. The degree of blast resistance or so called "field resistance" could be distinguished among different varieties in our disease nurseries.

D. V. W. Abeygunawardena, Ceylon: You stated that varieatal resistance to blast differs considerably with the year of testing, location and season. This is quite true in Ceylon as well. May I ask whether you have observed differential resistance to races according to the nitrogen supply to the plant. This fluctuation we have observed in Ceylon.

Answer: Under the field condition, the occurrence of blast disease is increased according to the increase of the amount of nitrogen supply. This is the trend commonly observed. We didn't particulary study the effect of different levels of nitrogen on the epidemics of a given race of blast fungus, so that we don't have the data of this kind at this moment, however, we have tested different sources and levels of nitrogen to the growth of fungus with the artificial media. Ten isolates of the blast fungus were used for this study. The results showed that the degree of utilization of nitrogen by isolates is differed from different forms of nitrogen compounds. For instance, among the inorgenic compounds, nitrate was utilized pretty well by all isolates tested, urea was also found to give good effect on the growth of fungus isolates. However, ammonium from nitrogen gave the poor growth of fungus isolates. It was found that there were notable differences in the growth of mycelium when different forms of nitrogen compounds was applied to a given isolate. Though we haven't conducted the similar experiment on the rice plant, we don't exactly know what effect will be. However, from the results of experiment I have just mentioned, I suppose, the degree of blast disease prevalence for a given race may be fluctuated according to different forms as well as different amount of nitrogen supply.

T. Yamaguchi, Japan: The degrees of occurrence of neck blast are effected by the climatic conditions at the heading stage. So the varietal resistance to neck blast by natural infection is apt to vary because of the different heading periods of testing varieties. What do you think about this problems.

Answer: The degree of neck blast infection is apt to vary because of the different heading time under the field condition. "Disease escaping" may usually be found among early heading plants. Therefore, strictly speaking, it may be difficult to determine the degree of infection and the mode of inheritance of neck blast resistance, unless the materials are cultured under a controlled condition and a certain race of fungus strain is artificially incoulated onto the individual panicle necks. However, practically it is not necessary to be ofraid of effect of disease escaping so much because according to Dr. Hashioka (1950), the correlation between heading date and neck infection percentage was not significant.

N. Murata, Japan: Isn't it relevant at this moment to ask Dr. Shiro Okabe to give us an outline of their computer studies on the usefulness of " multiple-gene " varieties and his opinion on the subject?

Answer: Yes, Dr. Okabe, would you please express your view on the usefulness of developing " multiple-gene " variaties.

T. Hirano, Japan: Please show the good parent of " field resistant varieties " in Taiwan.

Answer: This problem is the same as Dr. Okabe's. It has already been answered.

N. Oka, Japan: Could you briefly tell us how a " test field for blast resistance " is designed? Also, the method to classify races briefly?

Answer: To the first problem, an F_2 population ranging from 800 to 2,000 plants per cross is generally grown by most of Experiment station. At some stations, selection for blast resistance begin in F_2 generations: at other stations, testing for blast reaction follows the completion of preliminary yield trial. The selections from district trials are then entered into province wide uniform blast nurseries at five locations. At each location, each strain is planted in a two-row plot, a row consisting of 7 hills, each of three plants spaced at 22.7×22.7cm. An Italian variety Lomello is planted between the plots to induce a heavy epidemic of the disease. Randomized block design is used with three replications. High level of nitrogen fertilizer was applied and the field is often kept drain so that to induce the disease more easily. The extent of infection in leaves and neck is recorded.

To the second problem, regarding method of classifying races; first collection of disease specimen was made from the uniform blast nurseries. Pure cultures thus obtained were further subjected to single spore transfering to yeast-starch agar slants. Stock cultures were maintained on rice straw medium in small test tubes and stored at 4°c. 16 differential varieties of rice including 11 strains of *japonica* type, 5 strains of *indica* type plants were grown in iron flats (30 cm × 30 cm × 7.5 cm) which were placed in the greenhouse. Ammonium sulfate at the rate of 30 ml per flat was applied. Rice seedlings at the 3–4 laeves stage were inoculated by spraying with spore suspension. Five days after inoculation, the inoculated plants were observed according to types of legion classified as R (resistant) M (moderately resistant) and S (susceptible) groups.

D. V. W. Abeygunawardena, Ceylon: I would like to know the views of the participants in relation to growing of isogenic lives. Although this appears to offer prospects of combatting the disease now; will this not lead to the explosive appearance of new races.

Answer: I like to express my view on this point. We have found different blast resistant genes such as Pi-a, Pi-k, Pi-i, Pi-ta and Pi-z by Dr. Kiyosawa and Pi4, Pi13, Pi22, Pi25 by us. We know that more resistant genes involved in a given variety, the more resistant to the disease will be. Our question is, how these genes shall be put together without losing other good characters through crossing. Our experience told us that to attain such goal is not easy. The pure-line carrying a few genes of disease resistance developed by the ordinary method would not satisfy us. One of the alternatives is to develop isogenic lines which carry monogenic resistance to each race of blast fungus. The multigenic resistance then may be obtained by mixing different isogenic lines of the same variety. Since a resistant plant in a blend of isogenic lines would yield the same as in a pure stand, the increase in yield of a multipleline-mixture must be due to the reduction of epidemic of the diseas and also due to the increase in yield capacity of susceptible plant. The reason is that the fungus spore will be produced less in these multiple genic lines.

The multigenic lines were found to be more resistant to yellows disease of cabbage (Anderson 1933); and for resistance to oat stem rust, the so-called "Synthetic tolerant variety" of multiple line variety is being developed recently in the United States. Therefore, I think we could develop this kind of variety with rice also.

As we have reported that resistance to a given race of blast fungus in most cases controlled by a single dominant gene. If the monogenic resistance to blast is stable in all locations tested, the appearance of a new pathogenic race may make it desirable to build up multigenic resistance. Therefore, I think this kind of work is worthwhile to be carried out, even much labor and time are needed to breed one isogenic line.

K. Goto, Japan: In the table 6, appearance of new races 20–27, seems to be prevalent during 1964 1966, as compared with races 4–15 during 1960–1963. Was there any big change in distribution of varieties, or in application level of nitrogen fertilizer between these periods in Taiwan?

Answer: As I stated before, the disease specimen used to identify different races were collected from blast nurseries located at five locations. The pattern of race appearance was largely affected by the change of varieties at the blast nurseries in different years. Before 1963, those susceptible lines found in the test field were either discarded or subjected for repeated tests in the same field. However since 1964, all susceptible lines were discarded and were replaced by the new lines or varieties. In addition to the big change of breeding materials, more than 100 lines of FAO varieties were planted in the same field for blast resistance test. In addition to this, nitrogen level applied during 1960–1963 was 120–160Kg of N/ha, but from 1964 to 1966, it was increased up to 280Kg/ha. These might be the main reasons of race fluctuation in different years.

Reference for Paper 6

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