Rice Breeding at the National Agricultural Research Center for the Tohoku Region (NARCT) and Rice Varietal Recommendation Process in Japan

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Note

Rice Breeding at the National Agricultural Research Center for the Tohoku Region (NARCT) and Rice Varietal Recommendation Process in Japan

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Abstract : This report, specifically, aims to introduce the breeding methodologies at the NARCT as much as the varietal recommendation process being used in Japan which is considerably different from that in other countries. In addition, it aims to provide new insights through broader experience in rice breeding. Vastly covered by mountains and forests, Japan cleared about 3 million hectares for rice cultivation. Despite the scarcity in arable land and the geographical limitation that allows Japanese farmers to grow a rice crop only once a year, the country has incredibly managed to stabilize the domestic rice production and grain supply. This remarkable achievement was largely due to the following factors : vast irrigation networks, improved rice cultivation techniques, efficient mechanized farming practices, and use of improved varieties that are highly suitable to local growing conditions. In the improvement of rice varieties, long before the advent of the Green Revolution, Japan already had a long history of rice varietal improvement through classical breeding. The integrated rice breeding program has been implemented by the Japanese government since 1903. Complemented by the presence of highly organized farmers' cooperative systems and rice distribution channels, backed up with strong government support through reasonable pricing policy, the country's breeding programs for rice have achieved meaningful contribution to rice self-sufficiency. At present, there are 13 paddy rice breeding centers funded by the Ministry of Agriculture, Forestry and Fisheries (MAFF). Among the breeding centers, the National Agricultural Research Center for the Tohoku Region (NARCT) has the oldest history. It started the breeding in 1910 and has developed some popular varieties such as Rikuu 132. The variety Rikuu 132 has become a basic variety to improve grain quality, giving rise to other varieties like Koshihikari. In addition, NARCT contributed to rice breeding works like the hot water treatment in crossing. Hence, for young breeders, it is best to gain knowledge and learn additional skills in rice breeding at NARCT. Furthermore, to have an understanding of how Japanese breeders carry out their breeding objectives in response to the problems faced by the local farmers, this report was made. This report includes the rice cultivation and the history of rice breeding in the Tohoku region, the breeding targets of rice breeding at NARCT, the breeding procedure and the screening methods of important traits such as cold tolerance, resistance to leaf blast, resistance to panicle blast, identification of true blast resistant genes, eating quality and so on. This report also covers the rice breeding in prefectures as well as varietal recommendation process in prefectures. Work sharing for breeding and related activities at the NARCT are also illustrated.

Key words : Rice, Variety, Breeding, Tohoku, Japan, English report

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東北農研センターにおける稲育種および日本における稲品種普及システム：滝田 正*[1]・Renand O. Solis*[2]

抄 録：これは，他国とは異なる方式で行われている東北農研センターの水稲育種および日本における水稲品種普及システムについて外国に紹介するための英文報告である。日本は山林に囲まれた狭い大地に300万 ha の水田を切り開き，国民に十分に供給できる安定した米の生産を成し遂げた。これは，灌漑システムの確立，栽培的改良，機械化，それぞれの地域に適した品種育成の結果である。品種改良については，世界における緑の革命以前から，日本は独自に系統的に取り組んできた。そのシステム化された稲の品種改良は，政府によって1903年から始められたものであるが，良品種については県や農業協同組合の協力も得て種子供給体制も確立し，稲の品種改良は米の自給率向上に大きく貢献した。現在，農林水産省の水稲育種組織は13カ所あるが，なかでも東北農研センターの水稲育種は最も古い歴史をもっている。その育種は1910年に始まり，「陸羽132号」等の主力品種を数々育成し，日本の稲育種のリーダー的役割を果たしてきた。ちなみに「陸羽132号」は「コシヒカリ」のような良質・良食味品種のベースとなった品種である。また育種研究面では交配における温湯除雄法を開発したところである。したがって，東北農研センターにおける水稲育種を知ることは，若手ブリーダーに有意義であると思われる。さらに，日本の稲ブリーダーが個々の生産場面のニーズにどう対応しているかを知ることも参考になると思われる。そこで，ここではそうした観点から，東北地域における稲の栽培と品種改良の歴史，東北農研センターにおける稲の育種目標，育種方法，耐冷性，葉いもち，穂いもち，いもち病真性抵抗性遺伝子，食味等の重要特性の検定法について論述した。次いで，県における品種改良，品種の普及システムについて論述した。最後に，東北農研センターの育種事業における具体的な任務分担，育種事業と関連した生産者との関係などその他の業務にも言及した。

キーワード：稲，品種，品種改良，東北，日本，英文報告

Contents

Introduction

Vastly covered by mountains and forests, Japan cleared about 3 million hectares for rice cultivation. Despite the scarcity in arable land and the geographical limitation that allows Japanese farmers to grow a rice crop only once a year, the country has incredibly managed to stabilize the domestic rice production and grain supply. This remarkable achievement was largely due to the following factors : vast irrigation networks, improved rice cultivation techniques, efficient mechanized farming practices, and use of improved varieties that are highly suitable to local growing conditions.

In the improvement of rice varieties, long before the advent of the Green Revolution, Japan already had a long history of rice varietal improvement through classical breeding. The integrated rice breeding program has been implemented by the Japanese government since 1903. Consequently, the rice cultivars developed through this system became widely cultivated then. Further development of these cultivars led to the introduction of better high-yielding rice varieties.

Complemented by the presence of highly organized farmers' cooperative systems and rice distribution channels, backed up with strong government support through reasonable pricing policy, the country's breeding programs for rice have achieved meaningful contribution to rice self-sufficiency. At present, there are 13 paddy rice breeding centers funded by the Ministry of Agriculture, Forestry and Fisheries (MAFF) as shown in Fig. 1. In addition, there is one upland rice breeding center also funded by MAFF located near the National Institute of Crop Science (NIICS). NICS has a role to coordinate and plan the research for rice breeding. Hence NICS is the center of rice breeding.

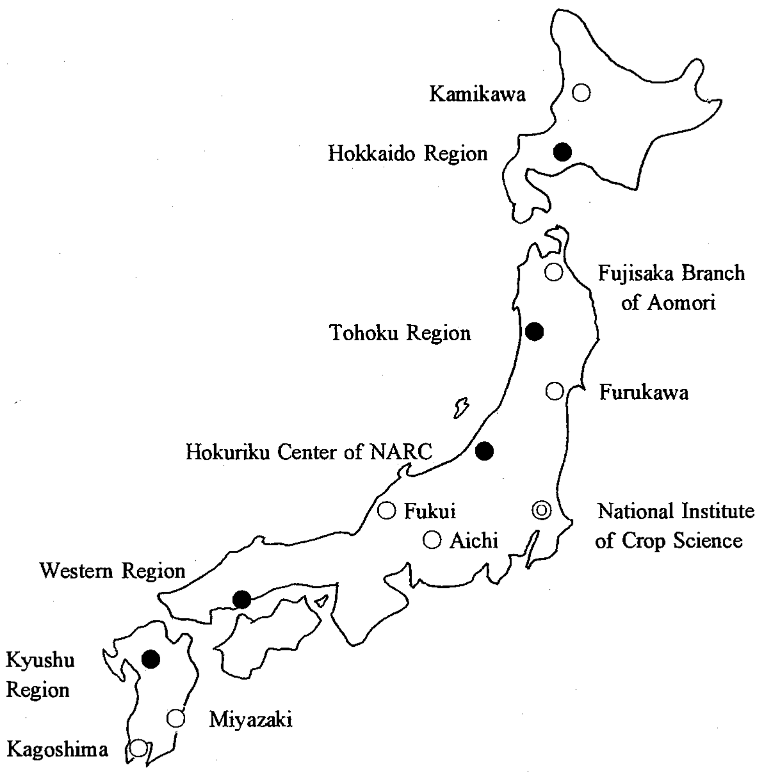

Fig. 1. Rice breeding center funded by the MAFF of Japan.
◎Planning and coordinating center for rice breeding,
●National Agricultural Research Center (NARC) and
○Prefectural Agricultural Experiment Station (AES)

Among the breeding centers, the National Agricultural Research Center for the Tohoku Region (NARCT) has the oldest history. It started the breeding in 1910 and has developed some popular varieties such as Rikuu 132. The variety Rikuu 132 has become a basic variety to improve grain quality, giving rise to other varieties like Koshihikari. In addition, NARCT contributed to rice breeding works like the hot water treatment in crossing. Hence, for young breeders, it is best to gain knowledge and learn additional skills in rice breeding at NARCT. Furthermore, to have an understanding of how Japanese breeders carry out their breeding objectives in response to the problems faced by the local farmers, this report was made.

This report, specifically, aims to introduce the breeding methodologies at the NARCT as much as the varietal recommendation process being used in Japan which is considerably different from that in other countries. In addition, it aims to provide new insights through broader experience in rice breeding.

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I. Rice cultivation in the Tohoku region and rice breeding at NARCT

1. Rice cultivation in the Tohoku region

Tohoku region is about 200 ㎞ north of Tokyo and consists of six prefectures (Fig. 2). It extends almost 200 ㎞ from Pacific Ocean on the east to the Japan Sea on the west. In the south, Fukushima has relatively warm climate, and rice varieties with late maturity like Koshihikari are cultivated. In Aomori, which is more than 400 ㎞ to the north and has short summers and long cold winters, the early maturing varieties are cultivated.

On the coast of the Pacific Ocean, cold wind called Yamase sometimes blows from the north-east from the Pacific Ocean in summer. This causes spikelet sterility which is a serious cold injury in rice. The Ouu mountains run through the center of the Tohoku region from north to south separating the Pacific Ocean side from the Japan Sea side. Since the mountains block the cold wind, the climate of the Japan Sea side is generally milder in summer. During winter, however, the mountains block the wet wind blowing from the west from the Japan Sea resulting in heavy snow on the Japan Sea side.

Rainfall in a year is about 1200 ㎜ on the

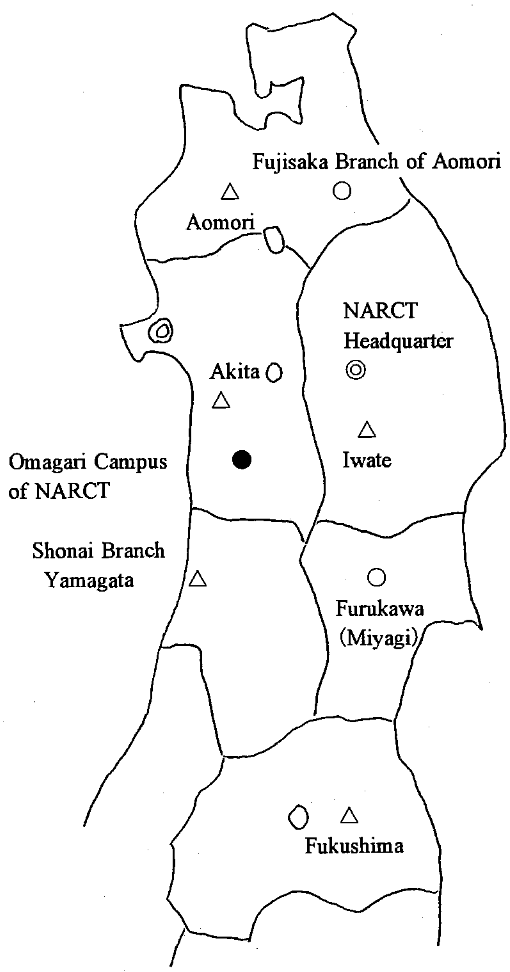

Fig. 2. Rice breeding laboratories in Tohoku.
●Region National Institute,
○Prefectural AES funded by MAFF,
△Other Prefectural AES

Pacific Ocean side and about 1800 mm on the Japan Sea side. This is mainly due to the difference in winter snow. Since there are vast forests and lots of dams to hold the water from melting snow, and irrigation canals are completely constructed, drought injuries is unlikely in paddy rice.

Rice is usually transplanted in May and harvested in September. There are more sunshine hours during the rice season on the Japan Sea side than on the Pacific Ocean side, thus the yield is obviously higher and more stable on the Japan Sea side.

However, area planted to rice was decreased gradually from 630,000 ha in 1965 to 433,000 ha in 2000 (Table 1). This is due to the fact that farmers shifted to planting other crops in the 1970's after Japan attained self sufficiency in rice in 1970. Although the rice production decreased remarkably, the Tohoku region contributes about 30% of the total rice production. So the Tohoku region is still an important place as "the rice bowl" of Japan.

The leading rice varieties in 1970 were Sasanishiki, Reimei, Fujiminori and Toyonishiki which have high yielding ability (Table 2). Nowadays, we have Hitomebore, Akitakomachi, Koshihikari and Haenuki which have good eating quality (Table 3). Good eating quality of Hitomebore and

Table 1 Total area and production of rice in national Japan and the Tohoku region

Year	Area (x1000ha)		Production (x1000t)		Yield (t/ha)	
	National	Tohoku	National	Tohoku	National	Tohoku
1955	3222	567	12385	2428	3.96	4.31
1960	3308	604	12858	2730	4.01	4.59
1965	3255	630	12409	2864	3.90	4.63
1970	2923	618	12689	3258	4.42	5.35
1975	2764	631	13165	3475	4.81	5.53
1980	2377	571	9751	2342	4.12	4.10*
1985	2342	572	11662	3302	5.01	5.77
1990	2074	522	10499	2946	5.09	5.65
1991	2049	520	9604	2583	4.70	4.97*
1992	2106	534	10573	2904	5.04	5.45
1993	2139	545	7834	1654	3.67	3.04*
1994	2212	558	11981	3236	5.44	5.81
1995	2118	539	10748	2805	5.09	5.21
1996	1977	503	10344	2807	5.25	5.58
1997	1953	500	10025	2798	5.15	5.60
1998	1801	459	8960	2415	4.99	5.26
1999	1788	458	9175	2577	5.15	5.64
2000	1770	454	9490		5.37	
2001	1700					

Note. 1) Area and production : Total of paddy and upland rice.
2) Yield : Average of brown rice in paddy rice.
3) * : yield affected by cold injury.

Table 2 Leading rice varieties in Tohoku region and the area planted

1960		1970		1980		1990		1995		2000	
Variety	Area(%)	Variety	Area(%)	Variety	Area(%)	Variety	Area(%)	Variety	Area(%)	Variety	Area(%)
Sasashigure	16	Sasanishiki	24	Sasanishiki	32	Sasanishiki	41	Akitakomachi	23	Hitomebore	30
Towada	16	Remei	19	Kiyonishiki*	18	Akitakomachi	15	Hitomebore	23	Akitakomachi	24
Norin 41	12	Fujiminori	15	Akihikari	15	Mutsuhomare	9	Sasanishiki	14	Koshihikari	12
Chokai	7	Toyonishiki*	7	Toyonishiki*	13	Koshihikari	6	Mutsuhomare	9	Haenuki	10
Hatsunishiki*	7	Yoneshiro	6	Sasaminori*	3	Hatsuboshi	4	Koshihikari	9	Tsugaru-roman	5

* : Variety developed at NARCT.

Table 3 Characteristics of leading rice varieties in Tohoku region

Variety	Maturity	Culm length	Lodging resistance	Grain yield	Eating quality	Cold tolerance	Blast resistance		
							Gene	Leaf	Panicle
Akihikari	Very early	M	◎	◎	△	△	*Pia*	◎	○
Akitakomachi	Early	ML	△	△	●	◎	*Pia, i*	○	△
Sasanishiki	Moderate	ML	△	◎	◎	△	*Pia*	△	△
Kiyonishiki	Moderate	ML	○	◎	○	△	*Pia*	◎	○
Toyonishiki	Moderate	ML	○	○	△	△	*Pia*	●	●
Hitomebore	Moderate	ML	△	△	●	●	*Pii*	△	○
Haenuki	Late	S	●	△	●	●	*Pia, i*	○	○
Koshihikari	Verylate	L	△	△	●	●	+	△	△

Note. Culm length, M : moderate, S : short, L : long, ML : between M and L.
● : Best, ◎ : Good, ○ : Acceptable, △ : Poor.

Akitakomachi is derived from Koshihikari known for its famous good eating quality (Fig. 4). However, Hitomebore and Akitakomachi have undesirable characteristics such as weak lodging and blast resistance.

2. History of rice breeding at NARCT

The Department of Paddy farming research at National Agricultural Research Center for the Tohoku region (NARCT) is in Omagari city of Akita prefecture while the NARCT headquarters is in Morioka city of Iwate Prefecture. The Omagari Campus was established in 1896 to develop technologies to increase the rice production in the Tohoku region. We celebrated the 100th anniversary in 1996. It is suitable to do research for rice cultivation and breeding at the Omagari campus because the climate represents the Japan Sea side of Tohoku (Fig. 3). In addition, the climate is favourable for blast disease development which is very serious in the Tohoku region.

Nowadays the Department of Paddy farming comprises six research laboratories. They are rice breeding, soybean breeding, crop eco-physiology, weed control, disease and pest control and soil management. The laboratory for soybean breeding is located in Kariwano town about 10 km west of the Omagari campus.

The rice breeding started in 1910. The famous varieties developed were Rikuu 132 and Toyonisiki. These were cultivated not only in the Tohoku region but also in other regions. Rikuu 132 which was released in 1921 became a representative variety. It was then early maturing, high yielding, with good eating quality, blast resistance and cold tolerance. In 1939 it was planted in about 200,000 hectares in the Tohoku region. However around 1963, it was replaced by the introduction of short culm varieties. But then, most of the leading varieties such as Sasanishiki, Akitakomachi, Hitomebore and Koshihikari as shown in Table 2 were offsprings of the Rikuu 132 (Fig 4). On the other hand, Toyonishiki which was released in 1969 was high yielding and resistant to blast, and with good physical grain quality (Table 3). Unfortunately, Toyonishiki had proved to have poor eating quality, and then the planting area decreased. However it contributed to the improvement of blast resistance as a parent material. For instance, Chiyonishiki and Manamusume, which are resistant to blast and have good eating quality, are the offspring of Toyonishiki.

3. Present breeding targets and the results at NARCT

There are seven prefectural breeding laboratories funded by the government or MAFF (Fig. 2) and these are concentrating on the improvement of eating quality (Chapter Ⅳ). However, at NARCT, we

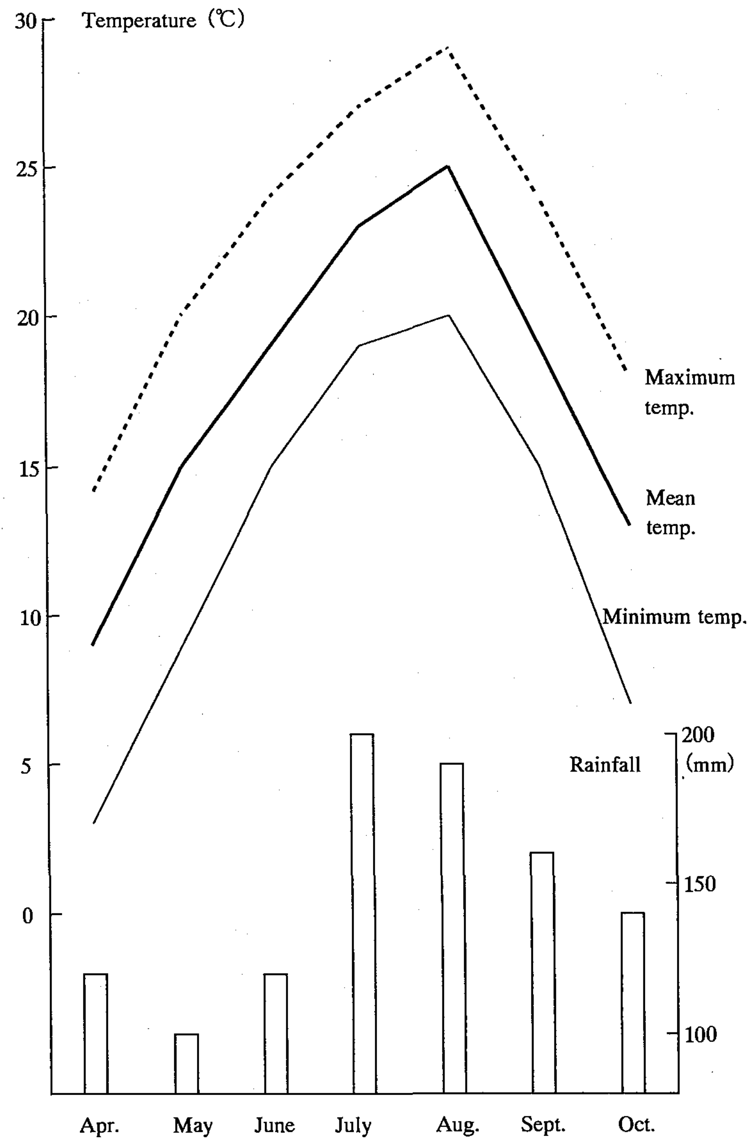

Fig. 3. Temperature and rainfall at Omagari during rice growing season.

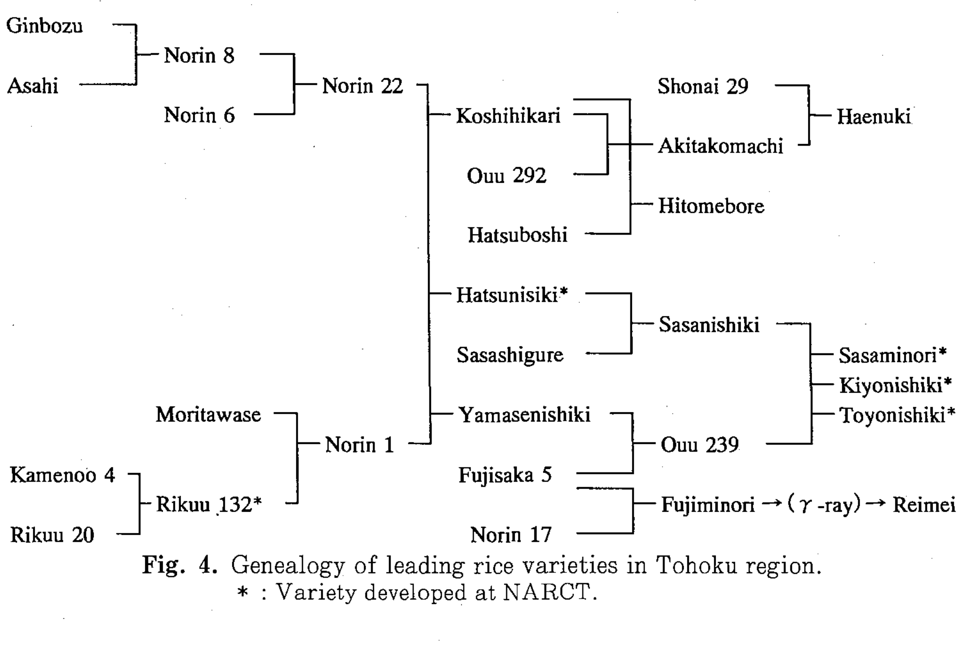

Fig. 4. Genealogy of leading rice varieties in Tohoku region.
* : Variety developed at NARCT.

Table 4 Rice varieties recently developed at NARCT (1993－2001)

Variety (Year released)	Maturity	Grain yield	Eating quality	Cold toleranc	Blast resistance Gene	Leaf	Panicle	Others
Asamurasaki (1996)	Early	△	Glutin.	△	*Pia*	○	△	Purple grain
Okuno-murasaki (2000)	Early	○	○	△	*Pib*	?	?	Purple grain
Snow pearl (1998)	Early	○	●	△	+	△	△	Low amylose
Fukuhibiki (1993)	Moderate	●	○	△	*Pia, b*	○	○	High yielding
Okiniiri (1996)	Moderate	●	●	◎	*Pia, i*	◎	◎	Blast resitance
Ouuu 354 (2001)	Moderate	◎	●	○	*Pia*	○	○	Low amylose

Note. ● : Best, ◎ : Good, ○ : Acceptable, △ : Poor, Glutin. : Glutinous

Table 5 National breeding projects conducted at NARCT

Project	Term	Fund (yen) in 2001
Breeding for direct seeding	2001－2004	5,564,000
Breeding for hybrid rice and new characteristics*	2001－2005	5,564,000
Breeding for animal food	2001－2003	2,602,000

* : New characteristics include low amylose, colored rice and rice for ornamental.

have five main targets, which are associated with the national projects (Table 5). Blast resistance and cold tolerance are not included in the projects but are indispensable traits in any breeding targets. The five main targets of NARCT are the following.

First is direct seeding which is very important as one of the ways for low cost production. In breeding, resistance to root lodging and seedling establishment are most important. Breeding has been carried out since 1994, and then some improved strains for root lodging were developed but seedling establishment is yet to be satisfied so far. The use of DNA markers for the selection is now on its way.

Second is high yield which is important for animal foods. We developed Fukuhibiki in 1993 which has an ideal plant type and 10 % higher yield than Akihikari which was once one of the leading varieties with high yield (Table 2, 3, 4). Fukuhibiki consistently yielded more than 8 tons/ha of brown rice. Fukuhibiki even gave 10 tons/ha at Aidu valley in Fukushima Prefecture. Breeding effort is also devoted to develop rice strains with superior yield and biomass as whole crop silage or feed grains. At NARCT, strains that produce exceptionally large grains have been bred for this purpose. It is found that their grains are suitable for feed grains because large grains are associated with high yield, distinguished from ordinary varieties and broken easily.

Third is hybrid rice, which technology has become a very popular approach in many rice-growing countries to overcome the stagnating yield potential of the current inbred rice varieties. Although the technology itself has not been of prime interest among Japanese rice breeders, we have embarked on the study of hybrid rice and heterosis for generating more basic knowledge. Then we decided to go for indica-japonica hybrids. Takita et al. (2000) confirmed that yields of the hybrids are more than 20 % higher than Fukuhibiki. We also found that the japonica-indica hybrid can be high yielding on account of the effect pyramiding the good characteristics from both of the indica and japonica (Table 6). For instance, japonica is superior in cold tolerance and long ripening period, while indica is superior in plant type and photosynthetic ability. Luckily, indica-japonica hybrid can possess all of these superior characteristics. More research on this aspect are currently going on.

Fourth is colored rice, of which the grains seem to be good for health because the colored rice

Table 6 Pyramiding effects of important traits in japonica-indica hybrid (Takita et al. 2000)

Type	Tolerance to low temperature	Plant type	Sink size	Length of grain ripening	Leaf Senescence	Yielding ability
Hybrid(J/I)	○ tolerant	○	○	○ long	○ late	◎ stable
Japonica	○ tolerant	△	△	○ long	○ late	△
Indica	× susceptible	○	○	× short	× early	△

◎ : Very good, ○ : Good, △ : Moderate, × : Poor.

grains contain some physical functional matter such as anthocyanin. They have not been improved for a long time. So we developed glutinous Asamurasaki with purple grains in 1996. Since the grains have the attractive purple fresh color, they are used as natural color materials in the food industry. In addition we developed the nonglutinous Okuno-murasaki with purple grains in 2000. Since Okuno-murasaki has nonglutinous large grains, it can be used as material for colored rice, colored rice wine and others. The nonglutinous red rice strain Ouu 370 will be released next year. Colored leaves and panicles are also interesting because they give beautiful scenery. We have already developed some strains which possess purple panicles or red panicles with conspicuous long awns.

Fifth is low amylose content which is useful for processing. We developed Snow pearl with low amylose content grains, which has good eating quality in cold rice condition and is suitable for instant food processing. It is also suitable as mixing material for low eating quality rice grains. We also developed Ouu 354 with low amylose content grains, however its low amylose gene is different from Snow-pearl. Furthermore, it has short culms.

II. Procedure of hybridization, selection and yield trials at NARCT

1. Planning of hybridization and crossing method

It is very fundamental that plant breeders should have broad knowledge about the materials used in crossing and generating new populations. The genetic traits of the parental materials, especially the major resistance genes and the other major traits that they possess, should be properly recorded. This is to ensure that crossing work results in the desired complementation of these traits in the F1 generation.

New genetic resources such as mutant lines and back-cross inbred lines that have been developed and thoroughly characterized in other breeding stations and research institutions are a common source of novel genetic traits. Generally, breeders in Japan avoid the use of lines or varieties that have vague background or origin and lack proper characterization of the traits that they intend to utilize in the hybridization program. They are practically careful in introducing new traits into their cultivated germplasm. Also, knowledge on parental backgrounds will provide easier evaluation of the resulting progeny lines.

A discussion meeting for the cross planning is usually held in March just after the regional winter conference for rice research, in which new breeding lines are reported. About 50 combinations are planned for ordinary targets. But more than 100 combinations are planned for breeding research.

At the NARCT, hybridization work usually starts in late July and can be done continuously until the end of August. Although off-season hybridization is possible inside the greenhouse with a heating device, it is not efficient due to the unfavorable weather.

Parental materials are planted separately in the field and sometimes are from the observational plots. Breeders opt for staggered planting to attain the synchronization of flowering. The main technique to sterilize the maternal plants prior to crossing makes use of an automated water bath that is commercially available.

At the heading stage, female plants that have unopened spikelets are potted out in late afternoon and taken inside a shaded area or cool dark room. This is to prevent the opening of flowers before sterilization time the next morning. One of the options is to store the potted plants inside an air-conditioned room, however this practice may cause difficulty in the opening of sterilized spikelets. On the other hand, male panicles are also taken in late afternoon and put in test tubes containing water, and then they are kept in a warm room to enhance the opening of flowers the next morning. Furthermore, there is another option to induce the opening of flowers in male parents. It is simply to immerse their panicles in a hot bath at 43 ℃for 40-50 seconds which is used for sterilization. These treatments are very efficient for doing the crossing earlier. After the confirmation of spikelet opening in male panicles, the sterilization of female plants is achieved by immersing the panicles into the hot bath at 43 ℃ for 5 to 7 minutes. Heat-treated female spikelets are allowed to open soon after the treatment, and then spikelets that fail to open are removed using ophthalmology scissors and this require lots of labor. Then the remaining opened spikelets are cross-pollinated in an isolated area with male parents as soon as possible.

2. Generation advance and bulk selection

Most of the F_1 seeds are sown in a green house in September soon after the cross-pollinated seeds have ripened. They are usually harvested in February, and then the F_2 seeds are sent to other stations for generation advance. F_1 seeds that are not sown in the green house are grown in a field next season. Then, the F_2 seeds either go to generation advance just one year later or to F_2 bulk selection the next year, which is not common in Japan.

The majority of the breeding stations in Japan have limited capability for rapid generation advance because of the unfavorable winter conditions. Through close collaboration with the Japan International Research Center for Agricultural Science (JIRCAS) in Okinawa, F_2 seeds are shuttled from the NARCT to JIRCAS station for early generation advance by bulk method. Bulked F_2 and F_3 populations are maintained without selection at JIRCAS, then the F_4 seeds are sent back to NARCT and planted as bulked populations (Fig. 5).

Individual plant selection is usually done for the F_4 generation according to breeding objectives. At this stage, selection is done for plant type, culm length, blast resistance and for highly heritable traits based on the criteria in the field. Three to four panicles are taken from each selected plant to constitute an individual line in the next generation. About 50 grain samples are dehulled for visual inspection of their physical grain quality. Plants that have poor grain quality are discarded.

3. Pedigree selection and family line selection

As illustrated in Fig. 5, the selected F_4 plants constitute single lines or pedigrees in the F_5. The single lines are planted in 3 m long two-row plots. The distance between hills is 15 ㎝ and the distance between single lines is 30 ㎝. About 36 seedlings are transplanted per single line. Each line is observed for maturity, plant type, yielding ability and segregation, and finally each of the single lines is selected by interests of the breeders. All of the selected lines are then evaluated for viviparity (tendency for early sprouting). Lines that exhibit a lesser extent of germination or strong dormancy are selected. Then three to four panicles are taken from each of the selected five plants in each

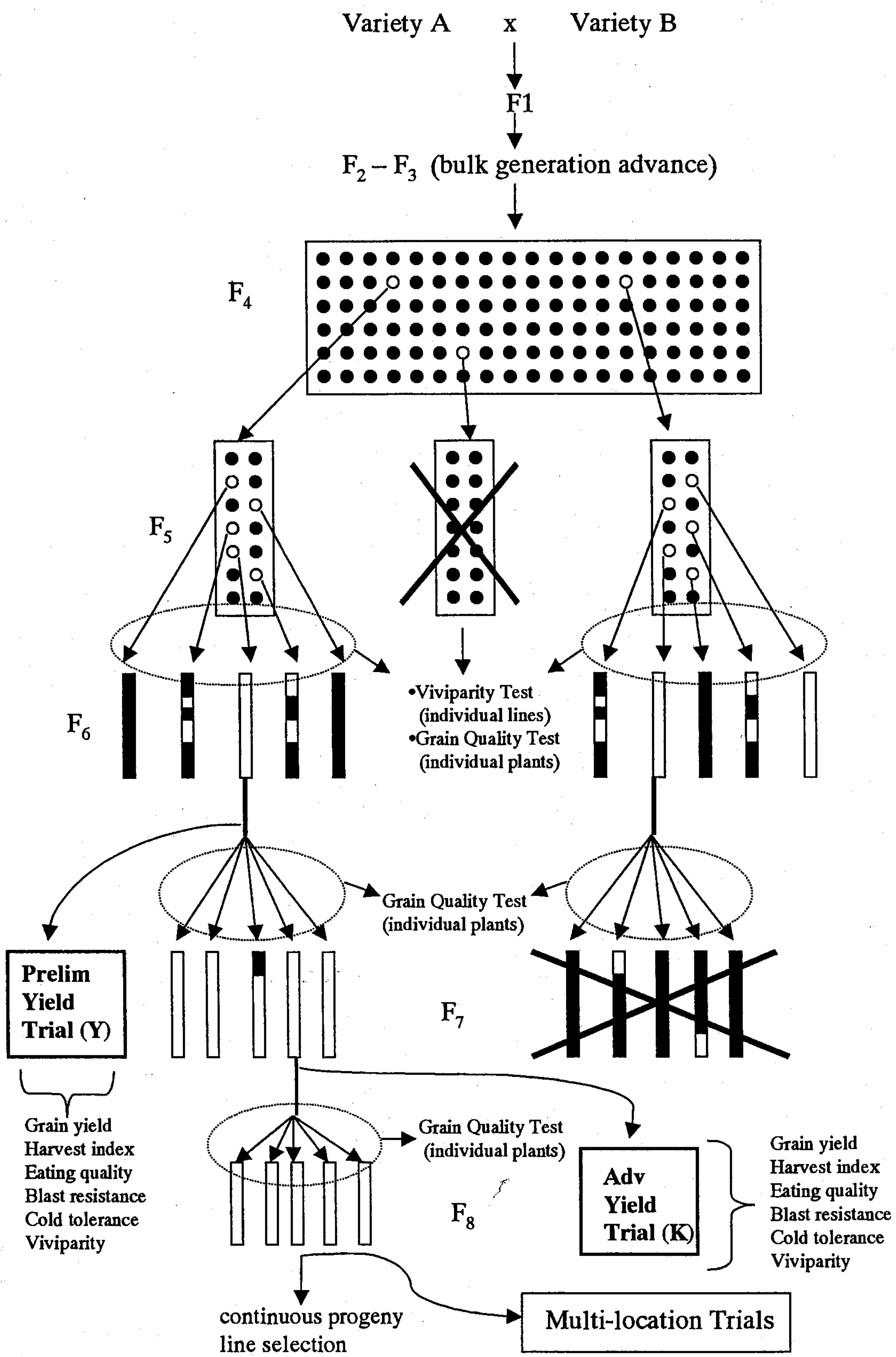

Fig. 5. Schematic diagram of the general breeding procedure at NARCT.

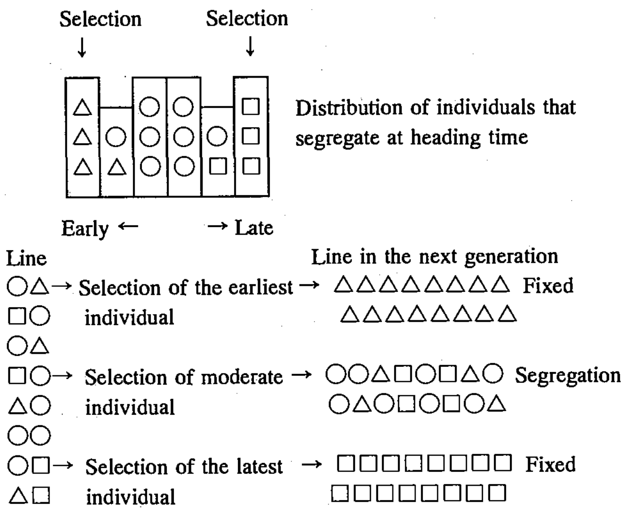

Fig. 6. A model of both ends selection in the segregating line at heading time (Takita 2000).

selected line. The physical grain quality of individual plants is examined from the harvested seeds in the same way as in bulk selection. As a result, some of the lines are further discarded and finally the five plants from each line will constitute one family lines in the next F_6 generation.

Once the single line is selected in F_5, the remaining seeds are collected together, and are used for the preliminary yield trial (Y trial). Some tests for important traits such as cold tolerance, the resistance to leaf and panicle blast are concurrently conducted. Consequently, in the next F_6 generation, the selection is not only based on observation of the lines but also yield trial and other tests. As a result, families are selected first, then each of the superior lines in the selected families is selected in the same way as the single line selection. When the F_6 lines are segregated, the breeders select the most uniform line within a family. After field selection, data on yield, physical grain quality, grain size, eating quality in the grains are taken, and more undesirable families are discarded. Finally, only 10-20 % of families are maintained every year.

This progeny selection provides a good system for simultaneous purification of lines during performance tests. It further ensures the availability of breeder seeds for subsequent multi-location trials. At the NARCT, the progeny lines are maintained to achieve accurate purification and countercheck. Breeders constantly examine the segregation, maturity, plant type, panicle type, resistance to blast and overall phenotypic acceptability of each progeny line in the field and select for advance trials. If segregation of heading time or culm length are observed within the line or within the single family lines, breeders generally select the type on both ends, that is the earliest type or latest type, or shortest type which seem to be homozygote genotypes (Fig. 6, Takita 2000). It is confirmed that both end selection is reasonable and efficient to get fixed lines in the next generation. This process of progeny selection is continued until a line is discarded or stopped to maintain the high purity of breeder seeds.

4. Yield trials and selection

Entry lines in the Y trials are normally planted in 4-row plots, 5 m long, 30 cm apart and with 15 cm distance between hills which makes 19 hills／m². Single hill usually contains three to four seedlings. Fertilizer is applied at the rate of 60 kg N／ha before transplanting and 30 kgN／ha 20 days before heading time. Planted in one replication, the entries are grouped according to maturity and breeding objectives. Observation of the lines is usually done at the tillering stage for evaluation of initial growth, at heading time for recording the heading date and at maturity for recording the date of maturation, lodging score and other pertinent information. When the line proved to have undesirable traits such as weak blast resistance and low yield, it is discarded right in the field and is never harvested in the yield trial.

For yield determination, the two-inner rows of 40 plants are harvested from the 1.8 m² portion of the plot, and their total weight and that of the threshed grains are measured on a hectare basis. The grains are dehulled and screened on a sieve with 1.8 mm mesh, then the yield of brown rice is measured at 15% moisture content. It is standard in Japan to express the grain yield in terms of brown rice yield per hectare.

After the yield determination, a portion is set aside for evaluation of the physical grain quality and 1000-grain weight, and the other portion is used to determine the eating quality of cooked rice, as shown in chapter Ⅲ. Usually conducted in winter, this is a long process and it takes several months to evaluate all the entries.

All Y entry lines are also planted in the nursery for the evaluation of leaf and panicle blast resistance, and cold tolerance. A viviparity test using panicles in yield trials is also conducted in autumn. The results from these tests are integrated with the data from the yield trials to form the basis for elevating the lines to advanced yield trials designated as K trials. In addition, breeders also take note of the field performance of the corresponding family lines in the pedigree field. When the Y entries show extreme variation among lines within a family, they may either be discarded or further purified. Then, only 10-20 % Y entries remain every year.

At the NARCT, new lines that are to be evaluated in the advanced performance tests bear the Ukei name and code number (e. g. Ukei 343). Hence about more than 20 new Ukei lines are added every year. Then the Ukei lines become the candidates for new important lines bearing the Ouu name and code number subjected to varietal recommendation test (VRT) or multi-location test at the prefectural Agricultural Experiment Station (AES) as shown in chapter Ⅳ. In the K yield trials, all of the Ukei and the Ouu lines are planted together in the same field with two replications. In addition, another cultivation method such as high N condition or direct seeding are used to evaluate further field performances. A the NARCT, randomized complete block design is not adopted in the yield trials because it is too troublesome to plant and observe in the breeding testing lots of lines. Instead, one or two check varieties are planted in every ten entries to distinguish the difference between the checks and testing entries. Furthermore, Ukei lines are sent to other AESs to evaluate the local adaptability. Other treatments are the same as the previous Y trials.

In winter, after integrating all of the data, less than 10 Ukei lines are finally selected. Then only two or three Ukei lines, which are obviously outstanding in both of the check varieties and old Ouu lines, are selected and given the new Ouu code (e. g. Ouu 371). Thus, Ouu lines result from final selection in the breeding laboratories. On the other hand, the other remaining Ukei lines continue to be evaluated again with the same Ukei number. This must be done before the regional winter conference because the new Ouu lines are to be reported during the conference.

5. Seed storage for advanced lines

All of the Ouu lines generally must be sent to the prefectural AES for the VRT until they will be discarded or recommended for new release. In the Ouu line stage, the K yield trials and the tests for important traits are conducted concurrently. In addition, seeds must be propagated to prepare for wide multi-location test in prefectures. When one of the Ouu lines is recommended for new release by prefectures, the breeders seeds or the lines are shared.

After the Ouu lines are finished in VRT, the seeds are stored as gene sources in two places. One is the breeding laboratory at the NARCT which developed the lines, and the other one is at the National Institute of Agro-biological Science which manages the research project on gene resources and possesses large long term seed storage rooms. The seeds are available and free of charge only by requests from researchers at the National Institute, otherwise they are not free but available.

Ⅲ. Important traits and the screening methods at the NARCT

Japan has a considerably large breeding network for rice improvement that is distributed throughout the main archipelago stretching along a 2,000 ㎞ northeast to southwest axis. The different agro-ecological regions of Japan reveal some distinct characteristics and striking differences in climate pattern that necessitate the development of specifically adapted rice varieties. The NARCT is one of the five regional National Agricultural Research Centers funded by the MAFF to undertake specific breeding objectives for paddy rice. Among the regional centers, the important traits at the NARCT have been cold tolerance and blast resistance. The other ones such as viviparity and grain quality are important throughout the country. To select the superior varieties, breeders have made efforts to improve the screening method. The following methods are presently used to evaluate the important traits.

1. Cold tolerance

In the Tohoku region, tolerance to cool temperature is one of the most important traits that have to be incorporated into the lines of rice. Irrigation water coming from the mountains is supplied to the paddy at a temperature of about 15 to 18 ℃ from May to June. The low water temperature during this stage causes the typical yellowing of leaves and sometimes death of non-tolerant seedlings. In this tolerance, indica is very susceptible while japonica is very tolerant. Low temperature during the vegetative growth causes delayed heading due to growth retardation, resulting in yield decrease associated with incomplete grain ripening. However, the damage caused by delayed growth is no longer serious nowadays because farmers use the early maturing varieties.

The damage at the reproductive stage about 12 days before heading is most serious because it causes the yield decrease directly. Such severe cold injury caused by cold wind called Yamase occurred six times during the past 30 years (1971, 1976, 1980, 1981, 1988 and 1993). The damage in 1993 was the most serious with more than 50 % yield decrease in three prefectures (Aomori, Iwate and Miyagi) in the Tohoku region. Hence we are concentrating on the tolerance at the reproductive stage (Takita 1994).

Spikelet sterility is a result of cold damage during the reproductive stage. Researchers generally believe that the meiotic stage of pollen formation is most sensitive to low temperature. Abnormal growth of pollen mother cells and incomplete separation of tetrad microspores have been commonly observed as direct effects of cold damage. The genetics of cold tolerance has been intensively studied in Japan. On the other hand, some reports suggest that the damage at heading time is also associated with sterility. However, the evaluation has not been conducted in breeding.

In most breeding stations in Tohoku, screening the breeding lines for cold tolerance is done by means of an automated system where cold irrigation water at a temperature of 19－19.5 ℃ can be

Table 7 Check varieties for cold tolerance in Tohoku region

Maturity	Tolerance level 2(very tolerant)	3－4	5(moderate)	6－7	8(very susceptible)
Very early	Hamayutaka	Cyubo 36	Kitaou	Hayanishiki	
Early	Hananomai	Yamauta	Reimei	Akihikari	Hideko-mochi
Moderate	Todoroki-wase	Koganehikari	Akihomare	Toyonishiki	
Late	Koshihikari	Ozora		Norin 21	

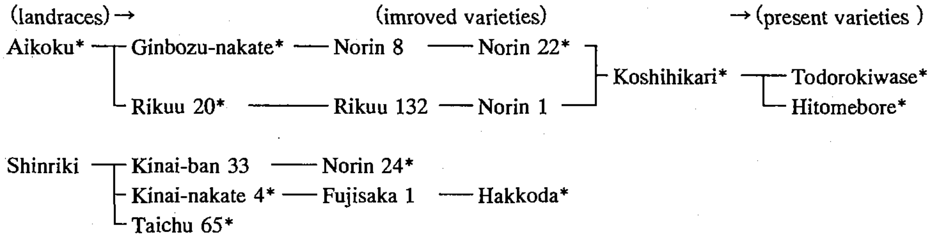

Fig. 7. Genealogy of cold tolerance in Japanse rice varieties.
* indicates tolerance (Sasaki and Matsunaga 1985).

maintained in the nursery. The facility makes use of thermo-sensors installed at several points in the nursery that are connected to the electronically controlled water pump unit. When the temperature in the nursery goes up, the pump automatically draws cold water from the well and supplies it to the nursery to maintain the screening temperature. The cold water is maintained at 20 cm depth from panicle initiation to the heading stage.

There are check varieties in each maturity group (Table 7). The evaluation is done together with the same maturity group. The degree of spikelet sterility is generally used to evaluate the tolerance of the entries with the scale 1 : 10％ to 9 : 90％. For instance, 8 to 9 will be scored in susceptible varieties such as Akihikari and Sasanishiki, and only 2 to 3 in more tolerant varieties such as Koshihikari and Hitomebore. By this method, tolerant lines can be separated from the non-tolerant ones by evaluating only five plants per entry.

In addition, breeding lines bearing the Ukei name or Ouu name are sent to several stations such as Furukawa where there are cold tolerance testing fields to evaluate the spikelet sterility. This evaluating system is very effective because breeders can have a general conclusion through the tests. Moreover, the data can be used directly when the breeder failed the test at their station. The same system is also being used in leaf and panicle blast tests.

Breeders take advantage of the high additive effect of the cold tolerance genes that allows them to pyramid these genes into the new varieties to increase their tolerance. For instance the most tolerant Hatajirushi (old name Jodeki) was released in 1997 and it showed a normal yield in the year 1993 when the most severe cold damage occurred. Since the tolerance was more than both of the parents, its tolerance is then the result of pyramiding effect. Sasaki and Matsunaga (1985) found that the cold tolerance is obviously inherited from the parents by descendants (Fig. 7).

2. Resistance to leaf blast

Rice blast caused by the fungal organism, *Pyricularia oryzae*, is the most serious disease in the region. The relatively high humidity during the growing season is very adaptable for blast disease development. Incidentally, the most popular varieties that are grown in Japan, such as Koshihikari and Sasanishiki, are very susceptible to blast, so many farmers resort to extensive use of fungicides to control the disease.

In breeding for blast resistance, rice breeders emphasize the importance of field or partial resistance over true or complete resistance. Partial resistance has quantitative inheritance that is governed by polygenes with additive effect. On the other hand, complete resistance is qualitatively inherited and conferred by single genes with major effect. The latter is based on the ability of a pathogen race to infect a specific range of hosts. Massive deployment of complete resistance in the field is believed to result in rapid breakdown of the resistance when the pathogen evolves into a more virulent strain, thus giving rise to an endless arms race between the host and the pathogen. Partial resistance appears to be more stable against the changes in the pathogenicity of the blast fungus.

In 1963 and 1964, a well-known and massive outbreak of blast disease occurred in three prefectures of the Kanto region north of Tokyo. It resulted from the breakdown of the blast resistant gene *Pik* in Japanese cultivar Kusabue and this occurred just two years after its release. Since this was the first breakdown after the first use of complete resistant genes, breeders were shocked seriously. Subsequent introduction of the other major resistant genes showed similar patterns, i. e. they lasted for only a few years. This prompted rice breeders to utilize partial resistance as a strategy to develop varieties that are more durable to the blast disease. In this sense, Toyonishiki with strong partial resistance has illustrated a good example in durable resistance (Table 2, 3). Complete resistance should be combined with partial resistance, or used in the development of multi line varieties. There are now some multi-line varieties but only the Sasanishiki multi line is presently cultivated. However, it is likely that a breakdown of all of the resistant genes in the Sasanishiki multi-line may occur in the near future.

Breeding materials are rated for blast resistance according to a standard scoring system (to be described later) with scales from 1 (strongest) to 9 (most susceptible). Breeders normally recommend varieties with a partial resistance score of 3 to 4, that is resistant to moderately resistant, but a score of 5 to 6 is also acceptable when the variety possesses other excellent traits. Breeders never give the highest score of 1 because they always leave room for improvement. The partial resistance of breeding lines is also evaluated in different stations such as Fujisaka in the same way as the evaluation for cold tolerance.

For screening the lines for partial resistance to leaf blast, seedlings are raised in the nursery under upland conditions. The entries and check varieties are laid out in half-meter furrows. The susceptible spreader variety is sown on the border and along the middle of the one-meter-row plots. In the beginning of June, more than 2000 entries including the check varieties are sown to evaluate the resistance against blast race 037.3 at the NARCT. This blast strain is compatible with plants having the true resistant genes *Pii, Pia, Pik, Pib, Piks, Pikp* and *Pikm*. The susceptible variety Inabawase is used as the spreader. Check varieties that exhibit known reactions to the blast strain are planted in every 50 entries. Three weeks after sowing, when the seedlings reach the 4 to 5 leaf stage, inoculation of the susceptible border plants is done by spraying with spore suspension taken from pure culture of the blast fungus. The nursery is isolated from the other plots by putting a net fence around the area. The net also serves as a wind break to promote formation of dew on the leaves, which is favorable for rapid growth of the blast fungus. The humidity during the rainy season from June to July is also effective. The rate of development of blast lesions generally depends on the humidity in the area. The Inabawase plants that show susceptible lesions one week after the inoculation are pruned and the leaves are scattered all over the nursery to spread the disease through the spreader plants.

Table 8 Scale for blast evaluation (Asaga 1981)

Scale	General description	Diseased leaf area
0	No susceptible blast lesions	0%
1	Few susceptible blast lesions	1%
2	A few susceptible lesions	2%
3	Intermediate number of susceptible lesions	5%
4	Many susceptible lesions	10%
5	A great many susceptible lesions and few dead leaves	20%
6	A few dead leaves	40%
7	Intermediate number of dead leaves	60%
8	Many dead leaves	80%
9	Extensive dead leaves	90%
10	Majority of plants are dead	100%

Table 9 Check varieties for partial leaf blast resistance in Tohoku region

Resistance	Partial resistance level				
gene	2(very strong)	3−4	5(moderate)	6−7	8(very susceptible)
+ or *Pia*	Cyubu 32	Kiyonishiki	Norin 41	Sasanishiki	Koshihikari
Pii or *Pia, i*	Todoroki-wase		Fujisaka 5		Inba-wase
Pik		Himeno-mochi	Mangetsu-mochi		Kusabue

About 5 weeks after sowing, the entries begin to exhibit the susceptible lesions and scoring of all entries is done every three days using the Asaga scale (Table 8). The average of three consecutive readings is computed for assessment of partial resistance. There are check varieties in each group of true resistant genes (Table 9). The final evaluation is done by comparing the data with check varieties.

3. Resistance to panicle blast

Breeding emphasizes resistance to panicle blast because it causes severe damage to yield and no chemical control is available. At the NARCT, evaluation for resistance to leaf and panicle blast disease is being done in separate nurseries. For panicle blast evaluation, the nursery must be situated in more humid condition to achieve a higher infection rate. When the air condition is dry, the incidence of panicle blast may be very low to allow accurate evaluation of susceptibility level and selection of resistant lines. An option to increase the humidity, particularly the amount of dew on the panicles in the morning, is to install water sprinklers around the nursery and sprinkle in the evening or to put a net fence around it for a wind break.

At the NARCT, test entries are planted in two adjacent rows like the pedigrees. The whole plot is surrounded by the susceptible spreader variety Inabawase, planted at both ends of the rows. Check varieties are also planted at regular intervals. Evaluation is done when the grains are half-matured (about 20 to 30 days after heading) to easily distinguish the blast-damaged panicles. The entries are scored for resistance using the modified Asaga scale (from 0 to 9), which is based on the percentage of blast-damaged spikelets. This scoring system is good enough for the evaluation of susceptibility level although the evaluation is done only by observation.

4. Identification of true blast resistant genes

The majority of the rice varieties that are cultivated in Japan possess true resistant genes either *Pii* or *Pia*. A few varieties contain *Pik, Pita-2* or *Pib* genes. When exposed to the blast fungi that are compatible with the resistant genes, some varieties would exhibit susceptible or resistance reaction at varying degrees due to the partial resistance. Before a promising line is to be recommended as a variety, breeders are normally required to submit information about the partial resistant and the complete resistant genes in the line.

On the other hand, prior to the evaluation of partial resistance of the breeding lines, it is an important prerequisite to identify the true resistant genes that they possess. It would be impossible to evaluate partial resistance of the lines without knowledge of the true resistant genes that they possess, and it could be extremely difficult when the lines possess so many true resistant genes. In Japanese varieties, only one or two major genes are normally maintained.

At the NARCT, pure cultures of the important blast races are maintained in the laboratory of disease and pest control for pathogenicity testing. Blast lesions taken from the differential cultivars are used for single spore isolation. The blast isolates are purified from single colonies and maintained in test tubes containing potato dextrose agar (PDA) medium. When inoculation is to be conducted, the fungi are serially propagated in oatmeal agar medium until they produce spores. The spores are harvested by brushing and then mixed with water to produce the inoculum. Inoculation is done by spraying the spore suspension on the test plants. True resistance is identified by determining the compatibility of the lines with a set of blast races through the pathogenicity test.

5. Viviparity

Viviparity (tendency for early sprouting) is an important trait that affects grain quality and storability. There is a rainy season from August to September when rice reaches the harvesting time (Fig. 3). In a spell of rainy days, grains of Japanese varieties have the tendency to sprout due to enough moisture and temperature.

For the test, three panicles are taken from each entry or plot or line with check varieties, and then they are kept in a moisture chamber at 30 ℃ for one week. The entries are scored for the germination rate from 0 : no germination to 9 : 90% germination and then evaluated by comparing them with the check varieties.

6. Physical grain quality

With the oversupply of rice in Japan, along with the declining rate in rice consumption, breeding efforts have given more importance to the generally preferred physical quality of grains and eating quality of cooked rice. The overall quality of rice is related to a number of factors like those of storability, nutrition value, eating quality and processing characteristics. However, at the present situation, breeding procedures for new rice cultivars give primary importance to the physical appearance of brown rice which is associated with milling recovery. The grains with large white belly or white core are not favorable. Grains susceptible to cracks are out of the question. Small grains are neither favorable because they are likely to fall down through the sieve.

During selection of individuals and the progenies in the subsequent generations, breeders at the NARCT evaluate the physical appearance of the grains according to their established scoring system for quality inspection (scale of 1 : best to 9 : worst). Generally, lines that have high frequency of white belly, white core, milky-white, white back and cracked grains are discarded during the evaluation. The glossiness of the grains is also considered in selection. Advanced lines in the yield trials are also subjected to grain quality inspection. When the advanced Ouu lines are sent to the varietal recommendation test, confirmation is done at the different stations for grain quality of the entries by comparing them with a given control variety using the same criteria.

7. Eating quality

Eating quality is believed to be the most important trait in rice as far as Japanese consumers are concerned. Eating quality greatly affects the market value. Competition for eating quality in the market has triggered the development and production of new varieties with excellent grain appearance and taste. High demand for such varieties has led to the development of new cultivars in Tohoku such as Akitakomachi and Hitomebore. These varieties have earned high reputation in the market and became the leading varieties now in the region owing to their quality that is comparable with that of the popular Koshihikari and Sasanishiki. Generally, in the high-quality rice varieties, an average wholesale price is more than 300 yen／kg of brown rice.

The amylose content of the grain starch has been regarded as a major factor that determines the starch quality thus, eating quality of cooked rice, although it is believed that other factors may affect the overall palatability. Recently, the auto-analyzer system specified for starch analysis of rice grains, particularly amylose content, has been adopted for rapid evaluation. Most japonica cultivars have amylose content of about 20％. Koshihikari and Sasanishiki, which are highly preferred by Japanese consumers, have relatively low amylose content of 16％ to 18％. They have sticky and glossy appearance when cooked. The prevalent temperature during the grain ripening period affects the amylose content of rice varieties, thus, the amylose content of rice grains produced in colder places like Hokkaido tends to be higher.

Although most breeding stations have the capability to quantify the amylose content, breeders rely mainly on sensory evaluation for selection. The reason is simply that there are no instruments which can compete with human senses. In addition, once the eating quality test is established, it is not laborious.

At the NARCT and other breeding stations, sensory evaluation of cooked rice is based on three criteria : physical appearance (whiteness and glossiness), stickiness and overall taste. Among the criteria, stickiness and glossiness are obviously associated with the overall taste. Since stickiness and glossiness are evaluated without eating, the overall taste is evaluated without much difficulty.

In the sensory evaluation, the samples taken from the yield trials are milled using a portable miller and boiled in electric rice cookers. Three entries are usually evaluated with two check varieties at one time. The two checks are usually one with good eating quality and the other one with poor eating quality. The scoring system has scales of $+1$ to $+3$ as better, 0 as equal, and -1 to -3 as poorer than the good check. The average score for each entry is calculated and used.

8. Adaptability for direct seeding

The declining price of rice in the Japanese market compels many farmers to expand their area of cultivation. Despite the remarkable increase in the rate of farm mechanization in Japan, problems such as the rapid ageing of the farmers and the diminishing amount of labor force in the field have confronted rice agriculture. On the average, the cost of rice production amounts to about 1.2 million yen per hectare, more than 10％ of which accounts for the cost of raising and transplanting the seedlings. These important concerns are being addressed by rice breeders through approaches that reduce the amount of labor required for rice cultivation, and one of them is direct seeding technology.

In Japan, direct seeding is mainly divided into two methods i. e. dry seeding and water seeding.

Dry seeding was carried out a long time ago and is still carried out in some special places. However, since puddling and leveling are not conducted in dry seeding, it was found that there are problems for seedling establishment and weed control due to rapid water percolation. In addition, dry seeding tends to be considerably late in seedling emergence and therefore considerably late in heading time. Hence, we concentrate on water seeding which is being practiced in mechanized ways such as broadcast seeding (on the surface of flooded soil) and anaerobic drill seeding (under the surface of flooded soil). Farmers commonly facilitate the practice of anaerobic seeding by coating the pre-germinated seeds with oxygen-releasing chemical Calper (calcium peroxide) because it is effective for stabilizing seedling establishment and root lodging. However, since the coating technology requires additional labor and costs, many farmers demand varieties that can establish well in anaerobic condition upon sowing without any chemical treatment. More breeding effort is deemed necessary to improve the performance of rice varieties under this condition. However it is likely that it will take time to improve such characteristics.

On the other hand, root lodging is a serious problem when rice is seeded on a soil surface by an ordinary broadcast method. Shorter stature, stronger culms and greater root anchorage confer higher tolerance to root lodging. Aside from its importance in direct seeding, lodging tolerance is a valuable trait for mechanized harvesting and for maintaining good grain quality. Breeders have been trying to incorporate thick, non-bending culm and vigorous rooting characteristics from different sources into japonica varieties in order to impart better root lodging tolerance. Since there are some Japanese varieties with strong resistance to root lodging it is likely that the improvement will be achieved soon.

At the NARCT, the adaptability to direct seeding is mainly evaluated in the yield trials by water seeding. In the test, chemical Calper is not used. Germinated seeds are sown on a soil surface in five rows using the drill seeding method, and then water is supplied until it is 10 cm deep. The other method is almost the same as in yield trials by transplanting. In the test, seedling emergence is fast and good because the water contains enough oxygen and gets warm by the sun. The problems are lodging in the seedling stage and ripening stage. The lines showing good resistance to lodgings and high yields are selected.

9. Adaptability for multi-location

At the NARCT, a local adaptability test is necessary to evaluate the wide adaptability of each Ukei lines which are the candidates for new Ouu lines. Breeders consider that the performance in other places are very important in the selection of outstanding lines. Japanese breeders are convinced that the outstanding performance of a line should not be site specific. Therefore local adaptability trials are being conducted in Japan.

The NARCT has eight prefectural Agricultural Experiment Stations (AES) to do the local adaptability tests which are supported by the MAFF. In addition, the NARCT has five more AESs where breeders themselves exchange materials with each other. Thus, the NARCT has a total of 135 entries at 13 places. Each line is usually sent to two or three places. Since each place has a different environment, lines should be sent to the places suitable for evaluation of the line specific trait, e. g. blast resistant lines, for places suitable to evaluate the disease.

IV. Breeding in prefectures and the rice varietal recommendation process

1. Breeding programs in prefectures

Rice is normally grown in Japan from April to October, but growing conditions vary from the Northern to the Southern parts of the country. Even within a region or within a given prefecture, growing environments for rice may have considerable variation. Temperature regime, paddy soil condition, topography and rainfall distribution are some of the factors that contribute significantly to this variation. Therefore, specific rice varieties adapted to the prevalent conditions in the region or prefecture must be developed to attain stable rice production.

On the other hand, the highly localized approach to varietal development has evolved as a result of demands from local farmers' cooperatives. The largest farmers' cooperative system in Japan is the Japan Agriculture (JA). This organization has many functions, and one of them is to provide an effective channel through which farmers can send their produce to wholesale markets. Within a prefecture, there are several JA district units that purchase the brown rice produced by farmers in the district and transfer it to the prefectural JA connected with the nationwide JA. More than 70 % of the collected rice is distributed to wholesale markets throughout the country where the price of rice is decided by a bidding system or negotiations between selling and purchasing parties. About 20 % is bought directly by the government at a subsidized price in order to achieve stability in prices and demand. In the market, where competition is high, rice varieties that have excellent qualities are generally sold at higher prices. So, it is very important among the local producers and the JA to have a choice of varieties that are highly adapted in their locality and at the same time command higher price in the market.

The prefectural government responds to these demands of farmers by setting up localized breeding programs to develop locally adapted varieties that have greater competitive ability in the market. Many prefectural AES have developed their own flagship varieties through this system, such as Akitakomachi for the Akita Prefecture and Hitomebore in Miyagi Prefecture. Thus, each of the six prefectures that comprise the Tohoku region namely : Aomori, Akita, Iwate, Miyagi, Yamagata and Fukushima, has at least one established AES that undertakes a breeding program for rice and other important crops in the locality. The prefectural breeding is either funded by the prefecture or by the MAFF.

2. Process of rice varietal recommendation in prefectures

In Japan, the prefecture has a role to release new varieties and to supply the seeds to farmers. Seed committees for rice are designated under a law by the MAFF. Hence each prefecture has its own seed committee for rice. The committee members are usually leaders of the AES, JA, extension offices and administrative office in charge of rice. The set of the tests to release new varieties is called the varietal recommendation test (VRT), which is carried out independently from the breeding in each prefecture and is administered partly by the MAFF fund. Since the tests are conducted in most of the prefectures concurrently it is also called the multi-location test.

In the VRT, most of the newly released advanced lines are tested. Advanced lines produced in each breeding laboratory in Japan bear the each characteristic local line name instead of a lengthy pedigree number for the purpose of identification (eg. Ouu ### for lines bred at the NARCT, Akita ###' for the Akita AES lines, etc.). Most of them are sent to the prefectural AES and evaluated in the VRT. The local line information in the test is maintained by systematic recording and computerized data base management. This system makes the identification of the lines and the evaluation of important traits more simple using data base analysis.

The tests to release the new varieties start from the VRT in the prefectural AES. In the first year, the AES selects the promising lines from those sent by the breeding laboratories. And this includes the breeding lines developed at their own AES. The lines that have shown outstanding performance or useful characteristics are elevated as promising lines. This is called preliminary yield trial in the VRT. The method of this test is almost the same as the yield trial in the breeding.

In the second year, selected lines are planted under two cultivations condition such as standard nitrogen (N) level and high N level. In addition, a few special outstanding lines, which are the candidates for new release, are planted at the various places in the prefecture. The latter is called te local adaptability test in the VRT and is carried out by extension officers and farmers in each district. Since the extension officers observe the growth and report the data about yield and grain quality in the district, they also have the responsibility to release new varieties. Then the same test must be continued for one more year. These sets of tests are called advanced yield trials in the VRT.

As the results over more than three years, in the prefecture where a line has shown consistent performance, or special characteristics that satisfy the preferences and demands of the local farmers and consumers, the line is recommended to the seed committee with all of the data including the VRT and the breeding. When the seed committee approves the line, it can be a variety for new release. The newly recommended line tends to be that developed in its own prefecture. But the recommended line can rarely be from other prefectural or national institutes. Hence, it is considered that the VRT is fairly conducted.

Once the recommendations have been made and approved by the committee, the prefectural AES starts to propagate the seeds. In addition, the breeders submit the reports to the regional conference in winter which is organized by the NARCT, and also submit the form with the new name to the MAFF for the registration of new varieties under the Seeds and Seedlings Law. If the prefectural breeding line was funded by the prefecture, the new name is given by the prefecture. If it was funded by the MAFF, the name is given by the naming committee under the MAFF, and the new name is published with a Norin number which certifies the excellent variety developed by the MAFF. In the committee, one of the names which breeders recommend is usually selected.

The function of the prefectural AES in the VRT is not only to evaluate and recommend new lines but to monitor the performance of previously released varieties. When a variety is proven to have deteriorated and lost its value in local production, the committee will have to revoke the recommendation that was previously granted and remove the variety from the pipeline. In this way, farmers maintain a reasonable number of recommendable varieties to choose from.

In the VRT, a group of breeders from different stations can monitor the performance of the entries that are being evaluated in the different AESs. During the field visit in autumn, breeders have the chance to observe the consistency of performance of the local name lines that they have developed. Maturity, crop stand, field resistance to blast and lodging tolerance are noted. The monitoring tour usually culminates in the regional breeding forum in autumn. This is participated in by all cooperators and breeders from the different prefectures to discuss the current results of the regional test as well as the recommendations that have to be made. Issues concerning the trends in rice production in the region and other matters are also discussed in the meeting.

3. Seed propagation and patents under the Seeds and Seedlings Law

The prefectural AES is also responsible for maintaining the breeder seeds of the released varieties, and ensuring enough supply of certified seeds for the farmers. The seed committee organizes a network of seed growers. The JA and extension officers are the members of this network that produce the certified seeds. Farmers usually order the seeds two years in advance through the JA. Then the seed committee will prepare the seeds the following year according to the demand. The plants are checked at heading time to eliminate the off-type plants and then the harvested seeds are again checked by the seed committee organized by extension officers. The seed price is two times higher than the brown rice in the market. Nowadays most of the farmers prefer the certificated seeds because it is laborious to produce pure seeds by themselves. When a variety is newly released, it is common that there are not enough seeds in the first year.

Under the Seeds and Seedlings Law, the seed committee must pay the patent to the prefectures or the National Agricultural Research Center which developed the variety. The patent is usually 0.16--0.32 % of the seed price which farmers buy. The patent term is 15 years in Japan.

V. Work sharing for breeding and related activities at the NARCT

1. Work sharing for breeding activities

In the breeding laboratory at the NARCT, there are four breeders and four field workers. In

Table 10 Work assignments at the rice breeding laboratory of NARCT

Assignment	Number of entries	Area (a)	Breeder in charge
1. Selection			
1) Crossing	50 combinations	5	B
2) F_1 plants	50 combinations	5	B
3) Generation advancement	50 combinations	0	B
4) Individual selection	50 combinations	40	A, B, C, D
5) Line selection	3000 lines	40	A, B, C, D
2. Yield trial			
1) Preliminary test	150 plots	15	C
2) Advanced test	200 plots	20	A
3) Local adaptability test	60 plots	5	A
4) Direct seeding test	150 plots	10	D
3. Evaluation of physiological traits			
1) Cold tolerance	600 plots	10	C
2) Leaf blast	2000 plots	5	B
3) Panicle blast	1000 plots	20	B
4) Determination of true resistance gene	200 plots	0	D
5) Viviparity	300 plots	0	D
6) Amylose content	50 plots	0	C
7) Protein content*		0	
8) Eating quality	150 plots	0	D
4. Seed storage and propagation			
1) Varieties for genetic resources	200 varieties	5	B
2) Propagation of important lines	20 lines	20	D
5. Breeding research		40	A, B, C, D
6. Exhibition etc.		20	C

* : New trait which will be evaluated after introduction of the instrument.

addition, the laboratory employs two or three part time workers for assistance.

There are many work assignments at the breeding laboratory (Table 10). They are divided into four groups, namely : selections, yield trials, evaluations of physiological characteristics and seed propagation. The selections include crossing, checking of F_1 plants, generation advancement of F_2 and F_3, individual selection, line selection and the evaluation of physical grain quality of harvested grains. Yield trials include preliminary tests, advanced tests, direct-seeding test, the other purpose yield trials, and evaluation at pre-harvesting and post harvesting. The traits recorded in the tests are heading time, lodging score, culm height, panicle length, panicle number, total weight, grain weight, 1000-grain weight and grain appearance. In addition, resistance to panicle blast must be scored when the blast disease is observed in the yield trial field. Evaluation of physiological characteristics includes tests for cold tolerance, leaf blast, panicle blast, identification of true resistant genes, viviparity, amylose content, protein content and eating quality. Seed propagation includes storage of many varieties for genetic resources and propagation of purified breeders seed for new release or varietal recommendation test. A total area of 2.6 ha is needed for all these breeding activities.

Japanese breeders generally do not rely on other laboratories. To evaluate important traits, all these are done by themselves. Assignments are fairly shared among them at th NARCT. But due to the bulk of work among breeders, the total lines are usually less than 3000 and total plots of yield trials are less than 600.

Table 11 Related activities and breeding research at NARCT

Assignment	Researcher in charge
1. Breeding activities	
1) Publishing	
Contribution of new varieties to Bulletin of NARCT	A
Information on new Ouu lines	B
Yearly breeding results	A
2) Reporting on breeding projects	
Direct seeding	D
Hybrid rice and new characteristic rice	B
Animal Food	A
Gene resources	C
3) Management of breeding	
Arrangement of field work	C
Administration of research budget	D
Control and distribution of seeds	B
2. Regional cooperation	
1) Organization of conference and forum	
Winter conference	A, B, C, D
Autumn forum	A
2) Construction of data base for varietal recommendation test	D
3) Consultation regarding varieties and breeding activities	A
3. Breeding research	
1) Analysis for varietal difference on crack formation	A
2) Gene analysis for partial blast resistance by QTL	B
3) Introduction of useful genes from wild rice	C
4) Utilization of DNA marker for selection of seedling growth	D

Note. A : Chief breeder, B : Senior breeder, C : Junior breeder, D : Fresh breeder.

2. Related activities and breeding research

Since breeders have the responsibility to rice varieties which not only farmers but also others are interested in, they have additional assignments (Table 11). These activities also should be carried out efficiently like those breeding assignments and are divided into three groups as follows :

First is the activity to conduct the breeding itself. This includes publication, reports for projects and management of the main breeding activities. The publication contains three copies about new release varieties, new Ouu lines and yearly breeding results. The reports for projects contain the report of annual results and the attendance of annual meetings for each of the four projects shown in Chapter I. The management of the main breeding activities includes the use of the research budget, arrangement of field work and efficient seed management.

Second is activity about regional cooperation and consultation. Cooperation includes organizing the forum in autumn for observation of rice performances in varietal recommendation test and the conference in winter for exchange of yearly results, and construction of a data base for varietal recommendation test. Consultation is mainly to give advice on the questions and needs of farmers and others.

Third is breeding research conducted by each breeder. This is analysis for varietal differences on crack formation in rice grains, gene analysis for blast resistance by QTL, introduction of useful genes from wild rice, and utilization of DNA markers for selection of seedling growth. With the bulk of breeding activities being handled by the four breeders at the NARCT, breeding research could no longer be accommodated, unfortunately.

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