

International Rice Research Institute: roles and challenges as we enter the genomics era

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The International Rice Research Institute (IRRI) was established in 1960 by the Rockefeller (New York, NY, USA) and Ford Foundations (New York, NY, USA) in response to food scarcity problems in the developing world. Today, it is the world's leading international research and training center for rice. Based in the Philippines, with operations in 11 other countries, it is one of 16 Future Harvest Centers funded by the Consultative Group on International Agricultural Research (CGIAR), an association of public and private donor agencies.

The Institute's goal is to find sustainable ways to improve the well-being of present and future generations of poor rice farmers and consumers and protecting the environment at the same time. Most of IRRI's research is done in cooperation with national agricultural research and extension systems (NARES), farming communities and other organizations of the world's rice-producing nations. Improving the rice plant by genetic means and using natural resources in rice-based cropping systems sustainably are two mainstays on IRRI's research agenda.

In 2000, IRRI celebrated its 40th anniversary and, in 2001, it observed the retirement of its principal plant breeder, Gurdev Khush, a World Food Prize laureate, after 34 years of service to the rice-growing world. These two events capped four decades of achievements that involved collaborative research between IRRI and the NARES of the developing world (Box 1).

The Green Revolution has dramatically increased the food supply in the developing world over the past four decades. The adoption of modern varieties leading to large productivity gains has been well documented* [1,2]. In Asia, the yield gain in rice has been



Semidwarf rice. Photograph by David Nance, courtesy of ARS, USDA.

crucial in keeping pace with the food demand by the growing population. Since 1962, the population in Asia has more than doubled from 1.6 to 3.7 billion. Rice production has grown by 170%, whereas the land area used for agriculture has grown by <30% during the same period. Increased production efficiency has reduced the rice price to ~50% in real terms over the past three decades[†].

The early increase in crop productivity came from a few genetic manipulations. The dwarfing genes in wheat and rice make shorter plants that can use nutrients without falling over. The improvement of pest resistance and grain quality further broadened the adaptability and acceptability of modern varieties. To date, new genes are continuously being incorporated into varieties to increase their tolerance for evolving pests and diseases and environmental stresses. Tapping into the genetic potential of the rice gene pool continues to be the most feasible strategy for sustaining productivity, even though the applications of some of these tools remain topics of active debate in society. We are now at the onset of a genomics revolution that offers even greater potential to improve crops. An increasing

number of organisms, including rice and other crops, are the subject of large-scale genome sequencing efforts. Robotics and informatics have enabled parallel analysis of genes, proteins and metabolites on an unprecedented scale. The application of the expanding knowledge and tools is vital to sustain the growth and vigor of plant improvement programs around the world. With the pivotal position of rice in plant genomics research, IRRI has a special role to play in bringing the benefits of new technologies to the poor.

Ensuring access to genetic knowledge and tools

Before IRRI, rice research was almost entirely supported by government institutions in the rice-growing countries. This trend of public support for rice research has continued for most of IRRI's history. The progress made in rice improvement has depended upon free access to germplasm and genetic knowledge from all sectors of rice science. IRRI's International Network for the Genetic Evaluation of Rice (INGER) and its predecessor, the International Rice Testing Program (IRTP), illustrate the benefits derived from exchanging germplasm and advanced genetic materials in rice breeding. Improved varieties in one country are often used as parents in the breeding programs of other countries. In essence, useful genes are freely available to any rice breeder.

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The availability of diverse genetic materials and knowledge is fundamental to any successful plant improvement program. Yet, this is also the most contentious issue confronting public research institutions at a time when the private sector shows an increasing

*Evenson, R.E. (2000) *Crop Genetic Improvement and Agricultural Development*, Report from Impact Assessment and Evaluation Group, CGIAR, 21–26 May 2000, Dresden, Germany.

[†]Hossain, M. *et al.* (2001) Research for genetic improvement of rice in Asia: investment, output, and the role of IRRI. In *Proceedings of 36th Annual All India Rice Research Group Meeting*, 10–12 April 2001, Pantnagar, Uttaranchal, India.

Box 1. Milestones in rice improvement at the International Rice Research Institute

- 1962:** The International Rice Research Institute (IRRI) makes the first crosses using parents that confer traits for a new semidwarf rice plant.
- 1966:** IR8, the first modern semidwarf variety, is released in 34 countries, setting in motion an era of vigorous agricultural research in Asia.
- 1975:** International Rice Testing Program (IRTP) begins operation and becomes a successful partnership, currently distributing elite lines to >90 countries.
- 1977:** IR36, with enhanced disease and insect resistance, is released and becomes the most widely grown variety of any crop in the world.
- 1985:** IR64, a tasty rice, replaces IR36 as the most widely planted crop variety, a title it still holds in 2002.
- 1988:** Cornell-IRRI DNA-marker map of rice is published.
- 1989:** To break the existing yield barrier, a new plant type (NPT) is conceptualized to increase total biomass and the harvest index of the rice plant.
- 1990:** *Xa21* gene for resistance to bacterial blight is transferred from *Oryza longistaminata* to rice, signifying the systematic use of the wild rice gene pool; IR72 is released and it outyields all other modern inbred varieties.
- 1993:** First set of hybrid rice varieties is released in tropical Asia; the Asian Rice Biotechnology Network begins and becomes a regional collaborative network for training and application of rice biotechnology.
- 1998:** An International Network on Hybrid Rice is established in collaboration with the Food and Agriculture Organization and the Asia-Pacific Seed Association to expedite the development and use of hybrid rice in Asia.
- 2000:** IRRI forms an international working group of national agricultural research and extension systems and advanced institutions to build a public resource platform for functional genomics.
- 2001:** First research samples of genetically modified vitamin A-enriched golden rice are brought to IRRI to initiate the development of agronomically acceptable vitamin A-enriched rice varieties; first NPT varieties are released in China, yielding 13–14 tons per ha.

interest in crop research that has been done largely by the public sector. This issue is particularly sensitive with rice. On the one hand, private investment can bring about new innovations and technologies for farmers. On the other hand, a shift in the balance of public and private investment in rice research has also raised concerns that some proprietary technologies might become unavailable to those who cannot afford them. Such concerns must be considered because gene identification, validation and application are occurring at an ever-accelerating pace. The key question is, can the model of free access to genes, germplasm, technology and knowledge exist and contribute under an increasingly protective environment that exercises intellectual property rights?

In 1998, the public International Rice Genome Sequencing Project (IRGSP) began with the goal of having the entire rice genome sequenced within ten years. The IRGSP is now a multi-country consortium coordinated by Japan's Rice Genome Research Program (RGP). As of

February 2002, ~56% of the 430 Mb of the rice genome is in the public databases (www.tigr.org/tdb/e2k1/osa1/). Chromosome 1 is completely finished and chromosome 10 is 98% done. This accelerated sequencing is, in part, stimulated by private-sector efforts. It is widely expected that the draft sequence of the rice genome will be published before the end of 2002 – way ahead of the IRGSP's original goal of completion by 2008.

Although at least two companies, Monsanto (St Louis, MO, USA) and Syngenta (San Diego, CA, USA), have produced draft versions of the rice genome, the IRGSP is serving the public interest in important ways. First, following the human genome standard, the IRGSP is committed to producing a highly accurate sequence (permitting only a 1 in 10 000 bases error rate). Although it will take longer to achieve, the public sequence will serve as the standard with which to annotate gene structures accurately and completely, and to identify important allelic variations and single-nucleotide

polymorphisms in the germplasm that are not artifacts of sequencing. Second, the IRGSP has galvanized government investment and created momentum for international collaboration. Most importantly, by committing to provide the genome data to the public, the consortium has essentially 'liberalized' rice genome knowledge, which, in turn, will leverage contributions from the public and private sector.

IRRI as producer and broker of knowledge and technologies

In this new research environment, IRRI's roles as a producer of knowledge and a broker in technology development and transfer between the various public institutions – and increasingly between the public and private sector – are becoming more important. IRRI's key assets are a wealth of genetic resources and collective expertise across biological disciplines that are directly relevant to rice production. We have invested in research infrastructure to provide support to our research partners and have the technical expertise to be a strong research partner with advanced research institutions (ARIs). IRRI has also adopted a policy on intellectual property that adheres to its principles and mission and, at the same time, allows it to collaborate widely with both the private and public sector to bring in new science to benefit the poor. To capitalize on the advances made in plant science research, IRRI can provide a link between ARIs and rice improvement institutions in the developing world. Highlights from several research activities illustrate how we are pursuing these objectives.

Public research platform for gene discovery

With the anticipated completion of the rice genome sequence, defining the functions of all rice genes is a feasible target. We believe that finding the functions of important rice genes and making them available provide the most empowering tools to the NARES. Unlike genome sequencing, functional genomics requires diverse expertise and partnerships to tap into the large pool of genetic materials developed for diverse environments and to bring together the expertise to evaluate a variety of traits. To move towards this goal, we have initiated an international functional

genomics working group to bring together research institutions interested in producing public goods (www.irri.org/genomics). The working group shares mutants and gene clones and contributes to public databases. Our ongoing effort is to engage our NARES partners in a collaborative gene discovery program. For example, we have established a microarray facility, we are developing a capacity for proteomics and we are nurturing bioinformatics expertise to analyze diverse genetic materials from our NARES partners. We anticipate that the resulting functional genomics database will be an invaluable resource for gene identification. Through such direct participation, we are producing a cadre of young developing-world scientists who are proficient in applying the products of new science.

Breaking through the yield barrier

To date, IRRI has been redesigning the rice plant's agronomic architecture, as illustrated by the development of the new plant type (NPT) (Box 1). As more is known about the biochemistry and biosynthetic pathways of plants, it might be possible to redesign the rice plant's biophysical structure. Interest is increasing in converting rice's rather slow and inefficient C_3 photosynthetic pathway to that of the more efficient C_4 pathway that exists in maize and sorghum [3]. Achieving this would allow the rice plant to become a more efficient user of solar energy and perhaps reach a yield potential unattainable by even the NPT. Collaboration with research institutions around the world is needed to bring together the expertise required in this frontier research.

Focusing on resource-poor and marginal environments

In spite of the impressive gains in the environments favorable to rice production (with good irrigation), yield improvement in rainfed areas has remained low over the past 40 years. As competition for the best agricultural land increases, more food must come from land affected by too much or too little water and poor soils. In these environments, alternatives to rice farming are limited and the low income level further limits options to buy food from the more productive area. The development of adaptive, high-yielding

and nutritious varieties must therefore be part of a strategy for improving the livelihood of people in these regions [4].

IRRI's medium-term research plan has a strong emphasis on developing adaptive germplasm for these fragile environments [5]. Traits conferring tolerance for salinity, drought, submergence, and soil mineral deficiency are priorities. Many of these traits are not necessarily controlled by simple genetic factors, and genome-wide analysis offers opportunities to identify important genes that help overcome these production constraints.

Nutritious rice

Besides productivity, we must develop rice that, as a food, can improve the diet and health of people living in these difficult environments. IRRI is concentrating its efforts towards developing micronutrient-dense grains that can provide a better complement of vitamins and minerals. IRRI is playing an exciting intermediary role involving work on improving the vitamin-A content of rice by engineering the plant to produce β -carotene in the grain. According to the World Health Organization, ~250 million people worldwide are deficient in vitamin A, putting them at risk of contracting various serious ailments. Rice plants do produce carotenoid compounds, but only in the green parts of the plant. Researchers from the Swiss Federal Institute of Technology (ETH) inserted the genes from daffodil and a bacterium into rice plants to produce pro-vitamin A in the modified grain [6].

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Golden Rice, as the modified grain has been dubbed by the media, has attracted much attention, especially since the announcement of an agreement reached between its European inventors and Syngenta to distribute improved seed at no extra cost to farmers in developing countries. IRRI is well positioned to be an intermediary between Syngenta and interested NARES to transfer the genes required for β -carotene biosynthesis into

popular tropical rice varieties. In January 2001, the inventors brought the first research samples to IRRI headquarters, initiating a public collaborative effort to develop agronomically acceptable Golden Rice plants. Because of what this new rice will mean to millions of malnourished poor, the eyes of the world are watching this initiative closely.

Applying biodiversity

There are growing concerns that modern agriculture will displace local traditional varieties, leading to the loss of indigenous biodiversity. Although the erosion of biodiversity is a real global concern, the use of biodiversity is not necessarily in conflict with such preservation. Indeed, tapping into the rich genetic diversity inherent in a crop species is a requisite for germplasm improvement. We believe that new tools and strategies can be developed at the genetic and crop production levels to achieve productivity and at the same time preserve biodiversity.

More than 100 000 accessions of rice germplasm from around the world are held in trust at the International Rice Genebank Collection at IRRI. This collection includes traditional varieties, farmers' local selections, and wild rice relatives. Although there have been some successful examples of extracting useful genes from the germplasm bank, the vast potential of this resource has been largely untapped. With more DNA sequences and biochemical pathways being elucidated, useful genes and allelic diversity from the germplasm bank can be identified. IRRI is currently initiating a systematic molecular and phenotypic evaluation of the conserved germplasm to identify genetic variation in traits that could lead to exciting opportunities for plant improvement.

At the farm level, we are implementing the concept of biodiversity to address production problems. A recent study in Yunnan Province, China, illustrates the use of diverse germplasm to control disease on a large scale [7]. The objective here is to control blast – a devastating fungal disease of rice – that has until now prevented the planting of traditional glutinous rice varieties that are highly valued in the market but susceptible to the disease. By interplanting glutinous rice with high-yielding hybrid

rice, hence making the field less uniform, we are seeing a significant reduction in disease. The result is higher yields and income for farmers. Although the tactics of diversification can vary according to locations and cultural practices, the principle of diversification can be used widely to improve the resilience of the crop against stresses and environmental perturbations.

More research alliances to bring benefits to the poor

For decades, the genetic improvement of rice has benefited from the sharing of germplasm and genetic knowledge among rice-growing countries. Such efforts have improved food security and touched the lives of millions in the developing world. Rice is now a genetic model of crop plants and at the frontier of genomics research. There has never been a time when rice research has received so much attention from the plant science community. IRRI is striving to capitalize on the talents and resources in the global research community and calling for more partnerships to channel the best science to

serve the poor [8]. Many challenges lie ahead – competing resources from other sectors, potential barriers to accessing germplasm and knowledge, and diminishing public support for agricultural research, just to name a few. However, the genomics era provides new opportunities for the plant science community to demonstrate the positive role of science in solving food and health problems in a world where >60% of the young children in some regions (e.g. South Asia) are stunted, underweight or both [9].

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