National Program of Rice Breeding in Japan

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A stable supply of quality rice to consumers and an increased rice yield are the national requirements. To meet these requirements, rice breeding in Japan is expected to develop new varieties with high yielding ability and good grain quality. In addition, new varieties should have high tolerance to diseases, pests and climatic injuries and adaptabilities to direct seeding and mechanized farming.

Organization of breeding programs based on ecological conditions

Japan is located from north latitude 25° to 45°, with climatic condition varying from region to region. The country needs different types of rice varieties that are well fitted to different environmental conditions. With the idea of 'Ecotype Breeding,' there are three breeding centers in the major regions classified by climatic specialities; namely, the Hokkaido Nat. Agr. Exp. Sta. in Sapporo for the low temperature region, the Hokuriku Nat. Agr. Exp. Sta. in Jyoetsu for the moderate temperature region and the Kyushu Nat. Agr. Exp. Sta. in Chikugo for the high temperature region. Each breeding center consists of two or three laboratories, one of which is responsible for the varietal improvement to cover the respective region, and the others are responsible for improving testing methods on selected characteristics or tolerance to diseases and pests, and for the tests of breeding materials developed by the varietal improvement laboratory.

Besides the breeding centers, each region has several breeding stations to meet the local requirement. Total number of the breeding stations is 11; one of which is for upland rice. Each breeding station has limited but specific breeding objectives. This system allows each station to provide varieties well fitted to each regional condition. In addition, 26 experiment farms are distributed from north to south for testing the adaptability of breeding lines at late generations to cultural conditions of the respective districts, and 15 experiment farms for testing disease resistance or cool-tolerance are located in specific areas where the disease or the cool-injury severely occurrs every year. The localities and the objectives of the breeding centers, breeding stations and experiment farms are shown in Table 1, 2 and Figure 1. In addition to the aforementioned breeding system for rice, fundamental researches on breeding work covering all crops are conducted at the National Institute of Agricultural Sciences.

Breeding procedure

Breeding centers and stations start their breeding programs with selections of parents, followed by artificial crossings. In most cases, F_1 plants are grown in green house during a winter season, then F_2 seeds are sent to the breeding stations located in the high temperature region, or they are grown in green house to pass the F_2 and F_3 generations within a year for shortening a breeding period. After the F_4 generation, a pedigree or a bulk method is applied according to breeders' choice.

Breeding lines at the F_7 to F_9 generation, which are developed at each breeding center or station after testing their local adaptability

Table 1. Localities and objectives of the breeding centers and stations

Region	Breeding Center		Breeding Station	
	Locality	Objective	Locality	Objective
Low temperature region	Sapporo	1. Varietal improvement for high tolerance to cool-injuries. 2. Improvement of testing method for cool-tolerance, and test. 3. Improvement of testing method for grain quality, and test.	Asahikawa	Varietal improvement for high tolerance to cool-injuries in the northern part of the region.
Moderately low temperature region	Jyoetsu	1. Varietal improvement for the moderately low temperature region and for mechanized farming. 2. Varietal improvement utilizing foregin rice varieties. 3. Improvement of testing method for various characteristics, and test.	Towada	Varietal improvement for cool-tolerance in the northern part of the region.
			Oomagari	Varietal improvement for blast resistance.
			Furukawa	Varietal improvement for the middle part of the region.
			Fukui	Varietal improvement for the southern part of the region.
Moderately high temperature region			Konosu	Varietal improvement for the eastern part of the region and for direct seeding.
			Inahashi	Varietal improvement for the mountainous area in the region and for high resistance to blast.
			Fukuyama	Varietal improvement for the western part of the region and for a short term cultivation.
			Mito (upland rice)	Varietal improvement for drought tolerant upland rice with good grain quality.
High temperature region	Chikugo	1. Varietal improvement for resistance to diseases and pests in the region. 2. Improvement of testing method for resistance to diseases and pests.	Miyazaki	Varietal improvement for pest resistance in the southern part of the region.
			Kagoshima	Varietal improvement for early planting cultivation.

and selected characteristics, are given local numbers; such as Saikai 62, Fukei 70, Hokkai 230 and so on. Breeding lines with local numbers are distributed to prefectural experiment stations in the respective region for screening candidates for the varieties to be recommended in the respective prefectures. Candidates for the varieties to be recommended should be tested for at least three years at the related prefectural experiment stations and for at least two years at several experiment farms scattered in the related prefectures to examine their local adaptability and production stability.

Experimental data of the candidate lines are examined by officials of Ministry of Agriculture, Forestry and Fisheries concerned in consultation with senior breeders of the breed-

Table 2. Localities and objectives of the experiment farms

Region	Experiment farm for adaptability	Experiment farm for testing selected characteristics	
	Locality	Locality	Objective
Low temperature region	Kitami Iwamizawa	Iwamizawa	Neck rot
Moderately low temperature region	Kuroishi Towada (Upland rice) Esashi Yamagata Kooriyama Nagaoka Toyama	Towada Inawashiro Oodate Souma Shonai	Cool-injury Cool-injury Neck rot Leaf blast and neck rot Bacterial leaf blight
Moderately high temperature region	Utsunomiya Chiba Nagano Shizuoka Gifu Shiga Tottori Okayama Oosaka Takamatsu Nangoku	Inahashi Akana Shimoina Tsuyama	Leaf blast and neck rot Neck rot Leaf blight Stripe virus
High temperature region	Fukuoka Kumamoto Usa Kagoshima Naha Kanoya (upland rice)	Aso Miyazaki Yabe Kumamoto	Neck rot Bacterial leaf blight Stripe virus Waika disease

ing centers and stations at the Annual Conference on Rice Breeding of the country. After their approval, the candidate lines are registered as Norin-number varieties, and are given their proper name, such as Hoyoku (Norin 130), Reimei (Norin 177), Kitahikari (Norin 236) and so on. The breeding centers or stations grow the original lines to keep their breeder's seeds, the prefectural governments produce their foundation seeds, and seed growers registered produce certified seeds to supply them to rice growers.

The first registered variety, Norin 1, was released in 1931, and the newest one, Norin 251, was released in 1978. In an average, three to five varieties were registered every year. Some of them were grown in large areas, while the others only in the limited area because of their narrow adaptabilities. Such rather large number of Norin-varieties have covered all rice growing areas in Japan, contributing yield increase and production stability.

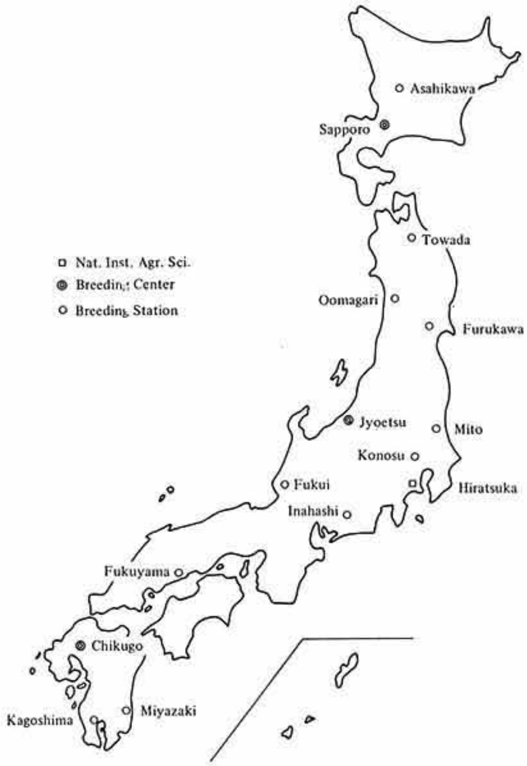

Fig. 1. Localities of breeding centers and breeding stations

Breeding programs in the low temperature region

In the low temperature region, paddy yield in usual years has increased rapidly, especially in the last half century; about 2.5 t/ha of paddy in 1925 to 6.0 t/ha in 1975. Of course, this great increase was caused not only by the varietal improvement but also by the improvement of cultivation techniques. Since cool-injuries have occurred with a frequency of every four years, the most important breeding objective in this region is to develop high yielding varieties with high tolerance to cool-injury.

Breeding for cool-tolerance: In the past, there were no early varieties possessing high yielding ability. Farmers, therefore, tended to plant middle or late varieties to get high yields in ordinary temperature years. However, the heading of these varieties is apt to be delayed when cool weather happens to occur during their vegetative growth period, with a result of poor maturing due to the low temperature in the fall season. Therefore, breeding of early varieties with high yielding ability has been keenly desired.

Early or short-duration varieties should also have high tolerance to the sterility type of cool-injury because their booting stage frequently coincides with a cool period in early summer. The relationship between sterility and grain yield in the cool year indicates an almost linear correlation, and the average temperature during booting stage shows a highly negative association with sterility occurrence. There are, however, distinct differences in sterility among existing varieties. For example, 'Hayayuki' which has the highest tolerance to sterility injury always shows the lowest sterility among all varieties tested at any districts in any years. The level of cool-tolerance of 'Hayayuki' is the target level in our present breeding program.

To develop varieties with higher level of cool-tolerance, genetic diversity of the world collections of rice should be utilized to widen a genetic background, because the cool-tolerant varieties in Japan are derived only from a limited number of native varieties. Varieties introduced from all over the world are presently examined for their cool-tolerance. It is expected that varieties specially introduced from northern latitude or high altitude zones have some different genes for cool-tolerance. Breeders in the low temperature region are making a great effort to develop high yielding varieties with short durations and cool-tolerance as high as 'Hayayuki.'

Breeding programs in the moderately low temperature region

In the moderately low temperature region, which shares more than half of the rice production of the country, severe outbreaks of blast disease frequently cause big crop losses, and cool-injuries also occur in the northern part of this region. Therefore, the breeding objective in this region is to develop not only high yielding varieties with good grain quality, but also varieties possessing high resistance to blast and tolerance to cool-injury.

Breeding for blast resistance: The breeding procedures in the past are classified into four categories: 1) accumulation of resistance genes of Japanese native varieties, 2) use of resistance of Japanese upland rice, 3) incorporation of resistance genes from Chinese varieties of japonica type, and 4) incorporation of resistance genes from indica varieties. Blast resistance is also an important breeding objective in other regions, especially in mountainous areas in the moderately high temperature region.

Since the establishment of rice breeding system in Japan, many crosses among native varieties have been made to develop blast resistant varieties, As a result, some outstanding varieties, such as 'Norin 22', 'Norin 23', 'Yamabiko', 'Fujiminori' and 'Ishikari Shiroke' were released. The resistance of these varieties is more stable and higher than those of their parental varieties, but they often suffer moderately from blast due to moderate degree of resistance.

Some Japanese upland varieties have a much higher level of resistance to blast but lower yields and poorer grain quality than lowland varieties. In 1922, an upland variety 'Sensho' was used for crossing with a lowland variety to develop varieties with a much higher level of blast resistance than lowland ones, then multiple crossing was employed to eliminate undesirable traits of upland rice. After crossing four times with lowland varieties, 'Futaba' was developed first. 'Futaba' developed 'Shuho', which further developed 'Wakaba', 'Homarenishiki' and 'Koganenishiki.' They have been planted widely in mountainous areas of the moderately high temperature region due to their stable and moderately high resistance to blast.

It had been observed that some foreign varieties including Chinese ones have extremely high resistance as compared with that of Japanese lowland varieties. The Chinese varieties of japonica type. 'Reishiko' and 'Toto', found to be highly resistant, were used as sources of blast resistance to avoid the hybrid sterility that often occurs in japonica-indica crosses. The first recommended variety derived from the hybridizations with these two introductions was 'Kusabue.' The high resistance to blast was due to the true resistance gene, *Pi-k*, from Chinese variety. Within three to five years after its release, however, it was unexpectedly affected by blast more severely than Japanese domestic varieties which had no true resistance genes. This was caused by the rapid propagation of fungal races virulent to the *Pi-k* gene and the lack of field resistance in 'Kusabue'.

High sterility which often occurs in japonica-indica hybrids makes it difficult to incorporate resistance genes from indica into japonica type. The sterility in backcrossed offsprings is caused by a cytoplasmic effect of the maternal indica parent, and the degree of sterility in hybrids varies with the maternal indica varieties employed. To eliminate hybrid sterility in backcrossed offsprings, indica varieties should be used as a male parent in the first hybridization or japonica varieties should be used as a female parent in backcrossing. True resistance genes which have been incorporated into japonica type are the *Pi-ta* and $Pi\text{-}ta^2$ genes from a Philippine variety 'Tadukan', the *Pi-z* gene from an American variety 'Zenith', the $Pi\text{-}z^t$ gene from an Indian variety 'TKM 1', the *Pi-b* gene from an Indonesian variety 'Bengawan' and the *Pi-t* gene from an Indonesian variety Tjahaja.'

To cope with the race differentiation of blast fungus, several breeding schemes have been proposed: 1) accumulation of three or more true resistance genes in one variety, 2) use of high field resistance genes in place of true resistance genes, 3) combination of true resistance genes with field resistance, and 4) development of multilineal varieties—a mechanical mixture of many phenotypically similar lines that genotypically differ for blast resistance.

Breeding programs in the moderately high temperature region

In the moderately high temperature region where various rice cultivation methods exist, main breeding objectives are to develop not only high yielding varieties with disease resistance but also varieties having adaptabilities to direct seeding and to short term cultivation.

Breeding for stripe virus resistance: As the result of recent trends toward early planting and direct seeding, stripe virus has become a major disease in this region. Since no varieties among existing Japanese lowland rice were found to be resistant to stripe virus, Japanese upland rice and foreign varieties were employed as sources of resistance. The first effort was to screen the lines carrying the stripe resistance gene of indica varieties with other agronomic characters of Japanese lowland rice from existing indica-japonica hybrids, originally developed for incorporating blast resistance genes into japonica type by backcross method. The experimental line 'St 1' was selected from the fifth backcrossed offsprings involving 'Norin 8' as a recurrent parent and an Indian variety 'Modan' as a donor. The recommended variety 'Mineyutaka' was developed from a cross involving St 1' as the second step of this project.

Breeding for non-seasonal short duration varieties: The breeding program for non-seasonal short duration varieties has been developed to meet the farmers' need to increase incomes by growing vegetables in rotation with rice on their small holdings. Non-seasonal short duration varieties require some specific characteristics; comparatively high yield, i.e. 5 tons/ha of paddy, with 100 to 110 day growing period from planting to harvesting, even when their cultivation is started in early spring or at the beginning of August. The varieties should have a short vegetative growth period and a weak photosensitivity with an intermediate degree of critical day-length. 'Fujihikari' was selected because of its desirable heading performance and comparatively high yield with good grain quality, and released to farmers to improve their rotation systems.

Breeding programs in the high temperature region

In the high temperature region where diseases and pests outbreak quite frequently, resistance to bacterial leaf blight, "waika" disease and brown planthopper is an important breeding objective in addition to high yield and good grain quality.

Breeding for bacterial leaf blight resistance: The first effort was to utilize the domestic resistance gene. 'Norin 27' was the first recommended variety carrying the resistance gene, *Xa-1*, from 'Kano 35,' and then the resistance was transferred to 'Asakaze'. However, in 1957, 'Asakaze' suffered severely by the disease due to rapid propagation of virulent bacteria. To cope with a change of pathogenicity of causal bacteria, breeders are looking for new genetic sources from the world collections. Causal bacteria so far isolated in Japan are classified into four groups based on the pathogenicity to differential varieties. The *Xa-1* gene expresses resistance to bacterial group I but susceptible to groups II, III and IV. Some indica varieties carrying the resistance genes *Xa-1* and *Xa-2*, such as 'Tetep', are resistant to the groups I and II but susceptible to groups III and IV. Native varieties 'Wase-aikoku 3,' 'Nakashin 120' and an indica variety 'Lead Rice' are found to be resistant to groups I, II and III but susceptible to group IV. The resistance of 'Wase-aikoku' is controlled by a dominant gene, *Xa-3* (*Xa-w*), and a local number line 'Chugoku 45' was developed as the first step of this program. Some IRRI lines are found to be resistant to all bacterial groups in Japan. Besides the true resistance, there are some varietal differences in resistance to enlargement of lesions. Therefore, breeders are trying to incorporate a wide range of true resistance gene and resistance to lesion enlargement into one variety.

Breeding for "waika" disease resistance: Recently, "waika" disease caused by a virus suddenly appeared in the high temperature region. The leading variety 'Reiho' suffered seriously from this new virus disease. Distinct varietal differences were observed among existing Japanese lowland varieties. 'Tsukushibare' was selected to be practically resistant, and it was recommended in place of 'Reiho' for the area where "waika" disease severely occured.

Breeding for resistance to brown planthopper: Resistance to brown planthopper is also an important breeding objective in this region. Since there are no Japanese varieties resistant to this pest, the resistance genes of indica varieties. *Bph 1* gene from 'Mudgo' and *bph 2* gene from 'ASD 7' have been incorporated into japonica type, but no recommended resistant varieties have been developed so far.

Breeding programs for high yielding varieties

In all the regions, the high yielding ability is commonly required besides the improved characteristics. Yielding ability has been progressing with the improvement of characteristics required in each region, such as cool-tolerance, disease-resistance and grain quality.

Shortening of culm length is one of the way to get high yields without lodging. Mutation breeding using X-ray, γ-ray and ethylen-imine treatment has been employed to develop short culm mutants. The first variety induced by γ-ray irradiation was 'Reimei.' It is shorter by about 15 cm in culm length than the original variety 'Fujiminori' without any changes of other agronomic traits. An advantage of growing 'Reimei' is to get higher yields without lodging than original one under heavy manured conditions. 'Reimei' rapidly took the place of 'Fujiminori.' Other example is 'Hokuriku 100' developed from 'Koshihikari' by mutation breeding. The short culm of 'Reimei' and 'Hokuriku 100' are widely employed in the present breeding program because of their high percentage of short culm segregates in their offsprings; 'Akihikari' was descended from 'Reimei.'

In the high temperature region, there was a short culm local variety 'Jukkoku' which was planted only in a limited area because of high susceptibility to blast and bacterial leaf blight. The short culm gene of 'Jukkoku' was employed to develop stable high yielding varieties, and 'Hoyoku' was developed from the cross with 'Jukkoku.' 'Hoyoku' is an epock-making variety in the high temperature region because of its outstanding high yield never found. Breeding with 'Hoyoku' developed 'Reiho' and 'Mizuho'.

IRRI varieties, such as IR 8 and IR 24, were used to incorporate their yielding ability and straw stiffness into Japanese type, but no varieties have been developed.

Plant type is the first criterion in selecting the high yielding ability. The plant type of the present high yielding varieties is characterized by erect leaf and short culm. 'Fujisaka 5' is the first high yielding variety possessing a new plant type. 'Hoyoku' and 'Yuukara' have the same plant type though their parentages are different each other. Most of high yielding varieties planted nowadays are descendants from these three varieties, and have a new plant type.

The breeding for direct seeding and mechanized farming is now underway; there are many factors affecting the varietal adaptability to direct seeding and mechanized farming. Nevertheless, existing varieties are well adapted to mechanical transplanting which covers more than 80% of rice area in Japan. Short stature varieties are also fitted to combine-harvesting because of no disturbance by lodging, and the glabrous gene from U.S. varieties is being incorporated into Japanese varieties to improve adaptability to combine-harvesting.

Conclusion

Although rice breeding in Japan has progressed step by step in the last half century, some problems still remain, and new problems related to the use of indica varieties as gene sources have come out. Nevertheless, rice breeding in Japan should widen its genetic background, because wide genetic diversity involved in indica group would contribute to improve japonica rice. Rice breeders, therefore, should continue their efforts to overcome the genetical barrier between indica and japonica groups and finally to satisfy both the farmers' requirement and the national demands.