Rice Breeding for Extremely Higher Yielding Ability by Japonica-Indica Hybridization

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As for the rice yields per unit area, Japan is one of the leading countries in the world. In 1984, partly due to good weather, the national average yield per ha recorded 5.17 tons of brown rice (6.46 tons of paddy). On the other hand, the rice consumption per capita has been decreasing year after year, and it is 75.7 kg in 1983, almost half of that in 1930's. Therefore, the government keeps adjusting the balance of supply and demand by restricting the planting area. In 1984, 517 thousand ha out of the total 2.78 million ha of paddy fields was planted to other crops such as wheat, soybean, forage crops, vegetables, etc. by converting paddy fields to upland fields, and other 39 thousand ha was left unplanted. In the future, much more acreage of paddy fields must be saved for upland crops, though about 700 thousand ha is poorly drained and not adapted to upland crops.

On the other hand, Japan imports nearly 2 million tons of feed grains per year, which is one of the causes of high cost of meat and milk products. Assuming that we can breed rice varieties of extremely higher yields, it may be possible to use them for producing feed grains, or in the future, it will contribute to food supply in over-populating countries. However, as for the genetic potential of Japanese rice varieties, it is considered that the improvement of the yielding ability is already reaching the plateau. The reason for this is that rice breeding in Japan had been conducted mainly by hybridization among Japanese varieties only, because of the emphasis on table quality and resistance to cooler temperature. Foreign varieties were often used as gene sources of resistance to pests, but only as non-recurrent parents in the backcrossing method.

The green revolution in China, tropical countries, and Korea was realized by semidwarf indica plant type with long panicles. The varieties produce even 50% more spikelets per unit area than common Japanese varieties. Without laying emphasis on rice quality, new rice breeding in Japan for extremely higher yields would be feasible by using those varieties as promising gene sources. Under such circumstances, the Ministry of Agriculture, Forestry and Fisheries started in 1981 a special coordinated project of rice breeding for the extremely higher yield.

Objectives and procedures of breeding

The final objective of the project was set at the 50% yield increase compared to the present level at different localities. To realize this, the period of the 15 year project was strategically divided into 3 stages. The first is 3 years, when varieties with yielding ability of 10% higher should be selected from the current material which had been bred primarily for better quality, and stability to environments, followed by high yields. At the same time, hybridization of Japanese varieties with different alien varieties be made for the following stage.

The second stage of 5 years aims at the yield 30% higher from the original level. In this period, selections from hybridization between different ecotypes are expected to be obtained. Paths for increased yields are supposed to be through increased number of

Table 1. National and prefectural agricultural experiment stations and research institutions concerned with breeding rice of extremely high yield

Category	Experiment stations and research institutions
Basic studies on breeding methods	NARC (2 labs), Hokkaido NAES*, Hokuriku NAES, NIAR***
Breeding and research on hybride rice	Univ. Ryukyu, NARC (2), Hokkaido NAES, Tohoku NAES, Hokuriku NAES, Chugoku NAES, Kyushu NAES, NIAR (4)
Breeding	NARC, Hokkido NAES, Tohoku NAES, Hokuriku NAES, Chugoku NAES, Kyushu NAES
Rapid generation advancement	TARC (Okinawa Branch)
Testing resistance for:	
Low temperature	Kamikawa PAES**, Fujisaka Branch of Aomori PAES, Furukawa PAES, Aichi PAES
Blast	Furukawa PAES, Ibaraki PAES, Aichi PAES, Kagoshima PAES
Bacterial blight and Dwarf	Miyazaki PAES
Brown planthopper	Kagoshima PAES

* NAES: National Agriculture Experiment Station
** PAES: Prefectural Agriculture Experiment Station
*** NIAR: National Institute of Agrobiological Resources

grains per unit area and/or through increased grain sizes. In this stage, efforts of adding tolerance to low temperature, reducing shattering habit, etc., are considered to be important because donors of higher yields had defects regarding these characteristics. The third stage is the following 7 years, when the final objective of 50% yield increase should be realized by improving and utilizing the lines bred in the previous stages, through enlarging the sizes and/or number of grains, improving plant type and resistance to pests and low temperatures. The 'hybrid rice' would perhaps be used as a tool of jumping up the yield level in this stage.

All of the 6 breeding labs of national agriculture experiment stations including NARC* are engaged in the breeding. They are supported by several labs from those stations concerning basic studies of breeding methods, and by all of 8 labs of prefectural experiment stations (MAFF**-designated rice breeding stations) concerning tests of specific characteristics such as resistance to low temperatures, diseases and insects, or yielding ability of gene source varieties and breeding lines.

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** Ministry of Agriculture, Forestry and Fisheries
*** Tropical Agriculture Research Center

Several labs of other national institutes and the University of Ryukyu join to the project for basic work on hybrid rice and disease (rice blast) control. Okinawa Branch of TARC*** serves to rapidly advance generations of hybrid populations, utilizing the subtropical climatic conditions. Table 1 lists those stations and research institutes concerned with breeding in the project.

In 1985, the project was further strengthened by adding many labs concerning pathological and entomological studies. As a whole, the project covers also the research area of plant physiology, agronomy, soil science and even nutritional studies of rice as feedstuff.

Breeding lines obtained from the first stage materials

The most outstanding outcome would be Chugoku 91, a very high yielding selection from Chugoku National Agriculture Experiment Station. The cross was made in as early as 1971 between a Japanese selection and a F_3 line from a complicated japonica-indica cross KC89 (Fig. 1). Characterized by long panicles with abundant spikelets and good plant type, which seems to originate from IR 8 and Taichung Native 1, Chugoku 91 was registered

Table 2. Characteristics of 'Akenohoshi' in comparison with the check 'Nipponbare'[9]

Variety and method of planting	Date of 50% flowering	Date of maturity	Culm height (cm)	Ear length (cm)	Ear count per m²	Yield of brown rice (kg/a)	Spikelet number per ear	Grain quality[c]
Transplanted[a]								
Akenohoshi	8.29	10.31	78	23.0	352	61.3	162	6
Nipponbare	8.25	10.13	77	19.9	471	50.9	82	4
Direct sown[b]								
Akenohoshi	8.20	10.9	79	20.5	393	55.9	123	5
Nipponbare	8.18	10.3	76	19.4	503	42.9	82	3

(Chugoku NAES)

a) Averaged data of 1980–1983. Date of transplanting: June 22–29
b) Data of 1983. Drill seeding of 50 grains per m with row spacing of 30 cm on May 11
c) Rating of 1 (best) to 9 (poorest)

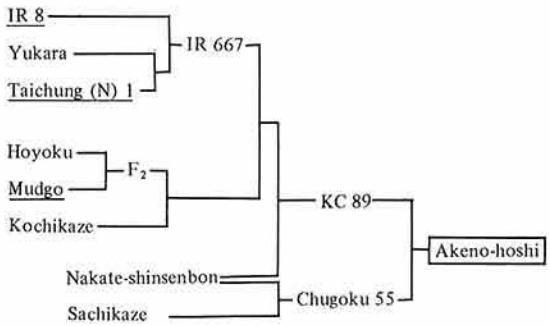

Fig. 1. Genetic background of 'Akenohoshi'
(Varieties underlined are indica.)

as Norin 274 and named 'Akenohoshi' (means morning star) in May, 1984. Due to its high spikelet number and also relatively higher sensitivity to cooler temperature, Akenohoshi needs longer maturing period (Table 2), sufficient warmer days and sunshine to get spikelets well filled. Therefore, it is considered to be adapted to the plains in the Seto Inland Sea Area. In 1984, the weather at the maturing period being quite favorable, Akenohoshi yielded 30% more than check varieties in several prefectures in the area. The grain appearance is fair under good maturing conditions, but tends to be dull and chalky under cloudy or cooler conditions. Akenohoshi seems to be more cross compatible with indica semidwarfs than other Japanese varieties, and be useful as a parental line in japonica-indica crosses.

Another selection from the same cross, Chugoku 96, is of a special type with long erect leaves and stiff, medium tall culms. The high total fresh weight suggests that this line would be adapted for a special use, i.e. whole crop silage, and tests for that purpose is being continued.

Though evaluation is further to be conducted, each station named several lines from japonica crosses. Among those, Hokkai 249 from Hokkaido National Agricultural Experiment Station seems to express its yield potential well especially when transplanted at the younger (2.5 leaf) stage. Hokuriku 123 from Hokuriku National Agricultural Experiment Station seems promising in Iwate Prefecture, and Hokuriku 125 in several prefectures in Hokuriku districts.

Breeding for the second stage

Semidwarf indica varieties were widely used in many stations except northern Japan as donors of high yield by increased number of grains per unit area. They are Milyang 23, Suweon 258, Iri 338, Taichung Sen 3, Nanjing 11, Non-gui 4, Gui-chow 2, IR 26, IR 36, RP 9–6, etc. The highest yield records of these varieties have been obtained in Shikoku National Agricultural Experiment Station since 1982. In 1982, 10.1 t/ha (brown rice) by Suweon 258, in 1983, 9.25 t/ha by Suweon 287, and in 1984, 9.53 t/ha by Gui-chow 2 were recorded by early transplanting. When transplanted later, their yield decreases drastically.

When these semidwarf indica varieties were crossed with Japanese varieties, they usually produced F_1 plants with much longer growth duration, taller culm height, longer panicles, and high sterility. Thus, the percentage of plants selected in F_2 or BCF_1 and even thereafter was extremely low compared to that in japonica crosses.[1,2,6,10]

In northern Japan, several very early indica varieties from southern China such as Er-jiu-qing, Hong 410, Uan-fang-zao, etc., were thought to be donors of new plant type with much bigger panicles than ordinary Japanese varieties. Other gene sources were varieties from Europe with large kernels and fairly good level of cold tolerance, such as Romeo, Raffaello, Arborio, etc. Defects of these are tall height, fewer panicles, easy shattering, panicle sprouting, and susceptibility to blast, stripe and other diseases. With similar characteristics, several breeding lines such as BG1 and 2 from Chokoto/Taiho were also used as gene sources.

Usually F_3 seeds harvested from roughly screened F_2 populations of japonica-indica crosses were sent to Okinawa, and grown during 2 years (4 or 6 generations depending on maturity) before sent back to breeding stations. By now, only 2 selections from japonica-indica crosses were named except Akenohoshi and Chugoku 96. Kanto 138 from Toyonishiki/Milyang 23//Toyonishiki, bred at NARC, is a very early selection. Its maturity, panicle count, and yield are comparable to Nan-jing 11, but culm is erect and taller by 15 to 20 cm. Hokuriku 130 from BG 1/Shu 3116 is outstanding for its heavy, long panicles with large kernels, 1,000 grain weight being more than 38 g (over 70% heavier than normal Japanese varieties). Unlike other large kernel varieties and selections, the yield of this line is higher than normal varieties, which is thought very promising as a parental line for the future (the 3rd stage) breeding program.

As it takes time to get good lines from japonica-indica crosses, indica-indica crosses are also sought to improve some important defects such as easy shattering and early leaf senescence of semidwarf indicas. Hokuriku 129 and 133 are selections from the cross Milyang 42/Milyang 25. The former is comparable to Nan-jing 11 in maturity, yield and grain quality, but its threshability is medium, plant type is much improved. The latter is a late selection, and compared to Suweon 258, later by 5 days, taller by 20 to 25 cm, heavier grains, harder shattering, and similar yielding ability in Hokuriku districts.

Findings in basic studies

Out of many performances obtained in basic research in the coordinated project, only some are highlighted here.

Plant height is a trait of great importance in the breeding of high yields. It is interesting that the semidwarf gene in major high yielding variety groups is the same, d_{47}. It is found in Dee-geo-woo-gen group, Jikkoku group, and Reimei group. In the project, efforts are focused on identifying allelic relationship between genes of short height varieties and d_{47}. So far, d_{47} was identified in Brazos, Calrose 76, Shiranui, IR 36, Taichung Sen 3, Shu 2783 (a mutant of Koshihikari), but genes of CP-SLO, Milyang 23, Guan-lu-ai 4, Kochihibiki, Kinmaze, Hokuriku 100 and several mutant lines of Koshihikari were not allelic to d_{47}.[4] The d_{47} gene was found linked to the gene *lax* with the recombination value 0.30.[3]

Grain shattering of semidwarf indica rice is a great problem in the breeding of this project. Easy shattering of japonica type varieties and breeding lines such as Shiranui, Arborio and BG 1 was found to be controlled by a single recessive gene. While, though the data are still to be analyzed, easy shattering of indica varieties and their related selections such as IR 24, IR 36, CR 44, RP 9-3, Milyang 23 is a dominantly inherited trait with different ratio of segregation when crossed with Reimei.[1] However, shattering of SC 2 and SC 3 (both from Taichung Native 1/5*Norin 29) was found recessive in the cross with Norin 29. In most cases, easy shattering was closely linked with short culm height.[7]

Table 3. Deviation of F_1 data from data of male foreign parents[6)]

Variety group of male parent[a)]	Number of varieties	Date of heading (days)	Culm height (cm)	Ear length (cm)	Ear count per hill	Resistance[c)] to BLB race		% Infested hills by stripe
						I	II	
Korean and Taiwan sd[b)]	8	18.0	24.0	1.0	8.6	-0.1	-0.8	-1.5
Tropical sd	6	16.2	17.8	0.02	7.5	-1.0	0.7	-0.7
Chinese sd	3	35.8	16.7	2.9	8.2	-5.5	-5.3	0
Chinese japonica	4	0.25	—	—	—	-0.8	-0.8	-90.8
Upland rice from Thailand & Laos	4	10.0	-0.25	2.5	5.4	-2.8	-1.0	8.8
Upland rice from Africa	4	12.5	3.25	1.1	8.7	0.7	-0.7	0
Italian	8	9.2	14.3	5.2	5.9	-1.6	0	-80.0

a) The Japanese female parent was selected so as to have F_1 plants resistant to stripe virus disease, using either Nipponbare (susceptible) or Kanto PL 3 (resistant) according to the nature of the male parent.
b) sd: semidwarf variety
c) BLB (bacterial leaf blight) race: I=T7144, II=T7147
Rating of resistance: 1 (highly resistant)~9 (highly susceptible)

Besides easy shattering, several characteristics are responsible to extremely low rate of plant selection in populations of japonica-indica crosses. Usually the rate is less than 0.1% even in BCF_2 (japonica recurrent), compared to around 5 to 10% in ordinary japonica crosses. Heterosis in growth duration and plant height are major problems.[1,6)]

As optimum temperature is higher at different growth stages than Japanese varieties (Hokuriku National Agricultural Experiment Station, unpublished), and the growth duration is decided mostly by BVP (basic vegetative growth period) in modern semidwarf indica varieties, they produce very late plants in F_1 and the following hybrid populations when crossed with Japanese varieties which are more or less photoperiod sensitive. This habit is especially remarkable in early varieties from southern China (Table 3).

Data from Hokuriku National Agricultural Experiment Station revealed that heterosis of culm height of over 140% was found only in Chinese semidwarfs.[10)] Based on the analysis of many characteristics of F_1 plants of 308 cross combinations between Akihikari (the common female parent) and other varieties (male), they selected the best 5 combinations, of which 4 were japonica-japonica crosses. Standard heterosis (compared to Akihikari) of panicle weight was 45 to 89%.[11)]

Regarding research on hybrid rice, while each breeding station is preparing male sterile lines of leading varieties in each district, or breeding restorer lines from japonica-indica crosses, basic studies are being conducted. Classification of male sterile cytoplasms is tried by the orthodox method of crossing each other and testing segregation in F_2 populations, or by the new biotechnological method of analyzing sequence of bases of mitochondrial DNA. Studies of flower characteristics such as sizes of stigmas and anthers, degree or percentage of stigma exsertion are conducted. A test showed that 48% of spikelets with exserted stigmas could be fertilized by pollen shedding on the next day of flowering.[5)]

Genetic analysis of blast resistance of many semidwarf indicas is being conducted. As most of them are immune to fungus races presently found in Japan, it has been impossible to evaluate the level of their field resistance. Therefore, many clones of the fungus were introduced to Japan from different countries of Asia, Africa, South America and Europe, and some races, which can infest all of the principal breeding materials (semidwarf indica varieties), were identified. On the other hand, methods of evaluating the level of field resistance are being sought.[8)] According to comparison of number of lesions by the spraying and length of lesions by the punching innoculation, the order of the resistance in 3 Korean semidwarfs was Iri 338, Milyang 30 and Suweon 258.

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