and surest way for increased yield in peasant agriculture is to maintain soil fertility by introducing leguminous green manure crops. But for increased production beyond the present stage, application of chemical fertilizers along with organic matters should be emphasized.

This report on field crops in Thailand discusses problems which apply not only to Thailand but to all of the newly developing nations in the Tropics, and is very useful for those concerned with tropical agriculture.

Requests for this book may be made to the Center for Southeast Asian Studies of Kyoto University. No. One in the Reports on Research in Southeast Asia, Natural Science Series; The Center for Southeast Asian Studies, Kyoto, 1966; 148 p. 24 plates, 4 in color.

Rice Breeding for Blast Resistance in Japan — A Role of Foreign Varieties —

K. NAGAI

Chief, 6th Laboratory of Genetics, Division of Genetics, Department of Physiology and Genetics, National Institute of Agricultural Sciences

Brief history on the breeding up to the birth of "Futaba"

It is well known that the increase in rice yield per unit area has been accomplished by the combined effects of heavy application of chemical fertilizers and breeding of fitting responsers. Since the fertilizer responsiveness of rice variety consists of 3 elements, straw stiffness or tolerance to lodging, resistance to blast disease, and responsiveness in a narrow sense, the reinforcement of these 3 characteristics has been major basic objective through the history of rice breeding for a half century. Especially, stress was put on the breeding of blast resistance in the earlier date because of lacking of effective fungicides.

To find resistant gene sources and to select hybrid lines, two kinds of screening practices became a routine for every breeder, one is the nursery trial for leaf attack, in which rice seedlings are grown on upland condition by late sowing under heavy dosage of nitrogenous fertilizer to induce outbreak of blast, and the other is the field trial for neck attack which comprises of late planting and heavily fertilized condition. In due course of time, some varieties from Formosa or Philippines were found to possess blast resistance much higher than any of domestic varieties around 1917, then attempt was made to introduce resistant gene into local varieties by hybridization. However these earlier works ended fruitless due to the mutual remote phylogenetical distance. Namely the sterility and heterozygosity appearing in the earlier generations and many kinds of undesirable characteristics brought from tropical varieties made difficult the then breeding procedure by straight crossing, far beyond the ability of breeders.

First successful result was obtained by the late S. Iwatsuki of Aichi Prefectural Agricultural Experiment Station, who challenged this difficulty and devoted himself to the breeding of blast resistance. He marked the high resistance shown by Senshō, Formosan upland rice variety which was said to be introduced by a soldier after Sino-Japanese War in 1893-4, and the first memorial crossing was made with Kinai-Ban 33 in 1922, which was also hybrids by his hand. To overcome sterility, discard characteristics of upland rice type, and enhance yielding capacity, he adopted unique multiple crossing, and after the efforts for near 20 years, he got new resistant varieties with practical value, Shinju and Futaba in 1936 and '41 respectively. The lineage is shown in Table 1-(1).

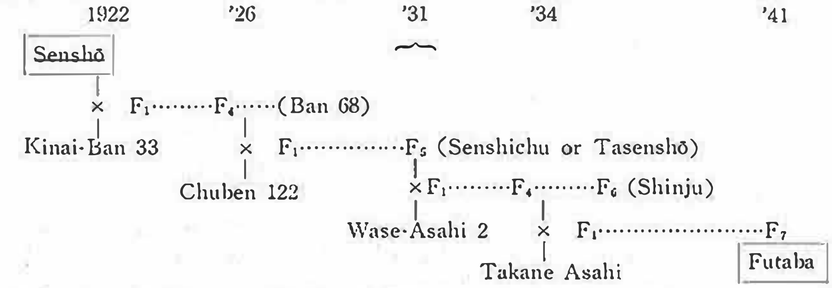
Though these varieties were not cultivated widely, more than 10 varieties, which recommended in the middle and western Japan, were derived from these two by himself.

Kinmaze which had once biggest acreage in Japan, was also connected with Tasenshō, appeared on the middle way of Senshō-Futaba course.

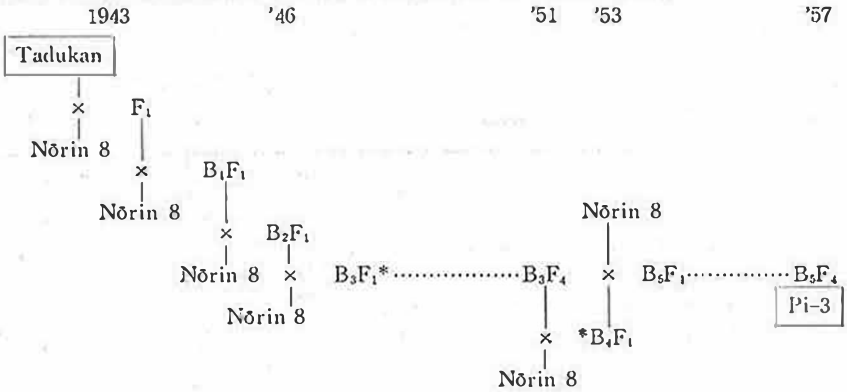
It is true that time and tide have faded these merits of S. Iwatsuki et al. and their works are thought as somewhat classic now, but the originality on their breeding could be evaluated properly by just remembering following two facts. 1). It was 1928–30 when S. Katō advocated the clear conception to classify cultivated rice into sub-species of Indica & Japonica, from the phylogenetical point of view. On the contrary, S. Iwatsuki started his breeding scheme much earlier than Katō's principle. 2). Theoretical base of orthodox back-crossing scheme might not be introduced fully in the 1920's.

Table 1. Lineage of three varieties derived from foreign materials.

(1) From Senshō to Futaba (by the late S.Iwatsuki)

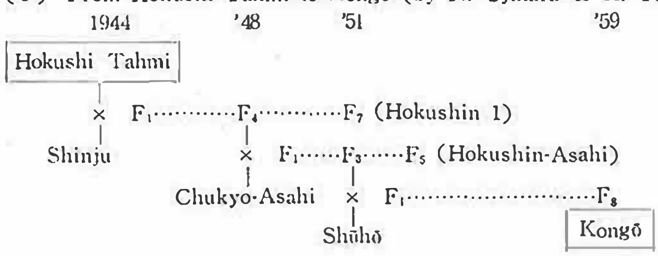


(2) From Tadukan to Pi-3 (by C.Shigemura & H. Kitamura)



* Reserved seeds for a year were used for B_3F_2 and B_4F_1 plants.

(3) From Hokushi Tahmi to Kongō (by N. Ujihara & K. Tanabe)



Varieties derived from foreign materials

Following the completion of Futaba, two Chinese varieties, To-to & Reishiko from Chekiang Province, China, and Tadukan, an upland rice variety from Mindanao, the Philippines were taken up as resistant parents, simultaneously in 1943, at the different Stations. In the case of To-to and Reishiko, any special procedure other than the ordinary pedigree method by straight crossing was not required to breed basic varieties for breeder, Kantō 51-55, because these two varieties belong to Japonica group, so didn't cause sterility troubles, though their characteristics of practical value were very inferior to the varieties in vogue, especially on straw stiffness, shattering habit and grain quality. In the other case, first achievement of breeding by the back-crossing method was set up when the basic varieties Pi 1–4 were derived from Tadukan, tropical Indica variety. These new varieties were considered as almost immune to rice blast, both of leaf and neck attack, so serial numder of Pi (Piricularia immune) was given. As the lineage of Pi 3 seen in Table 1–(2), the feature of this breeding procedure comprised of three back-crosses in succession, proceeding of generations by selfing, during which the selection on practical characteristics together with blast resistance was carried on, and the final reciprocal back-crossing. During the process convenient practice on nursery trial was settled and statistical and genetical studies were promoted. Principle of cytoplasmic effects for decreasing sterility percentage was advocated by H. Kitamura, one of the breeders, who recommended recurrent Japonica variety should be used as female parent at least once during the course of back-crossing. Thus in the case of Pi 3, Nōrin 8 was used as a female at the final crossing.

In Table 1–(3), lineage of Kongō or B. R. 1 (Blast Resistant) is shown as another example. This work was done by the successors of S. Iwatsuki at the same station, and the procedure was similar as the Senshō-Futaba course. Though Hokushi-tahmi, a doner parent, belongs to the Chinese Indica group, alike Senshō, the process was more simplified than the first example by S. Iwatsuki.

Pi 3–5 and Kongō are being used as the blast resistant parents most frequently at present, replacing Kantō 51–55, which were once most convenient gene sources. Many

Table 2. List of new varieties derived from the hybrids with foreign varieties.

Original foreign materials	→	Basic varieties for breeders	→	New recommended varieties obtained
1. Senshō (I)	Multiple cross	Futaba (1941)	Straight cross	Ayanishiki ('48), Fujisaka 5 ('49), Wakaba, Kotobuki-mochi ('50), Akibae ('53), Akikogane ('59), Setohonami ('60).
2. To-To (J) (Tu tao)	Multiple cross	[F_3 249]	Straight cross	Mangetsu-mochi, Kagura-mochi ('63), Tsukimi-mochi ('64).
	Straight cross	Kantō 51–52 ('50)	Straight cross	Ugonishiki ('63)
3. Reishiko (J) (Lichihon)	Straight cross	Kantō 53–55 ('50)	Straight cross	Kusabue, Senshūraku ('60), Teine, Yūkara, Ooyodo ('62),
		Imochi-Shirazu('51)	Straight cross	Tatsumi-mochi ('65).
4. Tadukan (I)	Back cross	Pi 1–2	Straight cross	Shimokita ('62), Tosasenbon ('66).
		Pi 3–4 ('57)		(Under trials)
	Multiple cross	Pi 5 ('61)		(Under trials)
5. Hokushi-Tahmi(I) (North China Tahmi)	Straight cross	Hokushin 1 ('51)	Straight cross	Sanpuku ('64), Tsuyuake ('65),
	Back cross	Hokushin-Asahi ('53)	Straight cross	Kongō ('62).
6. Taiwan Okaine (I)	Back cross	[B_3 F_4]	Straight cross	Yashiro-mochi ('61).
7. Zenith (J)	Back cross	[54BC-68]	Straight cross	Fukunishiki ('64).

Note : (I)……Indica, (J)……Japonica, ( )……Original chinese name.
————Straight cross,
════Back cross,
┄┄┄┄Multiple cross.

new recommended varieties will be derived from these basic varieties in the near future, but the present number of practical varieties connected with foreign materials are still quite limited as seen in Table 2. M●st of the varieties shown in the right column of the Table are registered and released by the Ministry, equivalent to the Nōrin varieties.

It should be mentioned here that the Ministry stopped following serial Nōrin numbers and started calling new varieties by the proper names after Nōrin 51 (1938). Total number of the paddy varieties registered by the Ministry attained to 180 for non-glutinous, and 45 for glutinous up to 1966, or total number of the varieties recommended by 46 Prefectural Governments, which included some selections or hybrids outside of Nōrin Nos., were also about 180 for non-glutinous and 43 for glutinous in 1964. Among these, total number of varieties having close relationship with foreign materials might not exceed 50.

As seen in Table 2, a bridge was required between foreign donor parent and new variety of practical value. For the construction of this bridge, basic variety, it took 15–20 years, and, in addition another 10 years were required to breed new variety. It may not be necessary to mention the phylogenetical distance existing between Indica and Japonica sub-species, but even within Japonica group, characteristics of Japanese leading varieties are so different from those of Chinese or American varieties that the increase in basic varieties is indispensable for the promotion of varietal improvement. Among 7 foreign materials listed in Table 2, from which at least one actually recommended variety was obtained so far, hybrids with Tadukan, Hokushi-tahmi and Zenith are still playing important roles. The utility of Zenith is mentioned later. Although these new varieties in Table 2 cannot be said as major varieties which cover vast extent of field, they are re●uisite in the tracts where blast disease is prevalent annually. However some varieties, like Ayanishiki and Fujisaka 5, were once grown extensively and also used as parents of many varieties.

Differentiation of the races of blast fungus

It was known in the earlier date that varietal reaction to the blast disease was not always constant but fluctuates depending on year or place. However, a shocking change was

Table 3. Races of rice blast fungi (***Piricularia oryzae***) registered up to 1965 and their responses to differential varieties.

Differential varieties \ Races		Group T			Group C									Group N					
		T-1	T-2	T-3	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	N-1	N-2	N-3	N-4	N-5	N-6
Group 1	Te-tep	M	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Tadukan	M	M	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Usen (Wutsen)	S	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Group 2	Chōkōtō(Can sian tao)	S	R	R	S	M	R	S	R	S	R	S	R	R	R	R	R	R	R
	Yakeik●(Ye chi ken)	S	R	R	S	M	S	R	S	R	S	S	S	R	R	R	R	R	R
	Kantō No. 51	S	R	R	S	S	S	S	S	S	S	S	S	R	R	R	R	R	R
Group 3	Ishikari-Shiroke	S	R	S	S	S	R	S	S	S	R	R	S	S	R	R	R	S	S
	Homarenishiki	S	S	S	S	S	R	S	S	R	S	S	R	S	S	R	R	R	R
	Ginga	S	S	S	S	S	S	S	S	R	S	S	S	S	S	R	S	S	R
	Aichi-Asahi	S	S	S	S	S	R	S	S	S	S	S	R	S	S	S	R	R	S
	Nōrin No. 22 or 20	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Note : Result of innoculation by spraying method.
R···resistant, S···susceptible, M···intermediate type.
( )···Original chinese name.

observed at Inahashi, mountainous zone in Aichi Prefecture in 1952 when Futaba, Kantō 51–53 and some of Chinese varieties, which were hitherto thought as highly resistant, suffered from blast very severely. Kantō 51–55 were similarly damaged at Shimoina, Nagano Prefecture in 1953. These happenings suggested the existence of physiologic races of fungus and the inversion of varietal resistance was thought to be caused by the rapid propagation of special race which is virulent to those varieties. Studies on blast race were started in 1952 by the micologists at several stations, but coordinated into the joint work by the National Institute in 1955. By 1961, the identification and classification of races by selected differential varieties and unified innoculation practices, were completed, after then studies on the distribution of races and its changes by year or season are in progress. 18 kinds of races registered up to 1965 and 12 differential varieties are shown in Table 3, with their typical reaction.

Both of races and differential varieties are divided into 3 groups. Speaking to the varieties, group 1 consists of three Indica, two from the tropics and one from Formosa, Group 2 consists of 2 Chinese Japonica and 1 derivative, but the last 3 consists of Japanese varieties only. On the races, classification can be done as follows:

- Group N……virulent to more than one variety in Group 3 but not in Group 1 & 2.
- Group C……virulent to more than one variety in Group 2 but not in Group 1.
- Group T……virulent to more than one variety in Group 1.

Thus it became necessary to investigate the reaction of current leading varieties to all known fungus races, and the breeding work stepped into the second stage.

From the results of investigations on the distribution of races in 1960–62, Group N races were found to be most common throughout Japan showing 65 % of total samplings, followed by Group C races of 30%, and Group T races are quite rare as yet, fortunately. Within group, N–2 is most prevalent with 30% of frequency, N–1, C–1 and C–2 are following to N–2. However, survey in 1963–64 displayed some changes on the prevalence of races, namely, N–2 was spreading more, and C–1, C–3, C–8 have expanded clearly, replacing C–2. In eastern Japan, the frequence of Group C races has been raised up rapidly as 50% or more in some Prefectures, accordingly C races are now dominating locally, replacing Group N races. Though the information on natural distribution of races and its changes is not enough, the expansion of C races are considered to be caused by the extension of varieties derived from Chinese materials. Actually in north Kantō region, Kusabue suffered from blast very severely in 1963 at its 3 rd year of recommendation, and in Hokkaidō, Yūkara and Teine were similarly attacked in the same year. These resistant varieties were derived from Chinese Reishikō as seen in Table 2 and the grade of damage was more serious than other varieties. These facts were quite suggestive of the local predominance of C races.

Studies on blast races were started in several countries using respective differential varieties, so the necessity of international identification was felt keenly. In 1965 Japan–US joint committee for the differentiation of races, made a proposal to adopt an international set of differential varieties which consists of 8 varieties. By this set, all cultures of fungus can be divided into 32 races of 8 groups. The mark of IA, IB,……meaning "international" was proposed to represent each group. Japanese races can be contrasted with the international ones as follows:

Japanese race	International race
T–1	IC–1
T–2	ID–10
T–3	ID–8
C–1	IF–1
C–2,–4,–5,–6	IE–1
C–3,–7,–8	IF–2
N–1,–5	IG–1
N–2,–3,–4	IH–1

Analysis of resistant genes

Following to the race studies, works on gene analysis of blast resistance was started at Divisin of Genetics of National Institute of Agricultural Sciences in 1959. Comparatively stabilized 7 kinds of fungus cultures belonging to races, T-1,-2, C-3, N-1,-2,-3, -4, were selected for this purpose and the inoculation by injection method was adopted by which more acute reaction was observed than the spraying method, commonly used in race studies. Results obtained up to 1966 made clear the existence of 6 kinds of major dominant genes governing blast resistance, in Japanese varieties. As some varieties have 2 genes together, the varieties can be divided into 11 groups as seen in Table 4.

Among number of domestic varieties, only 2 kinds of resistant gene, PiA & PiI could be checked, so the other 4 kinds were nothing but the introduction from abroad, namely PiK from Chinese varieties, PiZ from Zenith of U. S. and PiTa & PiTa-2 from Tadukan of the Philippines. On Tadukan or Tetep herselves, gene analysis is not yet finished, but

Table 4. Present status of gene analysis and classification of current varieties.

Type variety with its major gene (second line)	Reaction to the races* used for gene analysis							Varieties which belong to the same genotype
	T 1	T 2	C 3	N 1	N 2	N 3	N 4	
1. Shin 2 (nil)	S	S	S	S	S	M~S	S	Nōrin 8, 22~25, 29, Tōsan 38, *Ginga*, Hoonenwase, Koshihikari.
2. *Aichi-Asahi* Pi A	S	S	R	S	S	M~S	R	Zuiho, Nōrin 18, Kinmaze, *Homarenishiki*, Mihonishiki, Sasashigure, Yamabiko, Nagiho, Fujiminori, Hōyoku.
3. *Ishikari-Shiroke* Pi I	S	M	M	S	M	M	M	Fujisaka 5, Fukuyuki, Yoneshiro.
4. Shinsetsu Pi A, Pi I	S	M	R	S	M	M	R	Miyoshi
5. *Kantō 51* Pi K	S	M	S	R^h	R^h	R^h	R^h	Kantō 52~54, Kusabue, Mangetsu-mochi, Ugonishiki, Senshuraku, St-2, *Yakeiho*.
6. Toto Pi A, Pi K	S	M	R	R^h	R^h	R^h	R^h	Kongō, Teine, Yukara, Kagura-mochi Sanpuku, *Chokoto*
7. (Ta) Pi Ta	S	S	M	M	M	M	S	Yashiro-mochi, Paikantao (Formosa)
8. Pi-4 Pi Ta-2	M	S	MR	MR	MR	MR	M	Pi 3~5
9. Pi-1 Pi A, Pi Ta	S	S	R	M	M	M	R	Shimokita
10. Fukunishiki Pi Z	M	M	M	M	M	M	M	54BC-68, Ōu 243~4.
11. Zenith Pi A, Pi Z	M	M	R	M	M	M	R	Fukei 67, 73

* Exact name of each fungus culture should be mentioned here, but replacad by general race numbers for simplification.

1) Reactions of varieties to each race were obtained from the innoculation by injection method, therefore somewhat different from Table 3.
2) Names of variety written by italic represent differential varieties.
3) Grading of resistance :
   - R^h : No symptoms.
   - R : Brown specks (b-type) are predominant.
   - MR : b-type lesions are predominant, but the number is less than twice of other types of lesions.
   - M : Small lesions with brown margin (bg-type) are predominant or b-type are predominant but the number is less than the total of other types of lesions.
   - MS : (not appearing in the Table)
   - S : pG-type lesions are predominant.

presumed to be fairly complicated. Similarly, the behaviour of PiTa-2 gene is still being studied. Anyhow a role of foreign varieties on the breeding of blast resistance was well understood by these analysis. Varieties which will belong to Groups 7-9 are expected to increase in the near future as mentioned before, especially in the tracts where Group C races are dominating, because varieties in Groups 5-6 are susceptible to the most of C races. Resistant gene PiZ is very interesting, showing enough resistance in practical growing againt almost all known races, therefore, Fukunishiki and Fukei 67 or 73 will be used also as parents for the further crossings. A few words would be necessary on the varieties in Group 1. They seem to be lacking major genes but are not absolutely same. Quantitative differences on the reaction to each fungus race can be observed and even then, different reactions are seen sometimes to the foreign races. In addition, they are different clearly on the so-called field resistance*, for instance, Nōrin 22 is much better than Nōrin 20. These facts suggest that every variety within the same group, is different each other on the constitution of minor genes.

It seems very curious that any major gene could not be checked on many varieties bred by S. Iwatsuki, so it is difficult to evaluate this forerunner's merits by the base of gene. It is unlikely to attribute the then blast resistance of his varieties to the field resistance only, but possibility of confirmation of major gene is not expected, since his original material Senshō was lost nowadays. (In upland rice, there is a variety named Senshō, but this is a pure Japonica, different from Iwatsuki's material.)

Breeding of blast resistance in the 2nd stage

As for the breeding works in the second step, which would be no doubt more complicated, 2 countermeasures came into consideration.

1) To accumulate all known major genes into one variety, with supplements of minor genes.
2) To find mighty major genes of similar behaviour as PiZ, but having clearer resistance, desirably and introduce them into practical varieties.

In most of breeding stations efforts are made in the former direction, but a laboratory of the National Institute started works in the latter one in 1960. Here the breeding procedure of back-crossings is almost similar as that of Chūgoku Agricultural Experiment Station, where Indo-Japonica hybridization scheme was started in 1942 and Pi 1-5 were obtained. However, the artificial innoculation by selected races has become routine for the screening the exotic materials and individual or line selection on hybrid generations. Later on, important hybrid materials were shifted from Chūgoku Station for this purpose. Highly resistant varieties were found among Indica groups from India, Indonesia, Malaysia and the Philippines etc. Most probably, some basic varieties which express R^h reaction to all known races in Japan will be released in next fiscal year, from the crosses with Indian varieties, TKM-1 x Nōrin 8 & CO 25 x Nōrin 8, after 4 times of backcrossing in succession.

Usually the blast of neck attack is much more disastorous than leaf attack, however informations on the resistance to neck blast are still too scarce to the differentiation of fungus races or analysis of resistant genes. Blast resistance to leaf and neck attack is expected to be parallel in general but some exceptions were also reported. Since the artificial innoculation on panicles are not developed fully, special places, like Inahashi or Oomagari where neck blast is prevailing annually, are utilized for disease gardens to select

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For the artificial innoculation, irrespective of its practices, young seedlings of around 4th leaf stage are used, but some varieties display different blast resistance at the later stage of growth. This kind of resistance was known as field resistance, long before the differention of races. Nowadays it is considered as the collective effect of minor genes, and to be independeent from blast races. Utilization of the field resistance is still very important for the breeding of practical varieties.

hybrid materials.

Breeding of blast resistance was once the competition with the amount of fertilizer consumption but nowadays it has to compete with the propagation and mutation of blast fungus too. What would happen on fungus races when the acreage under new resistant varieties, like Shimokita, for instance, has been expanded in a good amount? Blast fungi belonging to Group T, which is existing in a minor percentage, can propagate freely on this variety but present predominant fungi, Race N or C, cannot survive on it, consequently proportion of Race T will be increased rapidly enough to cause out-break of disease severely. In this case the damage caused by Race T might be much more serious than before. This is the reason why the knowledges on blast fungus races and resistant genes of varieties are required, not only for rice breeders but for leaders of extension services.

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