5. PROGRESS IN BREEDING OF RICE VARIETIES FOR RESISTANCE TO BACTERIAL LEAF BLIGHT IN JAPAN

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Introduction

In Japan the first outbreak of bacterial leaf blight of rice was witnessed about 80 years ago. Previously prevailing mainly in the south-western Japan, this rice disease has been diffused throughout the country to be now one of the most important diseases in Japanese rice culture.

Notwithstanding the research progress in the control of the disease, any effective control measure has not yet been established practically except the planting of resistant varieties. Moreover, in view of the recent trend to demand a labor-saving and low production cost in rice cultivation, it will be the most desirable even in future to plant resistant varieties for the control of the disease.

Japanese breeders have succeeded in breeding of various blight resistant varieties which have been extended to various districts damaged annually by this disease. For instance, in Kyushu, where the disease outbreak is most prevalent, about 40 % of the rice planted acreage are covered today by the resistant bred varieties.

This report intends to review the historical outline on the breeding process of main Japanese rice varieties resistant to bacterial leaf blight and to present some practical method for testing resistance to the disease in breeding procedure.

Breeding of Resistant Varieties Originated From Kono 35

During the period 1900–30, the most dominant rice variety in western Japan was Shinriki. The planted acreage of this variety covered at one time more than 600,000 hectares because of its high yield due to its high response to fertilizer. On the other hand, as it was very susceptible to bacterial leaf blight, the damage was so great that the disease was once called "Shinriki-hagare" meaning leaf blight of Shinriki.

In those days, a resistant strain to this disease was selected from the paddy field planted with Shinriki variety at Kagoshima Agricultural College, and was named Kono 35 in 1926. This variety was planted only in a limited area in southern Kyushu because of its inferior characteristics except the resistance to bacterial leaf blight. Nevertheless, it has played an important role of an original variety in breeding practical varieties resistant to this disease in Kyushu.

1. For the purpose of breeding practical varieties characterized to be resistant to bacterial leaf blight, Kono 35 was crossed with Asahi 1 in 1936 at the Kumamoto Breeding Center in Kyushu. Asahi 1 was suscepitble to the disease but superior in yield and grain quality, as the leading variety after Shinriki in western Japan at that time. From the progenies of this cross, Norin 27 was bred in 1946. This variety was planted widely in western Japan, but its planted acreage has decreased because of its high susceptibility to blast and of its rather poor yield.

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2. Asakaze and Hayatomo are the blight resistant varieties, both bred out at Kyushu Agricultural Experiment Station from the cross of which parent was Norin 27. In those days, the leading variety in Kyushu was Norin 18 which was superior with its stable yield under the general cultivating conditions. And in spite of its moderate resistance to various obstacles in a common area, it manifested the defects in lodging under fertile condition and in susceptibility to bacterial leaf blight chronically outbreaking in some districts.

Asakaze (Takara×Norin 27) has the characteristics of high resistance to both lodging and bacterial leaf blight. Therefore, the rice growers in the areas annually suffering from above mentioned hazards began to plant this variety as soon as it had been introduced. For instance, in Beniya District of northern Kyushu, most of its paddy field (150 ha) was covered with Asakaze in the first year (1957) of its release. However, severe outbreak of bacterial leaf blight was witnessed in the fields planted with Asakaze which was to be blight resistant. And the same became a major problem of discussion.

Cooperative studies by breeders and plant pathologists on the cause of this disease outbreak found a new pathogenic bacterium strain (so-called Beniya strain) with a virulence capable to attack all resistant varieties so far established in Japan (Kuhara *et al.*, 1958). This finding paved the way to the restarting study on virulent type of bacterium of this disease.

Another defect of Norin 18 was the delay in maturation in northern Kyushu, thus, an earlier variety had been desired. Besides, the variety should be resistant to bacterial leaf

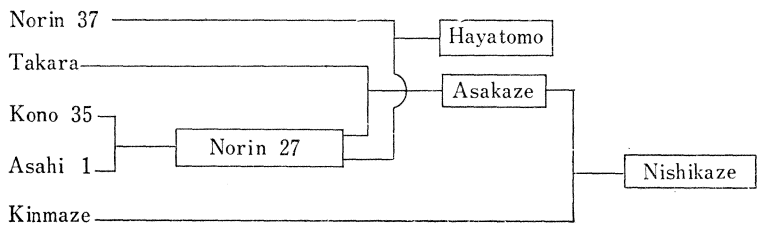

Fig. 1. Breeding process of bacterial leaf blight resistant varieties Norin 27, Asakaze, Hayatomo and Nishikaze.

Note: Underline shows original variety.

Table 1. Main characteristics of varieties originated from Kono 35.

Variety	Heading* date	Maturing	Plant type	Height	Resist. to lodging	Resist. to bacterial leaf blight	Resist. to blast		Grain quality	Yield ability
							leaf	neck		
Norin 27	Sept. 11	late	panicle	medium tall	fairly res.	res.	susc.	susc.	good	medium
Asakaze	Sept. 12	late	medium	medium	res.	res.	susc.	susc.	fairly good	high
Hayatomo	Sept. 10	late medium	panicle	medium	medium	res.	susc.	medium	good	high
Nishikaze	Sept. 6	early medium	tillering	short	res.	res.	medium susc.	medium	good	very high

Note: * Sown on May 25 at Kyushu Agr. Extp. Station.

blight and also be adaptable to "Akiochi-soil", particularly in northern coastal area of Kyushu. Hayatomo (Norin 37 × Norin 27) released in 1964, is now being planted as a suitable variety in these districts. The breeding process and the main characteristics of these resistant varieties are shown in Fig. 1 and Table 1 respectively.

3. The most popular variety in western Japan in recent years is Kinmaze which manifests an earlier maturing compared with Kyushu varieties and also, a high yielding with many tillers of short and stiff straw. But its defects are susceptibility to bacterial leaf blight and poor grain quality.

To improve these defects, Asakaze was used as a female parent for hybridization with Kinmaze at Kyushu Agricultural Experiment Station, and Nishikaze was bred and has been released this year of 1967. Nishikaze not only resembles to Kinmaze in plant type and maturing date, but has high yielding ability under fertile condition and good grain quality. Moreover, it is as resistant as Asakaze to the ordinal strains of bacterium of the disease. Now it is expected that this variety will spread over widely in western Japan because of its superiority. Breeding process and the main characteristics of Nishikaze are shown in Fig. 1 and Table 1 respectively.

Breeding of Resistant Varieties Originated from Shiga-Sekitori 11 and Shobei

A unique work in cereal breeding at the Aichi Prefectural Agricultural Experiment Station is highly evaluated. Many rice varieties have been bred out in this station. In Tokai region, where the Station is located, anual outbreak of bacterial leaf blight has been witnessed in several areas. So, the breeding work of resistant varieties to this disease was launched at this station in 1924 under the cooperative work between breeders and plant pathologists (Chizaki, 1935). Since Shiga-Sekitori 11 and Shobei had been recognized to be resistant to this disease, the breeding has proceeded on the basis of these two varieties (Kuwazuka 1933).

1. In 1924, Shiga-sekitori 11 was crossed to Shoyu, and two varieties, Zensho 17 and Zensho 26 were derived from the progenies of this cross. Both have been highly evaluated to be highly resistant to bacterial leaf blight, as they were obtained for the first time in breeding of resistant varieties by hybridization. Zensho 26, especially is distinguished, because of its good plant type. It was utilized several times as one of the second basic materials to breed practical varieties resistant to bacterial leaf blight and contributed to the birth of very excellent varieties which will be stated later in this paper. The main characteristics of Zensho 17 and Zensho 26 are shown in Table 2.

2. As the results of breeding based on another bacterial leaf blight resistant variety Shobei, Kogyoku was bred in 1932 from Shirosenbon × Shobei and Taiyo in 1933 from Asahi-mochi × Shobei. Among of them, Kogyoku is especially remarkable as a successor of highly resistant gene from Shobei.

Kogyoku, though it was released in 1938 to the lowland area suffering from this disease,

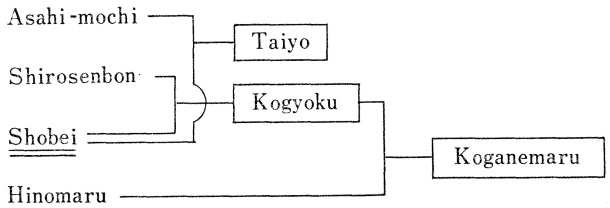

Fig. 2. Breeding process of bacterial leaf blight resistant varieties; Kogyoku, Taiyo and Koganemaru.

had several defects to be improved in the characteristics. So that Koganemaru bred in 1939 from Kogyoku×Hinomaru, was released in 1941 to replace Kogyoku. The breeding process of Kogyoku and Koganemaru are shown in Fig. 2 and their main characteristics are shown in Table 2.

Table 2. Main characteristics of varieties originated from Shiga-Sekitori 11 and Shobei.

Variety	Maturing	Plant type	Height	Resist. to lodging	Resist. to bacterial leaf blight	Resist. to blast		Grain quality	Yield ability
						leaf	neck		
Zensho 17	late	medium	medium	medium	res.	susc.	susc.	medium	medium
Zensho 26	late	tillering	medium	fairly res.	res.	susc.	susc.	fairly good	medium
Kogyoku	late	medium	medium	fairly res.	res.	susc.	susc.	medium	medium
Koganemaru	late	medium	medium	fairly res.	res.	susc.	susc.	good	medium
Sachikaze	medium	tillering	short	res.	res.	susc.	susc.	good	high
Nihonbare	early	tillering	short	res.	res.	medium	medium susc.	good	high

Both Kogyoku and Koganemaru are eminent for displaying unique resistance to bacterial leaf blight, and have been utilized many times not only as the breeding materials for breeders but also as the materials for investigation on genetics or pathology concerning the resistance. According to our breeding experience, it is easy to introduce the resistant gene from Kogyoku or Koganemaru to non-resistant varieties. However, such defects as the lack of blast resistance and poor yielding ability are accompanied with the results in most cases. Thus, no satisfactory variety in a practical sense has been bred directly from these two varieties.

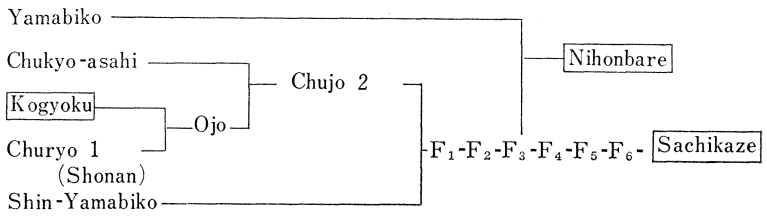

Fig. 3. Breeding process of Sachikaze and Nihonbare.

3. Breeders in Aichi Prefectural Agricultural Experiment Station attempted to breed excellent varieties for practical use by utilizing the highly resistant genes from Kogyoku. First, Kogyoku was crossed with Churyo 1 (later called Shonan) in 1940. Then, successive crosses was carried out between its offspring and the various varieties which had good characteristics suitable for this breeding program, and finally came to breed out Sachikaze in 1960.

Although this breeding process failed to introduce a blast resistant gene into the variety,

great advances were achieved in the improvement of such agricultural characteristics as maturing time, yielding ability and grain quality, in addition to the resistance to bacterial leaf blight (Miyazaki *et al.*, 1961). Therefore, Sachikaze is now recommended to rice growers in Aichi Prefecture as practically superior variety resistant to bacterial leaf blight.

During the breeding process of Sachikaze, another hybridization was carried out between its ancestral F_3 line and Yamabiko. Yamabiko is a popular parent in the breeding for practical blast resistant variety in Japan in recent years. Nihonbare was bred in 1963 from this cross. This variety is superior in various characteristics in a practical sense, showing the resistance not only to bacterial leaf blight but also moderately to blast, and is the most advanced variety among those originated from Shobei. Consequently, Nihonbare is widely planted from the central to the western region of Japan today.

The breeding process of the two varieties, Sachikaze and Nihonbare are shown in Fig. 3, and their main characteristics are in Table 2.

Breeding for Combining the Resistance to Bacterial Leaf Blight with High Yield

It is rather easy, as already stated, to introduce a bacterial leaf blight resistant gene into non-resistant varieties. However, it is not so easy to combine the resistance and the practical characteristics; particularly high yielding ability. Major efforts have been concentrated toward this point by Japanese breeders in the breeding for resistant varieties to bacterial leaf blight. From this standpoint, a group of varieties bred recently at Kyushu Agricultural Experiment Station, namely Hoyoku, Kokumasari and Shiranui can be regarded as the most promising varieties. The followings are the background and process of the breeding of these varieties.

About 20 years ago, a native variety called Jikkoku which was highly responsive to fertilizer and manifested a high yielding ability was planted in a fertile area in northern Kyushu. And since then, the planted acreage of this variety was increasing gradually in the region. This variety was also highly resistant to lodging due to its short and strong stems, but was very susceptible to various diseases. Particularly, it was the major defect of this variety to be highly susceptible to bacterial leaf blight which was prevarent in the area.

Zensho 26 was used as a male parent to introduce the resistant gene into Jikkoku in 1953. Both pedigree and bulk methods were applied in breeding process of this cross, and mass selections were also carried out in the fields in chronic-outbreak-district of the disease. The effort resulted in breeding out three varieties (Okada *et al.*, 1967), namely Hoyoku in 1961, Kokumasari in 1962 and Shiranui in 1964. Table 3 shows the main agricultural characteristics of these three varieties.

Table 3. Main characteristics of varieties derived from Zensho 26

Variety	Heading date*	Maturing	Plant type	Height	Resist. to loading	Resist. to bacterial leaf blight	Resist. to blast		Grain quality	Yield ability
							leaf	neck		
Hoyoku	Sept. 9	medium	tillering	short	very res.	res.	medium susc.	medium susc.	good	very high
Kokumasari	Sept. 10	late medium	tillering	very short	very res.	res.	susc.	susc.	good	very high
Shiranui	Sept. 8	medium	tillering	very short	very res.	res.	medium susc.	susc.	fairly good	very high
Oyodo	Sept. 13	late	medium	medium tall	medium	res.	res.	res.	good	high

Note: * Sown on May 25 at Kyushu Agr. Expt. Station.

The introduction and extension of these three varieties have brought about a rapid change in the distribution of rice varieties in Kyushu. Hoyoku became the leading variety only four years after the release of this variety (Fig. 4). About 30 % of the rice acreage planted in Kyushu today are covered with these three varieties.

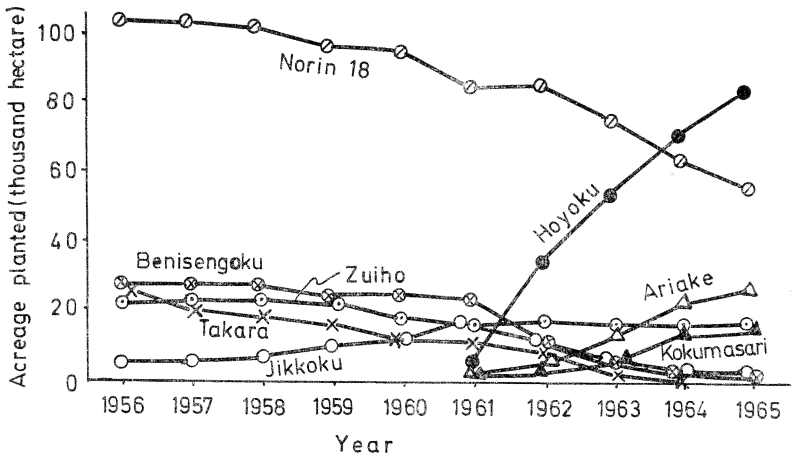

Fig. 4. Recent transition of main varieties for their acreage planted in Kyushu.

Breeding the Varieties for Resistance to Both Bacterial Leaf Blight and Blast

Heretofore, it has been assumed upon the breeding experience, that considerable difficulty would be confronted to breed out the variety resistant to both bacterial leaf blight and blast. However, a very recent finding in genetic research on resistance has clarified that the inheritance of resistance to each disease is independent, and indicated that it would be not so difficult to combine both resistant genes in one practical variety (Washio *et al.*, 1966). The variety, Oyodo bred out at Miyazaki Breeding Center in southern Kyushu in 1962 presents a bright prospect supporting this indication: As shown in Fig. 5, Oyodo acquired the resistant gene to bacterial leaf blight from the female parent Zensho 26 and the blast resistant gene of Chinese variety, Reishiko through Kanto 53. The main characteristics of Oyodo are as shown in Table 3.

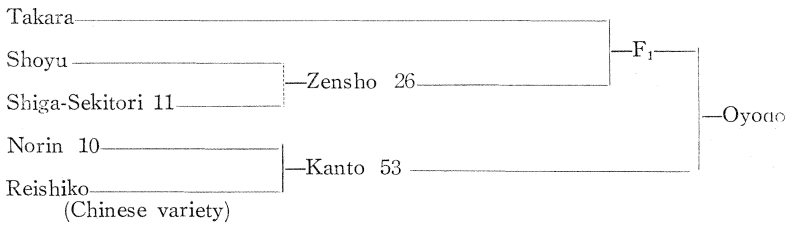

Fig. 5. Breeding process of Oyodo, a resistant variety to both bacterial leaf blight and blast.

Utilization of Exotic Varieties in Breeding for Resistant Varieties to Bacterial Leaf Blight

Most of the rice varieties so far bred in Japan for resistance against bacterial leaf blight

were derived from the hybridization of Japanese varieties. And those varieties manifested the sufficient resistance to the predominant strains of *X. oryzae*. However, the existence of various pathogenic strains which differ in the virulence has been clarified recently. And it has also been clarified that several pathogenic strains with high virulence which attack all of those resistant varieties are distributed in several districts throughout Japan (Kusaba, 1960). Accordingly, in future breeding research, a major effort should be directed toward the breeding of highly resistant varieties which manifested the resistance against such high virulent pathogenic strains of causal bacterium. Therefore, the necessity arises to find out the gene sources which may be involved in various rice varieties.

In order to ensure such an objective, the National Institute of Agricultural Sciences and several Regional Agricultural Experiment Stations have launched upon the research on the reactions of many varieties including those from foreign countries against various strains *X. oryzae* from 1958. And the findings so far have clarified that some of the exotic varieties, particularly those from South East Asian countries manifested a marked resistance to the highly virulent causal strains (Sakaguchi *et al.*, 1964; Washio *et al.*, 1966). Furthermore, the finding of some varieties highly resistant to both bacterial leaf blight and blast among the said varieties offers a bright prospect for a future breeding program. At present, the experiments are positively promoted to introduce these resistant genes into Japanese varieties by means of multiple-cross or back-cross methods.

Method of Testing the Resistance to Bacterial Leaf Blight for Breeding Procedure

In breeding of rice varieties for resistance to bacterial leaf blight, it is necessary to establish a method to facilitate proper determination of the degree of resistance to this disease. In case of natural infection method which is commonly applied, the appearance of disease symptom highly fluctuates by years. Sometimes no outbreak is witnessed. It is also necessary to give a due consideration to the evading of the outbreak by varietal difference in maturing time (Washio *et al.*, 1956; Aoyagi *et al.*, 1960).

The multiple- or bundled needle inoculation method to adult plants contrived by Mukoo *et al.* (1951), is one of the most accurate and practical methods easily to induce the disease outbreak and to diagnose the difference in resistance by varieties. Thus, this method is widely applied by many researchers. Table 4 shows an example of the results in the resistance test on rice varieties by this method.

However, this method has the defect that it requires much labor in inoculation, thus the number of materials to be treated becomes a limiting factor. Furthermore, the method is not adequate to study the resistance to infection under the field conditions. (Kiryu *et al.*, 1954).

Another inoculation methods, in which rice plants are sprayed with or submerged in bacterial suspension, make it possible to facilitate the symptom appearance similar to natural outbreak, although the results fluctuate to some extent by environmental conditions. Besides, this method surpasses the needle inoculation method in treating a number of materials within a short time. At Kyushu Agricultural Experiment Station, this method is applied effectively in breeding procedure for the selection of resistant lines to this disease by such a process as follows. That is, the rice plants are inoculated during the nursery stage, then transplanted in nitrogen rich field, and the degree of resistance is examined after heading when the disease symptom becomes distinct enough for the test.

The soak- (immerse-) inoculation method applied to seedlings just before transplanting (Yoshimura *et al.*, 1965; 1966) is also applied by breeders in Hokuriku Agricultural Experiment Station for the selection of resistant lines bred against bacterial leaf blight.

Table 4. Varietal reactions to two types of pathogenic strain of causal bacterium (Kyushu Agr. Expt. Station)

Year / Strain* / Variety	1961		1964		1965	
	S	H	S	H	S	H
Asakaze	0.0+	27.0	1.3	18.8	1.0	12.7
Hayatomo	0.1	25.6	–	–	–	–
Nishikaze	–	–	1.6	24.8	0.5	14.3
Hoyoku	0.1	33.8	1.7	17.3	0.7	12.6
Kokumasari	0.1	31.9	2.2	10.1	1.2	9.8
Shiranui	0.1	33.3	1.3	17.8	1.2	12.4
Kogyoku	0.2	29.8	1.1	14.5	1.3	11.3
Benisengoku	18.7	20.3	27.7	17.1	16.7	8.1
Norin 18	18.6	19.6	26.0	17.0	18.8	13.0
Jikkoku	28.5	30.7	30.7	17.2	22.9	13.6
Asahi 1	35.9	35.8	34.2	18.9	23.1	15.5
Kinmaze	32.4	35.0	–	–	26.6	18.7
Date inoculated**	Sept. 8		Sept. 14		Sept. 13	
Date examined	Oct. 6		Oct. 14		Oct. 12	

Notes: * S……standard strain, H……high virulent strain.
** Four needles inoculation method was applied to the enter of flag-leaf (10 leaves/plant, 5 plants/variety) at the stage just after heading.
Figures indicate lesion size in $\sqrt{(\text{mm})^2}$.

Table 5. Comparison of varietal difference of rice in lesion development between seedling test and adult test for bacterial leaf blight.
(1963, Chugoku Agr. Expt. Station)*

Bacterial strain / Stage tested** / Variety	Giken No. 44		Shinjo strain	
	Seedling test	Adult test	Seedling test	Adult test
Maratelli	0	0	3.1	0
Tokushu-daisuito	0	0	2.5	3.2
Nep vai	0	0	2.8	3.2
Daiyoshi	0	0	5.4	4.7
Kogyoku	0	0	5.6	2.1
Shimotsuki	4.0	2.7	3.6	2.3

Notes: * Summarized after Washio, *et al.* (1966)
** Seedling test; inoculated at 7th leaf stage. Adult test; inoculated at heading stage.
Figures indicate the degree of lesion development;
0: no symptom 7: severely diseased.

In case of the resistance test by inoculation, if it is possible to determine the degree of resistance at the seedling stage the efficiency is expected to increase in breeding procedure for the disease resistance. Table 5 indicates the results of an investigation on the relationship between seedling test and adult test by the bundled needle inoculation method carried out at Chugoku Agricultural Experiment Station. As shown in this Table, it was found that no variety that was resistant in the seedling test was susceptible in the adult test, although the reverse case did not always show such an accordance. Therefore, this seedling test method is considered effective to apply for the selection of highly resistant varieties to bacterial leaf blight (Washio *et al.*, 1966).

Conclusion

As stated above, many rice varieties resistant to bacterial leaf blight have been bred in Japan. However, it has been found recently that there exist some highly virulent strains among the causal bacterium of this disease. Moreover, because there is a prospect of further increase of these virulent strains, the breeding of higher resistant variety is in demand. In addition thereto, because the district with the outbreak of this disease is now expanding throughout Japan, it is urgently needed to breed new practical varieties resistant to both bacterial leaf blight and blast.

A few varieties, such as Nakashin 120 and a line selected from Wase-Aikoku 3, which have recently been recognized as the most resistant of Japanese varieties to the highly virulent bacterial strains of this disease, are now used in the breeding to ensure the objectives stated above. Resistant genes to both bacterial leaf blight detected in some Indica varieties are also being tested to be transferred into Japonica varieties.

However, we can not deny the possibility of a future emergence of new bacterial strains with much higher virulence. To counteract such an eventuality, not only the direct use of the resistant genes from a single variety but also the accumulation of those from many varieties including the introduced foreign varieties into one variety should be taken into consideration for the future breeding programme.

Discussion

H. Ito, Japan: "What kinds of desirable or undesirable characters are considered to be linked with the resistance to bacterial leaf blight?"

Answer: Only few findings have been so far obtained on the problem, but it is considered the leaf character and plant type have some relations with the resistance to bacterial leaf blight. According to the report by Dr. Kiryu *et al.*, the susceptible varieties are, in general, longer and wider in the leaf blade, more numerous in the number of fresh leaves and dense covering in the plant type, compared with resistant varieties. That is to say, in a susceptible variety, it is assumed the leaves have more chances to get wounds for bacterial invasion by frequent touch among them, and then assumed the atmospheric humidity within or between hills is relatively high under the thick covered leaves so as to be good for the condition of the disease development. From this viewpoint, it is expected the plant type with erect leaves is favorable to resist the disease, and in fact, many resistant varieties, Hoyoku etc., support this expectation with their errect plant type.

Then, according to our observative experience, as the general tendency, the leaf color is dark in susceptible varieties and light in resistant varieties. It can be considered the dark color means high N-content in the leaves, and this is to be profitable as the nutrients for the bacterium to multiplicate.

The plant type with solid and rough leaves may easily get wounds for the invasion of causal bacterium by touching among them, it is also said many varieties having leaves of

solid and rough touch are, in most cases, susceptible and these of smooth touch are resistant.

S. Wakimoto, Japan: I think the varieties having narrow leaf blade in Indica rice are generally resistant, is that true?

Answer: I have not much investigated on this character of Indica rice, but it is said also on Japonica rice. many varieties having short and narrow leaf blades are generally resistant to bacterial leaf blight. This has been already indicated in the answer to Dr. Ito.

S. Okabe, Japan: (1) How do you think the future stability of resistance of the varieties in Kyushu for the high virulent strain, "Beniya-strain?" (2) You have mentioned that, in spite of the rather simplisity of genetic factors which condition the resistance to bacterial leaf blight, it is not so easy to combine the resistance and the other agronomic characters. What do you think the main factors are, which interrupt the combination between resistance and high yielding ability?

Answer: (1) For the moment, any resistant variety against the high virulent Beniya-strain has not yet been bred in Kyushu. However, the distribution of this Beniya-strain is still only in a limited area, and the resistant varieties so far established are able to resist sufficiently the most prevarent bacterial strains in general areas. Furthermore, as it might not be considered the distribution of this Beniya-strain will expand in the near future, the degree of resistance of the existing resistant varieties will be stable enough under this situation in Kyushu.

On the other hand, needless to say, the future programme, is to breed the high resistant variety against Beniya-strain, and the present programme is also proceeding to this objective.

(2) I can not give the satisfactory answer, because it is mostly through our breeding experience. As the resistant varieties in general are regarded to have small or light colored leaves, it is a way of consideration that such factors in leaf characters are the minus factors for the yielding ability, and so I think such characteristics might possibly be a part of the interrupting factors. The resistant varieties, Kogyoku and Koganemaru are the representative of these characteristic with light colored leaves, and their yielding ability is poor. However, I have also to say this indication is not always true in every resistant variety.

Comments from S. Yoshimura: According to my experiments on the rice varieties resistant to the disease, there are some varieties that show considerable resistance against the causal bacterium type I, which possesses highly virulence, in addition to the varieties which you have mentioned. Among those varieties are Ohu 244 and its sister line. There varieties are bred from "Zenith". Recently in many parts of Japan, the bacteria having a high virulence are isolated from the diseased rice. Therefore, my opinion is that it is quite hopeful to pay much attention to the selection of the resistant varieties which belong to the variety "Zenith".

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