

PROJECT 7

Genetic enhancement for improving productivity and human health in fragile environments

The modern rice varieties developed for irrigated systems do not adapt well to unfavorable ecosystems and farmers obtain low and unstable yields and limited gains in profits when they adopt them. Risk reducers that offer more promise include enhanced seedling vigor, heightened tolerance or avoidance (through early maturity) of drought and submergence, improved ability to grow in soils with toxic levels of salt, iron, or aluminum or deficient in phosphorus or zinc, and strengthened resistance to pests and diseases, especially the blast fungus. The goal of Project 7 is to develop rice varieties that combine these traits with high and stable yields and consumer-preferred grain type.

Improving the efficiency and value of rice production in fragile areas promises immense gains in food security, human nutrition, poverty reduction, and environmental protection. In addition to providing more calories from

higher yields, improved varieties have the potential to offer enhanced levels of vitamin A, lysine, iron, and zinc. Because rice is prominent in the Asian diet, inexpensive, and easily stored, it is an ideal vehicle for enhancing nutrition among the poor.

In recent decades, researchers have discovered potential answers to many of these problems and aspirations in the genes of cultivated and wild rice. Scientific advances in biochemistry, physiology, and biotechnology have already produced promising genetic material and clear breeding strategies that can now be tapped for genetic enhancement of varieties for fragile environments. High levels of iron, zinc, and provitamin A, and tolerance for drought, submergence, phosphorus deficiency, and saline soils, are traits with good prospects for breeding into different rice cultivars.

IRRI is uniquely positioned to bridge, on the one hand, the upstream

research done in advanced research institutes and the private sector in industrialized countries and, on the other, the downstream research by NARES in developing countries to create varieties for rice farmers in highly diverse rainfed ecosystems.

Boosting the impact of this project are NARES-IRRI breeding networks, farmer participatory selection that recognizes the central role of women, and linkages with the International Network for Genetic Evaluation of Rice (in Project 1) and the Consortium for Unfavorable Rice Environments (in Project 9). The Asian Rice Biotechnology Network (in Project 2) facilitates the development and dissemination to NARES of germplasm and databases and the training of NARES scientists in new breeding, selection, and evaluation techniques. Animal and human nutritional studies on the bioavailability and food safety of micronutrient-rich rice are in progress.

Output 1: Superior germplasm for rainfed lowlands developed

A high-quality, blast-resistant version of the popular and highly valued Thai jasmine rice (KDML 105) with short duration, developed by IRRI in collaboration with the Thailand Department of Agriculture, was proposed for release in Thailand in 2005 (Output 6). This variety significantly reduces the risk of blast disease, which is endemic in northeastern Thailand. Also, its early maturity permits the crop to escape late-season drought, and will help small

farmers in drought-prone areas to stabilize their yields. The new variety is likely to be rapidly adopted by farmers in affected areas. Equally important, the methodology serves as a model for developing high-quality, resistant varieties elsewhere.

Other blast-resistant lines that differ in only one gene (monogenic lines) are being evaluated in Thailand and the Philippines. These monogenic lines, which are useful for identifying different strains of blast disease and the genes that confer resistance, have been



distributed to more than 30 institutions in 15 countries for identification of the blast strains and application in breeding.

We are developing superior rice hybrids for farmers in moderately drought-prone lowlands. So far, we have produced (cytoplasmic male) sterile lines for breeding hybrids for drought-prone rainfed lowlands. Results from India suggest that yields are at least 1 ton per hectare higher than with varieties presently in use. The sterile lines will next be crossed with elite lines adapted to rainfed lowlands to produce suitable hybrids.

Rice yield under moderate to severe lowland drought stress is a heritable trait. This finding, the result of years of trials at IRRI and the Indira Gandhi Agricultural University, Raipur, India, will enable breeders to confidently apply selection techniques that will lead to the development of varieties combining high yield and improved drought tolerance in farmers' fields. Thirty-seven useful lines have been identified using these techniques and their superiority has been confirmed in tests in India. Next, we will apply the approach to IRRI's lowland rice populations and support national programs in institutionalizing drought screening in managed-stress conditions for cultivar development.

Output 2: Superior germplasm for flood-prone areas and infertile lowlands developed

Evaluation of salt-tolerant lines selected by farmers in a participatory rice breeding project in Bangladesh continued. Four selected lines for the boro season in coastal wetlands were compared in farmers' fields to decide which varieties to release and seeds were submitted to the Seed Certification Agency. The evaluation will continue in the aman season. Other breeding lines were being evaluated for salt tolerance in India. We



will continue to send material to all participants in the Challenge Program on Water and Food for testing at each site and to other collaborators in research networks.

Research begun in 2003 on the mechanisms of submergence tolerance is now bearing fruit. Tolerance involves vigor, quick germination, higher activity of the enzyme amylase, and the generation of higher levels of ethylene. The findings mean that new fast screening techniques can be established based on these target traits. We now have 27 tolerant lines that show far greater survival (more than 60%) than do nontolerant varieties (9% for IR64). We will continue to look for any other physiological traits that may be involved. Work on marker-aided selection to speed up the incorporation of submergence into high-yielding varieties is also ongoing.

A key mechanism of tolerance for zinc deficiency in rice was identified: plant roots produce organic acids that make zinc more available for uptake. Existing mapping populations show variation in this trait, so we can rapidly move to map the regions on the chromosomes that control organic acid production. A new greenhouse screening method that

simulates zinc-deficient field conditions now allows large-scale screening for traits associated with tolerance as well as a means for rapid phenotyping to identify the genes or groups of genes concerned.

Output 3: Superior germplasm for infertile uplands developed

The search for genetic markers involved in upland drought tolerance has not led to the identification of a few genes with large effects. Thus, tolerance in these populations is probably controlled by many genes and selection of phenotypes remains the best approach to improving upland drought tolerance in the short term, while we continue to seek the underlying genetic basis. Indeed, from trials at IRRI in 2004, we now know that yield under this kind of stress is a heritable trait (as found in lowland stress). Two promising high-quality, short-duration lines, developed by direct screening under drought conditions, are currently being evaluated in drought-prone areas of eastern India. An IRRI-India drought breeding network based on direct selection for yield under stress is beginning.

In seeking better breeding strategies for low-input upland systems, our analyses of trials from India and Lao PDR have shown that, contrary to expectation, improved upland cultivars perform better than traditional varieties under low-input and high-input management. However, because trial results exhibit high variability, extensive testing in different environments will be needed to make yield gains.

IRRI scientists successfully incorporated five candidate genes for blast resistance into selected elite lines. High levels of resistance to seedling and neck blast were demonstrated by these lines in an area of high disease pressure in Almora, India. Success of the technique means that we can combine several chromosomal regions, each providing a different type of resistance, in different varieties to provide partial blast resistance in blast-prone areas. Markers for tracking effective versions of genes (alleles) on small regions of the chromosomes in advanced breeding lines are now available. Next, we need to track and recombine these alleles in additional populations.

IRRI scientists made progress during the year on two major upland problems for rice farmers—phosphorus deficiency and blast. Lines that we confirmed in 2003 to have superior phosphorus uptake (with the gene concerned [*Pup1*] finely mapped; see Project 2, Output 3) were crossed with blast-resistant lines. Third-generation data are now being analyzed. We will screen blast-resistant lines for incorporation of the *Pup1* gene and evaluate selected materials in further generations until the lines are stable, when field testing can begin. Combining quantitative blast resistance and tolerance for phosphorus deficiency with tolerance for drought will be the next task.

Output 4: Aerobic rice germplasm for water-scarce tropical environments developed

We now have a composite picture of aerobic adaptation: rapid growth in the vegetative stage; and maintenance of panicle elongation, spikelet fertility, and harvest index under moderate stress in the reproductive stage. The work involved deriving lines with high aerobic

adaptation by crossing the elite aerobic variety Apo with various lowland varieties, followed by four seasons of selection for yield under aerobic conditions. Advanced backcross lines are also being developed and their genotypes determined. Next, we will assess allele frequencies in the aerobic-adapted progeny of aerobic × irrigated crosses to identify the chromosomal regions that confer an advantage in aerobic rice systems.

Elite aerobic lines from upland × lowland crosses are being evaluated by breeding networks in Yunnan Province of China, India, Lao PDR, and the Philippines.

Hybrid rice is showing potential in aerobic conditions also. We plan to evaluate large numbers of rice hybrids under aerobic rice environments.

Output 5: Micronutrient-enriched rice to combat malnutrition in fragile environments developed

The year has been a busy and productive one in joint IRRI-NARES micronutrient research. IRRI distributed 10 elite iron-dense lines for evaluation by NARES in five countries (Bangladesh,



China, Indonesia, the Philippines, and Vietnam). NARES partners also identified elite lines with enhanced iron content, which will be shared among them and IRRI for evaluation. The evaluations are to confirm the elevated iron content and its distribution in the grain. (An earlier IRRI study, in which 300 women consumed high-iron rice, showed that the iron was bioavailable; the diet improved blood iron levels in nonanemic women.)

Transgenic rice plants that incorporate genes for beta-carotene synthesis and for enhanced levels of iron and protein in milled grain are now in place at IRRI. We are investigating varietal differences in expression of the incorporated genes, how these genes affect yield, and the effect of fertilizer on their expression. Although there has been concern about the use of such plants in some countries, they are well accepted in others. We will also continue to develop farmer-preferred cultivars incorporating these traits.

Output 6: NARES-IRRI partnerships in rice breeding enhanced

There is a need to integrate effective, low-cost methods of plant varietal selection (PVS) into breeding programs. Involving farmers is key to this. We found, for example, in experiments in India and the Philippines, that farmers' preharvest yield ratings and postharvest reports were similar to researchers' quantitative data. Farmers' experience, as both producers and end users, adds value to field trials. In collaboration with NARES, we produced a draft manual of PVS techniques to expand awareness of them among NARES. The techniques have already been incorporated in the Indian rainfed shuttle breeding networks and in the Lao PDR upland and rainfed lowland programs. Training materials on PVS will be upgraded for the NARES and we



will continue to promote the methods in breeding programs.

Ideally, all the shuttle breeding groups collaborating with IRRI should use the International Rice Information System (IRIS), both to trace pedigree and evaluation information and to input their data for sharing with all users of the system. Breeders are enthusiastic to use the system. However, coordinating data input remains problematic, an issue we are now examining.

To complement IRIS, we produced software in 2004, now freely available, for the design of field trials in low-input and drought-stress environments. The previous lack of convenient software precluded the design and analysis of sophisticated trials needed for an efficient breeding program in these environments. We will provide training in use of the software.

The Eastern Indian Rainfed Lowland Shuttle Breeding Network (EIRLSBN) is a collaborative NARES-IRRI network of rainfed rice breeding programs targeting flood-prone lowlands in eastern India. The network produced two varieties developed by the Narendra Deva University of Agriculture and Technology (Faizabad, Uttar Pradesh) and derived from IRRI crosses, which were recommended for release in 2004. One of them, NDR 8002 (IR67493-M2), was recommended for national release by the All-India

Coordinated Rice Improvement Project (AICRIP), and the other, NDR 96005 (IR66363-10-M-1-1-1-1), was recommended for release by the state of Uttar Pradesh. In addition to these releases, 41 lines developed by this network were under advanced national AICRIP testing in 2004.

In Thailand, collaboration between IRRI and the Department of Agriculture resulted in the development of two short-duration, blast-resistant jasmine rice varieties. These varieties were evaluated by farmers across northeastern Thailand in a large-scale IRRI-Department of Agriculture participatory varietal selection program in 2003 and 2004, funded in part by the Rockefeller Foundation. The short-duration varieties performed very well in the severe drought conditions of 2004 in the Khon Kaen area, and one is proposed for release to farmers in 2005. Responsibility for the advanced backcross program for short-duration jasmine rice was transferred to the national breeding program, which will also oversee the participatory testing and release of blast-resistant varieties of longer duration.

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