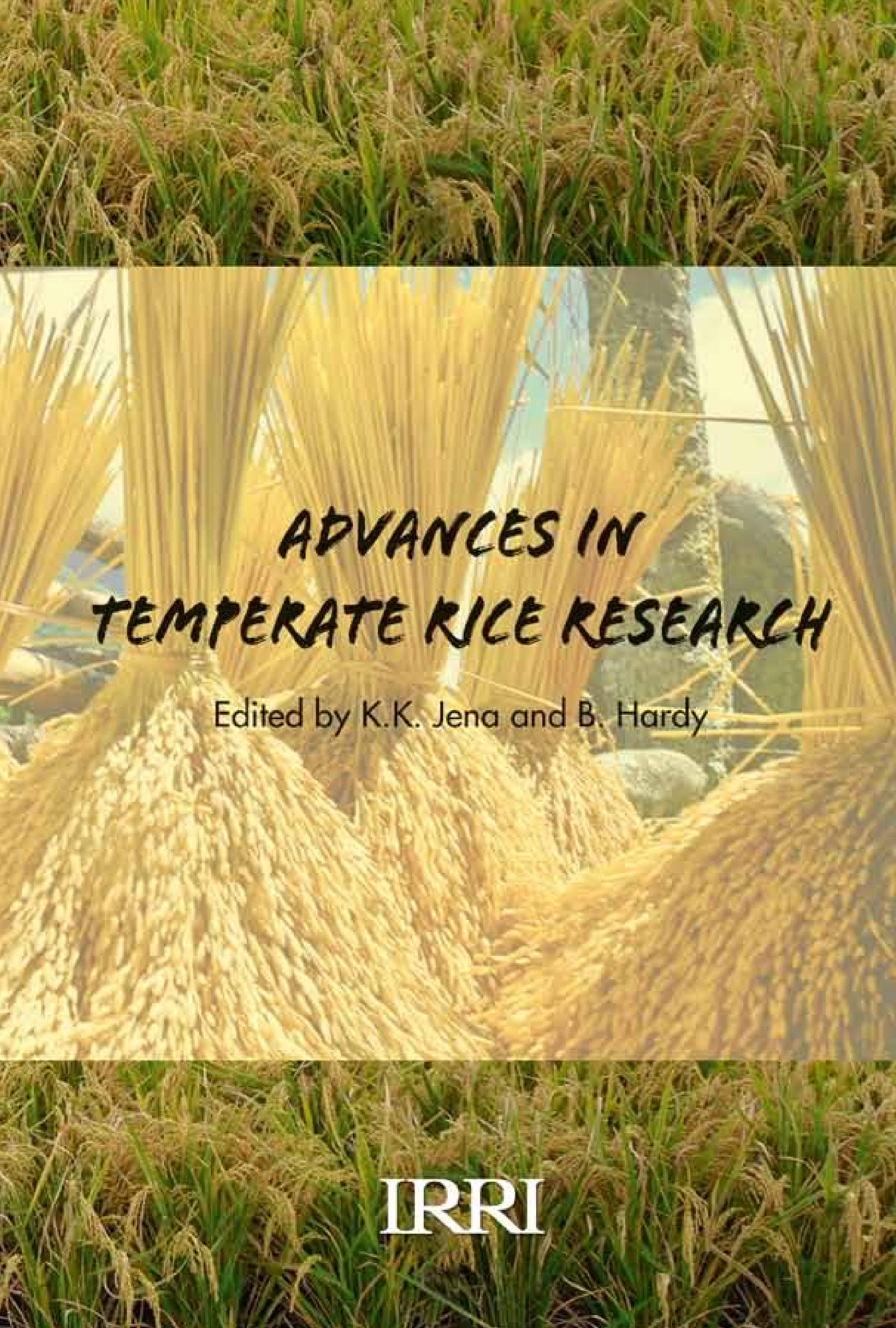

ADVANCES IN TEMPERATE RICE RESEARCH

Edited by K.K. Jena and B. Hardy

IRRI

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2012

IRRI

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today, IRRI is one of the 15 nonprofit international research centers that is a member of the CGIAR Consortium (www.cgiar.org). It is supported in part by government funding agencies, foundations, the private sector, and nongovernment organizations.

The responsibility for this publication rests with the International Rice Research Institute.

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Foreword

Global warming as well as biotic and abiotic stresses are major threats to rice production. Even though temperate japonica rice occupies only 20% of the rice cultivation area worldwide, the decline in its production is a major cause of food insecurity. The Temperate Rice Research Consortium (TRRC), established by the International Rice Research Institute (IRRI) in cooperation with the Rural Development Administration (RDA), Republic of Korea, is an appropriate forum to tackle the various constraints of temperate rice production. I am pleased to know that the members of the TRRC have submitted papers for the book *Advances in temperate rice research*, which I believe will be an important document for temperate rice improvement.

Several constraints limit rice production and productivity in temperate rice-growing countries and high-altitude regions in the tropics. Several million hectares of rice cultivation area in Africa, Asia, Australia, Europe, and South and North America are affected by low temperature every year, resulting in annual yield loss of 1–3.9 t/ha. Low temperature at the seedling stage damages boro rice production in Bangladesh and in high-altitude regions of Bhutan, Cambodia, Indonesia, and Nepal. The temperate rice germplasm in some temperate countries such as Kazakhstan, North Korea, and Uzbekistan has narrow genetic diversity with low yield potential (2–3 t/ha). Biotic stresses such as blast and bacterial blight diseases affect rice production because of the disease-conducive environment in temperate as well as high-altitude regions.

Collaborative research related to increasing production in temperate and high-altitude regions is important for rice improvement. In the areas of higher latitude, the rice-growing season is characterized by long days, greater solar radiation than in the tropics, a greater diurnal temperature range with lower night temperature limiting respiration losses, and lower disease pressure. Under these conditions, yield potential is considerably higher than in the tropics. Research and sharing of information can therefore play a pivotal role in understanding how yield potential can be increased.

Keeping in view world food security, we need to stabilize temperate rice production by creating solutions to the constraints in different countries. We therefore developed a coordinated research strategy through the TRRC jointly with the membership of 20 countries where temperate rice is produced, marketed, and consumed. I am very pleased that TRRC activities are continuously supported financially by Korea's RDA. Other countries such as Russia and Turkey have made small contributions to strengthen TRRC activities. The research products on high yield potential, blast disease resistance, and cold tolerance are shared among the member countries to develop improved varieties.

There is a need to strengthen the TRRC for enhancing scientific linkages and close collaboration among the members to develop valuable germplasm. IRRI makes a strong effort to be a partner with the members of the TRRC that are committed to using the latest knowledge and technologies for the improvement of temperate rice, which will eventually benefit the rural and urban poor in many countries.

Robert S. Zeigler
Director General

Temperate rice in Australia

Russell Reinke, Geoff Beecher, Brian Dunn, and Peter Snell

Rice production in Australia is limited to a relatively small geographic area in the southwestern part of New South Wales (NSW) (Fig. 1). Between 1,000 and 1,500 rice farmers grow rice in the Murrumbidgee Valley in NSW and the Murray Valley in NSW and Victoria. The average size of an Australian rice farm is around 300 hectares; however, rice is produced on an average of 60 hectares per annum, allowing a 4-year rotation between rice and other annual crops, and has historically included a legume pasture phase for livestock production. Most farms now have a cropping phase only, alternating between summer crops (including rice) and winter crops. In the absence of water limitations, annual rice production ranges from 0.8 to 1.4 million tons of paddy rice. The highest annual production was 1.7 million tons in 2001.

The key factor affecting recent production of rice in Australia has been limited water supply as a result of prolonged and severe drought conditions from 2002 until 2010. The impact on production is strongly evident in Figure 2. When irrigation water is not limited, 100,000–130,000 ha are devoted to rice production annually and the entire crop area is fully irrigated, using between 1,400 and 1,800 GL (1 GL = 10^9 liters) of irrigation water. The farm-gate value of the industry is around US$200 million, but, after processing, packaging, and flow-on effects to local communities, this rises to approximately $650 million.

The Australian rice industry faces a changing operating environment, with future production likely to average 800,000 tons of paddy rice and be more variable than in the predrought years. Projected climate variability will likely lead to reduced water availability, and the legislative reduction in the amount of irrigation water available to farmers through the Sustainable Diversion Limits arising from the Murray-Darling Basin Plan and other policy responses will lead to restricted production.

Although production has risen and fallen according to water availability, average yields have remained high. Drought conditions and the associated reduction in irrigation water supply have not affected yield because Australian rice farmers restrict the area sown to be commensurate with water availability at the beginning of the growing season. Hence, in a season of restricted production, the average yield generally remains high (Fig. 2).

The variation in average yields is principally due to low-temperature events during the reproductive stage of the crop. Progress on addressing this abiotic constraint

Fig. 1. The rice-growing region in Australia is centered on the Murray and Murrumbidgee river systems in southern New South Wales.

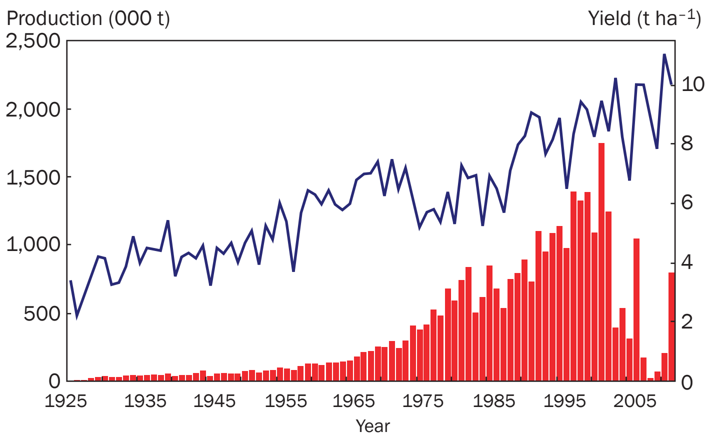

Fig. 2. Australian rice production and average yields for the period 1925 to 2011. The industry is based in southwestern New South Wales, with minor production in northern Victoria. Note the extreme decline in production after 2000 due to water limitations.

has been relatively slow because of the absence of a consistently cold selection environment and limited opportunity to establish an off-season nursery for testing. Stringent rules govern the movement of germplasm into the rice-growing area owing to strict quarantine regulations aimed at preventing the introduction of rice diseases, thereby precluding the use of such nurseries. Note that the low-yield events in Figure 2 uniformly reflect low-temperature damage during the reproductive phase and, since 1985, average yields in cold seasons have risen from 6 t ha^{-1} to around 7 t ha^{-1}. Crop management also plays a role in this increase, with increasing use of deep water (20–25 cm) during the reproductive period to help insulate the crop against low-minimum-temperature events.

The main research providers for the Australian rice industry include the NSW Department of Primary Industries (NSW DPI), a division of the NSW Department of Trade and Investment, Regional Infrastructure and Services, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and universities, including Charles Sturt University, Sydney University, Southern Cross University, and the University of Queensland. Relatively few human resources are directed at rice research. NSW DPI has two rice breeders, two research agronomists together with technical staff, a cereal chemist with three technical staff, and a number of extension personnel.

Major research targets

The key organization for funding and coordinating rice research in Australia is the Rural Industries Research and Development Corporation (RIRDC) and the research program aims to improve the productivity and sustainability of the Australian rice industry through the organization, funding, and management of a research, development, and extension program that is aligned with industry reality and stakeholder needs (RIRDC 2011). The following research targets are drawn directly from the RIRDC's 5-year plan for rice research, from 2012 to 2017.

Rice breeding

Because the Australian rice industry does not have any of the major rice pests and diseases, the rice breeding program is able to focus primarily on yield and quality traits. The rice breeding program seeks to respond to an evolving production environment by developing stress-tolerant rice varieties (tolerant of cold, heat, and drought) that reduce water use and maintain or enhance eating quality and yield.

The specific objectives of the breeding program follow:

- Reproductive-stage cold tolerance—to improve year-to-year stability of production and water productivity.
- Yield potential—to drive overall profitability in the rice farming system.
- Grain quality—including grain size and shape, grain appearance, milling (maximum whole grain after milling), and cooking quality (texture, gloss, softness on cooling).
- Shorter growth duration—principally to save water, but also to maximize management options and flexibility for rice growers.
- Improved tolerance of abiotic stresses such as straighthead (a physiological disorder resulting in malformed and empty florets), salinity, heat, and transient drought during establishment.

- Seedling vigor—to attain rapid establishment under the relatively low-temperature conditions at sowing and to build adequate biomass to support high yield.
- Lodging resistance.

Precision agriculture and sustainability

Precision agriculture and whole-farm system research offer further opportunity for rice production efficiency gains as well as identifying options for profitable rice-based farming systems in northern Australia. Understanding spatial variation and developing prescription tools for maximizing production are a priority. Rice growers, using yield loggers in their harvesters, report single-field yields from 8 to 18 t ha^{-1}.

Precision agriculture as a new management technology for farmers has developed through the use of global positioning systems, remote sensing of crop performance, and ground-based sensors of variations in soil properties—tools that allow the spatial monitoring of soil properties and crop growth. The technology to allow variable rate application of crop inputs is already available to farmers by both ground rig and aerial application.

However, the question of which factors contribute to soil, crop, and yield spatial variability and which factors should be used as a basis for zoning for the use of the variable rate application of inputs, to increase field profitability, remains to be answered. Precision agriculture already applies to rice growing in southeastern Australia with significant effort applied to identifying suitable land for rice, thus reducing percolation losses under rice fields and increasing water productivity. Variations in crop growth and yield related to land-leveling practices and the exposure of deep subsoil have been clearly identified. Work is continuing on the applications of nitrogen, phosphorus, and zinc required to reduce the poor growth and yield of rice on exposed subsoil material.

Targeted application of in-crop nitrogen is done at panicle initiation using remote-sensing imagery of crop biomass/vigor variability and through targeted crop sampling based on the imagery and use of NIR spectrometry of the rice plant material to estimate crop nitrogen content.

Although new production systems such as Delayed Permanent Water provide water savings of 10–20%, they also present a new set of crop establishment and management challenges (Dunn and Gaydon 2011). Crop establishment on heavy gray self-mulching clays remains problematic, with genetic and agronomic solutions sought to minimize this constraint. The Australian rice industry also recognizes the importance of investing in sustainability, and is actively involved in exploring the feasibility of new production areas in northern Australia and the challenge of understanding and embracing the carbon economy through quantifying greenhouse gas emissions under current and developing rice production systems.

Crop inputs, crop protection, and grain receival

The cost and effectiveness of crop inputs, including fertilizer and fuel, are significant drivers of grower profitability. Protecting the crop from weeds, pests, and diseases in a changing natural and regulatory environment is an ongoing challenge for growers. Possible expansion of the industry into northern Australia exposes production to new biosecurity threats. Receiving the best price for the quality and variety of grain produced provides important production signals for growers. This objective addresses input effectiveness and cost along with post-farm-gate investments in the rapid assessment of grain quality.

Extension, communication, and partnership development
This research objective recognizes and addresses the changing nature of public support for extension, the expansion of private-sector alternatives, including farmer groups, and the viability of new electronic communication systems. It also sets out to reinvigorate existing research partnerships.

Human capital formation and succession planning
The rice R&D plan requires appropriate human capital to implement it. When research funding was limited due to ongoing drought conditions, human capital formation was restricted in order to fund core research commitments. The current plan will rectify this underinvestment and the program must target research, industry, and grower skills.

Blue sky research
In this plan, "blue sky" research is defined as including novel or unproven approaches to industry concerns and high-risk/high-reward investments that tackle industry opportunities outside the program's core business. For illustrative purposes, blue sky research might include the use of polymer films to retain soil moisture and heat, novel uses for rice hulls and stubble, or the integration of new enterprises such as fresh fish production into the rice farming system.

Constraints to improving rice production

Water availability
The overriding constraint to rice production in southeastern Australia within each cropping season is the availability of irrigation water. The environment is characterized by an annual rainfall of approximately 350 mm, and high evapotranspiration throughout the growing season (October-March); hence, there is complete reliance on irrigation water to produce the crop.

Further, climate change predictions suggest a 16–25% reduction in average Murray-Darling stream flows by 2050 and a 16–48% reduction by 2100 (Pittock 2003, Christensen et al 2007, CSIRO 2008), which will likely result in reductions to irrigation water allocations in the future. In addition to forecast changes in rainfall and runoff, proposed legislative changes will act to limit the amount of water available to farmers for agricultural production.

Implementation of the Murray-Darling Basin Plan will result in the application of Sustainable Diversion Limits, which are the maximum long-term annual quantities of water that can be taken on a sustainable basis from the entire basin that will not compromise the environmental assets and the ecosystem functions, or limit the productive base of the water resource (Murray-Darling Basin Authority 2011).

The need to reduce rice water use is a longstanding goal, and Humphreys et al (2006) reported that the average field input water productivity (WP) of the total NSW rice crop over the past 20 years has almost doubled. This has been largely due to increased yields with the introduction of semidwarf cultivars, and partly due to reduced water use per rice field through monitoring and a policy of not growing rice in fields in which water use exceeds a threshold. Further, electromagnetic induction soil surveys have identified low-permeability areas more suitable for rice (Beecher et al 2002), resulting in reduced rice production on soils where substantial amounts of water are lost through percolation past the root zone. The net effect has reduced average rice crop water use for the region (Humphreys and Robinson 2003).

A more recent innovation is to restrict water supply during the vegetative stage of crop growth in order to improve input water productivity. Dunn and Gaydon (2011) reported on two seasons of field experiments and confirmed that input water savings can be achieved by delaying the application of continuous flooding until just prior to panicle initiation in drill-sown rice on red-brown earth soils in southeast Australia. Additionally, the experiments demonstrated increased input water productivity from higher levels of imposed crop water stress during the initial nonflooded period. Irrigation intervals of 160 mm cumulative evapotranspiration (including a crop factor, Kc) or more prior to delayed continuous flooding significantly improved input water productivity above that of the conventional drill-sown treatment (by 17% in year 2). Irrigating at 80/Kc-mm intervals resulted in a significant but lesser (9%) input water productivity increase over the control in the same year. Results from both trials are summarized in Table 1.

Low temperatures

The main cause of year-to-year variation in yield is the occurrence of periods of low minimum temperatures (<15 °C) during the reproductive stage. Average environmental conditions are shown in Figure 3, with high solar radiation throughout the growing season and a large diurnal range in temperature. Although the average minimum temperature during the reproductive stage is around 17 °C, variability about this mean is significant. It is common for temperatures to fall as low as 11 or 12 °C within the critical reproductive phase.

An example of the extreme temperature variability is shown in Figure 4. These data are from the 2009-10 rice season, and they show a sawtooth pattern of minimum and maximum temperatures during the early weeks of January 2010. Maximum temperatures steadily climbed from around 30 ºC to more than 40 ºC over the course of a week before dropping by 10–15 ºC quite rapidly. Minimum temperatures followed the same pattern, and three excursions below 15 ºC took place during the first 3 weeks of January 2010.

The entire reproductive stage usually spans the period from early-January to mid-February. Although long-term maximums average around 33 °C and minimums around 17 °C during the microspore development stage, the likelihood of damaging minimum temperatures (15 °C or less) is approximately 25% (Erskine and Smith

Table 1. Grain yield at 14% moisture for year 1 (200 kg N ha^{-1}) and year 2 (225 kg N ha^{-1}), ETo, rain, net water input (supply + rain – surface drainage), and input water productivity for two experiments. After Dunn and Gaydon (2011).

	Grain yield (t ha^{-1})	ETo (mm)	Rainfall (mm)	Net water input (mm)	Input water productivity (kg m^{-3})
Year 1					
Control	10.9	1,411	104	1,560	0.70
40 mm	9.2	1,382	104	1,400	0.66
80 mm	10.2	1,404	104	1,410	0.72
160 mm	10.1	1,411	104	1,330	0.76
LSD ($P < 0.05$)	0.9			90	NS[a]
Year 2					
Control	13.4	1,402	212	1,500	0.89
Flood	11.4	1,316	210	1,710	0.67
80/Kc mm	12.3	1,469	219	1,280	0.97
160/Kc mmm	12.2	1,482	219	1,180	1.04
LSD ($P < 0.05$)	0.9			160	0.10

[a]NS = nonsignificant.

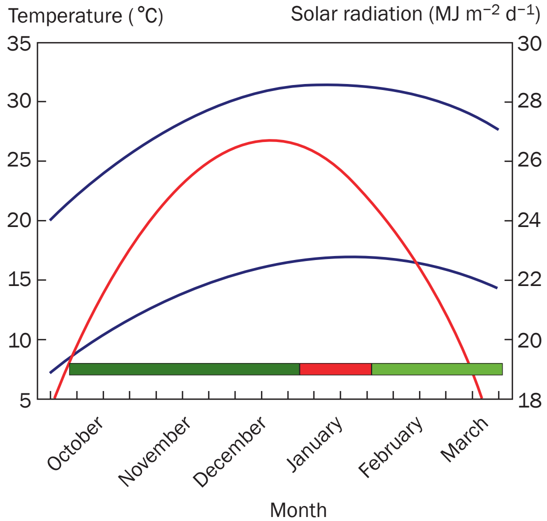

Fig. 3. Temperature and solar radiation throughout the rice-growing season at Yanco Agricultural Institute (35°S). Solid blue lines are maximum and minimum temperatures; red line is solar radiation. The solid bar at the base of the figure indicates the vegetative (green), reproductive (red), and maturation (brown) phases, respectively, for an average rice crop.

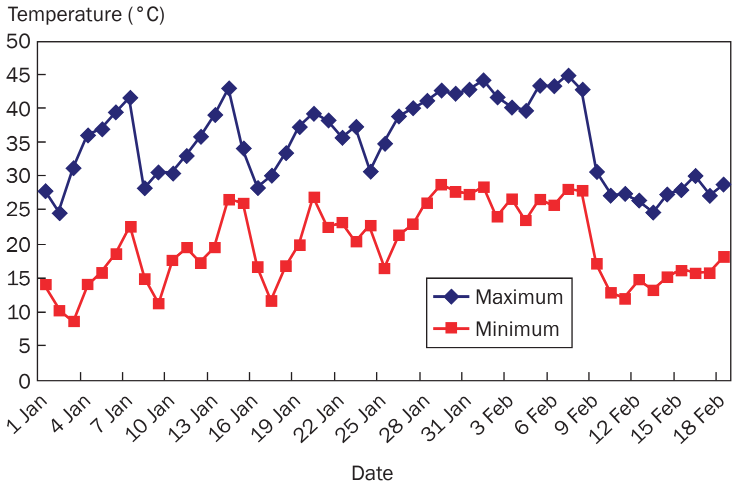

Fig. 4. Daily maximum and minimum temperatures during January and February 2009 at Yanco Agricultural Institute. Note the diurnal range of approximately 15 °C and prolonged period of high temperatures in late January and early February, followed by low temperatures in mid-February.

1983). Rice crops are generally sown to ensure that this temperature-sensitive stage occurs during the period when average temperatures, based on more than 40 years of weather records, are greatest. Hence, it is not possible to adjust either sowing time or maturity to further reduce the chance of damage. Year-to-year variability in yield is primarily associated with low-temperature damage occurring during microspore development, and to a lesser extent during anthesis. Angus and Lewin (1981) proposed a simple model of this effect and were able to forecast rice yields with an accuracy of ±0.58 t ha^{-1}.

Drill-sown trials with sequential sowing dates, including cold-tolerant control varieties with varying sensitivity to cold, have been shown to be an effective screening technique, capitalizing on naturally occurring fluctuations in minimum temperatures to assess variation in cold-induced sterility (Farrell et al 2006). The system involves sowing the nurseries earlier and later than the recommended sowing times to increase the likelihood of exposure to naturally occurring cold events. Minimum temperatures are closely monitored throughout the growing season to highlight when the 9-day average minimum temperature is 15 ºC or lower. Ten days after the minimum temperature threshold has been breached, individual panicles that are at flowering stage in the nurseries are tagged, as these are the panicles that were exposed to low temperatures at the microspore development stage. At maturity, these tagged panicles are harvested and assessed for the percentage of fertile spikelets. Results from this system of screening are shown in Figure 5, indicating the spikelet fertility in four populations following exposure to varying degrees of naturally occurring low temperatures. Low-temperature water, pumped from the lower levels of a small nearby reservoir, is used to exacerbate the impact of low temperatures in addition to

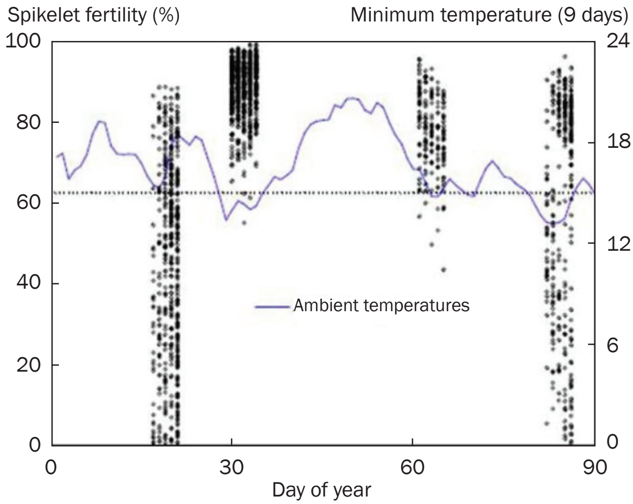

Fig. 5. Percentage of filled spikelets per panicle for four segregating populations superimposed on the 9-day average minimum temperature during the critical microspore development phase. Each point represents one panicle. For the left-most population, the 9-day average minimum temperature during pollen microspore development was 15 °C and the percentage of fertile spikelets was quite evenly distributed between 0% and 90%. For the right-most population, the 9-day average minimum was 13 °C, resulting in a similar range in spikelet fertility. The two remaining populations were less affected by low temperatures.

shading to decrease the warming effect of solar radiation following a low-minimum-temperature event.

This screening system has been used in the development of the rice variety Sherpa (Reinke and Snell 2011), which has demonstrated better cold tolerance than current commercial varieties throughout the on-farm testing program before release. Sherpa (tested as breeding line YRM69) had higher spikelet fertility than the commercial cultivars Millin, Quest, and Opus in a series of cold-tolerance nurseries, and had spikelet fertility similar to that of the cold-tolerant standard varieties Baijieming and Jyoudeki (Table 2).

Available genetic resources and type of genetic resources needed

The breeding program at Yanco maintains a small germplasm collection of approximately 1,400 varieties and breeding lines. A pivotal issue in the expansion of this important resource has been the assignment of intellectual property rights to varieties through the mechanism of plant breeders' rights and, in the U.S., through the granting of utility patents. This has affected the free exchange of germplasm, with the organizations that own the intellectual property insisting that, in the event of a commercial cultivar being produced from germplasm exchanged, royalty payments would need

Table 2. Mean spikelet fertility and standard errors for tagged panicles (number of panicles in parentheses) for varieties that experienced low night temperatures during young microspore development in cold-tolerance nurseries conducted over four crop seasons. An early and late-sown nursery were conducted in 2008.

Variety	2008	2008	2006	2007	2010
Baijiemang	78.02 ± 1.04 (12)	76.67 ± 4.09 (9)	*	78.08 ± 3.55 (6)	*
Jyoudeki	74.35 ± 2.58 (14)	*	83.17 ± 0.99 (17)	83.10 ± 3.09 (7)	93.24 ± 0.26 (220)
Quest	67.12 ± 2.94 (26)	68.49 ± 2.58 (18)	54.51 ± 2.63 (14)	77.92 ± 2.61 (9)	85.64 ± 0.52 (91)
Opus	62.63 ± 2.67 (37)	77.92 ± 1.91 (25)	*	83.01 ± 3.18 (2)	*
YRM69	78.26 ± 2.50 (16)	80.48 ± 1.94 (14)	67.48 ± 1.93 (13)	86.55 ± 1.37 (15)	91.32 ± 0.48 (54)
Millin	71.04 ± 3.41 (17)	*	57.33 ± 2.55 (14)	86.04 ± 1.02 (9)	*

to be negotiated according to the proportionate representation in the pedigree. The imposition of these legal requirements has limited germplasm exchange and eroded the flow of new germplasm to the rice breeding program at Yanco.

For the future, a ready flow of new varieties is crucial to the success of the program, to provide additional genetic variation for cold tolerance, drought stress, and traits associated with adaptation to water-limited conditions across a range of growth stages. Further genetic variation is also required to prepare for heat tolerance at critical growth stages under global warming scenarios.

Universal adoption of the standard material transfer agreements (SMTAs) developed by the governing body of the International Treaty on Plant Genetic Resources for Food and Agriculture may well assist in this regard.

One of the key issues facing the Australian rice industry is the imperative to reduce water use and improve water productivity. There is a need to define a clear strategy for the development of water-saving rice. Research is necessary into the extent of water savings through avoiding flooded conditions and, in particular, the yield penalties associated with exposure to more variable temperatures using this approach. An alternative would be the manipulation of seedling vigor, establishment, and crop maturity so that the rice crop is flooded for the shortest possible period consistent with the development of sufficient biomass to support high yield potential. Crosses with aerobic germplasm have already been made and populations are under development; however, selection protocols have not been developed for the Australian environment, which includes heavy clay soils, high evapotranspiration during the peak of the growing season, a large diurnal temperature range, and extreme seasonal temperature variability.

Strategies used, including biotechnology

Rice research in Australia is mainly based in the southeast corner of the continent where the rice industry is also located. The institutes involved are universities, federal and state government research institutes, as well as private research organizations.

Because most research projects are funded by the RIRDC, research subjects are integrated with the immediate requirements of the rice industry and the rice improvement program at Yanco. Rice research in Australia was boosted significantly by the Cooperative Research Centre for Sustainable Rice Production (Rice CRC), which was in effect from 1998 to 2005. The Rice CRC funded research in all areas from rice production to rice processing and commercialization. After discontinuation of the Rice CRC in 2005, the RIRDC continued to support some of these research projects. Research at the plant level mainly focuses on grain quality, plant nutrition (nitrogen), disease resistance, water-use efficiency, and reproductive-stage cold tolerance—the main yield-limiting factor of the Australian rice industry. However, investments are also made in developing enabling technologies that will be beneficial to the breeding program in the future.

Rice grain quality has always been a central part of the rice breeding program at Yanco. In particular, the program has focused on the objective measurement of rice grain quality. Australia is not a traditional rice-based culture; hence, few experienced rice consumers can evaluate differences in breeding lines. Thus, objective methods have been developed to evaluate the combination of aroma, texture, mouth feel, springiness, stickiness or dryness, the appearance of white rice, or the glossiness of cooked rice. For most of the 1970s and ’80s, the Australian rice industry focused on just two types of rice. Both were relatively low-amylose soft-cooking types. One was a medium-grain rice and the other long-grain. Since the early 1990s, the focus has expanded to a total of seven grain quality classes, including standard medium grain, larger medium grain for Middle Eastern markets, short-grain Japanese types, bold and chalky Arborio types, fragrant long grain, firm-cooking long grain, and soft-cooking long grain.

Two innovations have had a substantial impact on the rice breeding program in recent years. They are the implementation of the Cervitec grain inspector as a high-throughput method for examining visual quality on an individual grain basis and the integration of molecular marker testing for the microsatellite marker associated with granule-bound starch synthase (GBSS) activity in the temperate japonica germplasm group.

The capacity to measure length and width on all samples passing through the unreplicated and replicated stages has vastly improved our knowledge of grain dimensions, allowed better description of chalk distribution among lines, and provided information to select against cracked or fissured grains and thereby improve milling quality. A composite image in Figure 6 shows how grains with stress cracks have a sharp line of differentiation between the two colors, which can then be detected by training the artificial neural network that forms part of the Cervitec machine.

The measurement of apparent amylose using marker technology has improved the efficiency and effectiveness of selecting for specific cooked-grain texture. The integration of the molecular marker test as a routine element of the breeding program at the F_5 generation allows faster and more accurate selection in relatively early generations. Thus, we can choose parents based on their genotype and make more directed selection at early stages, keeping a higher proportion of lines to test for more complex quantitative traits such as yield and agronomic characteristics.

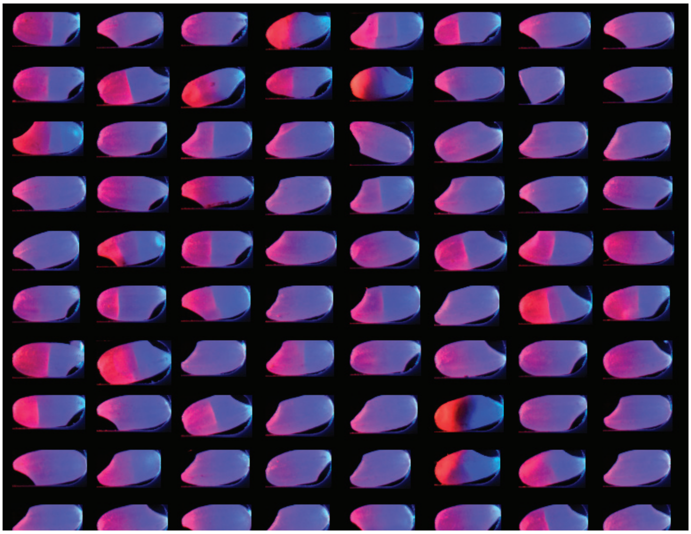

Fig. 6. Composite image of rice grains analyzed by the Cervitec™ 1625, showing a sharp differentiation of color in grains with stress cracks.

The breeding program emphasizes conventional breeding approaches, with extensive use of bi-parental crosses, triple or top crosses, and backcrossing to incorporate specific traits such as cold tolerance into adapted backgrounds. The commercial segment of the rice industry has decided on a policy of not allowing genetically modified rice to be grown within the rice quarantine area in order to protect its markets. This does not preclude research into genetic modification, but means that it is carried out via partner research organizations, and not at Yanco Agricultural Institute.

Expectations from the TRRC and possible contributions to the TRRC

In Australia, the sources for funding of rice research are limited. Significant periods of drought conditions and stringent water restrictions have in recent years put a lot of pressure on the rice industry. Lower rice production and concomitant lower research levies have reduced the capacity of funding bodies to support rice research at a time when larger research investments are needed to secure the future of the industry. The current climate confronts the rice industry with the following problems that need addressing:

- Improvement of abiotic stress tolerance: cold, drought, and heat tolerance.
- Improvement of water-use efficiency.
- Continuing the trend of tailoring varieties for specific international markets.
- The future threat of climate change, via high temperatures at critical growth phases or greater temperature variability.

The solutions to these problems are likely to require drastic changes in farming practices for Australian rice farmers, for instance, a shift to aerobic rice. All these changes require urgent investments in the breeding program and in fundamental research to back up the breeding program (e.g., an understanding of the physiological traits necessary for enhanced cold tolerance, tolerance of transient drought stress and adaptation to aerobic production systems, and the relevant molecular markers to facilitate selection for these traits). However, little funding is now available to support new research initiatives.

Our expectations of the TRRC are to

- Facilitate the exchange of germplasm for breeding future temperate japonica rice.
- Organize meetings between the partners on a regular basis to discuss research progress and exchange information in order to mitigate the isolation of the Australian rice industry from other rice production regions.
- Interact with other temperate rice programs and further the understanding of the genetic basis of rice grain quality traits and their modification in new breeding lines.
- Attract funding from parties interested in temperate japonica rice for collaborative research projects, for example, exchange of people (students), and travel.

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Temperate japonica rice in Bhutan

Mahesh Ghimiray

Status of japonica rice

Rice in Bhutan

Rice is indispensable in the Bhutanese culture, tradition, religion, way of life, and livelihood itself. More than 79% of the population is engaged in farming, with rice as the main crop. Rice is the most important and most preferred food crop of Bhutan and it is grown from tropical lowlands (200 m) in the south up to elevations as high as 2,800 m in the north. The total rice area in the country is estimated to be 18,635 ha (Table 1), almost all of which is irrigated. The average national rice yield is 2.92 t ha^{-1}. Domestic rice production was 54,325 tons in 2006, which meets only about 50% of the national requirement. The deficit is met from imports, averaging about 35,000 tons of milled rice annually from India. One of the cherished goals of the Royal Government of Bhutan is to obtain self-sufficiency in rice production.

Rice environments

The rice environments in Bhutan are broadly grouped into four zones according to altitude and rainfall: the warm temperate, dry and humid subtropical, and wet subtropical zones (Table 2).

Warm temperate (high-altitude) zone. The warm temperate high-altitude zone includes mainly the valleys of Paro and Thimphu, higher altitude areas of Punakha and Wangdue valleys, and parts of other districts. Approximately 20% of the total rice area falls in this zone. The highest altitude where rice is grown is about 2,800 m in Bumthang. Cultivation of rice at this altitude is a recent initiative and technologies are still being refined. During the rice-cropping season, the high-altitude environment has a low-high-low temperature pattern such as in Japan, northern China, and Korea. Therefore, low temperature is a problem in the early growth stage and also in the reproductive and ripening stages.

The climatic conditions allow only one crop of rice in a year. Rice is sown in February-March, transplanted in late May to mid-June, and harvested in October. Day temperatures during the growing season are generally not a major constraint. However, minimum temperature of below 15 °C combined with low water temperature at seedling and tillering stage can cause cold damage. Rainfall in this zone is rather low

Table 1. Paddy area and production in 2006.

District	Harvested area (ha)	Total production (t)	Yield (t ha^{-1})
Paro	1,196	4,876	4.08
Wangdue	1,252	4,883	3.90
Chhukha	512	1,507	2.95
Dagana	1,362	2,967	2.18
Gasa	52	117	2.25
Ha	68	138	2.03
Bumthang	3	11	4.20
Lhuentse	513	1,405	2.74
Mongar	527	1,500	2.85
Pemagatshel	44	140	3.19
Punakha	1,760	6,906	3.92
S/Jongkhar	733	1,385	1.89
Samtse	3,288	6,640	2.02
Sarpang	3,054	9,762	3.19
Thimphu	609	1,965	3.23
Trashi Yangtse	376	1,257	3.35
Trashigang	1,021	3,913	3.83
Trongsa	648	1,487	2.29
Tsirang	1,180	2,511	2.13
Zhemgang	437	956	2.19
Total	18,635	54,325	2.92

Source: RNR Statistics, MoA.

Table 2. The four rice agroecozones of Bhutan.

Rice zones	Altitude (m)	Rainfall (mm)
Warm temperate	1,800–2,800 (high)	650–850
Dry subtropical	1,200–1,800 (mid)	850–1,200
Humid subtropical	800–1,200 (mid)	1,200–2,500
Wet subtropical	200–800 (low)	2,500–5,500

and hence rice is grown as an irrigated crop. Small springs and the main rivers are the sources of irrigation. River water remains cold throughout the year since it originates from the snow-clad higher mountains.

Dry subtropical (medium-altitude) zone. The dry subtropical zone includes broad valleys of Wangdiphodrang and Punakha, and hill slopes and narrow valleys of Trongsa, Tashigang, Mongar, and Lhuentse. This is a mid-altitude zone with lower rainfall. In the lower valley bottoms up to an elevation of 1,500 m, low temperature is not a major problem for a single crop of rice. Rice is sown in March-April, transplanted in June, and harvested in October-November. Two crops of rice could also be grown. The first crop, transplanted in March by using seedlings raised in a poly-tunnel nursery, can be harvested in July and immediately an early-maturing second crop can be planted, which is harvested in November.

Humid subtropical (mid-altitude) zone. The humid subtropical (mid-altitude) zone includes the hills of Tsirang, Samtse, Gelephu, Tashigang, Zhemgang, Pemagatshel, and Chukha. This is a distinct humid hilly environment with substantially high rainfall. Almost all the rice is grown under irrigated conditions. The rice terraces are carved in hill slopes. Upland rice is also grown mainly in Zhemgang on a small scale under the traditional slash-and-burn *tseri* system. The dry and humid subtropical zones account for about 42% of the total rice area. Low temperature is not a major problem during the early crop growth stage. However, humid conditions favor disease development.

Wet subtropical (low-altitude zone). The wet subtropical low-altitude zone includes mainly the districts of Samtse, Gelephu, and Samdrupjongkhar and accounts for about 38% of the national rice area. It is a high-rainfall environment with higher temperatures. Diseases and insect pests are more common. Soil conditions are poor compared with those of other zones. Rice is grown mainly as an irrigated crop. However, in areas where irrigation is not assured, the crop is grown under rainfed conditions. Yields are generally lower than in other zones. The climatic conditions permit two crops of rice in a year though this is not practiced for varied reasons.

Traditional rice varieties

The traditional rice varieties of Bhutan are grown under diverse agro-climatic conditions and show high diversity. The landraces have adapted to this diverse environment and are unique genetically and morpho-agronomically. Not many systematic studies have been carried out to unravel their genotypic and phenotypic composition. Traditional varieties are generally heterogeneous for various traits; however, quantitative data to illustrate such heterogeneity are generally lacking. Morishima et al (1990) reported that Bhutanese landraces were highly polymorphic within a field and they also observed "weedy types" associated with a high degree of seed shedding and sterility.

Nationally, more than 65% of the total area under rice is still planted to traditional varieties, reflecting the high adaptability and suitability of these cultivars in the traditional farming systems. At higher altitudes, local rice is broadly classified into *Bja maap* (red pericarp rice) and *Bja kaap* (white pericarp rice). Maaps are predominant at high elevations, while Kaaps are more common at lower elevations.

In contrast to the red rice in other countries that is considered a weed, the high-altitude Bhutanese red rice is favored for its eating quality and commands a premium price in the local market compared with the white rice. The red coloration of the pericarp is usually controlled by a dominant gene (*Rc*), which is commonly distributed in wild and weedy types as well as in native cultivars (Oka 1988).

Bhutanese farmers grow and maintain a diverse range of local cultivars. A single farmer cultivates two to five rice varieties on small patches of land, exhibiting an excellent example of practical *in situ* conservation at the farm level (Duba et al 1995). The different varieties are meant to satisfy the varied needs of farmers, such as for *tho* (cooked rice), *zaw* (puffed rice), *sip* (beaten rice), *torm* (divine ritualistic figures), wine distillation, special religious occasions, etc. On-farm rice diversity is thus a reflection of the tradition, religion, and culture of the Bhutanese people.

The high-altitude varieties are characterized by cold tolerance at the seedling stage, tall stature, long growth duration, medium to low tillering, late leaf senescence, good panicle exsertion, high spikelet fertility, high shattering, fewer grains per panicle, heavier grains, red pericarp, intermediate amylose, and lack of seed dormancy (Chettri 1992). Some of the popular high-altitude varieties, especially from the valleys of Paro and Thimphu, are Naam, Hasey, Kochum, Thaembja, Bjanaab, Dumbja, Zhechem, Chumbja, Uzum, Dagozam, Sombja, Khembja, Rey Sakha, and Hamzam. Many of these cultivars could be the local variants of a major genotype selected over a number of years to suit micro-environments and farmers' needs. Some varieties are cultivated for specific purposes. For example, Dumbja is used for *sip* making as it is one of the few high-altitude varieties with white grains. Red-grain varieties are rarely used to make rice *sip* and *zaw*. Dumbja is also a sought-after variety for religious festivities.

Area, production, and productivity of japonica rice

The high-altitude areas where japonica rice is grown (above 1,800 m) make up about 20% of the total rice area (3,727 ha) and contribute about 30% to the total rice production (Table 3). Compared with other zones, the yield of japonica rice in the high-altitude areas is much higher (average 4.10 t ha^{-1}) although the area is limited. This is mainly due to relative freedom from insect pests and diseases, high soil fertility, and cooler climate at the ripening stage. Climatically, this zone is highly favorable for rice production.

Institutions and human resources for research

The research setup in the country has four Renewable Natural Resources Research Centers (RNRRC) guided by the Council for RNR Research of Bhutan (CoRRB) under the Ministry of Agriculture (Fig. 1).

RNRRC Bajo is given the national mandate to coordinate research on rice and liaise with regional and international research institutes for the exchange of information, expertise, and genetic materials. However, the main center for conducting the actual research on japonica rice is RNRRC Yusipang due to its location in Thimphu at an altitude of 2,300 m. The other RNRRCs also carry out rice research pertinent to their regions. The RNRRCs have their subcenters strategically located to cover all the rice agroecologies.

Table 3. Current rice area and production by altitude zones.

Altitude zone	Area (ha)	Current production (t)	Current yield (t ha^{-1})
High (1,800–2,800 m)	3,727 (20%)	15,280	4.10
Mid (800–1,800 m)	7,827 (42%)	25,655	3.15
Low (below 800 m)	7,081 (38%)	12,887	1.82
Total	18,635	53,822	2.95

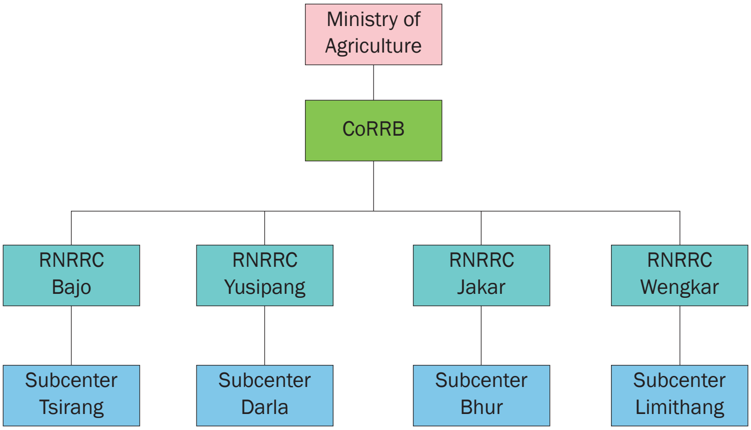

Fig. 1. Organogram of the research system in Bhutan.

In terms of human resources for rice research, only six officer-level staff with BSc or MSc degrees are fully engaged in research. These staff cater to the research needs of all the rice environments. The officer staff are supported by research assistants and field technicians. Agricultural extension is decentralized to the districts headed by the district agricultural officer. About 200 extension staff are posted at the subdistrict or block level.

Research initiatives and progress on japonica rice

In 1995, a severe blast epidemic caused by the fungus *Pyricularia grisea* swept through the higher elevations (1,800–2,800 m) and affected an area of about 1,200 ha with an average severity of 71%. The indigenous rice varieties were severely threatened. To avoid future epidemics, the Ministry of Agriculture formulated a long-term strategy to develop blast-resistant, high-yielding, cold-tolerant varieties for high-altitude areas. IRRI was invited to help.

Started in 1987, RNRRC Bajo already had a rice shuttle breeding program with IRRI that focused on the improvement of native Bhutanese varieties. Starting in 1996, the crossing of high-altitude varieties from Bhutan with blast-resistant and cold-tolerant varieties from elsewhere was expedited. Actual crossing was done at IRRI and F_2 seeds were shipped to Bhutan for selection, which was done at Geynekha (a known blast hotspot) jointly by RNRRCs Bajo, Yusipang, and the National Plant Protection Center at Semtokha. The aim was to develop improved rice varieties having blast resistance for Bhutan highlands.

The most visible impact of this program has been the identification and release of three new rice varieties that have sufficient tolerance of blast (Fig. 2) and cold and that outyield the local varieties. Two of the new varieties (Table 4), Yusirey Maap and Yusirey Kaap, are the direct result of the collaborative breeding program. The new

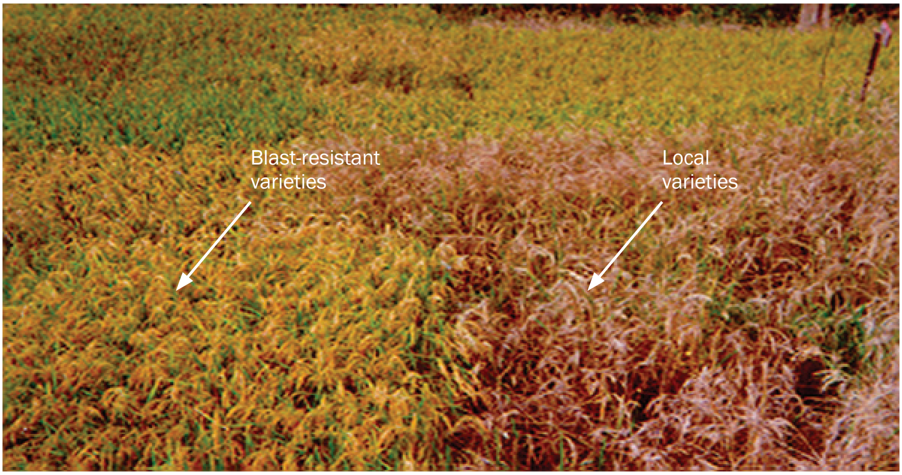

Fig. 2. Screening and selection of blast-resistant varieties at Geynekha.

Table 4. Pedigree and main traits of new rice varieties in Bhutan.

Cross designation	Parents	Local names	Main traits
IR66068-B-B-31-2-1	YR3825-11-3-2-1// YR3825-11-3-2-1/ Barkat	Yusiray Kaap	White grains; 90–95 cm tall; 170–180 days; average yield of 7–8 t ha^{-1}[a]
IR62746-B-4-8-1-1	Suweon 359//IR41996-118-2-13/Thimphu Maap	Yusiray Maap	Red grains; 115–120 cm tall; 170–180 d; average grain yield of 7–8 t ha^{-1}

[a]Average yield of local varieties is about 4.5 t ha^{-1}.

varieties are widely grown by farmers in Thimphu and Paro. Along with crossbred materials, introductions from other countries were also evaluated. A locally selected variety from the highlands of Nepal, Chummrong, was identified with adequate tolerance of blast and cold. This variety was also released in Bhutan as Khangma Maap.

The screening and selection of varieties have now been shifted to a new site at Khachadrapchu and the program continues. Local staff now do crossing at the site.

Apart from variety work, research on management aspects (nutrient management, weed management, nursery practices, etc.) is also given equal importance. One of the obnoxious weeds in the high-altitude areas is *Potamogeton distinctus*, locally known as "shochum" (Fig. 3). Yield reduction due to this weed has been recorded as high as 37%, despite farmers' practice of one to two hand weedings. Manual weeding is not very effective due to the weed's nature of easy propagation from any vegetative part, but affordable weedicides are not available locally.

Another pressing problem for farmers is the emergence of "weedy" rice among cultivated fields. The farmers of Thimphu and Paro reported the problem first in 1997

Fig. 3. Shochum in a transplanted rice field.

to the Ministry of Agriculture. Since then, research has been done in collaboration with IRRI and the weedy types have been identified as *Oryza sativa* f. *spontanea,* a hybrid between wild and cultivated rice (Loresto 1998). The weedy rice contaminates the cultivated crop, leading to yield loss and increasing weed pressure. The weedy rice is highly shattering and perpetuates year after year from dropped seeds. Although several recommendations are given to farmers, it remains a problem.

Constraints in japonica rice production

Japonica rice production in Bhutan faces several constraints. The major ones follow.

Low genetic yield potential of native varieties

The traditional rice varieties are typically tall, weak stemmed, and prone to lodging at maturity. Their genetic potential is limited by their plant architecture and they do not respond well to additional inputs such as inorganic fertilizers. Most of the native varieties have red pericarp, which is a preferred trait among farmers and consumers. The local varieties are highly diverse morphologically and perhaps genetically. No detailed studies at the molecular level have been conducted so far. Their yield potential is limited to about 5 t ha^{-1} under the best management practices by farmers. More than 80% of the rice area in the temperate zone is grown to local varieties.

Damage from cold temperature

The air temperatures during seedling growth and at the later ripening stage hover around 15 °C or below, making the rice varieties highly susceptible to cold injury. In the traditional method of raising seedlings, seeds are sown in February when temperatures are low and the seedbed duration extends over 3 months before transplanting.

The temperatures begin to drop sharply in September and, if transplanting is delayed, cold injury during flowering and ripening is inevitable. Therefore, high cold tolerance at seedling and ripening stages is a requirement.

Blast and other diseases

All the native Bhutanese varieties are susceptible to rice blast and the blast pathogen population is diverse in the high altitudes (Thinlay 1998). The 1995 blast epidemic affected the entire temperate rice region and resulted in losses estimated at 1,099 tons of paddy or an equivalent Nu 11 million (US$1 = Nu 42). In the high altitudes, blast occurs late in the season and infects the neck and nodes, leading to severe losses. Knowledge about different pathogen populations with different virulence is limited, which is a constraint for an effective resistance breeding program. Apart from blast, sheath blight caused by *Rhizoctonia solani* is common in the high altitudes, which also merits research attention.

Weeds

Apart from grasses and sedges, temperate rice fields are infested by an aquatic weed, "shochum" (*Potamogeton distinctus*), which is very difficult to control manually. The weed spreads rapidly, propagating from any living plant part, and the underground parts easily overwinter and grow back in the following year. It also spreads through irrigation water. Farmers normally carry out two to three hand weedings but this practice does not ensure complete removal of weeds from their fields. The use of the herbicide butachlor to control grasses and sedges, as is widely practiced by farmers, eliminates weed competition and allows shochum to proliferate. Some herbicides such as Sanbird (pyrazolate) and NC 311 (pyrazosulfuron-ethyl) have been identified as effective (Ghimiray 1993) but they are not available locally. The actual costs (after importing) are also prohibitive to farmers.

Weedy rice

Temperate rice fields are highly infested with weedy rice identified as *Oryza sativa* f. *spontanea,* possibly a hybrid between wild and cultivated rice. It is very difficult to identify weedy rice at the early growth stage and its highly shattering trait ensures its perpetuity in rice fields. Substantial losses occur in terms of both quality and quantity.

Suboptimal management practices

Farmers normally rely on organic sources (farmyard manure, home-made compost) to fulfill the nutrient requirements of rice. The average amount applied ranges from 10 to 12 t ha^{-1}. This amount may be inadequate in fields where inherent fertility is poor and where micronutrients are deficient. Suboptimal plant density due to wide spacing is another common feature. Rice transplanting and harvesting are usually delayed because of religious and superstitious beliefs (waiting for an auspicious day to begin at the community level), which often leads to grain shattering and yield loss.

Available genetic resources and their improvement

There is quite a rich diversity of traditional rice varieties in the temperate zone of Bhutan. Farmers grow and maintain an array of varieties for their varied needs such as for staple food, alcohol brewing, snacks such as *sip* and *zaw*, and speciality varieties for religious purposes. These varieties have high adaptation to local growing conditions and management systems. Some of the popular varieties are listed in Table 5.

Table 5. Some popular temperate rice varieties of Bhutan.

Variety name	Altitude (m)	Village	District
Kochum	2,570	Drugyal Dzong	Paro
Thaemja	2,450	Phubana	Paro
Hasay	2,440	Ngoba	Paro
Janaab	2,410	Nabesa	Paro
Khemja	2,400	Dophu	Paro
Rey Kaap	2,400	Longona	Paro
Gyamo Kaap	2,400	Misi	Paro
Naam	2,380	Joshilo	Paro
Kambja	2,350	Jagathang	Paro
Dumbja	2,300	Acho	Paro
Sombja	2,300	Nabesa	Paro
Zamsa Kaap	2,300	Zamsa	Paro
Kochum Maap	2,300	Phondo	Paro
Gangju Kochum	2,288	Lango	Paro
Janam	2,230	Changkha	Paro
Zhechum	2,140	Kharapji	Paro
Machem	2,100	Issuna	Paro
Khemjya (awned)	2,010	Chongkha	Paro
Kuchum	2,010	Chongkha	Paro
Chumbja	2,440	Dechencholing	Thimphu
Dangrey	2,440	Chapcha	Thimphu
Bjanam	2,385	Simtokha	Thimphu
Punakha Cupo	2,379	Chalumanfe	Thimphu
Uzum	2,360	Taba	Thimphu
Hamzam	2,260	Chalumaphey	Thimphu
Kurtepja	2,260	Chalumaphey	Thimphu
Ray Sakha	2,200	Kabjisa	Thimphu
Ray Naab	2,100	Sisina	Thimphu
Ngaja	1,830	Mendegang	Thimphu
Guenja	1,800	Mendegang	Thimphu
Dagozam	1,700	Mendegang	Thimphu
Zakha Kaap	1,700	Mendegang	Thimphu
Zakha Maap	1,700	Mendegang	Thimphu
Dorilo Maap	1,800	Tomji	Haa
Rey Naab	1,750	Rabji	Haa
Rey Maap	1,950	Shabji	Haa
Rey Kaap	1,950	Shabji	Haa

With the assistance of the International Rice Research Institute (IRRI) and the International Plant Genetic Resources Institute (IPGRI), nationwide rice collection missions were fielded in the 1980s. This resulted in about 200 accessions. More recently, the research and extension staff of the Ministry of Agriculture have been trained to undertake germplasm exploration and collection. Three training programs were organized annually from 1996 to 1998 with expert trainers from an IRRI-SDC project that included Bhutan as a collaborator. Rice collection expeditions have now resulted in a total of more than 350 accessions that are presently conserved at the Genetic Resources Center of IRRI. A working collection is also maintained at RNRRC Bajo. Facilities for medium- and long-term storage are now built at the National Biodiversity Center, Thimphu, and we are hoping to repatriate the collection from IRRI and also add to the collection.

The type of genetic resources needed for the country include prebreeding and crossbred materials for the temperate areas with cold tolerance and blast resistance as the main traits. Such materials can be directly selected under Bhutanese conditions or used in in-country breeding programs.

Strategies used, including biotechnology

So far, only conventional breeding methods are employed to some extent for the improvement of temperate rice. Such a program is running on a small scale for want of adequate human resources. The research system lacks advanced facilities, biotechnology, and molecular laboratories.

Expectations from the TRRC and possible contributions to the TRRC

For a small country such as Bhutan with a modest rice research program, there is much to gain from the Temperate Rice Research Consortium. Some of the obvious benefits and expectations are

- Building and upgrading of technical capacity for rice research and development. This would include both short training courses and long-term courses leading to MSc and PhD degrees. The identification of relevant courses, institutions, and facilitation of funds is crucial.
- Exchange and availability of appropriate genetic materials for selection and breeding for Bhutanese conditions. Cold tolerance and blast resistance are important characteristics.
- Exchange of scientific knowledge and expertise.
- What Bhutan can contribute to the TRRC is its vast rice genetic resources for research and development for similar environments elsewhere.

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Temperate rice in Central Asia (Kazakhstan and Uzbekistan)

Zakir Khalikulov, Torekhan Karlikhanov, and Zamonkhodja Djumanov

Kazakhstan and Uzbekistan are two Central Asian countries that grow temperate rice. Table 1 presents data on rice area, production, and productivity in these two countries. Two rice research institutes exist in Kazakhstan and Uzbekistan.

Uzbekistan has the Uzbek Research Institute of Rice located near Tashkent. Kazakhstan has the Priaralsky Scientific Research Institute of Agroecologies and Agriculture near Kzyl Orda City (near the Aral Sea). In total, the Uzbek Research Institute of Rice employs 59 people, of whom 36 are researchers, 8 are candidates of science, and 3 are doctors of science. It has seven departments: (1) rice breeding and physiology, (2) seed production, (3) agrochemistry, (4) patents and information, (5) laboratory grain cultures, (6) agrotechniques, and (7) mechanization. The institute has a central experimental site with 185.57 ha as well as branches in Karakalpakstan, Andijan, and Khorezm provinces. Until now, 12 rice varieties have been released in Uzbekistan. Ten of these varieties are japonica (Avangard, Alanga, Arpa-shaly local, Gulzar, Jayhun, Istiqbol, Nukus-2, Sanam, Tolmas, and UzRos 7-13) and two are indica (Lazurniy and Istiqlol). The main breeding activities at the institute focus on japonica rice varieties. The first national long-grain indica rice variety, Lazurniy, was released in 1981. Currently, 12 more rice varieties are being tested by the State Variety Testing Committee.

The Priaralsky Scientific Research Institute of Agroecologies and Agriculture employs 67 people, of whom 40 are researchers, 7 are candidates of science, and 7 are doctors of science. There are seven departments: (1) rice breeding, (2) seed production, (3) crop husbandry, (4) soil quality and agrochemistry, (5) vegetables and melons, (6) livestock, and (7) patents and information.

Major research targets for improving japonica rice and production technologies

Currently, rice breeding targets are higher yield (7–9 t ha^{-1}), early maturity (95–115 days), 68–70% more rice output from paddy, and lodging resistance, as well as resistance to salinity, and especially higher water-use efficiency. In addition, researchers are working in the region to introduce a new rice-soybean crop rotation. For this purpose, there is a need to breed new rice varieties with the above characteristics for better adaptability in this new crop rotation. Moreover, some emphasis is placed on new rice production technologies in the region using raised-bed planting, minimum tillage, and direct seeding, which are expected to improve soil fertility.

Constraints to japonica rice production and improving japonica rice

- Lack of knowledge on biotechnologies
- Soil quality degradation, including an increase in salinity, loss of humus, etc.
- Shortage of water resources, especially in Uzbekistan
- Inappropriate pest and disease management in Kazakhstan

Available genetic resources and type of genetic resources needed

Kazakhstan now has 730 accessions of japonica rice and Uzbekistan has 2,986 accessions. These rice accessions are mainly japonica type. The countries now need high-yielding, early-maturing, lodging-resistant accessions.

Strategies used, including biotechnology

Currently, traditional crossing methods do not use biotechnology.

Expectations from the TRRC and possible contributions to the TRRC

Kazakhstan and Uzbekistan have the possibility to exchange rice accessions with the TRRC for use in the selection process of different rice varieties from different nurseries, and to develop and implement joint projects in the improvement of rice varieties.

The TRRC could provide capacity building and training, including in biotechnology, for rice researchers in Kazakhstan and Uzbekistan.

Table 1. Rice area, production, and productivity in Kazakhstan and Uzbekistan.

Country	Year					
	2000	2001	2002	2003	2004	2005
Area harvested (000 ha)						
Kazakhstan	72.16	53.73	65.60	83.48	76.30	74.99
Uzbekistan	131.77	39.49	64.39	120.99	66.10	52.48
Production (000 t)						
Kazakhstan	214.30	198.70	199.09	273.34	275.85	310.00
Uzbekistan	154.80	67.80	175.10	333.70	181.23	165.79
Yield (t ha^{-1})						
Kazakhstan	2.97	3.70	3.03	3.27	3.62	4.13
Uzbekistan	1.17	1.72	2.72	2.76	2.74	3.16

Notes

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Temperate rice in Chile

Karla Cordero Lara

Rice cultivation in Chile

Rice has been grown in Chile since the late 1930s and the area, yield, and production have been variable over time. This crop uses irrigated soils with a high content of clay and/or impermeable layers of soil, with drainage problems that hamper the establishment of other crops. The rice area is located in three regions, Region VI (2%), Region VII (79%), and Region VIII (19%), all located in the central area of the country. The central valleys of Chile have a Mediterranean climate with hot, dry summers and cold and rainy winters.

The average yield of rice has been improving in recent years, due to good results from the research conducted primarily by the Instituto de Investigaciones Agropecuarias (INIA); these methodologies have allowed the national average yield to rise consistently, from about 26 qqm ha^{-1} in 1965 to more than 58 qqm ha^{-1} in the last three seasons. These technologies include the use of improved varieties, increased mechanization, and better management of crop fertilization, weed control, and water management. It is estimated that current varieties with national average yield can reach 65 qqm ha^{-1}. Good farmers exceed 70 qqm ha^{-1} and, in some years, can achieve 100 qqm ha^{-1}, a performance close to the estimated potential of varieties. In relation to management conditions, rice is grown only in areas under irrigation and flood, by pregerminated direct seeding, usually in October and the first week of November. It is fertilized with N, P, and K and only chemical control of weeds is done during the growing season, since Chile has no pests or diseases of economic importance. The harvest is between March and April, and the entire production is for domestic consumption.

Sowing area has been declining in recent years, now being 22,000 to 28,000 hectares.

Domestic production reaches 121,000 to 140,000 tons of paddy rice annually. The crop is produced mainly by small farmers. According to the last agricultural database, the average area per farmer reached 10 ha, the largest being 200 to 500 hectares.

Domestic producers have very good potential. World population growth will cause an increase in demand for rice production, but Asian countries no longer have a sufficient amount of surface area, so the Southern Cone countries will play an important role in future rice production.

Around 40% of the total rice consumption in Chile is imported. The imported grains are long and narrow, while domestic production is preferably long and wide grain. Domestic consumers still discriminate very little for quality, but there is a tendency to discriminate by brand in the middle and upper social strata. In fact, mills concentrate their offer in three quality segments: grade 2 (70%), grade 1 (16%), and parboiled (precooked) (9%).

The Rice Breeding Program at INIA

The Ministry of Agriculture created the Rice Breeding Program in 1953, which became part of INIA since its creation in 1964, located at the Regional Research Center (CRI) Quilamapu in Chillán, Region VIII (37º South latitude).

Since the establishment of INIA, the program has been developed at a national level, being active across the whole rice area. The main objectives of the rice breeding program are

- To increase yield potential.
- To achieve tolerance of low temperatures.
- To improve the quality of the grain (industrial, commercial, and culinary).
- To obtain earliness.
- To produce varieties with suitable agronomic characteristics (lodging resistance, height of about 1 m, panicle threshability, efficient use of nutrients, etc.).
- To achieve tolerance of stem rot and sheath blight.
- To increase diversity in types of rice (glutinous and aromatic).
- To achieve tolerance of herbicides.

The Rice Breeding Program has turned its efforts to the production of long, wide, and translucent grain varieties, and has taken some steps in the process of diversifying the types of rice. Specialty rice, which is that which is not common, in relation to shape, size, amylose content, endosperm color, and aroma, has a better price than standard rice that is sold more commonly in the world.

One of the recommendations of the expert who visited Chile, Dr. Ram Chaudhary, is that Chile "should move toward specific niche markets. Rice production could be diversified into specialty rice for which demand and prices are growing very fast." The different types of rice that are sold in the world today have opened a new path in the orientation of the national Rice Breeding Program.

Our program is now using conventional breeding, through methods of pedigree selection and breeding populations. The most advanced lines to be presented as varieties are submitted to a Regional Committee for their release and then to the National Committee. Then they are registered and tested by the Chilean Agricultural and Livestock Service, which gives a license or patent for marketing.

Notes

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Temperate rice in China

Zhi-Kang Li, Zetian Hua, Yongming Gao, and Guo-Min Sui

The Chinese population is projected to surpass 1.5 billion by 2030. As the staple food for most Chinese people, rice production has to increase by 50% in order to meet the projected demand. With a total annual production of 51.8 million tons, temperate japonica rice has been playing an important role in meeting the food demand of 1.3 billion Chinese people. Japonica rice is now grown on 25.5% of the total rice-growing area and it produces 28.8% of the total rice production in China. About 45% of the japonica rice is produced in northeast China and Helongjiang is the largest japonica rice-producing province, with approximately 2.5 million ha of japonica rice. Because of its good eating quality and higher prices, growing area and demand for japonica rice are on the rise in China recently despite the decrease in total rice lands as a result of fast economic development and urbanization in the last 20 years. Based solely on conventional breeding approaches, Chinese scientists have made significant progress in raising the yield potential of japonica rice during the last 50 years. This was achieved in the 1990s by developing new plant type lines formulated by professor Yang Shouren in Shengyang Agriculture University. These high-yielding new plant type japonica rice varieties typically have dark green leaves, compact plant type, erect or semierect panicles, and high spikelet density, which can reach 13 t ha^{-1} under ideal conditions. Progress in developing hybrid japonica lines has also been made and new japonica hybrids currently account for only about 7% of the total japonica area in China and can reach 14 t ha^{-1}. China has built up tremendous capacity in rice breeding and research during the last 20–30 years, with a total of 4,000+ rice breeders/geneticists and 5,000+ other scientists working on rice. The conventional breeding approach has been and remains the predominant method. More than 250 new rice inbred and hybrid rice varieties are now released to farmers annually, including approximately 100 japonica cultivars.

The process of conventional breeding by hybridization involves the generation of genetic variation for traits of interest by making crosses between different parental lines, selecting for superior individuals with improved target traits resulting from recombination of the parental genes in the segregating populations of the line crosses, and fixing rare superior individuals (genotypes) by continued selection and selfing, for developing new lines. The success of conventional breeding depends largely on two things: (1) the total amounts of useful genetic variation for target traits in breeding populations and (2) the accuracy and efficiency of selection for the useful genetic variation of target traits resulting from the recombination of parental genes. Thus, the more than 250,000 rice germplasm accessions, including both cultivated types and their wild relatives, maintained in crop gene banks worldwide, contain almost all gene resources for the future improvement of this important crop. However, a startling fact is that more than 95% of the rice germplasm collections worldwide have never been used in any breeding programs. At least three reasons are responsible for the low use frequency of germplasm. First, past efforts in studying germplasm resources were limited to the evaluation and description of phenotypic variation of morpho-physiological traits, resistances to biotic and abiotic stresses, etc., in order to identify those accessions with extreme phenotypes for traits of agronomic importance to be used as "trait donors" or as genetic stocks for breeding and genetic studies of target traits. Unfortunately, the accessions with extreme phenotypes are very few, particularly for resistances to biotic and abiotic stresses and, more often, those few accessions with extreme phenotypes are landraces with poor yield potential under modern high-input agriculture.

Second, the line-crossing procedures of conventional breeding schemes involve only a few parental lines. Thus, limited genetic variation for any target trait is present in breeding populations involving closely related parents, from which it would be hard to select and identify individuals with overall performance superior to that of parental lines and novel genotypes for target traits resulting from rare gene combinations. At present, little is known about the useful genes in the germplasm and the genetic basis underlying traits of agronomic importance. In practice, breeders have been choosing germplasm accessions as the parents in their breeding programs based largely on line performance in target traits. Thus, the inconsistency between genotype and phenotype for most complex traits, particularly quantitative traits, often misleads breeders.

Third, different types of molecular markers have been used extensively to characterize the genetic diversity of rice germplasm. Although these studies provide good estimates of the genetic diversity at the molecular level and phylogenetic relationships among different germplasm accessions, it remains unclear how useful these types of information would be for guiding breeders to use the germplasm more efficiently. As a result, the direct consequence of this low use of germplasm resources by conventional breeding approaches is the well-documented "monoculture" or low genetic diversity in commercially grown rice cultivars and their vulnerability to biotic and abiotic stresses. Japonica rice production in China faces a number of abiotic and biotic problems. Of the former, water shortage and drought, cold, salinity, and overuse of N fertilizer are the most important ones. Rice blast and false smut are the most important biotic problems. To solve these problems, Chinese rice scientists are calling for the initiation of a "Doubly Green Revolution" by developing "green" super rice varieties, which can produce high yield with less resources (water and fertilizer) and better disease or insect control. To overcome these problems, a national rice breeding network, the China National Rice Molecular Breeding Network (CNRMBN), was begun in 1998. The CNRMBN currently consists of 17 research institutions across China with financial support from the Ministry of Agriculture (948 programs). The CNRMBN was defined as a national breeding network in which the development of large numbers of trait-specific introgression lines (ILs) in elite genetic backgrounds by large-scale BC breeding (the material platform for gene/QTL discovery and DQP (Designed QTL Pyramiding)), deep exploitation of useful genetic diversity from the primary gene pool of rice, effective selection for target traits, discovery/allelic mining and characterization of QTL networks for traits of agronomic importance, and targeted trait improvement by DQP based on accurate genetic information from QTL networks in the well-characterized ILs are well designed and integrated. The goal of the CNRMBN was to develop superior inbred and hybrid rice cultivars with a significant improvement in yield stability, yield potential, and grain quality for the major rice-growing areas in China. The original objectives of the CNRMBN were the following:

- To broaden the genetic base of rice cultivars in the major rice-growing areas of Asia by maximizing gene flow from the primary gene pool into elite genetic backgrounds through large-scale backcross breeding activities.
- To exploit the hidden diversity of the primary rice gene pool for improving complex target traits.
- To develop IL sets for elite rice genotypes adapted to major rice ecosystems.
- To discover and characterize large numbers of QTLs and QTL networks underlying important rice traits; and to mine allelic diversity at important QTLs.
- To establish a genetic and phenotypic database for the developed ILs.
- To train a new generation of molecular rice breeders for China.

Of the 17 research institutions, nine are focusing on japonica rice. The CNRMBN has two technical components. The first one was to establish two gene pools, an elite gene pool (EGP) and a donor gene pool (DGP). The EGP consists of 30 commercially grown inbred varieties and parents of the best hybrid cultivars that were predominantly commercial varieties in different rice ecosystems of China, provided by the 17 participating institutes (each contributing one to three locally best commercial cultivars). The DGP consists of 169 lines that were selected to represent the maximum geographic and genetic diversity within *Oryza sativa* according to our knowledge. The DGP lines are largely complementary to the EGP lines in geographic origin, and contain several dozen landraces that have never been used in any previous breeding programs. Based on an assay with 101 simple sequence repeat (SSR) markers (Yu et al 2003), 68.2% of the parents belonged to the indica subspecies, 30.3% belonged to the japonica subspecies, and 1% were intermediate types derived from indica/japonica crosses, plus a deepwater rice, Jalmagna, from India, which forms a single solitary group. The genotypic data at 101 SSR markers form the molecular database of the parental lines, which have been greatly expanded during our gene/QTL discovery activities.

The second technical component of the CNRMBN involved massive BC breeding activities in all participating institutes to develop genomewide ILs for target traits in elite genetic backgrounds. In this process, each of the participating institutes used one to three locally best commercial cultivars as recurrent parents (RPs) and the rest of the lines in the EGP and DGP as donors to introgress desirable traits (QTLs) of the parental gene pools into the elite RP genetic backgrounds. The outputs will be many sets of ILs for all EGP lines. Specifically, each of the participating institutions used its one to three locally best adapted EGP lines as recurrent parents and the rest of the EGP and DGP lines as donors to create large numbers of BC_nF_2 bulk populations. Then, the BC_nF_2 bulk populations were screened for target traits, which were determined by each participating institution. The BC progeny having target traits from the screening were selected and progeny tested for both target traits and general performance in direct comparison with the RPs. Those homozygous BC progeny confirmed to have the target traits were identified as trait-specific ILs.

CNRMBN activities in China have resulted in the development of 49,412 BC_3/BC_2 bulk populations in 21 elite Chinese rice genetic backgrounds (Table 1), including six sets of japonica BC bulk populations. Large-scale screening of these bulks has resulted in the development of 7,491 ILs with one or more improved traits (tolerance of drought and salt, N and P use efficiency, disease resistance, and improved yield). In addition, the BC breeding activities have already resulted in the release of 16 new inbred or hybrid cultivars, with 40 promising ones in multilocation yield trials (Table 1).

Several distinctive features make our BC breeding program unique. First, it is the largest one ever reported regarding the numbers of donors and screened traits. In particular, the BC breeding program began without evaluating parental lines for the target traits. In other words, the donors in the CNRMBN were not selected based on phenotype for any specific target traits but on the geographic pattern of the genetic diversity in worldwide rice germplasm collections. Thus, these donors could be considered as a sample of the core collections of the primary gene pool of rice. Second, selection (screening) for tolerance of a particular stress was not based on donor performance for the target trait. Several important results were obtained regarding the amount of genetic variation for abiotic stress tolerance in the primary gene pool of rice and these suggest approaches for more efficient exploitation of this rich source of genetic diversity.

The most important conclusion is that there are tremendous amounts of "hidden" diversity in the primary gene pool of rice for all the traits we screened. This hidden diversity was reflected in at least two aspects. First, BC progeny showing transgressive performance of the target traits over the parental lines were obtained in most BC populations for all abiotic stresses we screened regardless of the performances of their donors. Because the levels of different abiotic stresses applied in our screening for drought, salinity, submergence, anaerobic germination, zinc deficiency, and low-temperature germination were very severe and typically killed the RPs and most donors, the selected BC progenies unlikely survived by escaping the stress (Table 2). This suggests the wide presence of genes for improved stress tolerance in the donors, which in some cases were not expressed in the donor phenotype (Ali et al 2006). Furthermore, our results indicate that the subspecific differentiation of indica and japonica within *O. sativa* does not seem to have specific implications regarding useful genetic variation for most traits we screened in this study.

Table 1. A total of 49,412 BC_3F_2/BC_2F_2 bulk populations and 7,491 ILs for specific traits derived from 2,451 crosses between 21 elite Chinese rice genetic backgrounds and 203 donors worldwide developed in the CNRMBN.

Genetic background	Type (subsp.)[a]	N_1[b]	N_2	N_3	N_4	N_5	Institute[c]
Chaoyou 2	**Inbred/restorer (J)**	**117**	**2,915**	**645**			**CAAS**
Shuhui 57	Restorer (I)	147	2,140	1,258			CAAS
Minghui 86	Restorer (I)	125	2,670	875			CAAS
Zhengshan 97	Maintainer (I)	123	1,390	958	4	1	HUA
9311	Restorer (I)	97	2,741	298	3		HUA
Zhong413	Restorer (I)	149	2,500	1,300			SAAS
Hanfeng	**Maintainer (J)**	**113**	**2,023**	**–**			**SAAS**
Chenghui 448	Restorer (I)	105	2,762	1,179	4	2	SCAAS
Chuanxiang 29B	Maintainer (I)	105	1,834	277	3	3	SCAAS
Liaojing 454	**Inbred (J)**	**98**	**2,494**	**906**	**2**		**SAU**
Fen-Ai-Zhan	Inbred (I)	104	2,560	2,078	5		GAAS
Yue-Xiang-Zhan	Inbred (I)	100	1,690	–			GAAS
C418	**Restorer (J)**	**138**	**2,685**	**3,407**	**3**	**2**	**LAAS**
Yunhui 290	Restorer (I)	123	2,528	427	3	1	YAAS
DJY1	**Inbred (J)**	**170**	**2,534**	**62**		**1**	**YAAS**
Zaoxian 14	Inbred (I)	100	2,605	761	2	1	AAAS
M3122	**Restorer (I)**	**100**	**1,023**	**142**	**3**	**1**	**AAAS**
Zihui 100	Restorer (I)	105	2,098	1,459	2	1	AAAS
Hui 752	Restorer (I)	127	3,192	1,203	4		JAAS
F6	Restorer (I)	127	3,458	7	2		JAAS
Zhong-You-Zao 81	Inbred (I)	78	1,570	23		3	CNRRI
Total		2,451	49,412	7,491	40	16	

[a]I and J represent indica and japonica subspecies. [b]N_1, N_2, N_3, N_4, and N_5 represent the numbers of crosses, BC_3F_2 or BC_2F_2 bulk populations, introgression lines (ILs) for specific target traits, promising lines tested in yield trials and genotyped with DNA markers, and new cultivars developed. [c]CAAS, HUA, SAAS, SCAAS, CNRRI, SAU, GAAS, LAAS, YAAS, AAAS, and JAAS represent Chinese Academy of Agricultural Sciences, Huazhong Agricultural University, Shanghai Academy of Agricultural Sciences, Sichuan Academy of Agricultural Sciences, China National Rice Research Institute, Shengyang Agricultural University, Guangdong Academy of Agricultural Sciences, Liaoning Academy of Agricultural Sciences, Yunnan Academy of Agricultural Sciences, Anhui Academy of Agricultural Sciences, and Jiangxi Academy of Agricultural Sciences.

Table 2. Some promising drought-tolerant and high-yielding japonica lines have been developed.

ILs	Number	Shandong		Hainan		Beijing	
		Stress	Nonstress	Stress	Nonstress	Stress	Nonstress
C418 (check)		10.67	15.46	12.75	16.28	13.23	17.96
C418/C71	10	14.52	17.91	15.92	18.75	18.75	20.99
ILs-check/ check (%)		36.1**[a]	15.8	24.9*	15.2	41.7**	16.9
C418/ Zaoxian14	6	14.30	17.26	12.45	13.21	16.84	20.89
ILs-check/ check (%)		34.0**	11.6	–2.4	–18.9	27.3*	16.3

[a]** and * = significant at 0.01 and 0.05 level.

Second, it was quite common to identify BC progeny with extreme phenotypes (tolerances). For instance, many BC progeny survived the severe zinc deficiency stress that virtually eliminated the best check, Madhukar (a landrace showing the highest zinc deficiency tolerance in more than 9,000 germplasm accessions screened). For salt tolerance, many ILs showed better tolerance than the tolerant checks, Pokkali and Bicol.

Third, when defined as the number of superior plants identified per BC population, the selection efficiency for abiotic stress tolerances in BC populations was highly dependent upon genetic background. In this study, a common population size of 100–250 plants was used in target trait screening of the BC populations. Under the highly stringent stress conditions for most target traits (the average selection intensity was less than 10%), this population size allowed the identification of surviving plants in most BC populations. The differences between the recurrent genetic backgrounds were at least partially attributable to the differences between the RPs for the trait-enhancing alleles they carry.

Fourth, selection efficiency was affected to a large extent by levels of stress applied. Our results indicated that high stress could significantly increase the accuracy of selection and reduce the number of total selected plants to a manageable size. For instance, the EC 12 dS m^{-1} normally used for screening salt tolerance at seedling stage was apparently too low since more than 80% of the plants in many BC populations were little affected by this level of stress. Instead, the EC 24 dS m^{-1} used in this study was more suitable for screening BC progeny from more susceptible recurrent parents such as NPT, and the EC 30 dS m^{-1} was better for those with a moderate level of ST (salinity tolerance) (IR64 and Teqing). Thus, it is necessary to adjust the level and timing of stresses based on the performance of RPs in BC breeding programs. Nevertheless, applying an appropriate level of stress in breeding for different types of stress tolerance remains a challenge. Fifth, selection efficiency for different target traits varies in different BC generations. Much higher numbers of surviving plants were identified in BC_2 populations than in BC_3 populations. This is not surprising since the number of QTLs from donors in random BC_3 populations is expected to be only half of that in BC_2 populations. Finally, it is generally believed that the levels of tolerance of/resistance to abiotic and biotic stresses tend to follow the order of wild species > landraces > modern cultivars, and the reverse is true for yield potential under modern cultivation as a result of domestication and long-term artificial selection.

Our results have challenged the general belief that resistance to/tolerance of biotic and abiotic stresses is more easily discovered in the wild species of cultivated plants than in the cultivated types themselves. Nevertheless, the wide presence and random distribution of genes for stress tolerance in the primary gene pool of rice are certainly good news for plant breeders. The high probability of being able to identify large numbers of stress-tolerant progeny in advanced BC populations achieved in this study demonstrated that, despite the complex genetics and the diverse physiological mechanisms underlying abiotic stress tolerances, introgression of genes from a diverse source of donors into elite genetic backgrounds through BC breeding and efficient selection is a powerful way to exploit the hidden diversity for genetic improvement of complex phenotypes, though the genetics of this "hidden" diversity for complex phenotypes remains a challenging but promising task for plant scientists to understand in the years to come.

Major progress for molecular breeding of japonica rice in the CNRMBN includes the following:

1. More than 800 crosses made between 7 elite japonica lines and 198 donors, and advanced to BC_2–BC_3.
2. More than 1,000 BC_3 bulk populations in three elite japonica genetic backgrounds developed and stored in SAGIC (Shanghai Agrobiological Gene Center).
3. More than 200 BC populations screened for different target traits and approximately 2,000 ILs developed.
4. More than 200 genes/QTLs for DT (drought tolerance), CT (cold tolerance), and ST (salinity tolerance) discovered and mapped for important traits using japonica ILs.
5. Four new cultivars developed, which are being tested in multilocation yield trials, and a large number of promising lines are in the pipeline.
6. A highly efficient breeding strategy, "breeding by designed QTL pyramiding," developed and demonstrated.

In conclusion, demand for and growing area of japonica rice are steadily on the rise in China. Conventional breeding has produced many high-yielding japonica rice varieties and hybrids in China; however, the genetic diversity of japonica rice in China has narrowed and it shows vulnerability to important biotic and abiotic stresses. A new breeding strategy by integrating molecular markers with conventional japonica breeding programs is in place and has proven useful for identifying and moving important alleles from donor lines. A highly efficient molecular breeding strategy based on introgression lines and accurate genetic information from identified QTLs are in place and are being extensively used in developing superior japonica rice cultivars with significantly improved yield stability and yield potential (Tables 3 and 4). Chinese rice breeders and scientists are willing to establish a fruitful collaborative relationship with scientists from other countries in japonica rice research in the adoption of conventional and modern biotechnology to benefit both commercial and subsistence farmers in China and the developing world.

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Table 3. Yield performance of some new promising japonica hybrids using restorers developed by BC breeding in the CNRMBN.

Hybrid	DSH[a]	Plant height (cm)	PPH	PL	SF (%)	KGW (g)	Yield (t ha^{-1})	HTC (%)
Liao30A/C372	159	120.5	13.4	19.9	85.8	25.6	11.83	9.41
Liao52A/C349	158	121.4	14.4	24.0	84.3	25.4	12.28	13.49
Liao99A/C372	161	110.4	15.1	16.9	89.6	25.4	12.66	17.01
Liao95A/C362	160	123.4	13.8	20.1	80.9	26.1	12.88	19.04
Liao52A/C372	160	122.2	14.8	26.1	69.4	24.6	11.88	9.81
Liao15A/C372	160	118.6	14.0	27.5	85.9	24.3	11.65	7.72
Liao52A/C358	159	124.6	11.9	19.9	89.6	25.4	11.49	6.19
Liao95A/C349	158	121.2	11.6	19.1	86.7	25.3	12.03	11.24
Liaojing 9 (check)	161	118.6	15.6	16.0	92.4	24.6	10.82	0

[a]DSH = duration from seeding to heading , PPH = panicles per hill, PL = panicle length, SF = spikelet fertility, KGW = kilo-grain weight, HTC = higher than check.

Table 4. Summarized activities in QTL identification and verification by DQP experiments in the CNRMBN.

GB	Type (subsp.)[a]	N1[b]	N2	N3	N4	N5	Institute[c]
Liaojing 454	Inbred (J)	>150	6	150+	26	624	CAAS/LAAS
Chaoyou 1	Inbred (J)	>150	6	300+			CAAS/TAAS
C418	Restorer (J)	>200	8	300+	30	583	CAAS/LAAS
Total		>300	20+	750+	56	1,207	

[a]J = japonica, I = indica. [b]N1, N2, N3, N4, and N5 represent the number of QTLs, traits, introgression lines (ILs), pyramiding crosses, and pyramiding lines, respectively. [c]CAAS = Chinese Academy of Agricultural Sciences, LAAS = Liaoning Academy of Agricultural Sciences, TAAS = Tianjing Academy of Agricultural Sciences.

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Temperate rice in Japan

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The Japanese islands are located between 23.5° and 45.3° N latitude and belong to a temperate climate zone. Our rice cultivation is carried out on plains and in basins where irrigation water is abundant. Almost 100% of the rice fields are irrigated. The agricultural population has decreased to 2.5 million and about 50% of these people are over 65 years old. However, potential rice production exceeds the demand for rice. To prevent overproduction, a policy aiming at the alternative use of rice fields has been promoted. Of the 2.6 million ha of rice fields, only 1.6 million ha were planted with rice in 2003. Brown rice productivity was about 5 t ha^{-1} in 2003. This was equivalent to 6.8 t ha^{-1} of unhulled rice yield. Most of the varieties are japonica, whereas indica varieties account for only 0.2%. Our major constraints to rice production are wind and flood, cool summer, and rice blast. Usually, typhoons cause wind and flooding damage in the southern and northern areas. Cool summer and rice blast cause yield losses mainly in the northern area and the elevated mountainous areas. In addition, damage from high temperature and rice-ear bugs has occurred frequently more recently. These two stresses cause an increase in pecky and white immature grains, which lower grain grades and prices.

Notes

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Temperate rice in Korea

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Rice is a traditional staple food crop in Korea, providing 31% of the calories for 49 million people and 25% of farming income in rural areas. Rice was grown on 1,010,000 hectares as of 2010, accounting for 58% of the total arable lands, with total production of around 5 million tons per annum.

Rice cultivation takes place in the irrigated lowlands mostly by machine-transplanting methods and hand-transplanting is practiced on only 1.2% of marginal rice land.

During rice growth periods spanning 6 months from mid-April to mid-October, average temperature changes from the lowest of 13 °C in April and October to the warmest of 25 °C in August. Thus, rice cultivation can easily face cold injury in spring and autumn. Currently, only japonica rice cultivars are grown in Korea. Since the experience of unprecedented yield loss from cold damage in 1980, cultivation of the high-yielding "Tongil-type" rice cultivars declined rapidly and only high-yielding japonicas have been grown in farmers' fields since 1990. In 2010, 20 mid- to late-maturing japonica cultivars were grown on 891,493 hectares, accounting for 92.9% of total rice area, and the cultivation of functional rice cultivars is increasing, which accounts for 4.3% of rice area.

The National Institute of Crop Science (NICS) is a government-funded crop research institution under the Rural Development Administration (RDA), in which nationwide rice research programs are an integral part of NICS programs. Rice research programs cover all rice research areas, such as rice genetics, breeding, rice quality evaluation, rice cultivation and physiology, postharvest, and biotechnology, etc. Also, two institutions are affiliated with NICS, the Department of Rice and Winter Cereal Crops and Department of Functional Crops. These research institutes conduct independent rice programs directed toward improving rice production of local areas of the southwestern and southeastern parts of Korea. Also, the provincial agricultural research institutes under provincial (self-governing) governments have their own rice research programs to attempt to solve rice problems facing provinces.

Major research targets for improving japonica rice and production technologies

The primary mission of the japonica rice breeding program in Korea is to develop superior cultivars that assure maximum and stable benefits for producers and consumers. Therefore, breeding efforts have been devoted to improving grain quality, yield potential, resistance to diseases and insect pests, and tolerance of environmental stresses. Especially, recent progress in the free trade agreement between countries is prompting rice breeders to develop premium-quality rice for Korean farmers' and consumers' acceptance. In this, breeding efforts are directed to developing superior cultivars with improved marketability, milling recovery, and palatability. For this purpose, simple and effective mass-screening methods, including molecular markers to select elite breeding materials, should be established.

Diversified grain types with high-value endosperm are important breeding targets for various food-processing activities. Developing specialty rice other than ordinary cultivars could increase rice consumption and international competitiveness. A variety of endosperm variants such as glutinous rice, giant embryo, strong aroma, black-purple rice, low and high amylose, high lysine content, and high mineral nutrients, etc., have been developed and are being incorporated into the elite high-yielding cultivars. Mutation breeding also successfully demonstrated its ability to create genetic variants with high-value endosperm in Korea. Breeding efforts for the diversification of morphological and physicochemical characteristics will be continuously intensified to enhance the usability for various food-processing and health-related purposes. However, disease and insect susceptibility of the specialty rice cultivars is projected to be a major drawback that needs to be overcome soon.

The importance of multiple resistance to disease and insect pests and tolerance of abiotic environmental stresses such as low temperature, drought, and adverse soil demonstrates an increasing demand for environment-friendly cultivar development. In tackling this problem, biotechnology is expected to play an important role related to the enhancement of host-plant resistance to insects and diseases. Currently, wide hybridization with useful alleles of wild rice and alien gene transfer are bringing about rapid progress to broaden gene pools for environment-friendly rice cultivars.

The decrease in available labor and rising cost for labor in rural areas are motivating rice farmers to shift from transplanting to direct seeding. Current high-yielding cultivars in Korea were selected and bred for transplanted rice culture. The design of new resource-use-efficient cultivars for direct seeding requires new knowledge on the biological growth potential of rice. Components of a new plant type concept for greater resource-use efficiency and yield potential may include (1) enhanced foliar growth with reduced tillering; (2) less foliar growth and enhanced assimilate export from leaves to stems along with sustained high nitrogen concentration; (3) a steeper slope of the vertical N concentration gradient in the leaf canopy, with more N present in the uppermost stratum; (4) expanded capacity of stems to store assimilates; and (5) improved reproductive sink capacity, with a prolonged ripening period.

Shorter growth duration and earliness of rice cultivars are major factors for high stable production in a multiple cropping system with cash crops. These cultivars should have such characteristics as faster leaf development, higher daily productivity, early vigor, and a good root system.

Rice breeding is a very complex science and many genetic problems need to be solved. Therefore, we believe that genetic knowledge and molecular technology should be integrated into rice breeding programs to enhance the efficiency of rice breeding for achieving another Green Revolution in rice.

Constraints to japonica rice production and improving japonica rice

Japonica rice production in Korea has been quite successful in maintaining self-sufficiency in rice production due to the development of high-yielding and high-quality japonica cultivars during the past 30 years. We believe that this achievement can be attributed to the rice yield potential of modern japonica cultivars released to farmers and the most adequate rice cultivation practices used by Korean farmers.

However, only five to six high-quality rice cultivars are predominantly grown in the country and the continued use of the same varieties for an extended period is likely to lead to a breakdown in resistance to diseases and insects, causing genetic vulnerability. Especially, the current emphasis on the top-quality rice in the world could entail the development of japonica cultivars without substantial resistance to pests and diseases in the near future. In addition, as the provincial government in Korea stressed rice policy for the production of environment-friendly rice products as a way to meet consumers' demand for no or low use of agrochemicals, worrisome prospects loom for yield loss and quality deterioration from damage by diseases and insects. This highlights the importance of breeding for durable resistance to pests and diseases and maintaining varietal diversity.

The aging of Korean farmers, the lower rice price due to rice imports, and the high cost of rice production have been the main practical concerns about rice production in Korea. It is also noteworthy that per capita rice consumption in Korea decreased dramatically from 120 kg in 1990 to 73 kg in 2010, which could suppress rice production in Korea.

Temperate japonica rice has been known to have less genetic variability than indica rice. Despite the narrow genetic diversity in japonica rice, breeders have made positive improvements for yield potential by conventional selection procedures while maintaining the desired grain quality characteristics. However, multiple resistance to major pests and environmental stresses should be strengthened in japonica rice to counteract future global climate changes.

Available genetic resources and type of genetic resources needed

Rice breeding goals in Korea have been diversified since 1990; hence, rice breeders have many genetic needs that must be met to reach these goals. Especially, in anticipation of global climatic changes in the near future that could cause unstable rice production, genetic resources with tolerance of drought, salinity, and cold and resistance to diseases and lodging are needed. However, these genetic resources are preferred to be associated with desirable grain quality. During the past years, Korean breeders have mostly been dedicated to breeding cultivars targeted for clear grain appearance, good eating quality, and appropriate grain shape. The physicochemical traits of Korean cultivars have become simple and similar; hence, diversifying grain traits is necessary with grain dimension from 3 to 10 mm, 1,000-grain weight from 10 to 70 g, amylose content from 0 to 37%, protein content from 4% to 18%, pericarp color from yellow-white to black-purple, and diverse aroma, embryo size, amylopectin structure, and mineral composition. For boiled rice, the current high-quality japonica cultivars should be complemented with high milling recovery and more nutritional content.

Specialty rice varieties need to be developed that would possess more diverse grain shape and physicochemical properties for a wide range of industrial purposes.

To strengthen the cultivation safety of japonica cultivars, wild rice germplasm should be secured to be used for long-term breeding. To develop short-growth-duration and direct-seeded rice cultivars for raising the efficiency of paddy rice fields and low-cost production, genetic resources possessing an adequate basic vegetative phase with relatively less photoperiod and temperature sensitivity are required. Also, direct-seeded rice requires low-temperature germination, excellent seedling stands, and tolerance of lodging and high density in Korean conditions.

Strategies used, including biotechnology

In Korea, a hybridization breeding method followed by pedigree selection has been routinely and commonly used in rice breeding programs. A systematic rice breeding program using this hybridization method started in 1915 and more than 200 cultivars were developed by this method.

Besides the hybridization method, other breeding technologies such as rapid generation advancement using a glasshouse, mutation, anther culture, heterosis, and molecular marker-assisted selection have been added to rice breeding programs, providing valuable tools to increase rice breeding efficiency.

Mutation breeding

The mutation breeding method by irradiation and chemical mutagens has often been used for special purposes. In the 1990s, modifying grain quality characteristics was successfully done by induced mutation. Three japonica cultivars, Goami 2, Beakjinju, and Seolgang, were produced through methylnitrosourea (MNU) treatment of Ilpum, a nonwaxy cultivar with the highest eating quality. Goami 2 has fibrous, nondigestible starch in the endosperm and is good for obese and diabetic patients. Beakjinju is a dull grain mutant with half-waxy content (9.1% amylose content) and it is suitable for brown rice recipes because the boiled rice does not easily become rigid after cooking. Seolgang is an opaque mutant with normal amylose content of 19.3%. This nontransparency is attributed to the even distribution of fine porosity in between starch granules in the endosperm. Because of this endosperm structure, Seolgangbyeo is suitable for manufacturing fermented foods such as rice kozi, sweet rice drink, and rice wine, etc.

Other related grain mutants with functionality or milling property could be detected if efficient screening techniques were available. Also, these useful mutants could be used as genetic stocks for mapping and molecular cloning of agronomically important genes.

Rapid generation advancement and anther culture breeding

Currently, the two most important technologies for shortening the breeding period are rapid generation advancement and anther culture. Korea grows a single crop of rice per year and it takes 13–15 years for the development of one cultivar under Korean climatic conditions. However, greenhouse facilities that allow two or three experimental rice crops a year have reduced the breeding cycle by 8–10 years for one cultivar.

Theoretically, anther/pollen culture is the fastest way to reach homozygosity. The haploid breeding through anther culture technique can also improve selection efficiency and save field space and labor. A rice anther culture breeding project that started in 1977 has been boosted up to a core project in the national rice breeding program. Through this method, 23 rice cultivars have been released since the development of the first anther-derived rice cultivar, Hwaseongbyeo, in 1985. Although the breeding period by anther culture could be different according to situations, it took 5–6 years by anther culture for a cultivar to be developed under a normal breeding schedule. Anther culture and the rapid generation advancement technique have been routinely used in rice breeding programs.

Wide hybridization

In Korea, the wide hybridization program started in the late 1980s, with the objective of transferring useful traits from wild *Oryza* species into the leading Korean varieties. It was hoped that a successful transfer of resistance to/tolerance of biotic and abiotic stresses and increased yield potential could be made from wide crosses with AA and other genome wild species into japonica cultivars. Currently, introgression lines with resistance to major diseases and insects, and a yield increase of 8% to 27% over a check variety, were successfully produced among the advanced backcross populations derived from crosses between *O. glaberrima* (AA), *O. rufipogon* (AA), and *O. minuta* (BBCC). These lines were analyzed with molecular markers such as simple sequence repeats, restriction fragment length polymorphisms, and amplified fragment length polymorphisms, and the wild alleles for increased yield were identified in the *O. sativa* genome, suggesting that useful transgressive variants could be created through wide hybridization between genomes. These lines could be used as the crossing parents to incorporate trait-improving alleles from wild species into cultivated rice.

Expectations from the TRRC and possible contributions to the TRRC

According to various estimates, Korea needs to produce 38% more rice by 2025 to satisfy food security. This demand would be met from reduced agricultural land, less water and labor, and reduced fertilizers and agricultural chemicals. To meet the challenges of more rice production under such constraints, we need to increase yield potential and obtain greater stability in japonica rice varieties.

The next attempts will be to protect and stabilize the gains in genetic improvement that have already been achieved. More emphases will therefore be placed on multiple resistance to diseases and insect pests, and tolerance of environmental stresses such as low temperature, drought, and adverse soil. Wide hybridization using wild species would be an efficient research target that is worthy of international pursuit with the use of biotechnology tools.

Breaking through the current yield ceiling may be possible when genotypes with a capacity for greater production of total biomass are identified. One strategy is to modify the canopy architecture of modern semidwarf high-yielding cultivars by minimizing unproductive tillers. The F_1 hybrid cultivar is another possible approach for the maximum use of heterosis in japonica rice development.

Notes

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Temperate rice in Nepal

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Rice is the major food crop in Nepal, supplying 38.5% of dietary energy, 29.4% of dietary protein, and 7.2% of dietary fat (FAOSTAT 2003). The crop is grown in diverse agroecosystems from lowland Terai to high hills. It was cultivated on 1.549 million hectares, with production and productivity of 4.21 million tons and 2.72 t ha^{-1}, respectively, in 2005-06 (MOAC 2006). As rice is grown under diverse soil and climatic conditions, growth in rice production is lower (2.07% per annum) than the rate of population growth (2.2% per annum). Ecologically, rice is produced in three zones, Terai and inner Terai-like environment (60–900 m), valleys and mid-hills (1,000–1,500 m), and high hills or mountains (>1,500 m), under different water regimes and land types with varying crop seasons (Table 1). The high hills or mountains consist of cool temperate regions whereas mid-hills consist of warm temperate regions.

The crop plays a significant role in the national economy, contributing 20% of agricultural GDP and accounting for 58% of total food grain production covering more than 50% of the agricultural area (MOAC 2006). The rice crop has three important by-products (rice straw, bran, and husk) that contribute substantially to agriculture, livestock, and agro-based industry. Rice straw meets 32–37% of total digestible nutrient for livestock; in turn, about 39 million tons of dung are available annually from cattle and buffalo in addition to milk and meat. Not only is rice a key source of food; it is also a major employer and source of income for the poor. Double cropping of rice ceases at around 900 m and reaches its altitude limit at 2,600 m (Sthapit 1995).

Area, production, and productivity of temperate rice including japonica

There is an increasing trend of rice yield per unit area in the country for the last two decades except for some lower values in some years (Fig. 1). This was due to prevailing drought in those years as 49% of the rice area is rainfed. Temperate rice consists of about 28.8% of the total rice area, producing 27.1% of total production with productivity of 2.55 t ha^{-1} (Table 2) (MOAC 2006). In warm temperate regions, three districts (Kathmandu, Lalitpur, and Bhaktapur) are the major potential areas for obtaining high yields compared with other districts in the country. These three districts cover 27,600 ha under japonica rice, with productivity ranging from 4.5 to

Table 1. Major rice production systems in Nepal.

Agroecological zone	Altitude (m)	Water regime and land type	Crop season
A. Terai and inner Terai			
Boro rice	60–200	Irrigated lowland	Oct.-June
Chaite rice	60–300	Irrigated lowland	March-July
Normal rice	60–300	Irrigated lowland, rainfed lowland	June-Nov.
Deepwater rice	60–100	Deepwater lowland	May-Dec.
B. Valley and mid-hills			
Chaite rice	300–900	Irrigated lowland	Feb.-June
Normal rice	300–900	Irrigated and rainfed lowland	May-Nov.
Upland rice	300–900	Rainfed upland	April-Aug.
Warm temperate rice	900–1,500	Irrigated and rainfed wetland	June-Oct.
C. High hills			
Cool temperate rice	1,500–2,621	Irrigated and rainfed wetland	April/May-Oct.

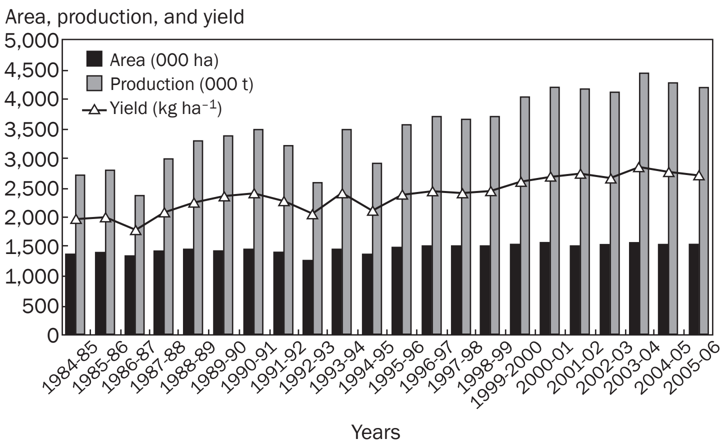

Fig. 1. Area, production, and yield of rice in Nepal.

5.1 t ha^{-1}. In cool temperate regions, japonica rice area covers about 13,000 ha, with productivity ranging from 0.76 to 2.20 t ha^{-1}.

A total of 20 rice varieties have been released for cultivation in warm and temperate regions of the country (Table 3). Four Taiwanese japonica rice varieties, Taichung 176, Chainung 242, Tainan 1, and Chainung 2, were introduced in 1950 in Nepal. The yield of these semi-dwarf varieties was found to be very impressive in fertile soil and they became successful in replacing some of the local landraces in the Kathmandu valley. These varieties were released in 1967 for general cultivation. These varieties were grown mainly for beaten rice (*Chyura*) and for a type of local liquor called *Jand*. The beaten rice from japonica rice fetches a higher price than indica type; therefore,

Table 2. Area, production, and yield of rice in different ecological zones (2005-06).

Ecological belts	Area (ha)	Production (tons)	Yield (kg ha^{-1})
Mountain (cool temperate)	64,676 (4.2%)	128,658 (3.1%)	1989
Hills (warm temperate)	381,591 (24.6%)	1,011,219 (24.0%)	2,650
Terai (plan area) (tropical and subtropical)	1,103,180 (71.2%)	3,069,402 (72.9%)	2,782
All Nepal	1,549,447	4,209,279	2,717

there is a demand for japonica rice in the Kathmandu valley and other cool temperate regions. Nowadays, there is demand for japonica rice in the plains area of the country (subtropical area) to be grown as winter rice, that is, boro rice.

Some other newly released rice varieties are also japonica type. Joshi and Bimb (2004) performed isozyme analysis on 39 rice varieties, of which 13 were identified as japonica type. These varieties are Chainung 242, Chandannath 1, Chandannath 3, Chhormmrong, Khumal 11, Khumal 5, Khumal 6, Khumal 7, Khumal 9, Machhapuchhre 3, Manjushree 2, Palung 2, and Taichung 176.

Institutions involved in temperate rice research

Rice cultivation is the main activity to improve the livelihood and enhance the economic growth of rural people. Nepal has to raise rice production to 5.7 million tons by 2030 for food sufficiency (FAO 2004). To achieve this goal and address the requirements of each production and agroecological domain, the National Rice Research Program (NRRP) has established a network with different research stations. The National Rice Research Program and Agricultural Botany Division (ABD) are the major government organizations responsible for breeding work in rice. Moreover, the ABD has the responsibility to do breeding work for temperate rice. Varietal testing as well as generating production technologies are done at the following Agricultural Research Stations: Pakhribas (1,300 m), Kabre (1,930 m), Lumele (1,650 m), Dailekh (1,450 m), and Jumla (2,380 m), located from warm temperate to cool temperate regions. Recently, the Biotechnology Unit located at Kathmandu has also begun some work, mainly isozymatic characterization of rice varieties and landraces.

Human resources in temperate rice research

Scientists working in different agricultural research stations and disciplinary divisions are working for varietal improvement as well as the generation of technologies for higher production in the fields of agronomy, soil science, pathology, and entomology. Five rice breeders from the National Rice Research Program, Agricultural Botany

Table 3. List of rice varieties released for hills and mountains of Nepal.

Rice variety	Method of improvement or parentage	Origin	Year of release	Yield (t ha^{-1})	Recommendation domain
1. Tainan-1	Tsai-Yuanchung/Dee-Geo-Woo-gen	Taiwan	1967	6.6	Warm temperate
2. Chainan-2	Cluamohu/Shiniri-Aikoku/Taicdhung 65	Taiwan	1967	7.8	Warm temperate
3. Chainung-242	Hsingchio /Taichung 170//Taipei 7/Taichung 45	Taiwan	1967	7.3	Warm temperate
4. Taichung-176	Tsai-Yuanchung/Dee-Geo-Woo-gen	Taiwan	1967	7.9	Warm temperate
5. Himali	Cica 4/Kalu	IRRI	1982	6.4	Warm temperate
6. Kanchan	CR 126-42-5/IR2061-21-3	IRRI	1982	7.6	Warm temperate
7. Khumal-3	China 1039/IR580	India	1983	6.5	Warm temperate, Chaite, and Barkhe
8. Palung-2	BG 94-2/Pokhreli Masino	Nepal	1987	6.1	Cool temperate
9. Khumal-2	Jarneli/Kn-LD-361-DLK-2-8	Nepal	1987	5.6	Warm temperate
10. Khumal-4	IR28/ Pokhreli Masino	Nepal	1987	6.3	Warm temperate
11. Khumal-7	Chaina 1039 DEF MUT/ Kn 18-361-1-8-6-10	IRRI	1990	7.0	Warm temperate
12. Khumal-9	K 28-76-D-1/Kn18-214-1-4-3	IRRI	1990	6.7	Warm temperate
13. Khumal-5	Pokhreli Masino/KA-1B-361-BLK-2-8	Nepal	1990	6.7	Warm temperate
14. Chhmrong Dhan	Selection from Ghandruk Local	Nepal	1991	4.2	Cool temperate (1,300–2,000 m)
15. Machhapuchhre 3	Fuji 102/Chhomroong Dhan	Nepal	1996	5.0	Cool temperate (1,300–2,000 m)
16. Khumal 6	IR13146-45-2-3/ IR7492-18-6-1-1-3-3	IRRI	1999	7.8	Kathmandu valley and similar areas
17. Chandannath 3	Selection from Yunlen-1	China	2002	6.0	Jumla valley (2,300 m) and similar areas
18. Chandannath 1	Selection from Jingling 78-102	China	2002	6.0	Jumla valley and similar areas
19. Khumal 11	Akudaka/Barkat	Nepal	2002	10.0	Kathmandu valley
20. Manjushree 2	Fuji 102/NR10157// Jumli Marsi/ IR9129-159-3//kn-lb-361-1-8-6-3)	Nepal	2002	8.3	Kathmandu valley
21. Khumal-8	Jumli Marsi/IR36	Nepal	2006	8.9	Foothills to mid-hills of Nepal

Division, and ARS, Jumla, Dailekh, and Lumle, are working to improve temperate rice. Plant pathologists are working to develop rice varieties resistant to blast and its management. An entomologist is looking to manage rice insects. An agronomist and soil scientist are engaged in how to make temperate rice cultivation more profitable in a sustainable way by managing natural resources. Two biotechnologists are also working in temperate rice research.

Research issues and targets for improving temperate and japonica rice and production technologies

The hills and high hills of temperate regions cover 28.8% of the total rice area, with 51.6% of the total population, but they have lower yield than tropical and subtropical areas, that is, the Terai (plain area) of the country. Indica rice is mostly grown in these regions, which have lower productivity than japonica rice. Rice has to be made available locally to feed the ever-growing population in these regions. Japonica rice has the genetic ability to outyield indica rice. A new management system should be developed and extended to farmers to optimize input use, increase efficiency, and cut production costs. Therefore, the following are the major research issues and targets for improving temperate and japonica rice along with their production technologies:

- High-yielding and leaf- and neck-blast-resistant rice varieties.
- Rice-eating consumers prefer less sticky or nonsticky rice at the time of cooking; therefore, rice varieties with better eating quality are needed.
- Cold tolerance at different crop growth stages.
- The cropping pattern is different in different locations. Long-duration rice varieties delay the planting of a second crop, which ultimately affects yield. Therefore, short-duration rice varieties are needed.
- In hills and high hills, 63.4% and 58.2% of the rice area is under rainfed conditions (MOAC 2006). Drought can prevail at any stage of crop growth. For this situation, drought-resistant rice varieties should be developed.
- Specific adoption of japonica rice varieties in the temperate rice-growing areas of the country.
- High-yielding japonica genotypes with resistance to cold injury (seedling stage) for winter-season (boro) rice in plains area.
- Nursery management for healthy seedlings to cope with cold injury.
- Natural resources are declining day by day and need to be managed in a sustainable way so that they can be used to achieve sustainable production of rice.
- Genotypes with higher yield cannot express their potential until the required inputs and management are proved in a collective way and in an integrated approach.

Constraints to production and improvement in temperate rice, including japonica rice

The yield gap is the primary constraint to increased growth in rice production in both tropical and temperate areas, and bridging the yield gap is the most immediate opportunity for increasing rice production. Rice yields are low and a large yield gap exists between what farmers are harvesting in their rice fields and what has been demonstrated by researchers (Adhikari 2004). Temperate rice experiences mainly cold injury at various crop growth stages along with blast disease in Nepal (Shrestha 1979). Specific adoption of japonica rice in certain locations of Nepal is limited to eating quality as this rice is sticky in nature. The following are the constraints that limit the improvement and production of both temperate and japonica rice:

- Consumers' preferences
- Limited germplasm
- Low genetic base of japonica rice
- Cold injury at various crop growth stages
- Leaf and neck blast
- Sterility in high hills (mountains) due to long-duration varieties
- Poor panicle exsertion
- Lack of area-specific information about farmers' preferences, priority problems, and indigenous management practices
- Declining soil fertility, poor plant nutrition and crop management practices
- Lack of low-cost rice production technology
- Small and fragmented landholdings
- Untimely and inadequate input/credit supply
- Inadequate postharvest technologies
- Poverty and illiteracy
- Poor marketing facilities

Genetic resources: availability and requirement

Rice research in Nepal began in 1951 with the collection and evaluation of landraces. Since then, a rice improvement program for hills and mountains also started simultaneously. During that period, the genetic resources for cold tolerance were limited to local germplasm. A systematic coordinated rice research program established in 1972 has developed linkages with IRRI under the Consultative Group on International Agricultural Research for the exchange of germplasm. NRRP has been receiving an International Rice Cold Tolerance Nursery (IRCTN) from IRRI since 1975 and using the outstanding rice lines directly or indirectly after rigorous evaluation. The ABD in consultation with the rice program started evaluation of a National Rice Cold Tolerance Nursery in 1978, including exotic, self-developed, and local landraces at different testing sites. Eight varieties were developed using IRCTN material as a donor parent. Chhomrong Dhan is a local selection and Chandannath 1 and 3 are selections from Jingling 78-102 and Yunlen 1, respectively. Fuji 102, Akiyudaka, Yungeng 3, Zenith, and Barkat have been selected and used as donor parents for cold tolerance in breeding programs.

After the introduction and release of Taiwanese japonica rice varieties, they were also used in breeding programs to develop high-yielding, cold-tolerant, and blast-resistant rice varieties. Cold-tolerant landraces Jumli Marshi, Pokhreli Masino, Jarneli, Anadi, Chhomrong, Phalame, and Kali Marshi are available and are being used in breeding programs.

The available genetic resources are not sufficient to address the constraints of temperate rice along with japonica rice. Therefore, genetic resources are required for the following:

- Cold tolerance at different growth stages
- Less sticky rice varieties with good eating quality
- Blast and BLB resistance
- Tolerance of low air and water temperature at seedling stage for boro rice
- Better straw quality

Strategies for temperate rice research

Inventory of the information

Rice is grown from 900 to 2,621 m. The needs and requirements differ from farmers to consumers due to variation in the agroecosystem. Farmers need high-yielding, cold-tolerant, and disease-free rice varieties whereas consumers need cheaper high-quality rice. The problems of farmers are also different. They have their own skill and knowledge to manage the rice crop. Information on these aspects is limited. Therefore, the first step should be to collect area-specific information about farmers' preferences and indigenous management practices beforehand to develop strategies for temperate rice research.

Characterization, evaluation, and use of landraces

Nepal has a diversity of local landraces in the hills and mountains that are not fully exploited. Both indica and japonica types have cold tolerance and other favorable traits and can be used to improve temperate rice. Chhomrong, Jumli Marshi, and Jurneli are such landraces.

Biotechnology and genetic enhancement

Recent advances in rice biotechnology have produced new tools to increase the efficiency of evolutionary and evaluation phases of rice breeding (Khush and Brar 1998). Thus, biotechnology has a key role to play in combination with conventional plant breeding in the genetic enhancement of temperate rice, particularly in relation to disease resistance, stress tolerance, and quality improvement. Therefore, QTL mapping and marker-assisted selection for stress tolerance, blast resistance, and quality aspects should be considered.

Sustainable production technologies

Sustainable rice production technologies are required. Closing the gap between potential and actual yield requires integrated approaches. An integrated rice crop management system is based on the understanding that overcoming limits in production has been extremely successful in closing the yield gap. Research on resource conservation technologies can lead to a significant reduction in the cost of production, particularly by increasing input-use efficiency. The development of low-cost technology is necessary in view of its growing importance.

Postharvest technology and agro-processes

Postharvest losses of rice continue to be enormous, ranging from 10% to 37% (FAO 2000). Significant progress can be made in increasing rice output by reducing postharvest and milling losses. Demand is growing for better quality rice, which should provide a stimulus for upgrading the milling infrastructure in the temperate rice-growing areas of the country.

Participatory rice technology transfer

Once rice technology, either varieties or production and management, is developed, it must be evaluated and validated with the participation of users. The extension of these technologies in isolation has experienced no or little adoption by farmers. Farmers' participatory varietal selection (PVS) and participatory technology evaluation and development along with other stakeholders is essential to have an impact from rice improvement and development.

Expectations from the Temperate Rice Research Consortium

In the age of globalization, rice research and development would be ineffective working independently. The solution is collective action of temperate rice-growing countries to join forces and share collaboration in the field of genetic material exchange and skills and knowledge for temperate rice research and development. The Nepal Agricultural Research Council has limited financial resources for rice research and development in temperate rice and requires support for strengthening basic and strategic research. Skills and knowledge of scientists need to be improved. Infrastructure and laboratories have to be developed and strengthened.

Contributions to the TRRC

The country has a diversity of landraces for cold tolerance and has developed high-yielding rice varieties. These materials can be shared with other partner countries of the TRRC for the improvement and development of rice varieties for temperate regions. Different people are working for temperate rice research and development, and their views, ideas, and skills can be exchanged among the partner countries.

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Development of indica/japonica rice lines at the Philippine Rice Research Institute

Emily C. Arocena and Thelma F. Padolina

Our indica/japonica breeding program focused on two ecosystems. One was irrigated lowland (IL) areas, the major rice-producing areas in the Philippines. The varieties developed were high yielding to obtain rice self-sufficiency. The varieties possessed excellent grain quality and resistance to insect pests and diseases, lodging resistance, non-to-moderate shatterability, and no on-the-panicle sprouting.

The other was cool elevated (CE) areas, where low temperature causes crucial injury to rice plants such as stunted growth or sterility, leading to unstable rice production. Therefore, incorporation of cold tolerance was a must, followed by high yield, good grain quality, and shattering resistance. Potential areas for this type of rice are the Cordillera Administrative Region (CAR), where two types of rice are required: (1) short-duration (6 months) improved bulu with tolerance of low temperature at the seedling stage during the dry season, and (2) short-duration (5 months or less) modern varieties with tolerance of low temperature at the reproductive stage in the wet season (WS). The WS environment is about 5,000 ha but the potential area is about 100,000 ha. In other areas with low-temperature problems, tropical japonica types were acceptable. Target areas are in the Cagayan Valley, Quezon Province, Bukidnon in Mindanao, and Canlaon, Negros Occidental, in the Visayas.

The program was implemented with three strategies. First, a japonica/indica (J/I) cross was employed, especially to improve grain quality and yielding capability. Second, on-site breeding for cold tolerance was undertaken in order to screen resistant or tolerant plants in hot-spot areas. Third, interdisciplinary collaboration at PhilRice was maximized to facilitate rice breeding.

Constraints to varietal improvement

Hybrid sterility in indica/japonica crosses

The behavior of hybrid sterility was studied in the 1993 WS on three single-cross F_1 progenies between japonica varieties and Philippine indica leading varieties along with parental varieties. In the following 1994 DS, the sterility of subsequent backcross B_1F_1 progenies was compared with that of F_1 progenies. Results indicated that the expected high hybrid sterility of the three single-cross F_1 progenies was as high as 77.0%. However, sterility declined to 23.1% in the progenies of subsequent backcrosses (Table 1). This finding benefited I/J breeding (Rice Breeding Records, 1993-1996).

Table 1. Hybrid sterility of F_1 progenies of J/I crosses and subsequent backcross (B_1F_1), 1993 WS-DS.

Materials	Year/season	Sterility (%)	No. of spikelets
(P_1) Koshihikari	1993 WS	7.1	65
(P_2) PSB Rc 10	1993 WS	15.1	134
(F_1) P_1/P_2	1993 WS	75.2	133
(B_1F_1) P_1/P_2 *2	1994 DS	27.3	135
(P_1) Koshihikari	1993 WS	7.1	65
(P_2) BPI Ri 10	1993 WS	11.0	118
(F_1) P_1/P_2	1993 WS	73.0	100
(B_1F_1) P_1/P_2 *2	1994 DS	24.1	117
(P_1) Toyonishiki	1993 WS	7.2	89
(P_2) BPI Ri 10	1993 WS	11.0	118
(F_1) P_1/P_2	1993 WS	82.8	119
(B_1F_1) P_1/P_2 *2	1994 DS	18.0	114
	Ave. sterility (%)		
P_1P_2	9.8		
F_1	77.0		
B_1F_1	23.1		

Cold damage

In the Philippines, particularly in the highlands of the Cordillera Region, the rice crop is exposed to low temperature during the seedling stage in the dry season (DS) and at the flowering phase during the wet season (WS). Cold tolerance was evaluated in the natural conditions of the target sites during both growth stages. In the DS, cold damage was manifested in the rate of germination (poor), slow growth, leaf discoloration from yellow to white, and stunted growth, whereas, in the WS, the damage is more serious and causes poor panicle exsertion, asynchronous flowering, spikelet sterility, and poor grain filling. The sterile type of cold injury is due to the failure of microspore development under low-temperature conditions (Satake 1989). In the selection process, one of the most visible criteria used for cold tolerance during the reproductive stage was panicle exsertion as reported by Nanda and Seshu (1979). Vergara (1991) further stated that low temperature causes poor emergence of panicles, because the last internode fails to elongate. This poor exsertion prevents spikelet exposition to allow proper pollination and even support disease infections, which contribute to further reductions in yield.

Blast

Concomitant to low-temperature stress, the most common disease is blast. In the Cordillera, both leaf and panicle blast become serious when the plants are under cold stress. Hence, an equally important breeding objective was blast resistance. PJ13 and PR27137 were resistant to blast under Benguet conditions.

Viviparity or on-the-panicle sprouting

The other major breeding consideration was viviparity or on-the-panicle sprouting, which is a barrier to the development of indica/japonica varieties. It is most pronounced when japonica rice varieties are used as donors to incorporate yield capacity or grain quality. Even Koshihikari, Japan's leading variety with the highest sprouting resistance, has not generated promising progenies. Most often, its progenies have even lower resistance than Koshihikari. Re-crossing with indicas could reduce sprouting but would accelerate another serious problem—heavy shattering.

Shattering habit

Now that mechanization has advanced to more than 95%, shattering becomes an unfavorable trait since it causes significant losses not only during the threshing process but also in preharvest and harvesting activities. It is currently considered of great economic importance and a major breeding consideration (Fukuta 1995). For example, in the wet season, when typhoons commonly occur and cause serious lodging, varieties must resist shattering. In the Cordilleras, where the methods of harvesting and storage also require nonshattering types, japonica germplasm, which is mostly nonshattering types, was used to improve the breeding lines.

Breeding strategies

Selection of parental donors from introduced germplasm

Introduced japonica germplasm was evaluated at cool elevated sites to identify superior types for direct use as a variety or for use in the crossing work. Duplicate samples of 248 introduced varieties and breeding lines that had been selected for cold tolerance since 1993 were further evaluated at Benguet State University (BSU), La Trinidad, Benguet, and Banaue, Ifugao, during the 1996 DS. As a result, entries with seasonal adaptation were selected. Nine japonicas were phenotypically acceptable in La Trinidad and eight were selected in Banaue based on across-DS testing (Table 2). Criteria for selection were as follows: seedling vigor as a measure of cold tolerance in the seedling stage from extra vigorous to vigorous, leaf color from green to dark green shade, and appropriate plant structure. The best entry, PR27137-CR153, has passed National Cooperative Trials (NCT) and is now in the last phase of evaluation prior to recommendation to the National Seed Industry Council (NSIC). Similarly, across the WS, 18 entries were selected that exhibited reproductive-stage cold tolerance, fairly good fertility, sufficient growth volume, and moderate reaction to blast (Table 3). A majority of these entries, however, were further used in hybridization to improve cold tolerance and blast resistance.

Artificial cold-tolerance screening

Through the JICA High Productivity Rice Technology Project, breeding was also pursued using japonica/indica crosses with japonicas as donor parents for cold tolerance. An artificial cold-tolerance facility was also built to augment field screening using cool-water treatment with a temperature of 18.9–19.0 °C submerged in 30-cm

Table 2. Phenotypic acceptability and other agronomic traits of selected japonica varieties across the DS in two locations, La Trinidad and Banaue, 1993-96 DS.

Entry	Seedling vigor[a]	Phenotypic acceptability[b]	Leaf color[c]	Ht[d] (cm)	TL (no.)	PnL (cm)	Remarks
La Trinidad, Benguet							
1. Norin PL 8	2	1	PG	73.5	23.5	15.0	Adequate GV
2. Hexi 15	1	3	DG	80.8	16.8	15.5	Vigorous
3. Hexi 25	2	1	DG	81.5	20.3	16.3	Adequate GV
4. Hexi 30	2	1	DG	79.0	15.5	15.5	Adequate GV
5. PR27402-CR60	1	3	G	64.3	20.8	16.5	Good fertility
6. PR27384-CR76	3	3	G	59.5	12.0	15.3	–
7. PR27137-CR153	1	1	PG	67.0	14.0	16.3	Good fertility, nonshattering
8. PR27396-CR192	3	3	PG	75.0	20.5	21.0	Good fertility
9. PR27401-CR183	2	3	PG	62.8	16.3	17.3	Good fertility
Banaue, Ifugao							
1. Norin PL 8	3	3	PG	75.0	15.3	17.8	Good fertility
2. Aikawa 1	5	5	G	81.0	6.5	19.5	Low tillering
3. Hexi 25	3	3	DG	79.3	16.8	16.3	Adequate GV and fertility
4. Hexi 30	3	3	DG	71.8	7.8	16.0	–
5. PR27387-CR98	3	4	G	65.3	24.8	18.3	Panicle weight type
6. PR27396-CR192	5	2	PG	–	–	–	Panicle weight type
7. Yunzen 79-19	3	3	DG	89.8	4.3	20.5	Adequate GV
8. Wansan 66	3	3	G	63.0	8.0	17.5	Early, good fertility

[a]1 to 2 = extra vigorous, 3 = vigorous, 5 = normal. b1 = excellent, 3 = good, 4–5 = fair. cPG = pale green, G = green, DG = dark green. dHt = plant height, PnL = panicle length, TL = productive tillers, GV = growth volume.

water depth from panicle initiation to heading (Fig. 1). Spikelet sterility was evaluated on the test entries.

This facility is expected to accelerate the breeding process delayed by the unstable conditions at the target sites.

Shuttle breeding

Screening of advanced breeding materials at the target sites (shuttle breeding) relied on natural conditions. These lines were improved by the incorporation of desirable characters of the japonicas into local varieties. Screening for field resistance to blast was also done at the target sites and an induced screening laboratory for blast was also started at PhilRice CES to study partial resistance.

Table 3. Selected japonicas with their outstanding traits evaluated across wet seasons at Banaue and La Trinidad cold-tolerance sites, 1994-96 WS.

No.	Variety/line	Maturity class	Source	Outstanding trait[a]
1	Bega	Very early	Romania	CT, F
2	Norin PL 8	Very early	Japan	CT, GV, F, MR to blast
3	Dalizhaoxi	Early	China	CT, GV
4	Diangen 8	Early	China	CT, GV
5	Hexi 2	Very early	Japan	F
6	Hexi 3-1	Early	Japan	CT, GV, F
7	Hexi 5	Very early	Japan	CT, GV, F
8	Hexi 9	Very early	Japan	F
9	Hexi 13	Very early	Japan	CT, F
10	Hexi 15	Very early	Japan	F, CT, GV
11	Hexi 25	Very early	Japan	CT, GV, F, MR to blast
12	Hexi 30	Medium early	Japan	CT
13	Hwanghae 60	Early	Korea	GV, CT, F
14	Koihime	Very early	Japan	F
15	Kokonoe-mochi	Early	Japan	F
16	Koshihikari	Very early	Japan	F, CT
17	Todorokiwase	Very early	Japan	CT, GV, F
18	Wan San 66	Early	Korea	CT, GV, F

[a]CT = cold tolerance, F = fertility, GV = good growth volume, MR = moderate resistance.

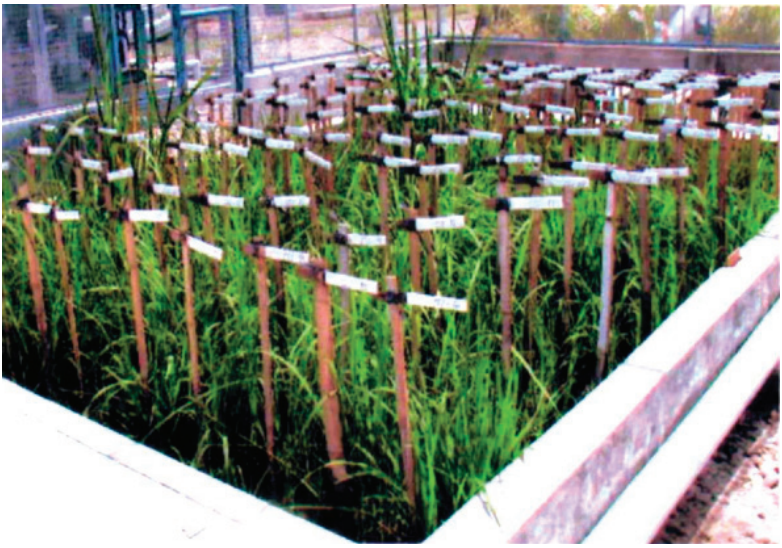

Fig. 1. Artificial cool-temperature tolerance screening facility at PhilRice Maligaya.

Use of mutation breeding and anther culture

In the process, a conventional method supplemented by nonconventional technologies, including biotechnology such as mutation techniques and anther culture, was employed. Mutants of japonicas such as Nipponbare generated some useful materials for further breeding but not as direct varieties. There were no anther culture-derived materials generated with cold tolerance, only improvements in tillering ability and maturity.

Development of promising lines

In the course of identifying promising lines since 1992, the immediate objective of varietal improvement was implemented. Stable yield, resistance to insect pests and diseases, and good grain quality remain the major breeding objectives. Improved evaluation and selection procedures as well as appropriate screening techniques for lodging, seedling vigor, cold tolerance, blast resistance, and shattering resistance were incorporated in the program. As such, the following lines were generated:

1. PR26670-PJ2 was approved as NSIC Rc104 or Balili on 18 January 2002. Balili can be planted in both seasons but in low- to medium-elevation areas only. It is a moderately cold-tolerant variety that was selected from line IR61728-4B-2-1 and its grain quality is similar to that of Todorokiwase, the mother parent. On average, this variety yielded 4,668 kg ha^{-1} and 3,868 kg ha^{-1} in the DS and WS, respectively, outyielding PSB Rc44 or Gohang by 28.6% during the DS and by 13.7% in the WS. It has moderate field resistance to blast. Based on a complete resistance test for blast, it was predicted to possess the *pi-i* and *pi-3* resistance genes. In terms of grain quality, this japonica-type variety has low amylose and hard gel consistency, which make it better than some traditional varieties such as Pinidua and Tinawen. It showed high yield potential in Benguet and Ifugao. Although it did not yield high in Kalinga and Mt. Province, its actual yield was still higher than that of the traditional cultivars. The yield and agronomic data, reaction to major pests and diseases, and grain quality profile of PJ2 are shown in Tables 4 and 5 and Figure 2. PJ2 was approved as NSIC Rc104 or Balili. PJ2 is intended for cool elevated areas (National Cooperative Testing for Rice Season Reports 1996 DS-1998 WS).
2. Another promising line, PR27137-CR153, was identified as promising in National Cooperative Trials and is now in the prerelease stage (Variety Promotion Project) to confirm farmers' acceptability (Fig. 3). This is the last step before varietal recommendation.
3. Three highly cool-temperature-tolerant lines, PJ9, PJ10, and PJ13, were identified for Benguet Province. Eight promising lines, PJ9 to PJ16, were initially identified. Repeated evaluation across the DS and WS confirmed the strong cold tolerance, stable field resistance to blast, and good grain quality of PJ9, PJ10, and PJ13. PJ9 and PJ10 were progenies of the cross Chiyonishiki/ Reiko 2. PJ9 matures in about 145 days and PJ10 in 133 days. Both were

Fig. 2. Field performance and japonica-type kernel quality of PJ2 (NSIC Rc104 or Balili).

Fig. 3. Promising line PR27137-CR153 in comparison with Kintuman, a Benguet traditional cultivar, BSU, La Trinidad, Benguet, 2001 DS.

nonshattering. PJ13, on the other hand, was selected from Tohoku 143/Gokei 2. It has very good kernel quality and shows resistance to viviparity. Under natural blast infection, these elite lines showed a susceptible reaction at the seedling stage in the blast nursery, but, in field conditions, these lines tolerated severe infection. The complete resistance of these lines was analyzed and the field resistance of these three lines was confirmed to be like that of Todorokiwase, a Japanese standard variety with strong field resistance. However, the yielding ability of these lines should be improved.

4. PJ20 (PR26875-4B-7-9-1) has moderate cold tolerance with fairly high yield potential (4,182 kg ha^{-1}) and strong field resistance to blast during the DS (Fig. 5).
5. PR29814-B-5-3-1-1 (a new entry) yielded at least 3 t ha^{-1}. The same entry was the top yielder in Bontoc, Mt. Province. Across all sites, however, PR29814-B-5-3-1-1 showed wider adaptability since it was adapted in both the dry and wet seasons.
6. For dry-season adaptation, initial selections were made from the preliminary yield trial (PYT 2004 DS), which showed better performance owing to higher cold tolerance, good fertility, and resistant reactions to blast and bacterial leaf blight. These lines were PR34110-B-45-1 (PR29809-B-13-3/PJ13), PR34131-B-4-1, and PR34131-B-21-1, both derivatives of the cross PR26875/PR27137-CR153 (Fig. 7). All three lines matured in more than 150 days.

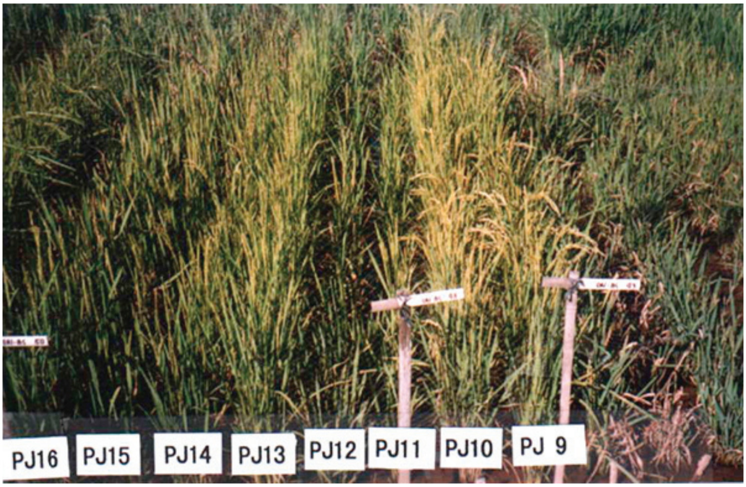

Fig. 4. PJ9, PJ10, and PJ13 showed cool-temperature tolerance and blast field resistance at BSU, 1999 WS.

Fig. 5. PJ20, a cold-tolerant and blast-resistant line, with better yielding potential also in the NCT-CT for WS, 2001.

Fig. 6. PR29814-B-5-3-1-1, its grain characteristics, and growth in the field, BSU, La Trinidad, Benguet, 2003 WS.

Fig. 7. Promising lines selected during the 2004 DS at BSU, La Trinidad, Benguet.

Table 4. Yield, other agronomic characteristics, and reactions to pests of PJ2 compared with PSB Rc 44 (based on NCT data).

Item	PJ2 (NSIC Rc104/Balili)	PSB Rc44 (Gohang)	Yield advantage (%)
A. Yield (kg ha^{-1})			
1. Replicated trials			
Dry season	4,668	3,630	28.6
Wet season	3,868	3,403	13.7
Across seasons	4,360	3,543	23.0
B. Maturity (DAS)			
Dry season	155	163	
Wet season	148	147	
Across seasons	152	157	
C. Plant height (cm)			
Dry season	93	90	
Wet season	94	93	
Across seasons	93	91	
D. Productive tillers (no. hill^{-1})			
Dry season	18	15	
Wet season	15	14	
Across seasons	16	15	
E. Reactions to			
Diseases			
Blast	5.8 I[a]	8.5 S	
Bacterial leaf blight	5.17 I	6.5 S	
Sheath blight	6.0 I	6.0 I	
Rice tungro virus			
Modified	100.0 S	100.0 S	
Induced	90.5 S	94.0 S	
Insect pests			
Deadhearts (SB)	–	–	
Whiteheads (SB)	28.43 S	–	
Green leafhopper	6.6 MS	7.0 S	
Yellow stem borer	–	–	
Brown planthopper 1	–	–	
Brown planthopper 2	5.4 I	5.5 I	
Brown planthopper 3	–	–	

[a]I = intermediate, S = susceptible, MS = moderately susceptible.

Current breeding initiatives

Realizing the value-added feature of japonica rice in the Philippines, the IRRI-Korea collaborative project on the development of japonica rice varieties was expanded with PhilRice as a NARES collaborator. The objective of the collaboration is to identify promising japonica materials for tropical cultivation, particularly under the joint project on *Germplasm Utilization for Value Added (GUVA)*. The breeding objective was to

Table 5. Grain quality characteristics of PJ2 and PSB Rc44.

Grain quality	PJ2 (NSIC 104/Balili)[a]	PSB Rc44 (Gohang)
Physico-chemical properties		
% amylose	17.6 L	22.5 I
% protein	9.3	9.1
Gel consistency	31.5 H	28.0 H
G.T. score	7.0 L	6.7
Milling potential		
% hulls	24.82	22.75 F
% brown rice	75.18 F	77.26 F
% milling recovery	64.15 G2	69.27 G1
% head rice	48.1 G1	38.8 G3
Physical attributes		
% chalky grains	6.1 G2	11.3 G3
% immature grains	0.0 Pr	0.0 Pr
Grain length (L in mm)	5.0 Sh	5.2 Sh
Grain shape (L/W)	2.0 I	2.1 I

[a]H = high, L = low, F = fair, Pr = premium, Sh = short, I = intermediate, G1 = grade 1, G2 = grade 2, G3 = grade 3.

identify japonica lines with adaptation to the tropics and with eating quality similar to that of Calrose of the U.S. and with improved plant type. Evaluation and selection of GUVA lines were conducted at the PhilRice Central Experiment Station in Muñoz, Nueva Ecija, and Benguet State University in La Trinidad, Benguet, during both the dry and wet seasons of 2006. In addition, a new set of seeds was screened for blast disease in BSU during the WS.

PhilRice Maligaya

During the 2006 DS, 163 lines, including check varieties, were evaluated. At PhilRice Maligaya, the materials were transplanted on 15 February 2006 using a systematic row arrangement (4 rows with 25 hills per row at 20 × 20-cm spacing). Problems with rats and severe stem borer damage (whiteheads) were encountered. Yield was estimated and other agronomic traits were also measured. In Table 6, yields were in the range of only 300 to 3,458 kg ha^{-1}. The best entry was IR80732-23-3-1-2, which matured in 108 days, had plant height of 87 cm, and had 17 productive tillers. It was one of the few entries with good phenotypic acceptability (scale 3) and it exhibited moderate resistance to whiteheads. The three other good entries were YR14323-69-2-3-2-1, HR17512-11-2-3-1-4-2-3-1, and IR68399-78-2-3-3-1. For stem borer field reactions, none exhibited strong resistance. However, 48 entries had moderate reactions. All these good materials will be used in the breeding program.

BSU, La Trinidad, Benguet

At BSU, 7 segregating populations and only 54 selected GUVA lines were planted under a systematic row arrangement design. Yield performance was estimated using only five plants. Other agronomic and physiological traits were also observed during

Table 6. Yield and agronomic characteristics of japonica progenies evaluated at CES, PhilRice, 2006 DS.

Entry no.	Designation	Yield (kg ha^{-1})	Maturity (30 DAS)[a]	Height (cm)	Tillers (no.)	Phenotypic acceptability (1–9)	Stem borer reaction[b]
1	IR78141-157-3-1-1	2,210	104	79	15	5	MR
2	IR79308-23-3-2-3	1,628	106	87	14	5–7	MS
3	IR80096-50-1-1-2	2,785	104	84	16	7	MR
4	IR80097-40-2-3	1,930	107	82	16	7	MR
5	IR80097-7-1-3	2,183	106	85	17	5–7	MS
6	IR80098-11-3-2-2	1,973	107	82	13	7	MS
7	IR80098-28-3-1-2	1,913	105	77	13	5–7	MR
8	IR80103-26-2-2-2	1,150	104	74	13	5–7	S
9	IR80106-4-3-3-2	1,565	104	79	13	7–9	S
10	IR80111-27-2-1	1,490	106	90	18	7–9	S
11	IR80111-6-2-2	1,630	103	88	10	7	MS
12	IR80112-49-1-3	1,800	96	88	12	7	MS
13	IR80126-50-1-2-2	1,158	96	88	12	7–9	MS
14	IR80128-10-2-2-2	1,110	103	85	14	7–9	MS
15	IR80538-4-2-2-2	545	98	85	17	9	S
16	IR80545-7-3-3-3	1,080	103	85	13	7–9	S
17	IR80730-12-2-2-2-2	1,080	103	82	18	7	MS
19	IR80730-1-3-2-1	2,920	101	82	14	5	MR
20	IR80730-17-2-3-3	1,758	102	88	14	5	MR
21	IR80731-15-3	1,483	106	86	15	7–9	MS
22	IR80731-19-1-3-3	1,105	111	85	17	9	S
24	IR80732-1-2-2-1-3	470	96	87	14	9	S
25	IR80732-34-2-1-2-2	2,625	100	89	18	5	MR
26	IR80732-34-2-1-3-2	2,513	95	90	16	5	MR
27	IR80734-15-3-2-2	790	95	83	18	9	S
29	IR80735-10-2-2-3	2,725	109	83	19	5	MR
30	IR80739-25-1-3-1	1,240	97	86	11	7	MS
31	IR80739-4-1-2-2	928	97	92	15	7	MS
33	IR80742-6-1-3-1	1,735	95	94	16	5	MR
34	IR80743-37-1-2-2	1,328	111	98	15	7	MS
35	IR80749-6-1-2-1	2,155	112	93	19	7	MS
37	IR80754-19-3-2-3	1,588	107	87	19	5	MR
39	IR80758-11-2-2-3-2	1,195	96	88	16	5	MR
40	IR80759-14-3-2-2	1,290	106	101	20	5	MR
41	IR80759-21-1-1-3	1,258	94	93	18	5	MR
42	IR80764-12-2-3-3	1,568	94	98	16	7	MS
43	IR80764-12-2-3-3-1	1,258	114	88	16	7	MS
44	IR80765-11-3-2-1	458	96	84	13	9	S
45	IR80765-17-1-2-1-3	715	98	90	15	5	MR
46	IR80767-8-1-2-3	1,338	104	92	18	5	MR
47	IR80768-3-1-3-2	808	95	100	17	7	MS
49	IR80771-18-2-3-3	905	104	93	16	7	MS
51	IR80772-4-3-2-3	1,700	106	97	22	3	MR
53	IR81090-7-1-3	2,500	99	99	20	5	MR
54	IR81090-7-1-3-2	1,483	115	95	14	7	MS
55	IR81091-7-1-2	863	99	94	12	7	MS

Continued

Table 6. Continued.

Entry no.	Designation	Yield (kg ha^{-1})	Maturity (30 DAS)[a]	Height (cm)	Tillers (no.)	Phenotypic acceptability (1–9)	Stem borer reaction[b]
57	IR81111-6-2-2	593	99	84	15	9	S
92	IR81551-2-2-3	655	105	75	16	9	S
93	IR81575-21-2-3	473	98	92	17	9	S
94	IR81575-21-3-3	623	106	87	20	5	MR
95	IR81578-22-1-1	925	108	94	18	5	MR
96	IR81578-22-1-2	1,183	100	80	20	7	MS
97	IR81578-22-1-3	870	116	100	10	5	MR
98	IR81218-17-3-2-1	600	115	86	18	7	MS
105	IR79300-15-2-3-2-2	1,628	115	82	19	5	MR
106	IR80096-61-1-2	2,090	105	76	20	7	MS
107	IR80097-40-3-1-3	1,300	111	73	18	5–7	MS
108	IR80098-40-3-1-2	2,238	108	76	22	5–7	MR
112	IR80730-3-2-2-2	2,698	108	72	17	3–5	MR
113	IR80732-23-3-1-2	3,458	108	87	17	3	MR
114	IR80732-34-2-1-2	1,925	95	88	16	3–5	MR
116	IR80747-25-3-2-3	1,063	102	89	18	5–7	MS
117	IR80771-20-3-1-3	1,453	104	91	15	5–7	MS
118	IR80771-7-2-1-3	2,265	103	90	16	3–5	MR
119	IR71121-35-1-1-1-2	1,708	103	79	12	5	MR
120	IR71131-BF 4-B-30-5-2	2,120	107	74	13	5–7	MR
121	IR73688-82-3	1,925	105	89	11	7	MS
122	IR73694-41-2	1,873	108	84	15	3–5	MR
123	IR77221-32-3-3-5	2,643	107	86	14	3–5	MR
124	IR77234-89-4-3-3	3,015	109	84	15	7	MS
125	IR78162-123-2-2-1	2,020	95	92	21	7	MS
126	IR80098-38-3-1-2	2,670	107	84	17	5–7	MS
127	IR80111-11-3-3	1,900	109	74	15	5–7	MS
128	SR22746-68-2-3-4-2-4	1,980	106	75	21	9	S
129	HR17512-11-2-3-1-4-2-3-1	2,705	106	76	24	3	MR
130	HR17570-21-5-2-5-2-2-1-5	2,208	104	78	21	5	MR
131	HR17570-21-5-2-5-3-3-2-4	1,313	103	73	23	7–9	MS
132	HR20654-32-1-3	3,398	104	80	17	3–5	MR
134	IR68331-R-R-B-22-2-2	2,718	107	78	20	5	MR
135	IR68333-R-R-B-19	3,475	104	82	21	3–5	MR
136	IR68333-R-R-B-22	3,020	99	83	15	3	MR
137	IR68349-131-2-2-3	1,533	101	75	22	7	MS
138	IR68352-14-1-1-1	2,575	109	73	24	3–5	MR
139	IR68373-R-R-B-22-2-2	2,768	116	77	22	3–5	MR
140	IR68399-78-2-3-3-1	2,685	116	79	24	3	MR
141	IR71121-35-1-1-1-2	2,840	105	76	23	3–5	MR
142	IR71131-BF 4-B-30-5-2	2,178	116	83	20	5	MR
143	IR72944-1-2-2	1,690	96	79	18	7	MS
144	IR73305-14-2-2	2,025	111	76	14	5–7	MS
145	IR73688-57-2	2,735	106	90	20	5	MR
146	IR73688-82-3	1,878	112	90	18	5–7	MS
147	IR73689-19-1	2,270	107	89	23	5	MR
148	IR73689-76-2	2,043	114	88	14	5–7	MS

Continued

Table 6. Continued.

Entry no.	Designation	Yield (kg ha^{-1})	Maturity (30 DAS)[a]	Height (cm)	Tillers (no.)	Phenotypic acceptability (1–9)	Stem borer reaction[b]
149	IR73690-7-2-1-1-3-2-2-1	2,730	116	84	18	7	MS
150	IR73694-41-2	2,660	116	86	15	5	MR
151	IR74506-28-4-3-2-1-3-2-2	1,235	96	83	16	7–9	MS
152	IR74520-29-4-2-2-2-4-1-1	2,085	116	83	22	7	MS
153	SR18518-BF 4-B-12-1-2	2,150	107	86	18	5–7	MS
154	SR22746-68-2-3-4-2-4	2,435	101	80	14	7	MS
155	HR17570-21-5-2-5-3-3-2-4	2,143	106	82	17	5–7	MR
156	HR20654-39-3-5	2,405	106	89	17	5	MR
158	YR14323-69-2-3-2-1	3,220	104	74	18	3	MR
159	YR17104-R-R-B-14-3	503	105	80	18	7	MS
160	Jinmibyeo	1,593	102	70	20	9	S
161	IR72	1,415	101	86	24	7–9	MS
162	Dasanbyeo	818	103	91	23	7–9	MS
163	PJ16	300	105	97	17	9	S

[a]DAS = days after sowing. [b]MR = moderately resistant, S = susceptible, MS = moderately susceptible.

the growth phases, including field reactions to blast. Segregating populations were selected by PhilRice and IRRI and all panicles selected were submitted to IRRI. General observations are shown in Table 7.

In Table 8, yield estimates were recorded in the range of 1,385 to 9,868 kg ha^{-1}. A majority of the entries were better than PJ16 (6,244 kg ha^{-1}). Exceptionally higher yields (>9 t ha^{-1}) were obtained from five GUVA lines, HR24580-21-2, IR80730-3-2-2-2, IR80754-19-3-2-3, IR80755-1-3-2-1-3, and HR17570-21-5-2-5-2-2-1-5. These lines exhibited moderate reactions to leaf blast and leaf color from green to pale green.

2006 WS results

PhilRice Maligaya

In addition to the evaluation of the GUVA lines, a hybridization program was implemented using selected lines for yield enhancement of both the GUVA and PhilRice breeding materials. Thirty-five crosses were generated, which generated 5–192 seeds (Table 9). These F_1 seeds were to be evaluated in the 2007 DS. In Tables 10a to 10c, 102 test entries were evaluated and compared with five check cultivars, IR72, Dasanbyeo, PJ16, PJ2, and PR27137-CR153. Among the entries, the best check was Dasanbyeo. All test entries were significantly lower in yield than Dasanbyeo. Moreover, all entries belong to the early-maturing group, with maturity ranging from 98 to 114 days. A majority, however, showed resistant to intermediate reactions to bacterial leaf blight.

Table 7. General observations on segregating populations, 2006 DS, BSU, La Trinidad, Benguet.

Population (F_4 bulk)	Seedling vigor	Leaf color[a]	Leaf blast	Remarks
KF976	5–9	DG	7–9	Segregating
KF985	3	G	3	Modern plant type
KF986	3	DG	3	Modern plant type
KF1014	3–5	G	5–7	Segregating
KF1015	5–9	G	5–7	Highly segregating
KF1035 (IR83509)	1–3	PG	3	Generally good plant type, not uniform
KF1036 (IR83510)	5–7	G-PG	5–7	Bit shorter, wide leaf, not uniform

[a]G = green, DG = dark green, PG = pale green.

Table 8. Yield and agronomic characteristics of japonica progenies evaluated at BSU, 2006 DS.

Index no. 2006 DS	Entry no.	Designation	Yield (kg ha^{-1})	Height (cm)	Tillers (no.)	Leaf blast	Seedling vigor	Leaf color[a]
2	1	IR79308-23-3-2-3	6,119	82	14	3	3–5	DG
9	2	IR80106-4-3-3-2	7,390	81	18	–	5	G
11	3	IR80111-6-2-2	3,665	83	13	5	5–7	G
12	4	IR80112-49-1-3	3,663	80	16	3	5–7	G
13	5	IR80126-50-1-2-2	1,725	82	16	3	5–7	G
15	6	IR80538-4-2-2-2	6,486	86	19	–	5	G
16	7	IR80545-7-3-3-3	5,050	83	16	3	5–7	DG
18	8	IR80730-12-2-2-3-3	3,565	89	20	5–7	5–7	G
19	9	IR80730-1-3-2-1	3,750	86	19	5	5–7	G
29	10	IR80735-10-2-2-3	4,523	88	19	–	3	G
31	11	IR80739-4-1-2-2	1,385	88	23	5–7	7	G
37	12	IR80754-19-3-2-3	9,468	87	21	5	7	G
38	13	IR80755-1-3-2-1-3	9,355	91	21	5	5	G
40	14	IR80759-14-3-2-2	5,915	93	20	–	5	G
54	15	IR81090-7-1-3-2	1,765	88	17	5	5–7	G
75	16	IR81238-25-1-2	5,780	87	21	3	3–5	G
78	17	IR81529-13-1-3	7,134	95	20	–	7–9	G
84	18	IR81537-21-3-3	3,965	99	19	3–5	3	PG
93	19	IR81575-21-2-3	1,978	98	18	5	7	G
99	20	HR24580-21-1	6,930	81	20	–	5	G
100	21	HR24580-21-2	9,868	98	20	–	3	G
105	22	IR79300-15-2-3-2-2	7,265	95	19	–	3–5	G
106	23	IR80096-61-1-2	5,398	100	18	–	1–3	G
112	24	IR80730-3-2-2-2	9,555	80	22	3	5–7	G
120	25	IR71131-BF 4-B-30-5-2	5,108	85	19	5–7	7	G

Continued

Table 8. Continued

Index no. 2006 DS	Entry no.	Designation	Yield (kg ha^{-1})	Height (cm)	Tillers (no.)	Leaf blast	Seedling vigor	Leaf color[a]
121	26	IR73688-82-3	9,133	89	19	–	3–5	PG
122	27	IR73694-41-2	6,900	89	21	–	3–5	PG
124	28	IR77234-89-4-3-3	8,635	82	19	–	7	G
128	29	SR22746-68-2-3-4-2-4	7,668	72	20	–	7	G
129	30	HR17512-11-2-3-1-4-2-3-1	6,398	79	22	–	7	G
130	31	HR17570-21-5-2-5-2-2-1-5	9,200	83	22	–	5	PG
131	32	HR17570-21-5-2-5-3-3-2-4	6,640	85	24	–	1–3	PG
133	33	HR20654-54-3-5	3,153	85	19	5	7	G
134	34	IR68331-R-R-B-22-2-2	5,223	88	20	5	7–9	G
136	35	IR68333-R-R-B-22	4,265	90	21	5	7–9	G
137	36	IR68349-131-2-2-3	7,283	79	22	–	1–3	PG
138	37	IR68352-14-1-1-1	7,190	73	19	–	5–7	G
139	38	IR68373-R-R-B-22-2-2	5,416	88	20	–	3–5	G
143	39	IR72944-1-2-2	6,453	79	22	3–5	5–7	G
145	40	IR73688-57-2	7,535	88	20	–	1–3	PG
146	41	IR73688-82-3	8,829	90	21	–	1–3	PG
147	42	IR73689-19-1	6,505	89	22	–	3	PG
148	43	IR73689-76-2	8,195	88	22	–	1–3	PG
150	44	IR73694-41-2	7,469	88	20	–	3–5	PG
152	45	IR74520-29-4-2-2-2-4-1-1	7,448	77	21	–	7	G
153	46	SR18518-BF 4-B-12-1-2	6,521	84	20	–	5	G
154	47	SR22746-68-2-3-4-2-4	6,115	69	21	–	7	G
155	48	HR17570-21-5-2-5-3-3-2-4	7,214	82	20	3	5	G
156	49	HR20654-39-3-5	6,753	82	22	–	5–7	G
157	50	HR20654-54-3-5	3,558	83	19	–	5	G
158	51	YR14323-69-2-3-2-1	4,679	69	19	–	5–7	G
160	52	Jinmibyeo	5,583	81	16	–	5	G
162	53	Dasanbyeo	3,710	62	17	–	5	PG
163	54	PJ16	6,244	93	19	3	5–7	G

[a]G = green, DG = dark green, PG = pale green.

Table 9. Extent of japonica crosses generated for the 2006 WS.

Entry no.[a]	Female parent	Male parent	Seed set (%)
TJF1 1	IR79308-23-3-2-3	PR30858-6-3-2-1-2-1-2-2-3-2)	28
TJF1 2	IR80754-19-3-2-3	C7541WH-12-2-1	30
TJF1 3	IR81090-18-3-3	PJ21	52
TJF1 4	IR81090-7-1-3	PR30536-B-17-1-3-1-1	30
TJF1 5		PR31379-2B-10-1-2-1-2	18
TJF1 6	IR81091-7-1-2	PR30536-B-17-1-3-1-1	18
TJF1 7	IR81111-6-2-2	PR34159-17-4	60
TJF1 8	IR81537-21-3-3	PR34142-5-1	5
TJF1 9	IR81535-17-1-2	PR30858-6-3-2-1-2-1-5-3-2-3	46
TJF1 10		PR30648-5-4-5-MB-2-2-MB-1	35
TJF1 11	IR81575-21-3-3	PR34056-B-19-1-2	34
TJF1 12		PR34142-5-1	30
TJF1 13		PR30858-6-3-2-1-2-1-2-2-53	92
TJF1 14		PR34159-40-1-1	30
TJF1 15	IR81578-22-1-1	PR31000-B-3-2-1-1	92
TJF1 16		PR30575-B-40-1-2-1-1	50
TJF1 17		Dinorado Susi-20kR-30-3	60
TJF1 18	IR81578-22-1-3	PSB Rc82	56
TJF1 19		C7313WH-19-3-3-1	15
TJF1 20		Matatag 11	18
TJF1 21	IR80732-23-3-1-2	Dinorado Susi-20kR-30-3	10
TJF1 22	IR80732-34-2-1-2	PR30648-5-4-5-MB-2-2-MB-1	19
TJF1 23	IR80747-25-3-2-3	PR37256-1-1	25
TJF1 24	SR22746-68-2-3-4-2-4	IR64	40
TJF1 25		PR34159-40-1-1	40
TJF1 26	SR22746-68-2-3-4-2-4	IR64	29
TJF1 27	IR72	C7313WH-19-3-3-1	70
TJF1 28		Matatag 11	48
TJF1 29	Dasanbyeo	PR30575-B-40-1-2-1-1	73
TJF1 30		Dinorado Susi-20kR-30-3	33
TJF1 31		PR33382-25-1-1	85
TJF1 32		PR30858-6-3-2-1-2-1-2-2-1-3	176
TJF1 33	PJ16	(New) restorer line	40
TJF1 34		PR33382-25-1-1	15
TJF1 35		PR31379-2B-10-1-2-1-2	36

[a]TJF1 = tropical japonica 1st filial generation.

Table 10a. Yield and agronomic characteristics of tropical japonica lines (Group 1) evaluated at CES, 2006 WS.[a]

Index no.	Selection	Yield (kg ha^{-1})	1	2	3	4	5	MAT (DAS)	HT (cm)	TI (no.)	PL (cm)	BLB	PA (1–9)
1	IR78141-157-3-1-1	2,623	##	##			##	103	99	14	25	MS-S	7–9
2	IR79308-23-3-2-3	3,178	##	##				107	101	11	16	R	3
3	IR80096-50-1-1-2	2,982	##	##				103	98	18	19	MR	5
4	IR80097-40-2-3	2,759	##	##			#	102	94	17	21	I-MS	3–5
5	IR80097-7-1-3	2,873	##	##			#	104	88	12	19	I-MS	5
6	IR80098-11-3-2-2	3,121	##	##				104	85	17	19	I-MS	3–5
7	IR80098-28-3-1-2	2,598	##	##			##	100	90	14	18	S	7
8	IR80103-26-2-2-2	2,622	##	##			##	103	77	14	16	I	7
9	IR80106-4-3-3-2	2,827	##	##			#	102	95	10	21	I	3
10	IR80111-27-2-1	2,576	##	##			##	105	95	20	22	I-MS	7–9
11	IR80111-6-2-2	2,443	##	##	#		##	103	94	–	21	S	5
12	IR80112-49-1-3	2,859	##	##			#	105	88	11	21	I-MS	3–5
13	IR80126-50-1-2-2	2,710	##	##			#	104	91	12	18	I	3
14	IR80128-10-2-2-2	2,796	##	##			#	104	90	10	21	I	3–5
15	IR80538-4-2-2-2	2,910	##	##			#	107	87	14	19	I-MS	3–5
16	IR80545-7-3-3-3	2,997	##	##				100	85	11	20	MR	3
17	IR80730-12-2-2-2-2	2,749	##	##				103	85	13	22	MR	3
18	IR80730-12-2-2-3-3	2,534	##	##			##	105	92	8	24	MR	3–5
19	IR80730-1-3-2-1	3,145	##	##				100	79	12	19	MS	5
20	IR80730-17-2-3-3	2,602	##	##			##	106	88	10	21	MR-I	5
21	IR80731-15-3	3,129	##	##				105	94	10	19	MR-I	3–5
22	IR80731-19-1-3-3	2,624	##	##			##	104	93	11	22	MR-I	3–5
23	IR80731-19-1-3-3-3	2,579	##	##			##	104	95	16	20	MS	7
24	IR80732-1-2-2-1-3	1,917	##	##	##		##	104	94	13	23	MR	3
25	IR80732-34-2-1-2-2	3,677	##	##				104	92	15	18	R	1
26	IR80732-34-2-1-3-2	3,594	##	##		**		105	102	15	20	R	1
27	IR80734-15-3-2-2	1,999	##	##	##	**	##	98	85	10	19	I	1
28	IR80734-22-1-2-2-3	2,640	##	##			##	105	84	9	22	R	5
29	IR80735-10-2-2-3	3,199	##	##				103	86	12	20	I	5
30	IR80739-25-1-3-1	2,612	##	##			##	106	91	10	19	I	7

Continued

Table 10a. Continued.

Index no.	Selection	Yield (kg ha^{-1})	1	2	3	4	5	MAT (DAS)	HT (cm)	TI (no.)	PL (cm)	BLB	PA (1–9)
31	IR80739-4-1-2-2	3,014	##	##				107	100	13	22	MR	7
32	IR80742-20-3-3-3	2,547	##	##			##	103	90	10	21	MS	9
33	IR80742-6-1-3-1	3,607	##	##		**		106	94	16	20	I	5
34	IR80743-37-1-2-2	2,543	##	##			##	105	98	11	20	MR	7
35	IR80749-6-1-2-1	2,382	##	##	#		##	101	93	15	22	MS	7
36	IR80752-4-1-2-2	2,603	##	##			##	102	92	14	21	MS	7
37	IR80754-19-3-2-3	2,509	##	##				102	94	13	21	MR	3
38	IR80755-1-3-2-1-3	2,300	##	##	#		##	105	95	16	21	I	5–7
39	IR80758-11-2-2-3-2	2,826	##	##			#	105	96	12	17	I	3
40	IR80759-14-3-2-2	2,301	##	##	#		##	103	90	11	22	I	3
41	IR80759-21-1-1-3	2,713	##	##			#	104	95	14	20	I	5–7
42	IR80764-12-2-3-3	3,854	##	##		**		105	103	13	22	I	5
43	IR80764-12-2-3-3-1	2,956	##	##			##	105	101	9	21	MR	7
44	IR80765-11-3-2-1	3,193	##	##				103	92	11	23	MR	7
45	IR80765-17-1-2-1-3	3,463	##	##		*		107	91	11	19	MR	3
46	IR80767-8-1-2-3	2,803	##	##			#	105	95	12	22	MR	5–7
47	IR80768-3-1-3-2	3,119	##	##				104	99	12	19	MR	5–7
48	IR80768-3-1-3-2-1	4,383	##	#	*	**		102	100	12	21	I	7
49	IR80771-18-2-3-3	2,409	##	##	#		##	103	100	13	20	MR	3
50	IR80771-7-2-1-3-3	5,052			**	**	##	115	121	13	22	I	7
51	IR80772-4-3-2-3	3,310	##	##		*		106	97	13	21	MR	3
	IR72	5,844			**	**	**	111	91	18	23	MR	5
	Dasanbyeo	5,358			**	**	**	109	97	19	22	I	5
	PJ16	3,358	##	##		*		107	95	12	24	MR	3–5
	PJ2	2,427	##	##	#		##	106	98	16	19	MS	3–5
	PR27137-CR153	3,769	##	##		**		106	92	15	20	R	1

[a]MAT = days to maturity, HT = plant height, TL = no. of tillers, PL = panicle length, BLB = bacterial leaf blight, PA = phenotypic acceptability. ## , # = Yield significantly lower than the check at 0.01 and 0.05 levels of probability, respectively.
** , * = Yield significantly higher than the check at 0.01 and 0.05 levels of probability, respectively. R = resistant, MR = moderately resistant, S = susceptible, MS = moderately susceptible, I = intermediate.

Table 10b. Yield and agronomic characteristics of tropical japonica lines (Group 2) evaluated at CES, 2006 WS.[a]

Index no.	Selection	Yield (kg ha^{-1})	1	2	3	4	5	MAT (DAS)	HT (cm)	TL (no.)	PL (cm)	BLB	PA (1–9)
52	IR81090-18-3-3	3,821	##	##		*		109	102	15	19	MR	3–5
53	IR81090-7-1-3	4,091	##	#		**		107	95	16	20	I	5
54	IR81090-7-1-3-2	4,326	##	#		**		105	97	16	19	I	3
55	IR81091-7-1-2	3,738	##	##		**		110	96	16	20	MR	5
56	IR81109-12-3-1	2,613	##	##			#	100	99	16	18	MS	7
57	IR81111-6-2-2	3,402	##	##				109	100	17	21	MR	5
58	IR81216-22-3-1	3,825	##	##		**		105	94	17	22	MS	7
59	IR81216-7-3-1-2	2,609	##	##			#	101	91	14	21	S	9
60	IR81216-7-3-2-3	3,193	##	##				100	93	11	21	S	10
61	IR81219-11-1-2	2,415	##	##			##	99	92	12	22	MR	9
62	IR81219-13-3-1-1	1,637	##	##	##		##	98	93	14	19	I	9
63	IR81219-13-3-1-3	2,585	##	##			#	98	90	15	20	I	9
64	IR81224-19-3-2	1,383	##	##	##	#	##	99	95	16	24	I	9
65	IR81224-5-1-3	2,777	##	##			#	99	91	13	22	I	5
66	IR81225-28-3-1	3,521	##	##		*		100	93	15	22	I	3–5
67	IR81225-28-3-2-1	3,081	##	##	##		##	101	100	19	23	I	3–5
68	IR81228-3-2-1-1	3,169	##	##				100	94	15	20	MS	9
69	IR81230-8-2-2-1	3,756	##	##		**		102	99	14	21	I	5
70	IR81231-22-1-3	3,702	##	##		*		103	100	15	21	I	5
71	IR81235-23-2-1	2,942	##	##				98	92	15	19	MS	5
72	IR81238-25-1-2	3,475	##	##		*		101	102	18	20	MS	7
73	IR81528-15-3-3	3,698	##	##		*		97	86	15	20	MS	5
74	IR1529-13-1-3	1,938	##	##	##		##	99	104	13	20	MS	5
75	IR81532-14-2-1	3,069	##	##				100	99	14	22	MS	5
76	IR81535-14-3-2	2,778	##	##			#	99	96	15	20	MS	5
77	IR81535-17-1-2	2,073	##	##	#		##	98	86	13	21	MS	7
78	IR81535-17-2-2	2,890	##	##				99	94	13	25	I	5
79	IR81537-21-2-1	2,624	##	##			#	105	100	16	23	MR	5
80	IR81537-21-3-3	4,244	##	#		**		106	100	17	25	I	3
81	IR81549-20-3-2	3,524	##	##		*		109	114	15	21	R	1

Continued

Table 10b. Continued.

Index no.	Selection	Yield (kg ha^{-1})	1	2	3	4	5	MAT (DAS)	HT (cm)	TI (no.)	PL (cm)	BLB	PA (1–9)
82	IR81551-1-3-3	2,562	##	##			#	101	89	15	21	I	3
83	IR81551-15-1-2	4,340	##	#		**		98	91	15	22	MS	7
84	IR81551-2-1-3	3,276	##	##				102	102	16	20	MS	5
85	IR81551-2-2-3	2,800	##	##				101	93	14	20	MS	5
86	IR81575-21-2-3	3,649	##	##		*		106	96	14	21	I	1
87	IR81575-21-3-3	3,514	##	##		*		111	101	17	20	I	5–7
88	IR81578-22-1-1	2,431	##	##			##	114	96	13	25	R	3
89	IR81578-22-1-2	3,230	##	##				103	88	15	20	I	3
90	IR81578-22-1-3	3,632	##	##		*		114	100	14	24	R	1
91	IR81218-17-3-2-1	2,864	##	##				104	100	17	21	I	7
92	HR24580-21-2	2,684	##	##			#	100	102	15	23	MS	5–7
93	IR77856-91-1-4-1	3,326	##	##				101	89	14	23	I	7
94	IR79038-56-1-3	3,185	##	##				100	98	16	20	I	5
95	IR79300-15-2-3-2-2	2,990	##	##				101	92	16	20	I	3
96	IR80096-61-1-2	3,112	##	##				102	90	13	19	MS	7
97	IR80097-40-3-1-3	2,596	##	##			#	103	90	15	19	MS	7
98	IR80098-40-3-1-2	2,975	##	##				99	85	18	20	MS	7
99	IR80106-28-3-3-3	3,015	##	##				104	91	16	21	I	5
100	IR80126-39-1-1-3	2,434	##	##			##	101	89	16	20	I	7
101	IR80128-19-3-2	2,808	##	##	#		##	104	89	15	24	I	7
102	IR80730-3-2-2-2	3,553	##	##		*		99	86	17	17	MS	5
	IR72(1)	5,844	–		**	**	**	111	91	18	23	MR	5
	Dasanbyeo(2)	5,358		–	**	**	**	109	97	19	22	I	5
	PJ16(3)	3,358	##	##	–			107	95	12	24	MR	3–5
	PJ2(4)	2,427	##	##		–	##	106	98	16	19	MS	3–5
	PR27137-CR153(5)	3,769	##	##		**	–	106	92	15	20	R	1

[a]MAT = days to maturity, HT = plant height, TL = no. of tillers, PL = panicle length, BLB = bacterial leaf blight, PA = phenotypic acceptability. ## , # = Yield significantly lower than the check at 0.01 and 0.05 levels of probability, respectively. ** , * = Yield significantly higher than the check at 0.01 and 0.05 levels of probability, respectively. R = resistant, MR = moderately resistant, S = susceptible, MS = moderately susceptible, I = intermediate.

Table 11. Results of blast field screening at BSU, 2006 WS.

Entry no.	Identity	Seedling vigor	1st reading	2nd reading	Remarks
1	IR80097-40-2-3	9	5	9	Susceptible
2	IR80111-6-2-2	7	5	7	Moderately susceptible
3	IR80112-49-1-3	9	5	9	Susceptible
4	IR80128-10-2-2-2	7	1	3	Moderately resistant
5	IR80730-12-2-2-2-2	9	1	7–9	Susceptible
6	IR80731-19-1-3-3	7	1	7	Moderately susceptible
7	IR80732-34-2-1-3-2	7	1	7	Moderately susceptible
8	IR80734-15-3-2-2	9	9	9	Susceptible
9	IR80734-22-1-2-2-3	7	5	7	Moderately susceptible
10	IR80742-20-3-3-3	7	3	9	Susceptible
11	IR80752-4-1-2-2	9	1	9	Susceptible
12	IR81109-12-3-1	9	1	3	Moderately resistant
13	IR81111-6-2-2	7	5	5–7	Intermediate to moderately susceptible
14	IR81216-7-3-1-2	7	7	7–9	Susceptible
15	IR81219-11-1-2	9	3	7–9	Susceptible
16	IR81219-13-3-1-3	5	5	7–9	Susceptible
17	IR81225-28-3-1	5	7	7–9	Susceptible
18	IR81225-28-3-2-1	3	3	7–9	Susceptible
19	IR81528-15-3-3	3	1	5	Intermediate
20	IR81535-14-3-2	7	5–7	7	Moderately susceptible
21	IR81535-17-1-2	7	1	9	Susceptible
22	IR81537-21-2-1	7	3	7	Moderately susceptible
23	IR81551-1-2-1	7	3	5–7	Intermediate to moderately susceptible
24	IR81551-1-2-3	5	3	7	Moderately susceptible
25	IR81551-15-1-2	3	5	9	Susceptible
26	IR81551-2-2-3	3	1	5–7	Intermediate to moderately susceptible
27	IR81578-22-1-1	3	5	7	Moderately susceptible
28	IR81218-17-3-2-1	5	5	5	Intermediate
29	IR82116-31-3-3	7	5	5–7	Intermediate to moderately susceptible
30	IR82127-26-2-2	5	1-3	7–9	Moderately susceptible
31	IR82228-12-2-1	5	5	7	Moderately susceptible
32	IR82228-12-2-2	3	5	5	Intermediate
33	IR82228-23-2-3	–	–	–	–
34	IR82225-11-3-1	3	9	9	Susceptible
35	IR82225-15-3-3	–	–	–	–
36	IR82226-34-2-1	–	–	–	–
37	IR82195-10-2-3	3	5	–	
38	IR82195-30-3-3	3	7	5–7	Intermediate to moderately susceptible
39	IR82195-33-1-1	3	9	5	Intermediate
40	IR82195-36-1-3	–	–	–	–
41	IR82195-52-2-1	–	–	–	–
42	IR82198-24-2-2	3	1	5	Intermediate
43	IR82198-33-2-3	3	7	5	Intermediate
44	IR82197-19-2-3	–	–	–	
45	IR82199-6-3-1	3	5	5	Intermediate
46	IR82199-28-1-3	3	1–3	5	Intermediate
47	IR82179-38-2-2	5	5	5–7	Intermediate to moderately susceptible
48	IR82184-7-3-1	3	9	Dead	Susceptible

Continued

Table 11. Continued.

Entry no.	Identity	Seedling vigor	1st reading	2nd reading	Remarks
49	IR82184-7-3-3	–	–	–	
50	IR82187-17-1-2	–	–	–	
51	IR82187-17-3-2	3	5	9	Susceptible
52	IR82187-17-3-3	7	3	9	Susceptible
53	IR82125-28-3-3	7	1	9	Susceptible
54	IR82125-30-1-2	5	1	9	Susceptible
55	IR82107-19-1-1	7	3	3–5	Moderately resistant
56	IR82107-29-1-2	7	3–5	5–7	Intermediate to moderately susceptible
57	IR82164-13-3-3	7	5	3–5	Moderately resistant
58	IR82164-48-1-2	9	5	3–5	Moderately resistant
59	IR82165-21-2-1	9	3	9	Susceptible
60	IR82165-30-2-3	9	1	9	Susceptible
61	IR82166-22-1-2	7	3	9	Susceptible
62	IR82166-36-2-3	9	3	9	Susceptible
63	IR82144-10-1-2	7	9	3–5	Moderately resistant
64	IR82144-10-2-3	9	3	5–7	Intermediate to moderately susceptible
65	IR82219-38-2-3	9	1	9	Susceptible
66	IR82219-43-1-1	9	1	9	Susceptible
67	IR82220-8-3-2	7	3	9	Susceptible
68	IR82220-17-3-1	9	1	9	Susceptible
69	IR82220-17-3-2	9	1	9	Susceptible
70	IR82336-27-3-2	9	1	9	Susceptible
71	IR82336-37-2-3	9	3	9	Susceptible
72	IR82340-4-2-1	9	3	9	Susceptible
73	IR82340-7-2-3	9	3	9	Susceptible
74	IR82340-8-1-2	9	3	9	Susceptible
75	IR82340-10-2-3	9	3	9	Susceptible
76	IR82340-13-2-2	9	3–5	9	Susceptible
77	IR82340-14-3-2	9	3–5	9	Susceptible
78	IR81535-14-3-2-2	9	3–5	9	Susceptible
79	IR81535-17-1-2-2	9	3–5	9	Susceptible
80	IR81537-30-3-3-2	9	3–5	9	Susceptible
81	IR81543-22-3-3-3	9	5	9	Susceptible
82	IR81578-22-1-1-2	9	1	9	Susceptible
83	IR81550-11-3-1-3	5	1	9	Susceptible
84	IR81528-15-3-2-2	7	1	5–7	Intermediate to moderately susceptible
85	IR81551-1-2-1-1	7	1	5–7	Intermediate to moderately susceptible
86	IR81551-1-2-3-3	5	1	3-5	Moderately resistant
87	IR81551-1-3-3-1	5	1	3-5	Moderately resistant
88	IR81551-2-1-3-3	–	–	7–9	Susceptible
89	IR81551-2-2-3-2	7	3–5	7–9	Susceptible
90	IR81551-15-1-2-3	3	1	7–9	Susceptible
91	IR81551-15-2-3-2	5	1	7–9	Susceptible
92	IR81216-7-3-1-2-1	7	3	9	Susceptible
93	IR1219-13-3-1-1-1	9	5	9	Susceptible
94	IR81224-1-3-3-3-1	3	3	9	Susceptible
95	IR81228-3-2-1-1-2	5	5	9	Susceptible
96	IR81230-10-2-2-2-1	5	1	5-7	Intermediate to moderately susceptible

Continued

Table 11. Continued.

Entry no.	Identity	Seedling vigor	1st reading	2nd reading	Remarks
97	IR81233-30-2-1-2-2	5	1	9	Susceptible
98	IR81241-26-2-1-2-2	5	5	5–7	Intermediate to moderately susceptible
99	IR81111-6-2-3-3-2	5	5	7–9	Susceptible
100	IR81214-6-1-2-3-3	3	3	5	Intermediate
101	IR80538-13-3-2-2-2-1	3	5	7	Moderately susceptible
102	IR80735-18-3-1-2-2-3	5	1–3	9	Susceptible
103	IR0768-3-1-3-2-1-1	3	1–3	5	Intermediate
104	IR79300-15-2-3-2-2	7	1	5	Intermediate
105	IR80747-25-3-2-3	7	1	5	Intermediate
106	IR80771-7-2-1-3	5	1	5–7	Intermediate to moderately susceptible
107	IR80106-4-3-3-2	5	1	5	Intermediate
108	IR80126-50-1-2-2	9	1	9	Susceptible
109	IR80730-12-2-2-3-3	9	3	9	Susceptible
110	IR80730-1-3-2-1	7	3	7	Moderately susceptible
111	IR80732-34-2-1-2-2	9	3	7–9	Susceptible
112	IR81216-22-3-1	7	3	5–7	Intermediate to moderately susceptible
113	IR81216-7-3-2-3	5	3	7	Moderately susceptible
114	IR81219-13-3-1-1	7	1-3	5–7	Intermediate to moderately susceptible
115	IR81224-5-1-3	–	–	–	
116	IR81229-17-2-3-2	3	1	3–5	Moderately resistant to intermediate
117	IR81230-10-2-2-2	9	PG	0–3	Resistant to moderately resistant
118	IR81238-25-1-2	5	5	5	Intermediate
119	IR81528-15-3-2	7	1	5	Intermediate
120	IR81529-13-1-3	7	1–3	7–9	Susceptible
121	IR81532-14-2-1	3	1	7	Moderately susceptible
122	IR81551-1-3-3	3	1	5	Intermediate
123	IR81551-2-1-3	3	1	5	Intermediate
124	HR17570-21-5-2-5-3-3-2-4	–	–	–	
125	HR20654-54-3-5	–	–	–	
126	HR20654-39-3-5	9	PG	3	Moderately resistant
127	IR78162-123-2-2-1	9	5	9	Susceptible
128	IR80098-38-3-1-2	–	–	–	–
129	IR80111-11-3-3	9	5	9	Susceptible
130	IR77856-91-1-4-1	9	9	9	Susceptible
131	IR80098-40-3-1-2	9	9	9	Susceptible
132	IR80732-23-3-1-2	9	9	9	Susceptible
133	IR80732-34-2-1-2	9	9	9	Susceptible
134	IR80771-20-3-1-3	9	9	9	Susceptible
135	IR68333-R-R-B-22	9	9	9	Susceptible
136	IR68349-131-2-2-3	9	9	9	Susceptible
137	IR68352-14-1-1-1	9	9	9	Susceptible
138	IR68373-R-R-B-22-2-2	7	5	9	Susceptible
139	IR68399-78-2-3-3-1	3	1	5	Intermediate
140	IR68331-R-R-B-22-2-2	7	1	7–9	Susceptible
141	SR18518-BF4-B-12-1-2	9	5	9	Susceptible
142	IR68333-R-R-B-19	9	5	9	Susceptible
143	YR17104-R-R-B-14-3	9	5	9	Susceptible

Continued

Table 11. Continued.

Entry no.	Identity	Seedling vigor	1st reading	2nd reading	Remarks
144	IR71121-35-1-1-1-2	3	3–5	5–7	Intermediate to moderately susceptible
145	IR72944-1-2-2	9	3	9	Susceptible
146	YR14323-69-2-3-2-1	3	1	7–9	Susceptible
147	IR71131-BF4-B-30-5	3	1	5–7	Intermediate to moderately susceptible
148	IR73689-76-2	7	1	7	Moderately susceptible
149	IR73694-41-2	5	3	3–5	Moderately resistant to intermediate
150	IR73688-57-2	9	5	5	Intermediate
151	IR73305-14-2-2	5	1	7	Moderately susceptible
152	IR73688-82-3	5	3	9	Susceptible
153	IR73690-7-2-1-1-3-2-2-1	9	5	5–7	Intermediate to moderately susceptible
154	IR74520-29-4-2-2-2-4-1-1	5	3	7	Moderately susceptible
155	IR73689-19-1	3	1	9	Susceptible
156	SR22746-68-2-3-4-2-4	9	3	9	Susceptible
157	IR74506-28-4-3-2-1-3-2-2	7	3	9	Susceptible
158	HR17570-21-5-2-5-3-3-2-4	7	1–3	9	Susceptible
159	HR20654-54-3-5	5	3	7–9	Susceptible
160	HR20654-39-3-5	5	1	7–9	Susceptible
161	IR78162-123-2-2-1	9	3	9	Susceptible
162	Jinmibyeo	9	3	9	Susceptible
163	IR72	3	3–5	9	Susceptible
164	Dasanbyeo	5	5	9	Susceptible
165	MS 11	7	3	9	Susceptible
166	PR26881-PJ 16	9	3	9	Susceptible

BSU, La Trinidad, Benguet

In this season, only the blast nursery was established, in September 2006. Some 166 entries were evaluated, using a modified field screening with spreader rows planted around the test entries. However, the spreader rows had very poor germination. Infected plants from nearby rice fields were collected and spread in the nursery. Seedling vigor was also observed. A few entries had poor germination. Two readings were undertaken for blast infection.

For seedling vigor, only 30 entries had a score of 3 (good); the rest had from 5 to 9. The final reading of blast infection showed severe reactions to most of the entries. However, it can be noted that the good entries, even if sandwiched among the highly susceptible entries, exhibited moderate to intermediate field resistance.

Overall, the GUVA lines exhibited a fair performance under Maligaya conditions in yield and other traits. However, it should be noted that the planting schedule was beyond the normal schedule. Hence, there is a need to re-evaluate the entries in the 2007 DS. Under La Trinidad conditions, the GUVA lines showed good yields under a lower temperature regime, which indicates the adaptability of the lines in semi-temperate conditions. Blast incidence at BSU, La Trinidad, proved to represent a good screening site. The lines that showed moderate resistance could be good donor germplasm.

Expectations from the TRRC

1. We are expecting enhanced collaboration to strengthen our japonica rice breeding program, research, and production technologies
2. Exchange of expertise on the different aspects of varietal improvement and production
3. Resource sharing specifically on germplasm exchange to broaden the diversity of our germplasm pool
4. Logistical support

Possible contributions to the TRRC

1. For germplasm exchange, the developed japonica varieties and advanced breeding lines are ready for sharing with the participating NARES for use in varietal improvement or direct use.
2. Our expertise and commitment to undertake japonica rice research to help in the development of technologies for farmers to increase production to attain self-sufficiency in the target environments.

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Problems of growing rice in Russia and ways to solve them

Evgeny Kharitonov

Several problems in temperate zones limit obtaining maximum rice yield of high grain quality to meet the requirements of consumers.

The climatic conditions of rice-growing regions all over the world are very different. The main rice output is obtained in tropical zones. Nevertheless, considering high crop plasticity, rice can be grown under very contrasting conditions.

The peculiarity of Russian rice growing is that rice is cultivated with specially engineered systems, developed by Russian scientists for the industrial technology of direct seeding into dry soil.

Heavy soils with limited filtration ability and saline and swampy soils were reclaimed for rice cultivation. These soils were not fit for any other crop.

Rice growing in Russia is the one of most northern in the world. The main rice plantings are situated between 44° (Krasnodar territory) and 49° (Republic of Kalmykiya and Astrakhan region) North latitude.

The yearly sum of efficient temperatures is from 2,700° (Republic of Kalmykiya and Astrakhan region) to 3,200° (Krasnodar territory). The period with air temperature higher than 15 °C lasts from 120 to 140 days. Recurrent cold weather sees temperatures from 8 to 10 °C (at the beginning of the vegetative period, May) up to 13 to 15 °C (during the flowering and ripening periods, August).

Despite the unfavorable soil and climatic conditions of the region, rice is cultivated in eight regions of Russia. The total area of rice systems in the country is 511,000 ha, but the sown area varies from 140,000 to 200,000 ha/year. The main region of rice cultivation in Russia is the Krasnodar region, where more than 80% of the total rice is produced.

Unfavorable factors for rice production in Russia are the same as in other temperate zones: temperature regime, rice diseases, and ecological insecurity.

Rice crop yield in Russia does not exceed 3.5 t/ha. During 2005-10, it became stabilized at 5.0 t/ha. In 2010, rice crop yield in the Krasnodar region was 6.3 t/ha, and the best farms obtained from 9.0 to 10.0 t/ha.

Both natural climate and human factors play a significant role in the effective work of the industry. Rice scientists' qualifications and their professional education help us gain high crop yield, and increase rice production.

Scientific research on rice growing in Russia is carried out by the All-Russian Rice Research Institute (ARRRI), situated in the Krasnodar region.

Breeding work started here in 1932. The rice gene pool of the ARRRI (working collection), which includes 6,400 samples, and genetic resources of the Vavilov Institute of Plant Industry (Saint Petersburg) are used in various breeding programs.

The japonica subspecies makes up 97.6% of the ARRRI collection of varietal samples. Introduced varieties of this subspecies are always present in the genealogy of all the most significant Russian rice varieties. They are the source of the most important features: fast maturity (Kendzo, a Japanese variety, brought from Korea, is the ancestor of Russian varieties); wide ecological adaptability (k-514, China, Manchuria); short stem and good productivity (Balilla, a grano grosso (large grain), Italy); and high quality of milled rice (Saturn from the U.S.).

Russian rice breeders combine traditional methods with new trends in fundamental research: biotechnology, biochemistry, physiology, and genetics.

Breeding work is carried out by the method of step hybridization first of all using varieties from Russian breeding, and a permanent use of definite donor traits from the global gene pool. The main trend of modern breeding is the release of short-stem varieties with high yield potential for the biotic and abiotic stress-resistant conditions of rice growing in Russia.

Part of the soils in Russia used for rice have a different degree of salinity. Therefore, the development of salinity-resistant varieties is one of the breeding trends in the country.

ARRRI studies salt-resistance mechanisms, develops new methods of breeding samples for the evaluation of salt resistance, and carries out a mass screening of breeding lines at different stages of ontogenesis. Such systematic work allowed developing the following salt-resistant rice varieties: Kurchanka, Sonata, Sonet, Fisht, Anait, and Sharm.

Comparative evaluation of rice varieties and varietal samples for salt resistance in breeding of different countries (Russia, China, Korea, Japan, Philippines, etc.) was performed in 2005 at the China National Rice Research Institute (Hangzhou) in the framework of cooperation with ARRRI. Many varieties belong to Russian breeding. In Russia, early and mid-duration varieties with a vegetative period of 100–125 days are mostly cultivated. During the sprouting period at low temperatures of soil, air, and irrigation water, varieties are very often subjected to stress, which causes a decrease in the number of sprouts and yield loss. Therefore, at ARRRI, breeding for cold-resistant varieties is carried out. The use of rice varieties Kuban 3 and Severniy allows us to start rice seeding before the optimal term and to finish harvesting before unfavorable autumn weather.

Within a framework of the TRRC coordinated by IRRI, ARRRI performs the work on the development of cold-resistant varieties using germplasm from the Philippines, South Korea, China, Egypt, and other countries. Within the framework of this work, the methods of evaluating samples for cold resistance in different stages of plant growth have been advanced, and the lines studied at the breeding nursery have been developed.

Problems connected with climate change are important for Russian rice growing. The scientists of the Institute study the variability in productivity of Russian rice varieties under the influence of this stress factor in order to forecast their reaction to air temperature rises during the critical vegetative stage (flowering and ripening). Both intervarietal and intravarietal variabilities are being studied, donors featuring resistance to high temperatures are being determined, and selection methods for adaptability to changing environmental conditions are being developed.

Blast is one of the most dangerous rice diseases for Russian rice growing as well as for other countries.

At the ARRRI biotechnology laboratory, genotyping of a local population of blast pathogens by both the phytopathological method (on the basis of the use of varietal differentiators) and marking of the pathogen population is carried out.

As research showed, one of the effective genes in the Krasnodar region is a gene with race-specific resistance to the *Pi-b* pathogen, which has already been cloned.

At the Japanese research center (NIAS), Dr. Suprun created an intragene DNA marker for this gene together with Dr. Fukuoka. We are very grateful to Dr. Okuno, director of the gene bank at NIAS, for giving us the opportunity of doing research.

This marker helps to perform mass screening of the ARRRI collection, without using a phytopathological test. At present, work on this gene introgression into prospective rice varieties using an intragene marker is being carried out. Work on pyramiding other genes with race-specific resistance to blast has also been performed. The program of *Pi-ta, Pi-b, Pi-z, Pi-zt, Pi-1, P-2,* and *Pi-33* gene introgression into Russian germplasm in such varieties as Flagman, Boyarin, Yantar, Khazar, Snezhinka, and Novator has been carried out. Lines with the pyramided resistance genes that undergo competitive variety testing have been developed.

Within the framework of the TRRC, there has been introgression of the *Pi-40* gene using molecular markers. Crossing with the Russian varieties such as Yantar, Khazar, Severniy, and Novator has been carried out; hybrid material for further cooperation with TRRC partners has been obtained.

However, a solution to all the problems only by means of breeding programs even on the basis of the recent achievements in fundamental research is impossible.

Success in obtaining stable yields and solving ecological problems is mainly achieved by using different growing technologies developed by ARRRI scientists.

If rice plants receive insufficient nitrogen, the plants do not use all their productivity potential, and excess N leads to a prolongation of the vegetative period; this increases the number of sterile spikelets and plant lodging and decreases resistance to fungus diseases. Therefore, ARRRI scientists pay special attention to the balanced nutrition of rice plantings in macro- and microelements; and for effective fertilizer dressing, a system of fertilizer application evaluation for crop yield planned has been developed, taking into consideration the individual features of each variety.

ARRRI works on integrated plant protection from weeds, pests, and diseases. Plantings are subject to examination during the vegetative period every year. The degree of their damage is evaluated and timely measures for saving yield are provided. On the basis of monitoring the ecological situation in the rice-growing area, some factors that negatively affect the plantings and environment are determined and timely eliminated.

ARRRI carries out research on rice cultivation with periodical irrigation in order to develop a water-saving irrigation technology that allows not only saving irrigation water but also cutting down expenses on its delivery. The technology has been tested on rice-growing farms of the Krasnodar region, where its economical efficiency has been confirmed under production conditions.

ARRRI has modern scientific equipment for biological, physical, and chemical research.

Much attention is paid to upgrading the professional level of the staff. Future specialists study in postgraduate courses of the ARRRI. The Institute's researchers consult rice-growing farms on rice cultivation.

ARRRI cooperates with international scientific centers in the area of rice-growing. On the basis of agreements, joint research with the International Rice Research Institute (Philippines) and the Rice Research Institute of Sichuan Agricultural University (China) directed toward developing heterosis of rice hybrids is being performed. There is cooperation with the Agricultural Research Service of the Department of Agriculture of the U.S.; Center of International Cooperation in Agronomy (CIRAD), Montpellier, France; Japanese Agricultural Research Center (Hokkaido), etc. Within this framework, Russian scientists not only undergo training and internships but also do the testing of rice varieties and samples in contrasting ecological conditions, identify donors of economically valuable features, and use them in breeding programs and advanced methods of work with rice germplasm.

We hope that collaborative work will help to unite efforts of rice scientists for use worldwide in releasing new rice varieties, developing cultivation technologies, and working out development concepts for rice-growing in the temperate zone in the near future.

Notes

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Rice food security and production in Turkey

Necmi Beşer, Halil Sürek

Turkey's rice production increased in the last 10 years as a result of improvements in soil preparation, planting methods, irrigation, rice cultivars, fertilizer application, plant protection, certified seed usage, harvest, and drying conditions. But, Turkey still has to import 25–30% of its rice consumption. Irrigation water is the most limiting factor for rice production in Turkey. Rice can be grown in nearly all regions of Turkey. The most important achievements to improve rice yield are obtained through variety improvement in Turkey.

Turkey has 18,092,000 ha of cultivated area and 13,907,355 ha of this is used for cereal production. The most important cereal is wheat and it is grown on 9,350,000 ha, followed by barley (3,640,000 ha), maize (550,000 ha), oats (150,000 ha), rye (140,000 ha), and rice (59,000 ha) (DIE 2002). The staple food for Turkish people is wheat and wheat consumption is 200–250 kg per capita. Rice consumption is very low (about 7–8 kg per capita) when we compare it with wheat consumption (Table 1). If we look at long-term statistics, we can see that the trend for rice consumption per capita is going up; on the other hand, the trend for wheat consumption per capita is going down. Rice production area ranged from 40,000 ha to 100,000 ha, and annual total milled rice production ranged between 150,000 and 452,000 tons depending on water availability and government policies during the last 50 years. This production is not sufficient for domestic consumption; thus, imported milled rice reached 200,000 tons in 1992, and this amount was more than that of domestic milled rice production in that year (DIE 2002). Since then, rice imports of Turkey continued to increase until 2002, and then began to decrease because of the increase in domestic production (Table 1). There are two reasons for Turkey's increasing rice production: an increase in rice production area and an increase in yield. Yield increases are coming from the introduction of new varieties and new production technologies. On the other hand, Turkey exports 20,000–30,000 of tons milled rice each year.

Table 1. Rice planting area, production, yield, imports, exports, total supply, consumption, and self-sufficiency in Turkey.

Year	Planting area (ha)	Production (paddy) (tons)	Paddy yield (kg/ha)	Production (milled) (tons)	Imports (milled) (tons)	Exports (milled) (tons)	Total supply (milled) (tons)	Consumption (milled) (kg/per capita/year)	Self-sufficiency (%)
2000	58,000	350,000	6.03	210,000	310,639	14,386	516,439	7.17	41.44
2001	59,000	360,000	6.10	216,000	323,278	11,760	534,958	7.39	40.64
2002	60,000	360,000	6.00	216,000	404,722	16,041	616,402	8.31	35.66
2003	65,000	372,000	5.72	223,200	125,285	13,937	344,021	4.30	69.34
2004	70,000	490,000	7.00	294,000	283,044	14,648	571,164	7.99	48.99
2005	85,000	600,000	7.06	360,000	221,250	16,580	577,650	8.01	63.82
2006	99,100	696,000	7.02	417,600	167,980	16,790	581,400	8.07	71.28
2007	93,900	648,000	6.90	388,800	236,364	20,948	621,276	8.68	60.46
2008	99,490	753,000	7.57	451,995	183,621	36,494	631,096	7.79	75.66

Source. www.tuik.gov.tr (2008)

As can be seen in Table 1, there is a need to improve rice production nearly 25% for Turkey to be self-sufficient (Table 1). The main constraint to increasing rice production is irrigation water (Beşer 1997b). Many climatic areas are suitable for growing rice and average rice yield is more than 7.5 t ha^{-1} in Turkey (Table 1) and rice growing is much more profitable than other field crops, but, rice is grown in a very limited area because of water shortage.

Rice-growing area and environment

Turkey is situated between 36° and 42°N latitude, and it is divided into seven political regions. Rice is grown in every region; however, Marmara, especially the European part of Marmara (Trakya), and the Black Sea Region are the main rice production areas (Table 2). The main rice-growing provinces are Edirne (in Trakya), Samsun (in the Black Sea Region), Balıkesir (in South Marmara), and Çorum and Sinop (both in the Black Sea Region). Rice can be planted in the second half of April as a first crop and in May or June as a second crop in the Mediterranean, Southeast Anotolia, and Aegean regions; on the other hand, it is planted in May only as a first crop in other regions. The number of cloudy and rainy days during the rice-growing period is very low and the temperature decreases gradually after pollination during grain filling, so these conditions are very favorable for high paddy yield in Turkey. Nevertheless, cold water and weather conditions during germination cause difficulties in stand establishment. Cold weather also sometimes affects panicle initiation and flowering in some regions (Sürek 1998).

Direct seeding is used traditionally as a rice-planting method in Turkey (Beşer 1997a). Seeds are soaked between 24 and 48 hours in water and then drained and left to pregerminate between 24 and 48 hours, and these pregerminated seeds are broadcast by hand or a centrifugal broadcaster into standing water in all regions except Diyarbakır and Bingöl provinces in Southeast Anotolia (Beşer 1997b). The applied seed rate is 120–130 kg ha^{-1} in Southeast Anotolia and 120–180 kg ha^{-1} in other

Table 2. Rice planting regions and their percentages in Turkey in 2008.

Region	Planting area (ha)	Yield (t/ha)	Paddy production (tons)	Planting area (%)	Production (%)
Marmara	67,825	8.03	545,025	68.2	72.4
Black Sea	20,218	7.20	150,876	20.3	20.0
Central Anotolia	4,896	6.93	33,945	4.9	4.5
Mediterranean	987	6.13	6,054	1.0	0.8
Southeast Anotolia	4,830	2.92	14,088	4.9	1.9
East Anotolia	784	4.10	3,214	0.7	0.5
Aegean	–	–	–	–	–
Total	99,490	7.57	753,000	100	100

Source. www.tuik.gov.tr (2008).

regions (Gaytancıoğlu 1997) and the recommended seed rate is 160–180 kg ha^{-1} for Turkish rice varieties and direct-seeding conditions (Anon. 1979-2002).

After 1990, farmers bought more complicated and bigger machinery for soil preparation. This helped farmers to prepare their paddy fields under all conditions. A laser-leveling machine, which is used only by rice farmers, may be the most useful one. Laser leveling gives farmers an opportunity for good stand establishment, good water management, and having a larger plot size and effective fertilizer and pesticide application.

All rice varieties grown in Turkey are japonica-type varieties. Turkey's rice production is very well mechanized now and yield is high to compete with imported rice. Rice mechanization, especially in the Marmara Region, has a very high standard according to other crops. Rice farmers generally use laser leveling and powerful tractors with more than 100 HP. Rice farm size is also larger in the Trakya Region than in other regions. If there is no water problem, Turkey can be self-sufficient for rice in ten years because the trend for rice production area in all regions is increasing.

National policies and strategies since 1990 for sustainable rice production

Rice production must be increased around 25% to be self-sufficient in Turkey (Table 1). But, it is very difficult to expand rice-growing area because of water shortages. Turkey's climatic conditions are very favorable for rice production; however, Turkish rice producers can have difficulties in selling their paddy because of cheap imported rice in some years. Thus, the government establishes some restrictions and increases the taxes on imported rice, especially during rice-harvesting time in Turkey. There is special support for rice production like for oil crops; US$50 per ton was paid as a premium for rice in 2006. In addition to that, the electricity in irrigation is 35% and 25% lower than that of home and industrial use, respectively. The government also supports rice production by giving a support price during harvesting. There is also support to encourage farmers to use certified seed. If farmers used certified seed, the government paid them $65 ha^{-1} in 2007. The government is also financing nearly all rice research activities to obtain high-yielding new rice varieties and growing techniques. Every district has a Rice Commission. Every rice grower must give information to the Rice Commission about rice production area and place every year before planting rice. The Rice Commission calculates the rice-growing area using dams, underground water, and river water sources and gives permission to growers for their rice-planting area. If there is a water shortage, the Rice Commission observes the rice-growing area and controls and rotates water. If a farmer grows rice without getting permission from the Rice Commission, he is punished and water is not given to him during water-shortage years. Water and mosquito control is the main working area of this commission. The Ministry of Agriculture and Rural Affairs and DSİ (State Water Affairs) decide how much area can be planted to rice taking into consideration water sources. Rice growing is forbidden in the Aegean and some provinces of the Mediterranean Region because of water shortages and mosquitoes in rice fields near tourist sites (Beşer 1997a).

To help rice production become self-sufficient, nearly all rice irrigation dams and systems were built by the government. Government policies changed during the last ten years and the government left irrigation systems to farmer organizations without taking any money from them. The farmer organizations do not give any money to the government for water cost but they pay all management costs and they collect this money from the farmers according to their rice field size.

The major constraints to sustainable rice production

Irrigation water is the most limiting factor for expanding the rice-growing area to increase rice production (Beşer 1997b). If there is enough water, farmers can grow rice in nearly all regions in Turkey. Rice has competed with other crops very well in the last 15 years. To be self-sufficient for rice, Turkey should build new dams or should find new technologies to grow rice using less water. For this, some research has been done at the Trakya Agricultural Research Institute, including on drip irrigation in rice. Turkish rice yield will be about 10 t ha^{-1} in the near future because some farmers can harvest more than 10 t ha^{-1} by using high-yielding varieties and good production technologies in some areas. The problem is that most of the rice farms are too small to follow these new technologies and buy the new machines. Large-size farms are mostly located in Trakya and Marmara regions and new technologies first enter from these regions.

Blast, bakane, helminthosporium, barnyardgrass, red rice, and some insects cause economic losses in paddy fields in Turkey. The first blast epidemic occurred in 1995 and then in 1997 in Turkey (Sürek and Beşer 1997) . Immediately after the first blast epidemic in 1995, information was given to farmers on seed treatment, foliar application of fungicide, low nitrogen rate, and rotation to prevent their crop from suffering from a blast epidemic.

Weed control is done effectively by introducing new-generation environment-friendly chemicals such as Cherokee, Gulliver, Nominee, Chlinger, Londax, Sindax, etc., and application techniques.

The high-technology combine harvester and dryer were introduced very fast in Turkish rice production 15 years ago. It has been estimated that combine harvester use reached nearly100% in 2007. The introduction of new technologies brought some new problems. Head-rice yield decreased if farmers did not manage well the optimum harvest moisture and drying conditions. Paddy drying with a paddy dryer also brought some problems. As is known, fast drying in improper conditions reduces head-rice yield, and this is seen as a small farmers' crop because small farmers have to hire a dryer. They are more careful about harvest moisture content now, but some problems still occur.

We can say that, if there is enough water for rice cultivation, high yield can be obtained from early rice varieties in every region of Turkey. But, the regions have different constraints, as given below.

1. The Marmara Region has a short growing period and early fall rains.
2. The Black Sea Region has a short growing period, early fall rains, cloudiness,

and humid and rainy days during growing, which brings high risk of blast infection.

3. Southeast Anotolia has high temperature during pollination, which causes spikelet sterility, and economic competition with cotton and wheat + second crop (i.e., maize, soybean).
4. The Mediterranean Region has high temperature during pollination, which causes spikelet sterility, and economic competition with cotton and wheat + second crop or vegetables.
5. Central Anotolia has a short growing period, low water temperature, and low night temperature.
6. East Anotolia has a short growing period, low water temperature, and low day and night temperature.
7. The Eagen Region has economic competition with cotton and wheat + second crop or vegetables.

Major achievements in rice research and development since 1990

The most important achievement in rice research was obtained in rice breeding in Turkey. Until 1997, mostly foreign varieties (Ribe, Rocca, Baldo, Veneria, Krasnodarsky-424) and local varieties (Akçeltik, etc.) were grown in Turkey, although a lot of Turkish rice varieties were registered. High-yielding Osmancık-97 was registered in 1997 and nearly 80% of Turkish rice production now comes from that variety. As a result of growing Osmancık-97, farmers get high quality and yield of paddy. They also reduce harvest costs with a harvesting combine machine for this semidwarf rice cultivar. We could say that, with the spread of these varieties, Turkey's rice production and yield increased sharply.

Most farmers are using optimum doses of fertilizer, as a result of transferring research results on fertilizer to farmers. Especially, the time and dose of nitrogen in rice growing are very important. A lot of research was undertaken at Trakya Agricultural Research Institute on fertilizer in the last 20 years to find optimum doses and application times for all registered varieties. Before these results, some farmers were using very low doses of nitrogen; on the other hand, some farmers used 250–300 kg N ha^{-1}, and then they clip the upper leaves of rice to avoid lodging. Optimum nitrogen doses for Turkish rice varieties range from 140 to 160 kg ha^{-1} and N should be applied at least twice. It is also very critical to apply N fertilizer 50–60 days after direct seeding (at booting stage). With the application of nitrogen within the advised time and at appropriate doses, farmers can obtain high yield and good-quality paddy with low cost. They can also prevent their crop from suffering from a blast epidemic. There is no problem in phosphorus doses; the problem is the application method for phosphorus; unfortunately, some farmers still apply phosphorus after seeding.

The other important fertilizer is zinc for rice production in Turkey. As a result of the project undertaken, some regions were found to have zinc deficiency. Zinc application has been widening in the Marmara Region very rapidly in the last ten years. Crop maturity is not synchronized. If zinc deficiency occurs, farmers may have grain kernels with various moisture content at harvest. Thus, moisture change among kernels especially reduces head-rice yield during drying. Farmers have obtained higher yield and quality of paddy with zinc application in the last 3 years in the Marmara Region. Various plant protection studies were carried out and their results transferred to farmers, including seed treatment and pesticide application technique for controlling barnyardgrass, bakane, blast, etc. Blast caused great economic damage in 1995 and then in 1997 in the European part of the Marmara Region (Sürek and Beşer 1997). Before this year, farmers did not know that blast could have such a devastating effect in paddy fields. Farmers were trained about the causes of blast and techniques for controlling blast. Red rice is also an important problem, especially in rice-growing areas without rotation. Foundation seed and certified seed are also produced by the Trakya Agricultural Research Institute to increase yield and quality and reduce red rice infestation in paddy fields.

Prebasic and basic seeds of all rice varieties are produced by the Trakya Agricultural Research Institute for Turkey. The increase in certified seed uses improved rice quality and quantity very much because of the reduction in blast, bakanae, white tip nematode, and red rice infestation in paddy fields.

Farmers used to sow up to 250 kg ha^{-1} of seed. Agronomic studies at the Trakya Agricultural Research Institute have shown that a seed rate of 160–180 kg ha^{-1} is enough for broadcasting pregerminated seed. These results have been introduced to farmers. This new seed rate reduced farmers' inputs and disease risk and increased farmers' paddy yield and quality.

Conclusions and recommendations

There is improvement in rice breeding and rice production technologies in Turkey. Paddy yield and rice quality were increased by introducing new rice varieties and production methods. Those also increased the competitiveness of Turkish rice. It can be said that Turkish rice yield will approach 10 t ha^{-1} in the near future because some farmers can harvest more than 10 t ha^{-1} paddy yield by using new varieties and good production technologies from soil preparation to drying. But, most rice farms are too small to follow these new technologies and buy the new machines. Large farms are mostly located in Trakya and the Marmara Region and new technologies first enter from these regions.

Turkey should increase rice production by 25–30%. There is not an easy way to reach this objective. Thus, a lot of research has been carried out and still many things should be done:

1. Rice is mainly grown in two regions but it is also grown in every region in the various micro- or macro-ecologies in small quantities. Thus, rice production area can be extended.
2. Rice breeding studies are carried out only at the two government institutes. The number of institutes should be increased and the private sector should be encouraged to enter rice breeding and do more seed multiplication.
3. More plant protection (improvement of blast-resistant varieties) and quality studies should be done.

4. There is still a gap between experimental and farmers' yield; thus, there is a possibility of increasing rice yield with extension and agronomic studies.
5. Some work needs to be done to establish different crop associations. After establishing rice associations, it is expected that farmers would be more active in rice research strategies and rice policies in Turkey.
6. There is also a need to support rice farmers politically against cheap imported rice.

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Temperate rice in the U.S.

Thomas H. Tai

In the U.S., rice production occurs in the Gulf Coast (27° to 31° N latitude—Texas, Louisiana, and Florida), the Grand Prairie and Mississippi Delta (32° to 36° N latitude—Arkansas, Louisiana, Mississippi, and Missouri), and the Sacramento Valley (38° to 40° N latitude—California). All public rice varieties produced in the U.S. are japonica although in recent years there has been a significant increase in the use of hybrid rice varieties in the southern U.S., which have been developed in the private sector. Temperate japonicas (predominantly medium-grain cultivars) are grown in California and tropical japonicas (mostly long-grain cultivars) are grown in the southern states. Rice is produced using irrigated direct-seeded systems. Dry seeding is the predominant planting method in the southern U.S. while water seeding is used in California and to some extent in Louisiana.

A total of about 3.38 million acres (1.36 million ha; Arkansas, 49%; Louisiana, 17%; California, 14%; Mississippi, 8%; Missouri, 6%; and Texas, 6%) of rice was planted (3.36 million acres harvested) in 2005. The average yield was 7.4 t ha^{-1}, ranging from 8.3 t ha^{-1} in California to 6.6 t ha^{-1} in Louisiana. Of the approximately 500,000 acres (200,000 ha) of rice grown in California, more than 90% is medium grain. Short-grain cultivars, which are grown exclusively in California, account for about 6% of production while long grains, which are primarily grown in the southern U.S., represent 1% to 2% of California rice. The value of the rice crop is approximately $1.7 billion and this represents about 2% of the total value of U.S. field crops. The U.S. is a major exporter of rice, typically trailing only Thailand and Vietnam. About 40% of the rice grown in California is exported to Korea, Taiwan, Japan, Turkey, and Jordan.

Although rice production in the U.S. can be traced back to the seventeenth century with the introduction of long-grain tropical japonicas to South Carolina from Madagascar, rice improvement activities began only in the early 1900s. In addition to those early cultivars, U.S. breeding programs are based on introductions from Southeast Asia, Japan, and Europe. The development of rice varieties is largely a public effort in the U.S., with contributions made by U.S. Department of Agriculture (USDA) breeders and the various states. In recent years, the activities of the USDA (Agricultural Research Service, ARS; www.ars.usda.gov/) have shifted from breeding of new varieties to the development and characterization of germplasm (prebreeding) and basic research, including genomics. Major research efforts are located at the USDA-ARS Dale Bumpers National Rice Research Center (Stuttgart, Arkansas) and the USDA-ARS Rice Research Unit (Beaumont, Texas), where projects range from genetics and germplasm enhancement to disease resistance and grain quality. Other USDA-ARS scientists located throughout the U.S. also focus on various aspects of rice research.

All the major rice-growing states maintain active breeding programs. In the southern states, these breeding programs are operated by the Agricultural Experiment Stations of the respective state university systems, with strong financial support from rice growers and producers. Southern rice breeding programs cooperate in an annual Uniform Regional Rice Nursery, in which advanced lines are tested at various locations. In California, the public breeding effort is led by the Rice Experiment Station, which is directly supported by the growers and producers of California. This program cooperates closely with the University of California at Davis and the USDA-ARS.

In 2005, the USDA Cooperative State Research, Education, and Extension Service (CSREES) funded a Coordinated Agricultural Program project aimed at exploiting the advances in rice genomics. This cooperative project, called RiceCAP (www.uark.edu/ua/ricecap/), brings all of the major public rice breeding programs and a number of leading rice and rice-related genomics groups in the U.S. together to address two major industry problems, milling yield and sheath blight (caused by *Rhizoctonia solani*). These problems are of primary interest to southern U.S. rice production.

Major research targets for improving japonica rice and production technologies

California and the southern U.S. states represent two distinct temperate environments. Although there is significant overlap in research targets for the development of improved cultivars and production technologies, each region presents unique challenges relating to climate, production systems, and markets. Specific differences include an emphasis on seedling vigor and cold tolerance (both vegetative and reproductive) in California and disease resistance and improved milling yield in the southern U.S. cultivars.

In California, the temperate environment provides almost ideal conditions for rice production as evidenced by some of the highest yields for inbred rice cultivars in the world. Nevertheless, yield and yield stability are of the highest priority to breeders as well as maintaining superior cooking and eating quality associated with California medium-grain (Calrose) rice. Typically, the growing season is characterized by warm, long days and cool nights with very low humidity. As a result, biotic diseases have relatively less impact than in the significantly more humid environment of the southern states and California cultivars have little resistance to major pathogens such as rice blast and sheath blight. Stem rot (caused by *Sclerotium oryzae*) and aggregrate sheath spot (caused by *Rhizoctonia oryzae-sativae*) are the most prevalent diseases in California. As the predominant planting practice in California is water seeding, breeding efforts have focused on seedling vigor and cold tolerance as well as lodging resistance. The cooler temperatures present in California during pollen development also make breeding for reproductive cold tolerance (tolerance of blanking) a major target for improvement.

Research priorities in the southern U.S. also include higher yields and better grain quality (particularly in relation to yield, i.e., milling quality). The humid environment found in the Mississippi Delta and Gulf Coast regions is very favorable for fungal diseases such as rice blast and sheath blight. With the availability of blast-resistant germplasm, more research emphasis has been placed on sheath blight in recent years. In general, the tropical japonicas bred for the southern U.S. have better resistance to fungal diseases, but are less tolerant of low temperatures during pollen development. Cold tolerance in relation to germination and stand establishment is also of interest in this region as earlier planting and expanding growing areas further north may solve water problems to some degree. Since most rice is dry seeded, weed control is the most costly input and red rice is a major problem. Herbicide-tolerant induced mutants have been developed and have had some commercial success.

Constraints in japonica rice production and for improving japonica rice

The primary production constraint is the control of weeds, including red rice. GMOs are currently not an option although induced mutants have been identified and developed into cultivars now grown in the southern states. Water seeding in California provides some weed control. Seedling vigor (including cold tolerance) and lodging resistance are important for water-seeded systems. Although the water supply in California is not a major issue, competition for water resources in the southern states is increasing and is directly responsible for a reduction in the area under production in Texas. Declining water resources in the Grand Prairie region of Arkansas are also of concern.

The japonica rice varieties grown in the U.S. are based on two very small pools of introductions in the southern U.S. (tropical japonicas) and California (temperate japonicas). This narrow germplasm base represents a major constraint to the genetic improvement of japonica rice. Intellectual property rights are an extension of this constraint as the exchange of germplasm has been restricted in recent years. U.S. breeding programs are now routinely patenting new cultivars although breeding materials are openly exchanged among the public rice breeding programs. Concerns over GMOs represent another constraint to developing improved rice. Recent identification of GMO-contaminated rice in the southern U.S. has had a negative impact on research in this area (with the exception of studies to determine outcrossing and to improve detection).

Available genetic resources and type of genetic resources needed

The U.S. rice germplasm collection is relatively limited. Most breeding programs focus on germplasm or breeding materials obtained directly from sources. Recent emphasis has been placed on characterizing a subset of the U.S. collection (about 10% of the collection or 1,700 to 1,800 accessions) both phenotypically and genotypically (W. Yan, USDA-ARS, Stuttgart, Arkansas). A collection of genetic stocks (Genetic stocks—*Oryza*) has begun at the USDA-ARS Dale Bumpers National Rice Research Center in Stuttgart, Arkansas. Among this collection are indica germplasm derived from IRRI breeding lines that exhibit grain quality characteristics comparable with those of elite tropical japonicas grown in the southern states (J.N. Rutger, USDA-ARS, Stuttgart, Arkansas). For some time, it has been recognized that indicas are capable of very high yields in the southern U.S. although grain quality has been a serious problem and crossing indicas with tropical japonicas has not produced improved cultivars. The development of indica germplasm adapted to southern temperate regions ("temperate indicas") may prove to be an effective approach to developing improved cultivars rivaling the elite tropical japonicas. Efforts of the RiceCAP consortium have resulted in the development of several resources (e.g., mapping populations, marker data, and expression data) for milling yield and sheath blight resistance (www.uark.edu/ua/ricecap/). A number of rice mutant populations for reverse genetics have been developed in the U.S. using transposon tagging (V. Sundaresan, UC Davis) and chemical mutagenesis (Y. Jia and J.N. Rutger, USDA-ARS, Stuttgart, Arkansas; T. Tai and L. Comai, USDA-ARS and UC Davis).

Given the small germplasm pools upon which U.S. rice cultivars are based, access to more diverse germplasm remains an important need. Japonica germplasm with very high cold tolerance, resistance to lodging, resistance to stem rot and aggregate sheath spot, and seedling vigor (in relation to water seeding) would be of interest to California. Aromatic germplasm is of interest to both California and southern U.S. breeding programs. In addition to breeding materials, there is significant interest in mapping populations and mutants (insertional and chemical) for use in the genetic dissection of milling quality, disease resistance, seedling vigor, and cold tolerance (particularly reproductive). Although marker-assisted selection (MAS) has been used to develop a few U.S. cultivars, more cost-effective technologies and the identification of appropriate situations to apply MAS are concerns.

Strategies used, including biotechnology

Currently, strategies for the genetic improvement of japonica rice include conventional pedigree and backcross breeding, induced mutations (early flowering, semidwarf, herbicide tolerance), anther culture, and, to a very limited extent, MAS. Hybrid rice is also employed in the private sector with some success. A novel approach taken by J.N. Rutger has been the development of indica germplasm adapted to the southern U.S. using materials generated at IRRI (G. Khush), which have grain quality comparable with that of the U.S. elite tropical japonicas. The development of genetically engineered rice for the U.S. has been limited to the private sector, with testing performed in cooperation with some public breeding programs. The lack of acceptance of GMOs, particularly for export, has strictly limited this strategy.

Possible contributions to the TRRC and expectations from the TRRC

Contributions from my research program would involve cooperative research on seedling vigor and cold tolerance, resistance to cold-induced blanking, and resistance to stem rot and aggregate sheath spot. We have recently identified candidate genes for two major seedling cold-tolerance quantitative trait loci (QTLs) from the widely grown California cultivar M202. Work is under way to clone and characterize those genes and assess their impact on low-temperature tolerance under field conditions. A large recombinant inbred line mapping population derived from the cross M202/IR50 was developed during this project. The population consists of about 480 lines (F_{10}) that are available for distribution. We have also developed a Nipponbare population for reverse genetics (Targeting Local Lesions in Genomes, TILLING) using chemical mutagenesis. A TILLING resource/service is being constructed in cooperation with Dr. L. Comai (UC Davis) and plants exhibiting various mutant phenotypes are also being collected for future use/distribution.

It is expected that the TRRC will facilitate the establishment of cooperation in the area of tolerance of low-temperature stress (additional areas of common interest may also be a focus of cooperative research), including the exchange of genetic resources (i.e., germplasm, mapping populations, mutants) and data (i.e., genotypic and expression profiles). It is expected that ideas and expertise will be exchanged through annual workshops and the hosting of researchers by consortium members. An important goal should be leveraging available genomics resources to address the specific needs of temperate rice production.

Notes

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Temperate rice in Uruguay

E. Deambrosi, F. Pérez de Vida, and A. Roel

Rice is one of the most important agricultural products in Uruguay, where more than 90% of production is exported. The rice sector has been very dynamic and has increased area almost five times and grain yield by 60% since 1970.

Uruguay is growing approximately 160,000 hectares of irrigated rice in rotation with pastures for beef production; 85% of the area is planted with indica cultivars adapted to temperate climate and 15% of the area has tropical japonica cultivars. Almost all are long-grain varieties. Grain yield is the highest in Latin America, reaching 7.3 t ha^{-1} in the 2005-06 season. Average yield of the last three seasons was 6.5 t ha^{-1}.

Rice research in the country has shown very good integration with the private sector. The Rice Growers Association (ACA, Asociación de Cultivadores de Arroz) and Rice Millers Association (GMA, Gremial de Molinos Arroceros) permanently interact with the Instituto Nacional de Investigación Agropecuaria (INIA) Rice Program to discuss and define research lines and priorities. INIA's Rice Program has a highly qualified staff of 18 scientists with master's and PhD degrees working on different research topics. INIA also has a good structure and equipment, as well as a long history of cooperation with international partners such as RDA-Korea, UC-Davis-USA, USDA-USA, and FLAR (Fondo Latinoamericano para Arroz de Riego), and private companies such as Rice-Tec, BASF, etc.

Major research targets for improving japonica rice and production technologies

Breeding priorities are in developing tropical japonica and indica long-grain cultivars, although some work is done on temperate japonica cultivars.

Most local breeding efforts are devoted to developing tropical japonica cultivars demanded by local rice millers because of their wider marketability. In particular, breeding is oriented toward long fine-type grains with cooking quality similar to that of U.S. varieties from southern states. Local crosses and introductions of genetic material from the U.S. provide genetic variability for breeding.

Japonica germplasm adapts very well to most Uruguayan rice-growing regions (the traditional rice region is the Merin Lagoon basin that has about 70% of the total rice area). However, environmental conditions strongly suggest breeding for cold tolerance in both the vegetative and reproductive stages for gaining yield stability.

A secondary effort has been conducted in breeding temperate japonica cultivars by introductions and a few local crosses, and, in the medium term, more resources are going to be devoted in this direction.

Apart from breeding, the INIA Rice Program has an integrated research strategyin crop management, including nutrition, soil management, pathology, weeds, irrigation, precision agriculture, and foundation seed production.

Constraints to improving japonica rice production

The following constraints are the most important:

- Risk from cold temperature occurring during the reproductive phase
- Disease pressure from *Sclerotium oryzae* and *Rhizoctonia oryzae sativae*
- Weed competition
- Relatively poor adaptation to no-tillage dry direct seeding, low seedling vigor, and low stand establishing ability compared with indica-type genotypes
- Yield plateau already reached, which is below that of indica-type potential

Available genetic resources and type of genetic resources needed

Because of the obligation of the breeding program to keep grain milling and cooking quality very high due to export market demand, there has likely been a narrowing of genetic variability of the material used. Sporadic efforts have been made through foreign introductions (1998 and 2007 both from the U.S.; 2005 from Korea). However, it is necessary to have a more sustained flow of genetic material for evaluation and breeding, as well as some supply of resources from prebreeding initiatives. In this way, the INIA rice breeding program participates in the FLAR partnership, which successfully provides indica-type breeding material (F_3 populations and some sets of experimental lines).

Strategies used, including biotechnology

Some 100–120 crosses are made yearly; populations are grown and selection by pedigree is conducted until the F_5 and F_6 generations, when some stages of evaluation are carried out. Grain milling quality, productivity, and disease tolerance (*Pyricularia*) are the main screening factors.

Through a research agreement with Korea's Rural Development Administration (RDA), we incorporated one greenhouse and an outside growing chamber. These facilities allow the extension of our growing season for experimental material, which also allows detailed studies under well-controlled conditions, specifically for conducting research and screening on plant material for cold tolerance.

INIA has advanced biotechnology facilities and scientific staff centralized in the Biotechnology Unit (Las Brujas Experimental Station), which handles the research requirements of all crops cultivated in the country. Two of these scientists specifically participate in rice research. Additionally, a new facility is going to be set up shortly at the rice experimental station (Treinta y Tres) to routinely generate doubled haploids and use marker-assisted selection in the rice breeding program.

Expectations from the TRRC and possible contributions to the TRRC

The expectations are that being part of a network that will focus on genetic materials that are important for our rice production system will allow us to progress on the constraints cited above. The highly qualified scientific staff and facilities for conducting research mean that INIA could make significant contributions to the TRRC.

Notes

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