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Rice Biotechnology: A Need for Developing Countries

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Rice, the most important food crop of the developing world, feeds more than two billion people as a staple food. Its improvement since the Green Revolution has been enormous, and biotechnology in the genomics era offers unique scope for further improvement to attain environmentally friendly sustainable agriculture. Nutritious rice with high iron and beta carotene in polished seeds has been developed with genetic engineering technology. It is now possible to use *Bt* or *Xa21* rice in farmers' fields with reduced pesticide use. Farmers can produce more rice with built-in plant protection at a reduced cost. Policymakers should look into the potential use of biotechnology, provide access to intellectual property rights (IPR), and make improved rice seeds available free of IPR for resource-poor farmers.

Key words: biotechnology, genetic engineering, nutritious rice, plant protection, rice.

Introduction: The Importance of Rice

Rice feeds more than two billion people worldwide and is the number one staple food in Asia, where it provides 40–70% of the total food calories consumed. Rice is also used for animal feed and provides the major source of income for rural people; high-quality rice brings in additional income. Due to the Green Revolution, a quantum leap in rice yield took place over the past three decades, although increased food production did not eliminate poverty and hunger. The yield increase did help to avert famine and prevent a greater disruption of the food supply in Asia—unlike in some countries of Africa, where a lack of infrastructure and political will resulted in the failure to take advantage of Green Revolution techniques.

Today's global population of six billion is expected to reach eight billion by 2020. We must therefore produce 25–40% more rice with less land and water and with a reduced use of agrochemicals. Rice yield has been stagnant for the last three decades, despite the improved varieties and technologies in place. Therefore, biotechnology—particularly genetic engineering—may provide ample scope for enhancing rice yield and plant protection, enable rice to grow in drought and saline conditions, and lead to more nutritious rice for reducing malnutrition.

Genomics and Biotechnology

Genomics refers to DNA sequencing, the routine use of DNA microarray, and proteomics. Genomics-based strategies for gene discovery, coupled with the validation of transgenes by genetic transformation, have accelerated the identification of a functional profile of candidate genes. Cultivated rice has evolved for centuries through domestication, which preferentially narrowed the diversity of genetic resources. It is also important to explore wild rice species and characterize their genes for further use rather than storing them in a gene bank.

The recent rice genome sequences developed by Monsanto, Syngenta, and the Beijing Genomics Institute (BGI), along with ongoing research in the International Rice Genome Sequencing Project (IRGSP), have accelerated gene discovery and rice improvement. However, advances in plant biotechnology must be deployed for the benefit of developing countries using a strong public-sector agricultural research effort (Conway & Toenniessen, 1999; Beachy, 2003). Recognizing the tremendous value of genomics research for rice improvement, the International Rice Research Institute advocates broad collaboration in rice research involving the private and public sectors, with emphasis on the need to provide the best science to serve the poor (Cantrell & Reeves, 2002).

The Green Revolution and Genetic Engineering

The International Rice Research Institute released IR8, the first high-yielding modern rice cultivar for irrigated tropical lowlands. Since then, efforts to improve the rice plant for higher yield and desirable characteristics continue, but innovations are needed to break the yield barrier (Figure 1; Datta & Khush, 2002). Genetic engineering provides an efficient and precise breeding tool in which genes of interest (such as *Xa21* for bacterial blight resistance, *cry* for stem borer resistance,

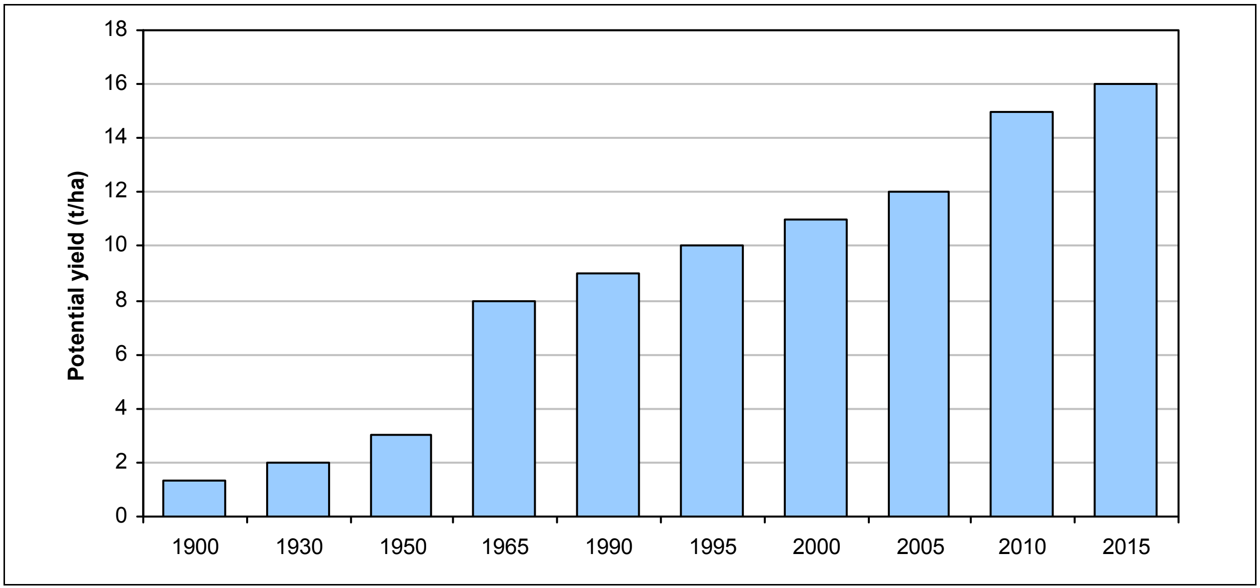

Figure 1. Progress in the yield potential of rice.

ORF2 for virus resistance, *DREB/TPSP* for drought and salinity tolerance, *chi11, RC7*, and *NPR1* for fungal resistance, *psy and crtI* for provitamin-A biosynthesis, *glgc* for higher grain filling, and *PEPC* for C_4 photosynthesis) have been incorporated in rice and have shown excellent performance in most cases (Table 1). Pyramiding of *Xa* genes by marker-assisted breeding has also been shown to work well in rice; this technique is now extensively used in India, Philippines, China, Indonesia, and Thailand under the Asian Rice Biotechnology Network (ARBN) program. I have summarized a few selected examples of the development of transgenic rice and its potential use in developing countries (Table 1) and emphasized two potential areas—plant protection and nutrition improvement—for immediate use.

Plant Protection

Farmers in developing countries do not capture a significant portion (20–70%) of the potential yield in favorable ecosystems primarily because of biotic and abiotic stresses. Losses caused by weeds, yellow stem borer, leaffolder, sheath blight, blast, bacterial blight, and various abiotic factors have remained largely undiminished despite considerable investment in cultivar improvement. Limitations in conventional breeding arise because of the lack of resistance genes in cultivated rice germplasm (*Oryza sativa* L.) and inadequate understanding of phenotypic variability. Hence, transgenic research offers unique opportunities to overcome these problems and to produce improved cultivars with reduced yield gaps. Bt rice has now been field evaluated for several years in China (Figures 2, 3, & 4; Tu, Zhang, et al., 2000; Ye, Tu, Hu, Datta, & Datta, 2001) and has shown resistance against several insect pests—the striped stem borer (*Chilo suppressalis*), yellow stem borer (*Scirpophaga incertulas*), pink stem borer (*Sesamia inferens*), leaffolder (*Cnaphalocrocis medinalis*), and green semilooper (*Naranga anescens*)—and excellent agronomic performance (28% higher yield than that of seed-derived control plants). The second generation of Bt rice with multiple *cry* genes with different receptor-binding protein is now in progress; this may delay

Figure 2. Transgenic Bt rice (MH63) showing healthy growth (T). Control MH63 (C) shows natural infestation of leaffolder.

Table 1. Transgenic rice developed with genes of agronomic importance.

Gene	Trait	Cultivar	Remarks
Xa21	Resistance to bacterial leaf blight	IR72, IR64, IR68899B, MH63, BPT5204, Pusa Basmati-1, IR50, CO39	IR72 field-evaluated in China, India, and Phillipines
Bt (cry1Ab, cry1Ac, cry1Ab+cry1Ac), cryIIA	Resistance to insect pests	IR72, IR64, MH63, IRRI-NPT, Vaidehi	IR72 and MH63 field-evaluated Hybrid Bt rice now grown in China
Chitinase (chi11, RC7), tlp D-34	Sheath blight resistance	IR72, IR64, CBII, Swarna	Transgenics showed enhanced protection against fungus
Xa21 + Bt + PR genes	Resistance to bacterial blight, stem borer, and sheath blight	IR72	Transgenics showed broad-spectrum multiple resistance
PPT	Resistance to herbicides	IR72, Koshihikari, NHCD, etc.	Works very well under field conditions
PEPC	C_4 rice	IR68899B	Enhanced photosynthetic efficiency
ORF2[a] for serine protease and RNA-dependent RNA polymerase	Resistance to rice yellow mottle virus	ITA 212 (FARO 35), Bouaké 189, BG90-2	Transgenics showed resistance against low- and high-dose virion and RYMV RNA inocula
TPSP[b], DREB	Abiotic stress tolerance	PB-1, BR29, IR68899B	Transgenic rice showed tolerance for drought, salt, and low-temperature stress
psy, crtI, lcy	Provitamin-A biosynthesis	T-309, IR64, BR29, Nang Hong Cho Dao, Mot Bui, IR68899B, Immeyobaw	Transgenics showed yellow-colored endosperm by beta-carotene accumulation
ferritin	Iron storage	IR68144, BR29	Transgenic lines showed increased iron and zinc accumulation in seeds

Note. Data modified from Datta and Khush, 2001.

[a] *Data from Pinto et al., 1991.*

[b] *Data from Garg et al., 2003.*

Figure 3. Transgenic MH63 (T) showing resistance to YSB and control MH63 (C) showing YSB symptoms.

Figure 4. Transgenic (T) hybrid Bt rice Shan you 63 showing resistance and control (C) showing susceptibility to pest attacks.

Figure 5. Transgenic homozygous IR72 (T) showing resistance reaction against bacterial leaf blight with much less lesion length than nontransformed control (C) under field conditions at Wuhan, China.

Figure 6. Transgenic IR72 with *Xa21* showing bacterial blight resistance with excellent agronomic performance under field conditions in the Philippines.

pest evolution even longer. Xa21 rice, initially reported by P. Roland's group from the University of California-Davis (Song et al., 1995) is now further developed in several indica backgrounds and is being field evaluated in the Philippines, China (Tu, Datta, Khush, Zhang, & Datta, 2000), and India (Figures 5 & 6). Yellow mottle virus-resistant rice, herbicide-resistant rice, sheath blight-resistant rice, and abiotic stress tolerant rice have been reported by several groups (Table 1; Datta, Datta, Soltanifar, Donn, & Potrykus, 1992; Datta, Baisakh, Thet, Tu, & Datta, 2002; Pinto, Kok, & Baulcombe, 1999; Lin et al., 1995; Garg et al., 2002), including our unpublished work with the *DREB* gene (in collaboration with Dr. Shinozaki's group).

Figure 7. IR64 Golden rice seeds (right) showing beta-carotene expression, control (left) showing no expression after polishing.

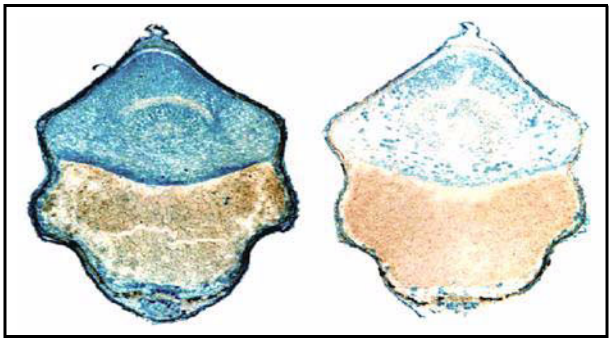

Figure 8. Transgenic rice seeds with high iron (left) and control (right) after polishing.

Nutrition Improvement

Eight hundred million people worldwide live below absolute poverty levels, and the majority of these women and children are malnourished as they do not have access to the essential food basket. It might take another 50 years or more to reduce their poverty or improve their economic growth, which depends on political will, population control, and social reforms. Availability of nutritious rice may force governments to prioritize decisions to distribute more nutritious rice free or at a minimal cost, which will benefit poor people (Datta, 2001).

Rice engineered with genes for β-carotene biosynthesis (Ye et al., 2000) resulted from an intellectual property donation from several multinational companies, including Syngenta, Monsanto, Bayer, and Mogen. These genes are now used in developing tropical elite indica rice using the nonantibiotic selectable marker *pmi* (phosphomannose isomerase) gene (Figure 7; Datta et al., 2003), which might be able to reduce vitamin A deficiency. Moreover, iron has been enhanced in indica rice by introducing the *ferritin* gene driven by the endosperm-specific promoter (Figure 8; Vasconcelos et al., 2003). It is also possible to improve the essential amino acids (such as lysine) in rice; work is in progress in collaboration with DuPont. As we have shown by pyramiding transgenes (*Xa21*, *Bt*, PR-protein genes) functioning in a homozygous single elite cultivar (Datta et al., 2002), it might be possible to incorporate the genes for β-carotene and enhancement of iron and protein in a single rice variety to achieve the "dream rice" for those who need it most.

Concluding Remarks

Rice is a diverse crop that grows in different ecosystems. The Green Revolution saved millions of people with additional food but could not prevent hunger and poverty because of certain limitations and inadequate management available to take full advantage of the Green Revolution.

Current gene evolution should provide wide scope for the application of biotechnology across ecosystems and crop barriers. Farmers require improved seeds. A biotech-based package of improvements can be incorporated into seeds, which should reach farmers with further information on appropriate practice and management and confirmation of their safety. Policymakers should look into their potential use and provide access to intellectual property rights irrespective of the nature of their ownership. Intellectual property rights should not be a barrier to advancing this technology for the benefit of human beings. The United Nations declared 2004 "the year of rice." Let us hope that all rice germplasm, including biotech-based products, will remain as a public good in good faith and with international understanding for the greater benefit of all people—particularly resource-poor people.

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