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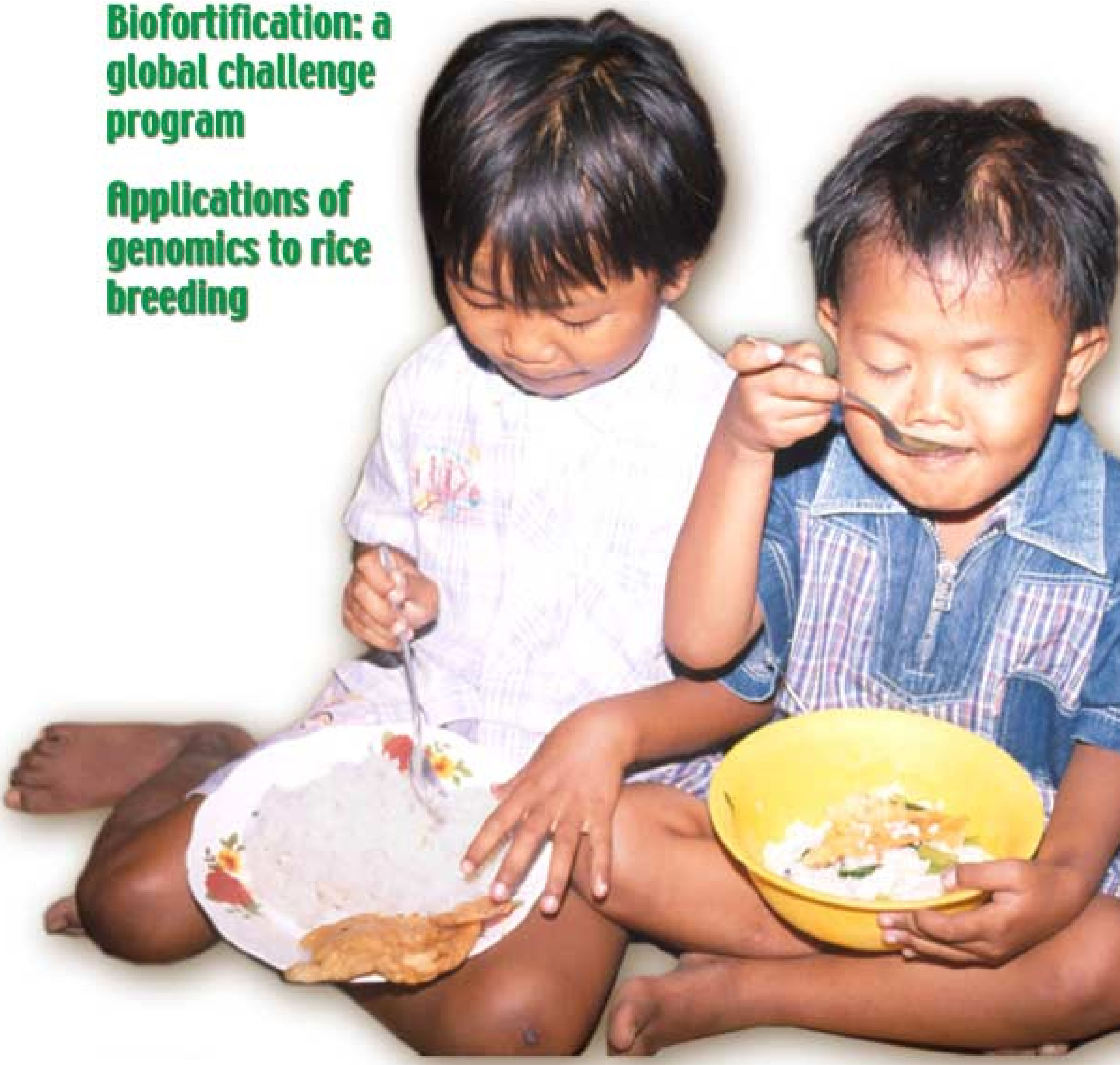
International Rice Research Notes

Biofortification: a global challenge program

Applications of genomics to rice breeding



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The *International Rice Research Notes* (*IRRN*) expedites communication among scientists concerned with the development of improved technology for rice and rice-based systems. The *IRRN* is a mechanism to help scientists keep each other informed of current rice research findings. The concise scientific notes are meant to encourage rice scientists to communicate with one another to obtain details on the research reported. The *IRRN* is published twice a year in June and December by the International Rice Research Institute.

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MINI REVIEW

Biofortification: A Global Challenge Program

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A Global Challenge Program on Biofortification with proposed funding of US$90 million over 10 years has just been approved by the Consultative Group on International Agricultural Research (CGIAR). Program researchers in collaborating agricultural and public health (nutrition) disciplines will apply food systems strategies to deliver more nutritious staple crops to resource-poor consumers. Improved grain will be richer in iron, zinc, vitamin A, selenium, and iodine, as needed.

Introduction

This paper is a personal view of how the philosophy and strategy for the Biofortification Challenge Program will develop in rice to achieve its objectives. Full funding of the Program is as yet incomplete and a program leader for it has only just been advertised (March 2003).

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A team of plant breeders, agronomists, chemists, human nutritionists, social scientists, and others will develop the Global Challenge Program (GCP) on Biofortification into a US$90 million international effort to redress nutritional poverty as a result of approval given to the proposal by the CGIAR-Annual General Meeting in Manila, Philippines, in October 2002. Nine CGIAR centers are involved, along with designated national agricultural research and extension systems (NARES) and universities in both developing and developed countries. The rice subprogram will draw on more than $700,000 annually to support the effort to improve the nutritional value of rice, especially for iron, zinc, vitamin A, calcium, iodine, and selenium—all being nutrients especially low in rice and widely deficient in resource-poor, rice-consuming communities. The research involves feeding trials in humans both in controlled conditions and in free-living, village-based comparisons, capacity building, farmer participatory research, agronomic extension work, as well as the core rice breeding and biotechnology work for which IRRI is well known. The effort will be the largest yet to proceed within the new conceptual framework of the productive, sustainable, and nutritious food systems paradigm for agriculture and public health.

Overview of the proposal

A new paradigm for agriculture in the 21st century was proposed (Welch and Graham 2000) that views agriculture as an instrument for public health and focuses attention on the role of agriculture in delivering nutrients to humans and animals in balanced amounts that can sustain maximal physical and mental activity of the humans who are simultaneously the drivers of the food system and its dependents. This is known as the productive, sustainable, and nutritious food systems paradigm for agriculture and public health.

The GCP in Biofortification seeks to apply the food systems approach to research within the crop-based CG centers responsible for staple crop improvement, including IRRI and its NARES and advanced research institution (ARI) partners. In all, the GCP in Biofortification will support research and development of nutrient-dense cultivars of 17 crops, 6 Phase 1 crops, and 11 Phase 2 crops. The six Phase 1 crops—rice, wheat, maize, beans, cassava, and sweet potato—have already completed an exploration of the germplasm and initial studies of the genetics and genotype by environment (G × E) interactions, and are therefore poised to take advantage of a major input of resources. Phase 2 crops are about to begin primary germplasm screening

and will have less funding in the first 4 years: these crops include peanut, lentil, cowpea, pigeon pea, sorghum, millet, barley, banana, plantain, potato, and yam. Funding will support capacity building and farmer participatory research with NARES partners and will be allocated also for partner research in biotechnology, studies of bioavailability, strategic initiatives, economics and social marketing, not to mention administration and communications.

Progress in rice

Analysis of rice lines in the IRRI germplasm bank was begun in 1994 by Dr. D. Senadhira with the aid of modest exploratory funding by the Danish International Development Agency (DANIDA) and the United States Agency for International Development (USAID). Since then, some 12,000 entries have been analyzed for essential minerals by ICP spectrometer at the Waite Analytical Services of the University of Adelaide. Because of significant site and season effects, all materials to be compared were grown together with reference lines at the same site and the daughter seed so obtained was sent for analysis. This laborious process eliminates effects of seed nutrient content caused by varying mother-plant environment. A summary of the first broadly based survey of rice germplasm carried out in this way is shown in Table 1 (Gregorio et al 2000).

Improved cultivars with exceptionally high iron or zinc concentration were not found in this series of screening, but several aromatic rice varieties were found among the high-iron varieties. A series of seven comparisons of aromatic and nonaromatic varieties was made: two sets typical of the studies at the seven locations on the station (Graham et al 1999) are shown in Table 2. In a subsequent study of a doubled-haploid population (Azucena / IR64), the linkage between aromaticity and high iron density was shown to be quite weak, only one of four quantitative trait loci (QTLs) for high iron being located on the same chromosome arm as the aroma locus and at some distance from it (Gregorio et al 2000).

Several tests have been conducted to examine the effect of soil and climatic factors on the iron and zinc concentrations in grain (G × E). In one, four varieties were grown on normal and saline soils in a coastal area in Pili, Iloilo, Philippines, in the 1992 wet season and their harvest was analyzed for iron and zinc in grain. In salt-sensitive IR29, grain iron increased under saline soil conditions and, in tolerant varieties (IR74, IR9884, and Pokkali), there appeared to be a reduction in iron concentration, though slight. Independently of tolerance for salinity, zinc concentrations of these lines decreased as the salinity increased. At the time of the planting experiment on the IRRI farm in the 1994 dry season, the differences observed were not significant for iron concentration but were slightly and significantly so (P<0.01) for higher zinc concentrations in grain from earlier planting (Graham et al 1999). The biggest effect, seen in several experiments, was a higher iron concentration with increasing nitrogen fertilizer application. As expected, though this has not been subjected to formal experimentation, iron concentrations tend to be lower in upland conditions (G. Gregorio, IRRI, pers. commun.).

Table 1. Iron and zinc concentrations in brown rice varieties grown under similar growing conditions in six sets at IRRI, Los Baños, Philippines.

Variety set	Samples (no.)	Fe (mg kg^{-1}) Mean ± SE (range)	Zn (mg kg^{-1}) Mean ± SE (range)
Traditional and improved varieties	59	13.0 ± 2.6 (9.1–22.6)	24.0 ± 4.7 (13.5–41.6)
IR breeding lines	350	10.7 ± 1.6 (7.5–16.8)	25.0 ± 7.6 (15.9–58.4)
Traditional and improved varieties	63	12.9 ± 3.1 (7.8–24.4)	24.4 ± 4.7 (16.5–37.7)
Tropical japonicas	250	12.9 ± 1.5 (8.7–16.5)	26.3 ± 3.8 (17.1–40-1)
Popular varieties and donors	199	13.0 ± 2.5 (7.7–19.2)	25.7 ± 4.6 (15.3–37.3)
Traditional and improved varieties	18	13.8 ± 2.3 (10.8–18.0)	24.2 ± 4.1 (19.9–33.3)

Table 2. Elevated concentrations (mg kg^{-1}) of iron and zinc in aromatic rice varieties in comparison with nonaromatic types grown at IRRI, Los Baños, in 1996 (Gregorio et al 2000).

Aromatic line	Fe	Zn	Nonaromatic line	Fe	Zn
Set 1					
Basmati 370	16.3	34.4	IR8	12.3	17.3
Gaok	16.0	26.4	IR36	11.8	23.1
Azucena	18.2	29.3	IR74	11.2	24.0
Set 5					
Ganje Roozy	18.1	36.6	Bg 379-2	11.3	20.5
Banjaiman	18.1	33.3	BG1370	11.5	19.5
CT 7127	17.1	32.4	UPLRi 7	10.8	20.9
Lagrue	19.0	34.8	Tetep	10.7	24.1

is the obvious location for a critical mass of scientists in grain quality; micro-nutritional quality; nutrition science; organic, micronutrient, and analytical chemistry; biochemistry; and grain processing. This core of specialties will not only support the breeders and agronomists involved in improving rice nutritional quality—and researching more efficient ways of doing so—but will also be the focus of capacity building in NARES and the conduit for the flow of knowledge from their colleagues in ARIs to other IRRI staff leading the effort in agronomy and plant breeding. Finally, these researchers will be involved in developing new products that contribute to better nutrition. Research on milling efficiency will be critical to the outcomes of this GCP.

In tests on rats and human cell cultures, the extra iron in high-iron lines is bioavailable (Welch et al 2000). Therefore, based on the apparent link between high iron and aroma, advanced lines of Dr. Senadhira's cross of a traditional aromatic rice with a high-yielding modern variety (Zawa Bonday/IR72) were analyzed for minerals. Three high-yielding lines with high iron and zinc concentrations, good disease resistance, and good cooking quality were identified. One of these, IR68144B-2-3, was multiplied for bioavailability studies in humans. A preliminary feeding trial with mildly anemic women was conducted to determine the logistics for a larger feeding trial that is currently under way with nearly 300 participants. A local market rice, C4, is being used as a low-iron control, and such is the quality of the two rice lines that they are consumed in almost equal amounts. The trial is a double-blinded study such that neither the subjects nor the experimenters know the key to the treatment assignations. This trial is now being wound up and data assessment is under way.

Evolving a plan for biofortification research at IRRI

As milled rice has the lowest iron concentration of any known staple crop yet is the major food source for nearly half of the world's population, it is essential that a major thrust of the Bioforti-fication GCP be in improving the nutritive value of rice. IRRI

Accordingly, a new Center for Grain Quality and Nutrition Research at IRRI to be the focal point of the GCP and its outreach to rice-growing countries is under development. It is proposed that it be staffed by three or four internationally recruited scientists in the abovementioned disciplinary areas and have a lead scientist drawn from among the senior staff. The center ideally will also take responsibility for the existing grain quality laboratory (to be upgraded substantially) and a new plant micronutrient laboratory that will analyze grain produced by the breeding and agronomic research efforts. Both laboratories will be equipped with advanced quality assurance procedures. They will have service, research, and capacity-building roles.

It is intended that all rice-breeding programs will adopt nutritional and cooking quality objectives, using the additional resources available in the GCP. Faster and cheaper methods of analysis of grain for iron, zinc, and carotenoids are needed and will be researched by the team. The overall objective is to incorporate these new traits in the highest-yielding material so that its impact in the marketplace is assured because farmers will want to grow it for the yield advantage. This is especially important in an unsophisticated market that will not pay extra for better nutritional value. At the same time, because of the synergy between these micronutrients in enhancing the absorption and function of each other (Graham et al 2000), a parallel strategy will be to incorporate high-iron, high-zinc, and golden rice traits in that one variety. Such a variety will help overcome not only single deficiencies of iron, zinc, or vitamin A but also multiple deficiencies of them and do so more efficiently so that modest expression of each trait (and therefore fewer genetic loci involved), rather than maximal expression, may be adequate to solve the problem. This strategy also has the advantage of having an identifiable product (being yellow) in the marketplace, and this can be promoted as being healthy for infants, children, and pregnant and lactating women.

A particular opportunity exists for agronomic research and extension within the GCP. Of the five most prevalent micronutrient deficiencies (iron, zinc, vitamin A, selenium, and iodine—affecting 4–5 billion people [WHO 2002]), only three can be addressed by fertilizer increasing the concentration in the grain: zinc, selenium, and iodine (Graham et al 2001); the other two, iron and vitamin A (β-carotene), can only be meaningfully improved by plant breeding/biotechnology. Generally speaking, higher concentrations in grain can be achieved by fertilization than by plant breeding but the problem is that, for selenium and iodine, there is no yield incentive to encourage farmers to use fertilizer. This could be achieved by legislation to require fertilizer companies to coat urea for rice production with traces of these two ultra-micronutrients, or by treating irrigation water in the main irrigation channels wherever this approach would work. Delivery of these potentially toxic but essential ultra-micronutrients through the food system is the safest way to do so, eliminating the possibility of toxicity, while at the same time ensuring their widest distribution. Demonstration of efficacy in all situations is needed. In the case of zinc, there is a yield advantage in half of all soils, and probably more than half in the case of rice because of its inherent sensitivity to this deficiency. The high-zinc seeds, moreover, are more nutritious not only to humans but to the next generation of seedlings, which become more vigorous and better able to withstand weed competition, pathogen and pest attack (including suppression of motility and symptom expression in viral diseases), and other stresses, including salinity, since zinc controls membrane permeability.

Future strategies

Functional genomics is likely to increase greatly the efficiency by which breeders can optimize this program. At the same time, further research into gut physiology will probably create new opportunities. A current example is the prebiotic polysaccharides, fructans. The human gut does not have the enzymes to cleave these chains into absorbable sugars so they reach the colon intact where bifidobacteria, present in small numbers normally, can use fructans as an energy source, can multiply, and, by a variety of effects, can increase the absorption of iron, zinc, and calcium from the colon. As these fructans also contribute to stress tolerance in the vegetative plant, there may be opportunities to explore a potential win-win situation. Another factor in the future is the likely full recognition of phytate as an essential nutrient and the establishment of minimum requirements in the diet for its various functions, including prevention of cancers, especially colon cancer. The improved efficiency of genetic transformation technology is likely to contribute faster, safer, and more effective ways to improve the nutritional value of rice.

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Applications of genomics to rice breeding

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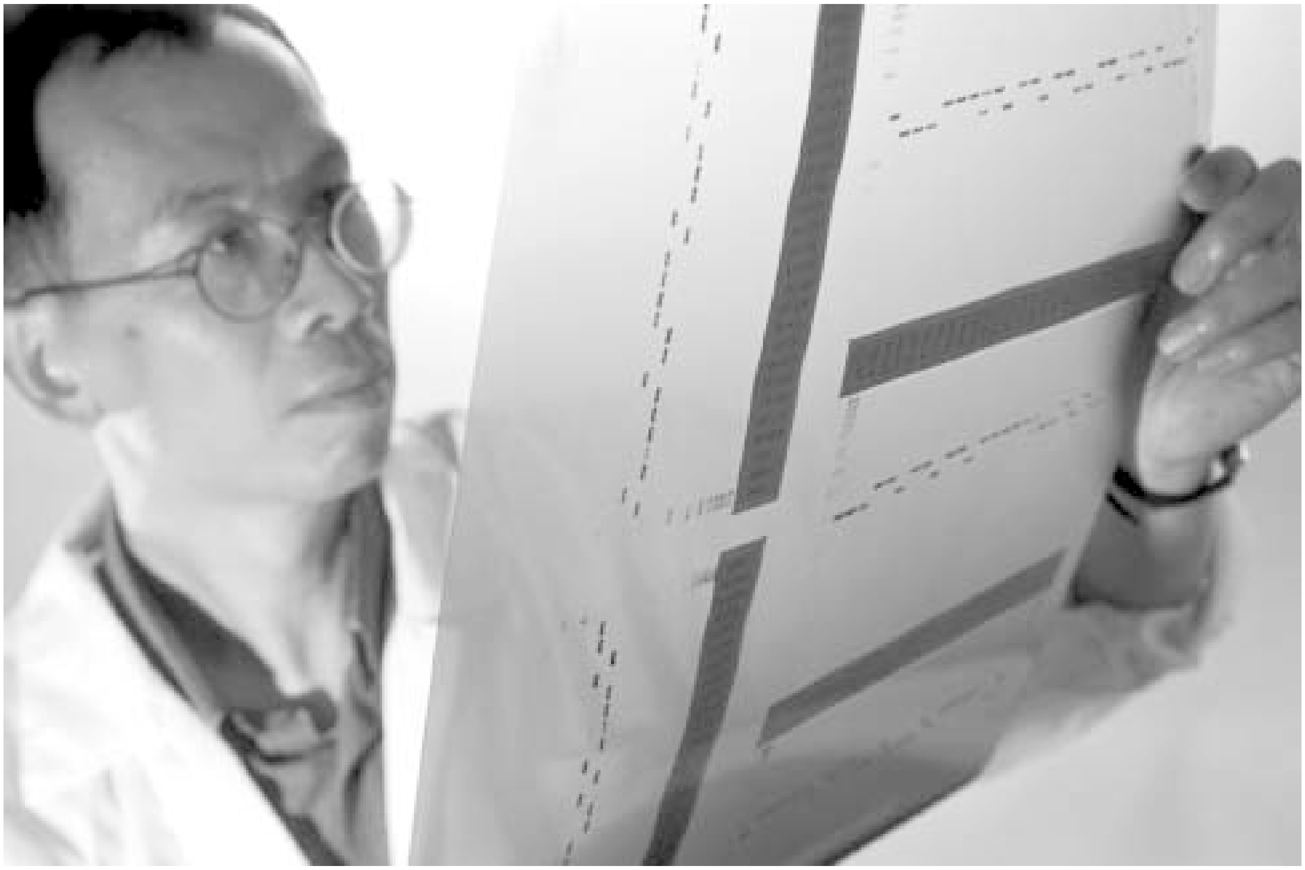

Genomics can be defined as the mapping, sequencing, and functional analysis of genomes, the entire genetic complement of an organism. Before high-throughput DNA sequencing was available, genomes were studied largely by mapping using genetic markers. With the complete genome sequencing of many organisms and the development of powerful methods of gene discovery, the identification of functions for thousands of genes is proceeding rapidly (functional genomics). The fields of structural and functional genomics are intimately related, and this mini-review will consider applications of these fields to rice breeding.

Rice has been at the forefront of plant genomics because of its small genome size and relatively low amount of repetitive DNA, its diploid nature, and its ease of manipulation in tissue culture. In the 1990s, many advances occurred in the application of molecular markers in rice (see reviews in Mackill and Ni 2001, Temnykh et al 2001, Xu 2002). Some of the milestones include (i) the development of the first restriction fragment length polymorphism (RFLP) map (McCouch et al 1988); (ii) the application of markers based on the polymerase chain reaction (PCR) such as random amplified polymorphic DNA (RAPD) (Zheng et al 1991), amplified fragment length polymorphism (AFLP)

(Cho et al 1996; Mackill et al 1996), and simple sequence repeat (SSR) markers (Wu and Tanksley 1993; Zhao and Kochert 1992, 1993); (iii) the identification of quantitative trait loci (QTLs) (Ahn et al 1993, Wang et al 1994); and (iv) map-based cloning of a disease resistance gene (Song et al 1995).

Rice is the second plant genome to be completely sequenced, after the model plant species *Arabidopsis thaliana*. Two groups announced draft sequences of the *indica* (Yu et al 2002) and *japonica* (Goff et al 2002) subspecies. The completion of a high-quality draft of the rice genome sequence by the International Rice Genome Project was announced on 18 December 2002 (http://rgp.dna.affrc.go.jp/rgp/Dec18_NEWS.html).

Availability of the complete genome sequence is a major achievement and should stimulate large-scale gene discovery in rice and other plant species. Discovery of genes controlling economically important traits can be used for applications in marker-assisted selection (MAS), improving rice through transgenic approaches, and discovery of new beneficial alleles in the germplasm (allele mining).

Marker-assisted selection

A significant advance in the practical utilization of molecular markers was the development of SSR markers, also referred to as microsatellite markers (McCouch et al 1997). These markers are based on repeats of short DNA sequences (2-5 bp) that are highly polymorphic and easy to detect. The high polymorphism means that these markers can be used in germplasm that is closely related (Ni et al 2002, Yang et al 1994). The markers can be detected with relatively low-cost manual gel systems or can be carried out on a large scale using DNA sequencing equipment (Coburn et al 2002). A fairly dense SSR map has been published (McCouch et al 2002). However, with the entire DNA sequence of rice, SSR markers can be developed that are within a few thousand basepairs (bp) of any gene. For example, the sequence published by Goff et al (2002) indicated the presence on average of one SSR repeat (defined as at least eight repeats of 2-4 bp) every 8 kb for a total of 48,351 in the genome. Of course, not all of these repeats can be developed into SSRs.

Mapping agronomically important genes itself can provide useful information for plant breeders. This is particularly true in the case of traits that are controlled by multiple genes of similar phenotypes. The most common example is for disease resistance genes. While meticulous genetic studies identified the major genes controlling major-gene resistance to Japanese blast isolates (Kiyosawa 1974), the systematic study of resistance genes for tropical blast races was hindered by the existence of multiple genes in many varieties and isolate differences between countries. Molecular mapping now allows researchers to rapidly determine whether they are working with a completely new resistance gene or whether it is located in the vicinity of an already described gene (Liu et al 2002). The blast resistance genes in rice are now being systematically identified and characterized (McCouch et al 1994, Tsunematsu et al 2000).

With existing technology, the use of molecular markers is still quite expensive for application on a large scale in rice breeding programs. Use of MAS will be more beneficial for specific applications. Examples of where MAS would be advantageous include selection for traits that are difficult or expensive to measure (e.g., salt tolerance, restorer genes); pyramiding multiple genes that confer a similar or identical phenotype (e.g., multiple genes for resistance to blast or bacterial blight); or selecting against the donor chromosomal segments in a backcrossing scheme (Mackill and Ni 2001, Ribaut and Hoisington 1998, Young and Tanksley 1989).

Many rice scientists are now beginning to use markers for these types of applications. Restorer genes are a good example where phenotyping is very time-consuming, requiring determinations of spikelet sterility in testcross progeny, and several *Rf* genes have been mapped (Komori et al 2003, Yao et al 1997). Hittalmani et al (2000) used MAS to combine three blast resistance genes—*Pi1* on chromosome 11, *Piz-5* on chromosome 6, and *Pita* on chromosome 12—into a single genotype. Huang et al (1997) pyramided four resistance genes, *Xa4*, *xa5*, *xa13*, and *Xa21*, using PCR-based markers. Sanchez et al (2000) transferred three bacterial blight resistance genes into three susceptible rice lines possessing desirable agronomic characteristics. Davierwala et al (2001) used markers to pyramid bacterial blight resistance genes *Xa4* and *xa5*.

Molecular markers are particularly useful for accelerating the backcrossing of a gene or QTL into an elite cultivar or breeding line. Markers linked to the gene can be used to select plants possessing the desired trait, and markers throughout the genome can be used to select plants that are genetically similar to the recurrent parent (background selection) (Hospital et al 1992, Young and Tanksley 1989). This

put systems in such a way that large numbers of plants can be assayed for a particular allele. An example of a high-throughput, nongel-based approach is the Taqman® system (Livak et al 1995).

Genes that can be mapped on the rice chromosomes will become easier targets for identification. Studies in *Arabidopsis* have shown the potential of using the DNA sequence to identify new microsatellite markers in particular regions for saturation mapping at high resolution (Casacuberta et al 2000). High-throughput genetic mapping using multiplexed SSRs and small mapping populations can be used to rapidly map important genes (Ponce et al 1999) and determine their sequence in relatively small positional cloning experiments (Lukowitz et al 2000). In rice, positional cloning has been laborious but recently successful for genes controlling disease resistance (Bryan et al 2000, Song et al 1995, Wang et al 1999, Yoshimura et al 1998), heading date (Kojima et al 2002, Takahashi et al 2001, Yano et al 2000), and semidwarfism (Monna et al 2002). The complete genome sequence will accelerate positional cloning greatly.

In addition to this forward genetics approach to gene discovery, the reverse approach, or proceeding from gene sequence to function, will be very powerful. In the reverse approach, SNPs are sought in candidate genes to identify the phenotypic effects of these genes. Known SNPs can be used to identify new candidate genes through association mapping (Buckler and Thornsberry 2002, Rafalski 2002a, 2002b). Phenotypic differences that correspond to particular SNPs may be the result of the sequence change. These SNPs can then be used for MAS or screening germplasm and elite breeding lines (for example, see Ellis et al 2002). In fact, even without identification of a SNP, candidate genes can be used to screen germplasm for a trait of interest,

approach is thought to be promising in rice because a number of rice cultivars are widely grown for their adaptation, stable performance, and desirable grain quality. Chen et al (2000) used such an approach to transfer the bacterial blight resistance gene *Xa21* into Minghui 63, a widely used parent for hybrid rice production in China. Ahmadi et al (2001) used a similar approach to introgress two QTLs controlling resistance to rice yellow mottle virus into the cultivar IR64.

Application of functional genomics

The sequencing of the rice genome will facilitate the identification of many important genes. The forward genetics approach for identifying functionally important genes derives from a known allelic difference conferring an improved phenotype. In such an approach, the objective is to identify a sequence change conferring the improved phenotype. Such a sequence change can then become the basis for a marker that is specific for that allele. These types of markers will always cosegregate with the trait of interest and should also be polymorphic in any cross. Such a marker will often be based on a single nucleotide polymorphism (SNP). Numerous assays are available to detect these SNPs (Kirk et al 2002). The SNPs can be detected in high-through-as has been recently shown for quantitative resistance to rice blast disease (Ramalingam et al 2003).

While SNPs in candidate genes offer many advantages as molecular markers, SSR markers could still be useful for MAS even after the identification of candidate genes. Their convenience, codominant inheritance, and high polymorphism may make SSRs preferable over SNPs identified from the favorable allele. SSR markers adjacent to or within genes can serve for this purpose. An example is the *waxy* gene, which contains a microsatellite within it (Bligh et al 1995). Differences in amylose content are associated with alleles of this microsatellite (Ayres et al 1997).

MAS using gene sequences identified through functional genomics will be a powerful approach for improving rice through conventional hybridization and selection strategies. In addition, the cloned genes can be introduced directly into rice by transformation. In rice, this is currently being practiced for the bacterial blight resistance gene *Xa21*, the first resistance gene cloned in rice (Tang et al 2001, 1999; Tu et al 1998, Zhai et al 2002, Zhang et al 1998). We can expect similar progress for other identified genes.

The transgenic approach will achieve results similar to marker-assisted backcrossing. Although it might be expected to be faster and more accurate, there are in fact still constraints to the use of transgenics, including undesirable genetic alterations resulting from the transformation process and the time it takes to satisfy biosafety regulations. Transgenics will be more useful when similar results could not be achieved with conventional breeding. When a number of genes are cloned, they could presumably be combined in the same construct and introduced together. For example, multiple resistance genes introduced in this manner would segregate together in subsequent manipulation by conventional breeding (Michelmore 1995). These could then be introduced into other varieties by crossing and would segregate as a single genetic factor.

In addition to using native rice genes in transformation, these genes can be up-regulated or down-regulated by changing the promoter or using antisense constructs. For example, Quimio et al (2000) achieved higher submergence tolerance through overexpression of the *pdc1* gene coding for pyruvate decarboxylase. Similarly, an antisense for the *waxy* gene was used to reduce amylose content (Terada et al 2000).

Perhaps the most exciting application of this approach will be the identification of different versions of rice genes from other species. The genomes of cereal species have similar gene content and structure (Gale and Devos 1998, Goff et al 2002). The structural and functional genomic analysis of rice will enable similarly wide-scale gene discovery in other cereals. Orthologous genes will be similar in sequence and function to those in rice but could result in markedly different phenotype. These genes will be available for introduction into rice to produce new types of plants with many novel features.

Gene expression in plants is under complex regulation that is also genetically controlled. Transcription factors are important regulators of plant development and can have large effects on phenotype by influencing the expression of many genes. The levels of transcription factors are under genetic control and can be studied like other quantitative traits (Schadt et al 2003). These levels might be associated with important agronomic traits. For example, transcription factors can regulate expression of many downstream genes involved in response to stress (Chen et al 2002, Kasuga et al 1999, Stockinger et al 1997).

Mining the germplasm collection

The identification of function for the estimated 50,000 rice genes will be a long-term undertaking. Some information regarding gene function can be determined by high-throughput gene-expression studies based on microarrays or from large mutant collections that have deletions or insertions in most of the rice genes. These studies will assist in identifying the conditions under which various genes are expressed, and the phenotype that results when they are knocked out or their expression is altered. The pathway and biochemical function will ultimately be assigned. However, their practical use for breeding will depend on identifying variants (alleles) in the rice germplasm that confer superior phenotype.

Molecular markers have already been shown to facilitate introduction of agronomically useful QTLs from exotic cultivars or wild relatives (Tanksley and McCouch 1997, Tanksley and Nelson 1996). Favorable genes or alleles from wild species of rice have been detected after backcrossing to elite cultivars (Moncada et al 2001, Xiao et al 1998). Similarly, this approach can identify alleles from exotic cultivars that result in improved phenotype, even though the parent may not possess this trait (Li 2001). Such approaches, however, can only sample a small number of accessions. Molecular methods, on the other hand, can be used to screen a large number of accessions through a pooling strategy. This can be used to screen germplasm collections for alleles of candidate genes that are involved in important processes of the plant, even though known variants for these genes have not been observed through genetic studies. A DNA bank is currently being developed for a core collection of the rice gene bank at IRRI to undertake allele mining (K. McNally, pers. commun.).

Large-scale application of genomics to breeding will result from new technologies that reduce the cost and increase the throughput of the assays. Gel- or capillary-based DNA sequencers can be used in genotyping, but microarrays or other non-gel systems may allow whole-genome analysis of large number of plants commonly grown in breeding programs. Ultimately, the goal will be to rapidly assay the genetic makeup of individual plants in breeding populations. Producing "graphical genotypes" (Young and Tanksley 1989) of each plant or progeny row will allow the breeder to determine which chromosome sections are inherited from each parent and will greatly expedite the selection process and minimize the need for extensive field tests. These new tools will greatly enhance, but not replace, the conventional breeding process.

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Molecular tagging of a new bacterial blight resistance gene in rice using RAPD and SSR markers

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Bacterial leaf blight (BB) disease caused by *Xanthomonas oryzae* pv. *oryzae (Xoo)* limits rice yield in all major rice-growing regions of the world. As the bacterial pathogen is difficult to manage, the development of host-plant resistance is considered the most effective and economical means to control BB. Twenty-four major genes conferring resistance to various races of the pathogen have been identified and used in rice breeding programs (Lee et al 2001). Several varieties with high or moderate resistance to BB have been released under the auspices of the All India Coordinated Rice Improvement Project (AICRIP). Variety Ajaya (IET8585), released in 1994 under AICRIP, is highly resistant to all pathotypes in India (DRR 1996).

To study the genetics of disease resistance in Ajaya, a segregating population was developed from a cross between susceptible variety IR24 and Ajaya. Genetic analysis of the segregating population indicated a recessive gene in Ajaya that confers resistance to Indian pathotypes (Table 1, Fig. 1). The F_2 population was screened with randomly amplified polymorphic DNA (RAPD) and simple sequence repeat (SSR) primers to tag the recessive resistance gene in Ajaya.

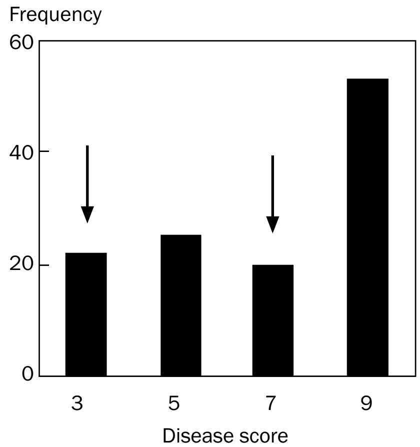

Fig. 1. F_2 segregation pattern for disease score of the cross IR24/Ajaya. Means of the parents are marked by arrows.

From a survey of 80 RAPD primers (Operon), we identified one primer (OPA 12) that amplified one polymorphic band between the resistant and the susceptible parents. Bulk segregant analysis revealed that the OPA 12 primer amplified a 1,467-bp band only in the resistant parent and the resistant bulk. The F_2 segregation pattern and linkage analysis showed that the OPA 12_{1467} marker was linked to the resistance gene in Ajaya at a distance of 5.0 cM (Table 2).

Microsatellite analysis of the parents and the F_2 population was carried out with 23 microsatellite (SSR) primers located on chromosomes 4, 5, 8, and 11 (these harbor other known BB resistance genes). Two SSR markers located on the long arm of chromosome 5, RM39 and RM31, were polymorphic. The segregation pattern and linkage analysis of the F_2 revealed that the $RM39_{130}$ marker was linked to the resistance gene at a distance of 14.5 cM, while the RM 31_{150} marker was linked to the gene at a distance of 17.7 cM on the other side. Microsatellite markers RM390, RM122, and RM13 linked to the *xa*5 resistance gene are located on the short arm of chromosome 5 (Blair and McCouch 1997). Thus, the different location of the newly identi-

Table 1. Reaction to Indian pathotype 1 of F_1 and F_2 populations from the cross Ajaya/IR24.

Cross	F_1 reaction	F_2 reaction (disease score)			Ratio	χ^2
		Resistant	Heterozygote	Susceptible		
Ajaya/IR24	Susceptible	30	58	32	1:2:1	0.19

Table. 2. RAPD and microsatellite analysis.

Type of marker	Primers analyzed (no.)	Polymorphic primers (no.)	Linked markers	Linkage distance (cM)
RAPD	80	5	$OPA12_{1467}$	5.0
Microsatellite (SSR)	23	2	$RM39_{130}$	14.5
			$RM31_{150}$	17.7

fied gene for BB resistance in Ajaya indicates that it is not allelic to the *xa5* gene.

For the allelism test, Ajaya was crossed with near-isogenic line IRBB5 of IR24. One hundred and twenty F_2 plants from this cross were screened for segregation of resistance to the Indian *Xoo* isolate. The segregation pattern is given in Figure 2. The occurrence of 53 susceptible plants in the F_2 population deviated significantly (χ^2 = 23.51, P<0.0001) from the expected 1:3 ratio, indicating that the gene in Ajaya is nonallelic to *xa5*.

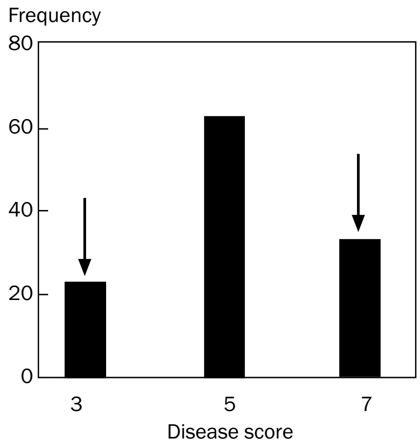

Fig. 2. F_2 segregation pattern for disease score of the cross Ajaya/IRBB5. Means of the parents are marked by arrows.

The results of phenotype screening and molecular analysis clearly indicate that Ajaya carries a recessive gene different from *xa5*. A new symbol, –*xa5*(t), is proposed for this new gene.

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Participatory assessment of medium-duration, high-yielding varieties for improved yield and efficient rice production in Bay Islands, Andaman

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Most of the area under rice (12,000 ha) in the Andaman Islands is planted to long-duration photoperiod-sensitive traditional variety C14-8. Besides its very low productivity (1.8 t ha^{-1}), this variety is not suitable for medium upland valley cultivation as it would delay the sowing of a second crop (vegetables / pulses) in the cropping sequence. A participatory rural appraisal pointed to the farmers' need for medium-duration high-yielding rice varieties (HYVs) in these areas (Conway 1985).

We conducted an experiment in 15 farmers' fields to assess the performance of several recommended medium-duration HYVs under the IVL Program of NATP. HYVs IET6314, Ponni, Quing Livan No. 1, and Taichung Sen Yu were compared with the farmers' variety (IR31851) during the monsoon season (June-October) in 2000 and 2001 in the villages of Mithakhari and Ograbaj. The experiment was conducted in a randomized block design with 15 farmers as replications. (Their soils have similar physicochemical properties and they use the same management practices. Soil is sandy loam and has a pH of 6.5, 0.53% organic carbon, and medium NPK.) Twenty-one-day-old seedlings were transplanted in the second week of July; the crop was harvested in October. No chemical fertilizer was applied, but plant protection measures were implemented as needed. The group of farmers ranked the varieties at final harvest and after 1 mo of consuming the grain.

The growth, yield, and economic data of the four varieties tested were better than those of the farmers' variety in both years (Table 1). IET6314, the tallest (115.3 cm), was on a par with Ponni (110.4 cm) but significantly higher than the others. Quing Livan No. 1 and IR31851 did not differ in plant height. Ponni recorded the maximum number of panicle-bearing tillers hill^{-1} (13.4) and the longest panicle (24.4 cm), on a par with IET6314 but significantly higher than the other varieties. Spikelet sterility was maximum in the farmers' variety

Table 1. Growth, yield, and economics of medium-duration rice varieties in farmers' fields.

Parameter	Farmers[1] variety (IR31851)	Quing Livan No. 1	Taichung Sen Yu	IET6314	Ponni	LSD (P = 0.05)
Plant height (cm)	94.8	92.7	112.35	115.3	110.4	5.7
Tillers (no.)	11.9	10.4	10.9	12.2	13.4	1.5
Panicle length (cm)	21.7	22.0	22.6	23.5	24.4	0.8
Spikelet fertility (%)	77.4	85.3	92.6	89.1	92.5	7.9
Av yield (t ha^{-1})	5.2	5.3	5.4	5.3	5.4	1.1
Gross returns ($ ha^{-1})	531.9	544.3	561.8	547.4	561.8	
Net returns ($ ha^{-1})	71.3	83.7	101.2	86.8	101.2	
B:C	0.15	0.18	0.22	0.18	0.22	–

(22.6%). Though Taichung Sen Yu recorded the maximum number of fertile grains (92.6%), this value did not differ significantly from those observed in other varieties. Taichung Sen Yu and Ponni recorded the maximum grain yield (5.5 t ha^{-1}), which was 5.6% higher than that of the farmers' variety (5.2 t ha^{-1}). The grain yields of Quing Livan No. 1 (5.3 t ha^{-1}) and IET6314 (5.3 t ha^{-1}) were also significantly higher than that of IR31851. Compared with those of the farmers' variety, the gross returns, net returns, and benefit-cost ratio obtained from cutivating Taichung Sen Yu and Ponni were higher. A marginal benefit of $12.40–29.90 was recorded with the recommended HYVs over the farmers' variety.

The participatory matrix ranking of these varieties by farmers revealed that, even though the yields of Ponni and Taichung Sen Yu were both significantly higher than that of the farmers' variety, Taichung Sen Yu was more preferred because of its greater tolerance for lodging and its better taste (Table 2). But the variety most preferred was Quing Livan No. 1. Despite its low yield advantage, it was the top choice because it has greater tolerance for lodging and insect pests and diseases, has a better taste, and has bolder grain than the other HYVs.

This study confirms the findings of Pramanik et al (2001) and clearly shows that, apart from yield, farmers look at several other criteria in selecting varieties for their fields.

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Table 2. Participatory matrix ranking of rice varieties (1–5 scale). [a]

Characteristic	Farmers' variety (IR31851)	Quing Livan No. 1	Taichung Sen Yu	IET6314	Ponni
Yield	3	3	5	4	5
Tolerance for lodging	3	5	5	2	2
Taste	4	5	4	3	3
Keeping quality	3	5	4	3	4
Tolerance for insect pests	3	4	3	3	3
Leaf-blade sharpness	3	5	4	3	3
Grain size	Medium	Bold	Medium	Medium	Fine

[a]Uses a scale of 1–5 where 1 = least/minimum and 5 = best/maximum. Matrix score was the group ranking.

Evaluation of germination, cold tolerance, and seedling vigor of boro rice germplasm

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Boro rice cultivation is a special system of rice cultivation in low-productive, waterlogged, low-lying deepwater land during November-May in eastern India. In such land, neither kharif (Jul-Oct) rice nor rabi (Nov-Apr) wheat is successful because of excess water. The boro crop is usually sown in November and transplanted when the temperature starts rising from January onward. The average minimum temperature during this period varies from 8 to 12 °C. Crop productivity is very high (Thakur and Mishra 1990); consequently, boro rice has become popular in Bihar and eastern Uttar Pradesh. The suitability of rice varieties for boro cultivation mainly depends on their germination, tolerance for low temperature at the seedling stage, and seedling vigor.

Twenty-one rice genotypes received from different institutions—IRRI, Philippines; Directorate of Rice Research, Hyderabad; Rice Research Station, Chinsurah, West Bengal; and RAU—were evaluated in this study. The plant materials were sown on 10 Nov and germination vigor scores were recorded using the *Standard evaluation system for rice* (IRRI 1996).

Most of the genotypes developed at IRRI and RAU were superior to those developed at Chinsurah and Hyderabad, recording more than 80% germination (see table). The seedlings of these genotypes remained green. Genotypes IR53970-100-3-3-2, IR59471-2B-20-2-1, and Boro 5-1B-6-3-3-4-1-1-1 showed moderate tolerance for cold at the seedling stage. The highest seedling vigor was observed in RAU1345-2, followed by IR55275-8-8-1-1-3, IR56383-77-1-1-1-1, IR61608-2B-70-2-2-1-2, Prabhat, and Gautam. Temperatures below 10 °C have an adverse influence on water absorption by decreasing respiration, which ultimately slows down germination (Aleshin and Aprod 1960). RAU1345-2, IR56383-7-7-1-1-1-1, IR55275-8-8-1-1-3, IR61608-2B-70-2-2-1-2, Prabhat, and Gautam had similar cold tolerance scores and showed the least damage in seedlings. They also had good seedling vigor.

An ideal genotype suitable for boro cultivation should have a high germination percentage, good cold tolerance, and high seedling vigor. The genotypes RAU1345-2, IR55275-8-8-1-1-3, and IR61608-2B-70-2-2-1-2 may be suitable for boro cultivation in the eastern region of India as they had a better score than Gautam, which was developed earlier (Thakur et al 1994). These genotypes even showed better recovery after cold stress. Their yield potential and tolerance for biotic and other abiotic stresses are being evaluated.

Germination, cold tolerance, and seedling vigor of selected genotypes.

Genotype	Germination percentage	Cold tolerance score[a]	Seedling vigor score[a]
RAU1344-3-2	83.0	5	5
RAU1345-2	93.6	3	1
IR59471-2B-20-2-1	65.3	5	5
IR55275-8-8-1-1-3	86.0	3	3
IR56383-77-1-1-1-1	84.0	3	3
IR53970-100-3-3-2	83.6	5	5
CN869-5-14-1-1	79.3	7	7
CN815-KGR—882-5-2	65.0	7	7
RAU1411-4	64.6	7	7
RAU1411-10	56.0	9	9
PSRM-1-16-48-1	74.3	7	7
RP2194-14-2-6-1	75.3	7	7
RP2333-383-30	68.3	9	9
RP2240-86-84	64.0	9	9
RP2240-59-54	73.0	7	7
RAU1345-1-2	84.0	7	5
IR61608-2B-70-2-2-1-2	83.0	3	3
RAU1400-3-7-2B-1	81.0	7	5
Boro-5-1B-6-3-3-4-1-1-1	81.0	5	5
Prabhat (check)	89.6	3	3
Gautam (check)	84.0	3	3

[a]Scored using the *Standard evaluation system for rice* on a scale of 1–9 for seedlings, where 1 = seedlings dark green, 3 = seedlings light green, 5 = seedlings yellow, 7 = seedlings brown, 9 = seedlings dead. From tillering to maturity, on a scale of 1–9, where 1 = plants have a normal color; rate growth and flowering normal, and 9 = plants severely stunted, with leaves brown, development much delayed, and panicles not exserted.

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A widely commercialized two-line super hybrid rice, Liangyoupeijiu

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A two-line hybrid, Liangyoupeijiu, was released by the Jiangsu Academy of Agricultural Sciences (JAAS) and the China National Hybrid Rice Research and Development Center (CNHRRDC) from the cross Peiai 64S / 9311 (no. 65002). The female parent, Peiai 64S, was an environment-sensitive genic male sterile (EGMS) javanica line bred by CNHRRDC with the wide compatibility gene *S5-n* from Padi, a variety from Indonesia, and the temperature-sensitive male sterility character from an EGMS line, Nongkeng 58S, a mutant from japonica cultivar Nongkeng 58. The male parent was an elite line developed from Yang Dao No. 6, an indica cultivar released by JAAS.

Liangyoupeijiu is an improved plant type with erect uppermost leaves. Compared with the widely grown indica check hybrid, Shanyou 63, it has a higher light transmission rate and a lower light extinction coefficient from middle to late growth stages. With a high level of heterosis and plant ideotype, the hybrid showed high yield potential, good grain quality, and strong resistance to bacterial leaf blight and blast. The hybrid has a maturity of 150 ± 24 d, 15–16 leaves on the main stems, and an average grain yield of 8.4 ± 2.6 t ha^{-1} (data obtained from 19 testing sites of the multilocational trials in southern China in 1999 and 2000). During the 1999-2000 national test for super hybrid rice in Hunan and Jiangsu, Liangyoupeijiu was grown at 38 testing sites (at each site, the hybrid was grown in a test field of 6.7 ha). Its grain yield averaged 10.5 t ha^{-1}. A grain yield as high as 15.3 t ha^{-1} was obtained in Binchuan County, Yunnan Province, in 1999. Table 1 shows the growth and yield characteristics of the hybrid. Liangyoupeijiu has good grain quality (most of its quality parameters met the high-quality standards set by the China Rice Research Institute) (Table 2). As a result of the two-line system of seed production, the hybrid has consistently achieved a seed yield of 2–3 t ha^{-1} (seed of 98% purity) in the last 5 years.

For yield potential and grain quality, Liangyoupeijiu is well known as the prototype of the "super hybrid rice," its discovery hugging the headlines in 2000. The hybrid has been registered as the first two-line hybrid. It had spread to more than 2.5×10^6 ha during 1999-2002 in southern China and in Southeast Asia, including Vietnam and the Philippines.

Table 1. Growth and yield characteristics of Liangyoupeijiu using data averaged from 19 testing plots in southern China in 1999 and 2000 multilocation trials.

Plant height (cm)	Maturity (d)	Grain yield (t ha^{-1})	Panicles ha^{-1} (no. $\times 10^4$)	Spikelets $panicle^{-1}$ (no.)	Seed set (%)	1,000-grain weight (g)
112 ± 19	150 ± 24	8.4 ± 2.6	2.6 ± 0.5	166 ± 59	76.5 ± 18.8	26.2 ± 2.4

Table 2. Evaluated grain quality characteristics of Liangyoupeijiu compared with the standard.

Characteristic	Liangyoupeijiu[a]	Standard[b]
Brown rice (%)	81.1 ± 2.7	>81
Milled rice (%)	73.6 ± 3.7	>72
Head rice (%)	55.5 ± 9.7	>59
Length (mm)	6.75 ± 0.39	>6.5
Length/width	3.0 ± 0.15	>3.0
Chalk rice (%)	27.7 ± 22.0	<10
Chalkiness (%)	3.94 ± 3.46	<5
Transparency	1.67 ± 1.02	<2
Alkali spreading value	5.67 ± 1.29	>4
Gel consistency (mm)	72.1 ± 8.0	>60
Amylose content (%)	20.3 ± 6.2	<22
Protein content (%)	9.78 ± 1.39	>8

[a]Tested by CRRI in 1998-2001 at seven different testing sites. [b]Standard values for high grain quality (class I) indica rice in China.

Comparative effects of root-knot nematode *Meloidogyne incognita* on yield performance of seven Asian rice and 13 *Oryza sativa/O. glaberrima* interspecific progenies

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The presence of *Meloidogyne graminicola*, *M. salasi*, *M. triticoryzae*, and *M. incognita* in upland rice has been reported. The reports indicate that *Meloidogyne* spp. constitute an environmental stress to the crop (Greco et al 2000, Mian et al 1999). Root-knot nematodes are ubiquitous in the tropics and three of the four most important species of these nematodes are found in West Africa, with *M. incognita* being the most frequently encountered in the field. A recent breakthrough in rice breeding is the production of fertile progenies from *O. sativa* L./*O. glaberrima* Steud. interspecific crosses using anther culture techniques (Jones et al 1997). Several promising lines of these interspecific hybrids have been sent to national agricultural research systems for identification and evaluation. In this study, 13 upland lines of these hybrids were compared with seven well-known *O. sativa* varieties for reaction to an inoculum of 5,000 *M. incognita* eggs per stand.

Sandy loam topsoil used for the experiment was heat-sterilized for 90 min at 65 °C and rested for 6 wk to regain stability. It was thereafter distributed into 240 five-liter plastic pots, each pot receiving 5 kg of soil. Seeds of FARO 43 (ITA 128), FARO 48 (ITA 301), IRAT317, WAB181-18, IR47701-6-B-1, IDSA10, and Moroberekan (*O. sativa* varieties); and WAB450-I-B-P-33-HB, WAB450-24-3-2-P18-HB, WAB450-24-3-1-P37-HB, WAB450-I-B-P-38-HB, WAB515-B-16A2.2, WAB365-B-1-H1-HB, WAB450-I-B-P-157-2-1, WAB450-11-1-1-P50-HB, WAB326-P-B-24-L_2-L_1, WAB189-B-B-B-8-HB, WAB450-1-13-P-160-HB, WAB249-B-B-B-6-HB-I, and WAB340-B-B-1-HB (interspecific hybrids) were pregerminated in sterile soil. One 7-d-old seedling of each line was transplanted into the pots. Each seedling was inoculated with 5,000 ± 66 eggs 1 wk after transplanting. Noninoculated plants served as the control. The resulting 40 treatments were replicated six times in a completely randomized design. Plants were watered regularly and symptom expression was observed daily. For the first phase of the experiment, 10 wk after inoculation, data on plant height, number of leaves, number of tillers, and shoot and root weight were collected from three randomly selected replicates per treatment (Afolami 2000). The extent of root galling was determined after carefully washing off the soil from the roots with tap water. The number of galls per root system was determined using a stereomicroscope. Roots were subsequently weighed, cut into about 2-cm pieces, and thoroughly mixed. A 10-g subsample was then taken for egg and juvenile extraction using the Hussey and Barker (1973) sodium hypochlorite method. The total number of juveniles and eggs from each root system was estimated from these subsamples in each case. Similarly, the total number of juveniles from soil was estimated from a 25-g subsample.

The three remaining replicates of each treatment provided data for the second phase of the experiment: number of panicles, number of spikelets, number of grains per panicle, total number of grains per plant, weight of grains per plant, and weight of 100 seeds.

Data collected from both phases underwent analysis of variance; this included number of eggs recovered from roots, number of juveniles from root and soil, number of nematode-induced root galls, and reproduction factor of the nematode to natural logarithm.

Results show that FARO 48 (ITA 301), WAB450-I-B-P-33-HB, WAB450-24-3-2-P18-HB, and WAB450-24-3-1-P37-HB were tolerant of the nematode (Table 1). The table indicates preliminary ratings based on the usual gall index (GI) and reproduction factor (R) (Sasser et al 1984) and final ratings based on economic yield and R as modified by Afolami (2000). The results indicate that preliminary ratings of the varieties based on GI and R alone successfully predicted actual tolerance or susceptibility to the nematode based on yield plus GI and R in only eight cases. It has been advocated elsewhere that

Table 1. Comparison between resistance ratings[a] of 20 rice varieties using the prescribed standards (Sasser et al 1984) at 10 wk.

Variety	Rating 10 wk after inoculation+[a]			Rating based on economic yield at maturity (mean++ grain yield)			Final resistance rating	Remarks
	GI[b]	R[c]	Preliminary resistance rating	A Inoculated (g plant^{-1})	B Control	A–B		
FARO 48	1.0	26.99	Tolerant	65.73	63.90	1.83 ns[d]	Tolerant	Consistent with expectation
IDSA10	4.0	62.01	Susceptible	32.89	69.52	–36.63*[e]	Susceptible	Consistent with expectation
WAB181-18	3.0	30.06	Susceptible	127.39	113.83	13.56*	Tolerant	Not consistent with expectation
Moroberekan	3.0	62.11	Susceptible	35.84	49.00	–13.16*	Susceptible	Consistent with expectation
WAB450-I-B-P-33-HB	2.0	17.61	Tolerant	57.68	57.15	0.53 ns	Tolerant	Consistent with expectation
WAB450-24-3-2-P18-HB	2.0	27.65	Tolerant	125.56	75.79	49.77*	Tolerant	Consistent with expectation
WAB450-24-3-1-P37-HB	1.0	11.63	Tolerant	74.68	56.70	17.98*	Tolerant	Consistent with expectation
WAB450-I-B-P-38-HB	4.0	43.19	Susceptible	64.38	109.59	–45.21*	Susceptible	Consistent with expectation
WAB515-B-16A2.2	2.0	18.46	Tolerant	60.38	93.68	–33.30*	Susceptible	Not consistent with expectation
IR47701-6-B-1	2.0	18.83	Tolerant	78.78	111.20	–32.42*	Susceptible	Not consistent with expectation
WAB365-B-1-H1-HB	3.0	37.08	Susceptible	37.60	91.84	–54.24*	Susceptible	Consistent with expectation
WAB450-I-B-P-157-2-1	1.0	6.84	Tolerant	84.52	104.65	–20.13*	Susceptible	Not consistent with expectation
WAB450-11-1-1-P50-HB	1.0	5.79	Tolerant	62.23	65.67	–3.44*	Susceptible	Not consistent with expectation
WAB326-P-B-24-L2-L1	2.0	14.85	Tolerant	32.50	56.16	–23.66*	Susceptible	Not consistent with expectation
FARO 43	2.0	8.16	Tolerant	35.89	65.63	–29.74*	Susceptible	Not consistent with expectation
WAB189-B-B-B-8-HB	2.0	8.88	Tolerant	43.60	74.01	–30.41*	Susceptible	Not consistent with expectation
WAB450-I-B-P-160-HB	2.0	25.76	Tolerant	53.19	70.13	–16.94*	Susceptible	Not consistent with expectation
WAB249-B-B-B-6-HB-1	1.0	8.31	Tolerant	52.00	66.73	–14.73*	Susceptible	Not consistent with expectation
WAB340-B-B-1-HB	1.0	7.09	Tolerant	34.70	57.30	–22.60*	Susceptible	Not consistent with expectation
IRAT317	1.0	7.06	Tolerant	67.47	71.80	–4.33*	Susceptible	Not consistent with Expectation

[a]+ = 5,000 eggs of *Meloidogyne incognita* inoculated 1 wk after transplanting. ++ = mean of three replicates. [b]GI (gall index): 1 = 1–2 galls; 2 = 3–10 galls; 3 = 11–30 galls; 4 = 31–100 galls; 5 = >100 galls. [c]R = nematode reproduction factor = final number of juveniles and eggs (P_f)/initial inoculum (P_i). [d]ns = not statistically significant. [e]* = statistically significant difference ($P \leq 0.05$). Ratings based on actual yield performance of varieties (Afolami 2000).

two phases of root-knot nematode screening experiments be done to assess the ultimate effect of the nematode on yield, the number of galls induced by the nematode activities, and the level of reproduction of the nematode on the crop varieties. This will be useful in categorizing any variety as resistant, tolerant, susceptible, or hypersusceptible. IDSA10, WAB450-I-B-P-38-HB, WAB365-B-1-H_1-HB, and Moroberekan were susceptible to the nematode according to both ratings—all showed a high GI (52.7%), high R (41.3%), and significant grain yield loss (59.1%).

If resistance were understood to mean that the nematode did not reproduce on the plant and caused no statistically significant yield loss, as would be expected from a truly resistant variety (Cook 1974, Afolami 2000), none of the 20 varieties tested was resistant. However, one Asian rice variety—WAB181-18—and two of the NERICA (new rice for Africa) lines—WAB450-24-3-2-P18-

Table 2. Effect of *Meloidogyne incognita* on days to 50% flowering, panicles plant^{-1}, spikelets panicle^{-1}, grains panicle^{-1}, grain yield, and 100-seed weight of 20 upland rice varieties.[a]

Variety	Inoculum level (eggs stand^{-1})	Days to 50% flowering	Panicles plant^{-1}(no.)	Spikelets panicle^{-1} (no.)	Grains panicle^{-1}(no.)	Grain yield (g pot^{-1})	100-seed weight (g)
FARO 48	0	93.00	30.67	15.00	83.33	63.90	2.87
	500	93.00	30.33	15.00	86.67	65.73	3.13
	Difference	0.00 ns	0.34 ns	0.00 ns	–3.34*	–1.83 ns	–0.26*
IDSA10	0	65.00	19.00	15.67	146.00	69.52	2.91
	500	72.00	14.00	10.33	94.00	32.89	2.91
	Difference	–7.00*	5.00*	5.34*	52.00*	36.63*	0.00 ns
WAB181-18	0	93.00	35.67	16.00	127.67	113.83	2.96
	500	93.00	40.33	15.33	126.33	127.39	2.96
	Difference	0.00 ns	–4.66*	0.67 ns	1.34 ns	–13.56*	0.00 ns
Moroberekan	0	95.00	15.00	12.33	130.67	49.00	2.60
	500	95.00	11.00	12.33	130.33	35.84	2.82
	Difference	0.00 ns	4.00*	0.00 ns	0.34 ns	13.16*	–0.22*
WAB450-1-B-P-33-HB	0	72.00	18.00	14.00	127.00	57.15	3.54
	500	79.00	13.33	15.00	173.00	57.68	3.52
	Difference	–7.00*	4.67*	–1.00*	–46.00*	–0.53 ns	0.02 ns
WAB450-24-3-2-P18-HB	0	79.00	13.33	17.00	227.33	75.79	2.82
	500	79.00	20.33	15.67	247.00	125.56	2.42
	Difference	0.00 ns	–7.00*	1.33*	–19.67*	–49.77*	0.40*
WAB450-24-3-1-P-37-HB	0	77.00	18.00	15.00	126.00	56.70	2.90
	500	77.00	17.67	14.67	169.00	74.68	2.97
	Difference	0.00 ns	0.33 ns	0.33 ns	–43.00*	–17.98*	0.07*
WAB450-1-B-P-38-HB	0	73.00	25.00	15.00	175.33	109.59	2.81
	500	73.00	15.00	12.67	171.67	64.38	3.38
	Difference	0.00 ns	10.00*	2.33*	3.66*	45.21*	–0.57*
WAB515-B-16A2.2	0	88.00	14.00	16.00	267.67	93.68	2.77
	500	88.00	14.67*	19.67	164.67	60.38	2.83
	Difference	0.00 ns	–0.67	–3.67*	103.00*	33.30*	–0.06*
IR47701-6-B-1	0	91.00	24.00	14.00	185.33	111.20	2.49
	500	91.00	17.00*	13.33	185.33	78.78	2.15
	Difference	0.00 ns	7.00*	0.67 ns	0.00 ns	32.42*	0.34*
WAB365-B-1-H1-HB	0	93.00	19.00	17.00	193.33	91.84	2.43
	500	93.00	12.00	17.33	125.33	37.60	2.83
	Difference	0.00 ns	7.00*	–0.33 ns	68.00*	54.24*	–0.40*
WAB450-1-B-P-157-2-1	0	75.00	29.00	14.00	144.33	104.65	2.62
	500	75.00	22.00	16.00	153.67	84.52*	2.59
	Difference	0.00 ns	7.00*	–2.00*	–9.34*	20.13*	0.03*
WAB450-11-1-1-P50-HB	0	75.00	20.00	12.00	131.00	65.67	2.71
	500	75.00	19.00	12.00	131.00	62.23	2.65
	Difference	0.00 ns	1.00*	0.00 ns	0.33 ns	3.44*	0.06*
WAB326-P-B-24-1-2-L1	0	84.00	23.00	10.00	97.67	56.16	3.07
	500	84.00	15.00	13.00	86.67	32.50	3.29
	Difference	0.00 ns	8.00*	–3.00*	11.00*	23.66*	–0.22*
FARO 43	0	88.00	15.00	16.33	175.00	65.63	3.18
	500	88.00	13.33	15.00	107.67	35.89	2.49
	Difference	0.00 ns	1.67*	1.33*	67.33*	29.74*	0.69*
WAB189-B-B-B-8-HB	0	88.00	15.00	15.33	197.33	74.01	3.62
	500	88.00	12.00	15.00	145.33	43.60	3.53
	Difference	0.00 ns	3.00*	0.33 ns	52.00*	30.41*	0.09*
WAB450-1-B-P-160-HB	0	90.00	16.00	13.67	175.33	70.13	3.10
	500	90.00	13.00	13.67	163.67	53.19	2.92
	Difference	0.00 ns	3.00*	0.00 ns	11.68*	16.94*	0.18*
WAB249-B-B-B-6-HB-1	0	90.00	14.00	13.67	190.67	66.73	3.48
	500	90.00	12.00	15.00	173.33	52.00	3.24
	Difference	0.00 ns	2.00*	–1.33*	17.34*	14.73*	0.24*
WAB340-B-B-1-HB	0	87.00	18.00	17.00	127.33	57.30	3.04
	500	87.00	12.00	13.00	115.67	34.70	3.04
	Difference	0.00 ns	6.00*	4.00*	11.66*	22.60	0.00 ns
IRAT317	0	79.00	24.00	13.00	119.67	71.80	2.62
	500	79.00	23.00	13.00	117.33	67.47	2.62
	Difference	0.00 ns	1.00*	0.00 ns	2.34*	4.33*	0.00 ns
LSD		0.00	0.66	0.70	1.86	2.81	0.0016

[a]* = significant difference at 5% level of probability; ns = not significant.

HB and WAB450-24-3-1-P37-HB—were so tolerant that inoculated plants produced statistically higher yields per plant than the control (Tables 1, 2). In FARO 48 and WAB450-I-B-P-33-HB, there was no significant difference between the yield of inoculated and nematode-free plants. These five varieties are considered to be truly tolerant of *M. incognita* and are therefore recommended for further farmer participatory evaluation in West Africa.

This study emphasizes the need to screen all new hybrid lines intended for release to farmers. However, for the older method of screening, one concern is the use of GI as a measure of plant damage. This does not always accurately predict the effect of *Meloidogyne* spp. on yield, the ultimate test of resistance as far as farmers are concerned. To avoid confusion resulting from such discrepancies, yield must reflect the extent of crop damage and, on this basis, judgment and rating of resistance, tolerance, susceptibility, or hypersusceptibility can be made. GI can be regarded as a preliminary measure of plant reaction to infection by the nematode.

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Evaluation of CMS lines for various floral traits that influence outcrossing in rice (*Oryza sativa* L.)

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Outcrossing was reported to be a function of floral morphology and flowering behavior of both the A lines and the male parents (Oka and Morishima 1967). This study was carried out to evaluate the extent of variation in floral traits in some common A lines.

The experimental materials were composed of 15 male sterile (A) lines and their maintainers (B). The traits evaluated were days to 50% flowering, panicle emergence, and average period of time (in minutes) from the opening of lemma and palea of individual florets to closing of the florets. The angle of lemma and palea at peak anthesis (in degrees) was measured when the floret was fully opened. The size of the stigma (mm^2) was likewise calculated. Broad-sense heritability was calculated using the method of Hanson et al (1956).

The floral traits of 15 cytoplasmic male sterile (CMS) lines and their maintainers were evaluated under different environments (Table 1). In general, the A lines showed longer duration of opening of lemma and palea, poorer panicle exsertion, more pronounced stigma traits, and wider angle than the B lines. But IR68888B and CRMS 31B showed a longer period of floret opening than the A lines. CRMS32B and DRR2B showed a wider angle than their A lines. Although Pusa 5A showed 68.22% panicle emergence and PMS11A showed a small stigmatic surface (0.96 mm^2), their other desirable attributes, along with a good opening of lemma and palea, led to a good seed setting (Table 1). Very high coefficients of heritability were found for stigma size, average period of lemma and palea opening, and angle of lemma and palea at peak anthesis (Table 2). The greater the angles of lemma and palea, the greater the exser-

Table 1. Analysis of variance, genetic parameters of variation, and mean performance of 15 cytoplasmic male sterile lines (A) and their maintainer lines (B).[a]

Source	df	DAS		PE (%)		DOLP (min)		AOLP (°)		PV(%)		SOS (mm^2)		SS (%)	
	A/B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Analysis of variance															
Replication	2	11.07	0.20	2.96	3.25	0.56	1.74	1.33	1.68*	–	0.09	0.003	0.004	0.01	0.15
Treatment	14	246.11**	266.77**	40.44**	77.54**	170.00**	151.10**	13.96**	13.17**	–	5.50	0.49	0.43**	26.35**	29.39**
Error	28	7.14	5.81	4.82	1.56	3.62	2.48	0.51	0.32	–	0.04	0.00	–	1.00	0.27
CD at 5%		4.47	4.03	3.67	2.13	3.06	2.63	1.20	0.95	–	0.35	0.09	0.14	1.70	0.87
Genetic parameters of variation															
Mean		92.75	89.70	71.70	90.90	52.32	50.39	23.96	22.82	–	96.26	1.16	0.96	23.22	81.54
CV (%)		2.88	2.68	3.06	2.61	3.50	3.12	2.99	2.49	–	0.22	4.74	3.06	4.29	0.63
Range (max)		105.66	102.66	80.04	98.00	67.50	60.33	27.73	26.60	0.00	98.50	2.24	2.11	28.29	87.55
Range (min)		78.33	74.33	66.49	83.83	40.50	39.16	21.00	19.73	0.00	93.66	0.60	0.57	16.95	76.54
Variance (P)		86.79	92.79	16.69	26.88	59.08	52.01	4.99	4.60	–	1.86	0.15	0.20	9.45	9.97
Variance (G)		79.65	86.98	11.87	25.32	55.46	49.53	4.48	4.28	–	1.82	0.16	0.21	8.45	9.70
PCV		10.04	10.74	5.70	5.99	14.67	14.31	9.33	9.40	–	1.42	35.21	39.49	13.24	3.87
GCV		9.62	10.40	4.81	5.38	14.24	13.97	8.83	9.07	–	1.40	34.89	39.38	12.51	3.82
Mean performance															
COMS8A/B		78.83	74.33	74.80	97.16	40.50	39.16	21.40	20.20	0.00	97.16	1.21	0.90	20.82	84.53
COMS9A/B		82.33	79.33	73.56	87.50	47.50	45.00	24.26	23.73	0.00	94.66	0.89	0.77	23.02	78.37
COMS10A/B		90.00	86.00	68.59	96.88	47.16	39.50	24.00	21.06	0.00	95.83	1.20	1.05	22.00	84.16
CRMS31A/B		105.66	102.66	72.46	88.82	48.50	51.00	23.66	19.73	0.00	95.16	0.63	0.57	22.90	78.51
CRMS32A/B		100.33	98.00	72.04	92.16	50.66	49.33	21.20	23.40	0.00	97.00	0.79	0.62	21.73	83.62
DRR2A/B		87.66	85.33	70.54	88.83	47.50	44.33	21.00	22.53	0.00	95.03	0.60	0.58	21.51	80.09
Pusa 5A/B		99.00	96.00	68.22	86.61	57.83	56.16	27.13	25.33	0.00	96.16	1.32	1.14	26.01	81.11
IR68886 A/B		78.33	74.66	66.49	86.17	45.50	51.00	24.66	22.73	0.00	96.33	1.24	1.04	20.81	80.50
IR68888 A/B		88.00	84.33	67.29	91.75	45.50	47.66	22.60	21.53	0.00	94.50	1.00	0.68	16.95	79.51
IR68897 A/B		92.00	88.66	71.23	85.29	50.50	45.33	22.40	20.00	0.00	93.66	1.30	1.10	22.12	76.54
IR58025 A/B		89.66	87.33	76.93	97.11	60.66	55.50	27.73	26.60	0.00	98.00	1.59	1.11	26.90	86.50
IR62829 A/B		92.66	89.00	80.04	96.83	67.50	60.83	27.00	25.13	0.00	97.33	2.24	2.11	28.29	87.55
PMS10 A/B		103.00	100.00	69.81	98.00	60.50	60.33	25.73	24.13	0.00	96.33	1.33	0.93	26.54	80.99
PMS11 A/B		104.66	102.33	70.28	87.75	54.66	50.83	23.20	21.86	0.00	98.50	0.96	0.71	25.51	81.68
PMS14 A/B		99.66	97.66	73.30	87.55	60.33	60.00	23.46	24.40	0.00	97.33	1.20	1.15	23.23	79.47

[a]** = significant at 10% level, * = significant at 5% level, DAS = days to 50% flowering, PE = panicle emergence, DOLP = duration of opening of lemma and palea, AOLP = angle of opened lemma and palea, PV = pollen viability, SOS = size of stigma, SS = seed setting, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation.

Table 2. Broad-sense heritability values (h^2) for different floral characters in rice (A lines).

Character	h^2 (%)
Days to 50% flowering	91.8
Panicle emergence (%)	71.1
Average period of opening of lemma and palea (min)	94.3
Angle of lemma and palea at peak anthesis (°)	89.7
Size of stigma (mm^2)	98.2
Seed setting (%)	89.4

tion and surface of the stigma, and this led to higher seed setting percentage. These results indicate that visual selection can be used efficiently to identify these traits. High heritability for stigma characteristics was reported by Yang et al (1986) and Neves et al (1989).

The lowest heritability, coupled with the lowest genetic advance, was reported for panicle emergence percentage. In the maintainer lines, high heritability was shown by all traits. With respect to pollen viability percentage, high heritability coupled with the lowest genetic advance was noted. Similarly, Table 3 shows significant phenotypic and environmental correlation coefficients between floral traits and seed setting percentage. In our study, correlations between six characters were worked out in all possible combinations at the phenotypic and genotypic levels for the CMS lines. The magnitude of genotypic correlation coefficients was greater than the corresponding phenotypic correlation values. This suggests a strong genetic association between the traits and phenotypic expression caused by environmental influence.

Days to 50% flowering and panicle emergence did not show any significant correlation with any of the floral traits at the phenotypic level. Neves et al (1989) reported no correlations between stigma characters. At the environmental level, the average period of lemma and palea opening showed a high and positively significant correlation with panicle emergence percentage.

It can be concluded that floral traits such as duration and

Table 3. Estimates of phenotypic (p), genotypic (g), and environmental (e) correlation coefficient pairs between characters in A lines of rice.[a]

Character		Panicle emergence (%)	Average period of lemma and palea opening (min)	Angle of lemma and palea at peak anthesis (A°)	Size of stigma (mm²)	Seed setting (%)
Days to 50% flowering	g	0.001	0.541	0.131	–0.119	0.495
	p	–0.027	0.503	0.119	–0.115	0.472
	e	–0.0178	–0.008	–0.003	–0.047	0.248
Panicle emergence	g		–0.048	–0.267	–0.540	0.585
	p		0.004	0.243	0.547	0.452
	e		0.528*	0.170	0.089	–0.085
Average period of opening of lemma and palea (min)	g			0.725	0.671	0.854
	p			0.655**	0.641**	0.786**
	e			–0.146	–0.153	0.019
Angle of lemma and palea at peak anthesis (A°)	g				0.707	0.757
	p				0.673**	0.680**
	e			0.229	0.014	
Size of stigma (mm^2)	g					0.555
	p				0.516*	
	e				–0.088	

[a]* = significant at 5% level, ** = significant at 1% level.

angle of opening of florets, size of stigma, and panicle emergence percentage are mainly responsible for influencing outcrossing. Among the A lines, IR62829A, IR58025A, Pusa 5A, PMS10A, and PMS11A showed good rates of seed setting. These may be recommended for use in hybrid seed production for the upland irrigated ecosystem. On the other hand, IR68888A, IR68888B, and DRR2A exhibited poor performance. New CMS lines should therefore have a longer floret opening period, bigger stigma surface, and wider lemma and palea angle to increase their seed-setting percentage and to achieve higher yield. Breeders working in hybrid seed production programs should give greater importance to these traits.

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Distribution of p-*SINE1-r2* at the Wx locus in cultivated and wild rice in Thailand

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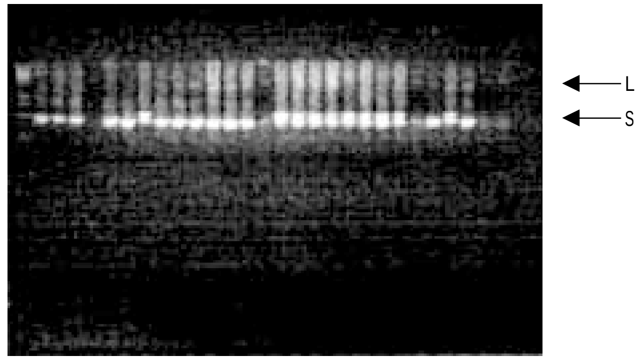
Short interspersed elements (SINEs) are retrotransposons that make their copies by the retroposition of RNA made by RNA polymerase III (Motohashi et al 1997). These are generally found in animals and plants. Umeda et al (1991) and Mochizuki et al (1993) reported the existence of the *p-SINE1* family in rice. Furthermore, Hirano et al (1994) reported that the *p-SINE-r2*, a member of the SINE family, is found only in two closely related species with the AA genome, *Oryza sativa* and *O. rufipogon*. This element is located in the 10th intron of the *Waxy* gene (Umeda et al 1991). Mochizuki et al (1993) suggested that *p-SINE1-r2* could be useful for classifying various rice strains with the AA genome.

Yamanaka et al (2003) recently suggested that the wild ancestors of *O. sativa* were differentiated into two groups at the waxy locus and that this strongly corresponded to the annual-perennial differentiation in the primary gene pool of *O. sativa*. To shed light on the gene pool of cultivated and wild rice with the AA genome in Thailand, 167 strains consisting of both cultivated species and their wild relatives *(O. nivara* and *O. rufipogon)* were surveyed in terms of *p-SINE1-r2* distribution. Total DNA was isolated from fresh leaves by using the CTAB method (Doyle and Doyle 1987). Polymerase chain reaction (PCR) and nested PCR to detect the presence or absence of *p-SINE-r2* were carried out using protocols described by previous researchers (Yamanaka et al 2003). The figure shows the results of a gel electrophoresis exhibiting the presence / absence of *p-SINE-r2*.

The table shows the distribution of *p-SINE1-r2* among rice materials from Thailand. All 106 *O. sativa* cultivars and most (35 out of 38) *O. nivara* accessions contained *p-SINE1-r2* at the waxy locus. Of the 112 perennial *O. rufipogon* accessions, 69 (61.6%) did not have *p-SINE1-r2* and the remaining 43 were heterozygous for *p-SINE1-r2*. Our results are consistent with those of Yamanaka et al (2003) and suggest a strong association between the presence of *p-SINE1-r2* at the waxy locus and perenniality in rice. However, the presence of *p-SINE1-r2* in two annual *O. nivara* accessions suggests that genetic hitchhiking is most likely responsible for the observed association.



Gel electrophoresis showing the absence (S = small band) or presence of *p-SINE1-r2* (L = large band) at the waxy locus of rice materials from Thailand. Lanes showing two bands (L and S) are heterozygotes.

Distribution of *p-SINE1-r2* at the waxy locus in cultivated and wild Thai rices.

Species/strain	Habit	Cultivars (no.)	With *p-SINE1-r2*	Without *p-SINE1-r2*	Heterozygotes
O. sativa	Annual	106	106	0	0
O. nivara	Annual	38	35	2	1
O. rufipogon	Perennial	112	0	69	43
Total		256	141	71	44

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Association between physicochemical characters and cooking qualities in high-yielding rice varieties of diverse origin

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We studied the correlation of physicochemical characters of rice grain with cooking qualities in 56 high-yielding genotypes representing different ecogeographical conditions in Bangladesh, China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Sri Lanka. The physicochemical characters are grain length (L), grain breadth (B), L-B ratio of grain, hulling percentage, and milling percentage. The cooking qualities are amylose content, alkali spreading value, water uptake, volume expansion ratio, and kernel elongation ratio. The objective of the study was to establish the relationship between these characters to assess the cooking quality of a variety on the basis of phenotypic characteristics.

The positive significant correlation of L with the L-B ratio of grain and the negative significant correlation with B (see table) indicate that, when grain size increases, its shape also increases, but its boldness is reduced. These results confirm the findings of Hussain et al (1987). The positive significant association of L and grain shape with milling percentage and the negative significant association of B with milling percentage indicate that the longer-grain types are better than the wider-grain ones in terms of milling recovery. Chauhan et al (1995) reported no relationship between kernel shape and milling recovery. Hulling and milling recovery were not influenced by amylose content and alkali spreading value. This result supports the earlier findings of Hussain et al (1987).

The positive correlation of amylose content with water uptake, volume expansion ratio, and alkali spreading value indicates that high-amylose rice varieties will absorb more water at low gelatinization temperature and will produce a greater volume of cooked material. This positive and significant correlation between amylose content and water uptake was also reported by Hussain et al (1987), but Chauhan et al (1995) found a negative association between these two traits. Madan and Bhat (1984) reported a positive and significant association of amylose content with volume of cooked rice and water absorption. The negative significant correlation between L and amylose content and the absence of correlation between amylose content, B, and L-B ratio explain the reduced amount of amylose in slender grains. Kernel elongation ratio was found to be not related with either amylose content or alkali spreading value. It was related significantly and positively with volume expansion ratio and water uptake but negatively and significantly cor-

Correlation coefficients among physicochemical characters and cooking qualities in high-yielding rice varieties of diverse origin.[a]

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Grain length (L) (V1)	–0.686**		0.961	0.091	0.0403**	–0.29	–0.419**	–0.039	–0.252	–0.403
Grain breadth (B) (V2)			–0.913**	0.057	–0.272*	0.182	0.12	0.013	–0.06	0.143
L/B of grain (V3)				–0.059	0.288*	–0.12	–0.11	–0.049	–0.046	–0.103
Hulling percentage (V4)					0.242	0.182	–0.037	–0.14	–0.18	0.038
Milling percentage (V5)						–0.15	–0.076	–0.249*	0.295**	0.097
Amylose content (V6)							0.291*	0.282*	0.295**	0.097
Alkali spreading value (V7)								0.175	0.214	-0.04
Water uptake (V8)									0.715**	0.248
Volume expansion ratio (V9)									0.305*	
Kernel elongation ratio (V10)										

[a]* = significant at 5% level; ** = significant at 1% level.

related with L. Alkali spreading value, which is an indirect measure of gelatinization temperature, showed a significant positive association with amylose content, suggesting that gelatinization temperature decreases when amylose content of a variety increases. Tomar and Nanda (1981) had the same results. Chauhan et al (1994) observed a positive nonsignificant association between these two traits. Contrary to present findings, Chauhan et al (1995) reported a significant negative association between amylose content and alkali spreading value. The present study observed a negative significant association of alkali spreading value with L and no association between alkali spreading value, B, and grain shape, an indication that long grains have reduced amylose content and require a higher gelatinization temperature than bold grains. The observed positive significant association among water uptake, volume expansion ratio, and amylose content indicates rice quality and consumer preferences in Kerala and supports the findings of Tomar and Nanda (1981).

Correlation studies between physicochemical characters and cooking qualities revealed that longer-grain types have a higher milling recovery than wider-grain ones. High-amylose rice varieties absorb more water with low gelatinization temperature and produce more cooked material. When the amylose content of a variety increases, cooking time increases. Selection for improved amylose content would result in a correlated improved response in other cooking qualities.

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Lienge, a new medium-duration upland rice variety released in Republique Democratique du Congo

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Several upland rice varieties have been cultivated under upland (dryland) conditions, the main rice ecosystem in RDC. RY1 (IRAT2) is a 140-cm-high, medium-duration (120 d), blast-resistant, and lodging-tolerant variety. It was particularly selected for its high grain yield (av 3.2 t ha^{-1}) and yield stability across locations. It was released in 1982, replacing R66, an old cultivar with a yield of 2.5 t ha^{-1}. However, RY1 is sticky when cooked. It is less acceptable to consumers who prefer cooked rice that is harder, flakier, whiter, and denser in appearance and that remains soft even when stored overnight. This quality of RY1 rice after cooking could be attributed to its low amylose content (15.6%) and this has resulted in poor acceptance by farmers.

We aimed to develop medium-height (130-150 cm), lodging-tolerant, medium-duration (120–140 d), blast-resistant, and high-yielding (more than 3.0 t ha^{-1}) varieties with good grain characteristics (length more than 9 mm; length / width of at least 3; width / thickness more or less 1; 1,000-grain weight more than 30 g; and endosperm translucency at least 60%) and good cooking quality (amylose content at least 22% and cooking volume expansion more than 350 mL 100 g^{-1}).

Five pure breeding lines selected from three crosses—OS6 / IRAT13 (PR40), OS6 / IRAT13 / / OS6 / IRAT112 (PR51), and PR40-1-2-1 / ITA128 / / IRAT13 (PR68)—were compared with RY1 during two wet crop seasons in 2000 and 2001 at the Yangambi research station (Table 1). Soil at the site is

Table 1. Yield of five selected breeding lines and check variety RY1 at Yangambi.

Breeding line/variety	Cross	Main yield (t ha^{-1})[a]		
		2000	2001	Av
RY1 (IRAT2, check)	560/var. of RDC	3.4 a	3.1 ab	3.3 ab
PR40-1-5-3a	OS6.IRAT13	3.3 a	2.7 b	3.0 b
PR40-1-4-1a	OS6/IRAT13	3.1 a	2.8 b	3.0 b
PR40-1-4-1c	OS6/IRAT13	3.6 a	3.4 a	3.5 a
PR51-5-1-7-7-3aGL	OS6/IRAT13// OS6/IRAT112	2.8 a	2.0 c	2.4 c
PR68-11b	PR40-1-2-1/ ITA128//IRAT13	3.1 a	3.0 ab	3.1 ab
Av		3.2	2.8	3.0
CV (%)		10.6	11.8	8.5

[a]In a column, means followed by the same letter do not differ significantly from each other at the 5% level by Duncan's multiple range test.

Table 2. Plant characteristics of five selected breeding lines and check variety RYI at Yangambi (av of 2 y).

Characteristic	RY1 (check)	PR40-1-5-3a	PR40-1-4-1a	PR40-1-4-1c	PR51-5-1 -7-7-3aGL	PR68-11b
Days to 50% flowering	94	98	96	97	96	98
Duration (d)	122	126	125	124	122	125
Plant height (cm)	145	164	159	150	147	152
Lodging (score)[a]	3	5	5	3	3	3
Panicle exsertion[a]	3	1	3	3	1	1
Grain length (mm)	9.62	9.82	10.50	10.20	10.30	10.30
Grain width (mm)	3.62	3.22	3.20	3.30	3.60	3.10
Length/width	2.65	3.05	3.30	3.10	2.90	3.30
Width/thickness	1.40	1.35	1.30	1.40	1.40	1.30
1,000 grain weight (g)	41	36	38	39	45	33
Translucency (%)	66	86	89	86	82	85
Volume expansion at cooking (mL 100 g^{-1})	308	360	372	389	353	354
Disease reaction[a]						
Brown leaf spot	R	R	R	R	MR	R
Leaf blast	MS	MS	MS	MS	MS	S
Leaf scald	R	R	R	R	R	R

[a]Scored using the *Standard evaluation system for rice*, June 1988.

sandy with 20–30% clay and is lighter at the surface than at depth. Annual rainfall and monthly temperature averages are 1,885 mm and 24 °C, respectively. The 2-year experiment was laid out in a randomized complete block design with four replications. Plots were 3 m × 5 m, in which 4–7 grains per hill were sown at 30 × 20-cm spacing.

Yield variation among entries was found only in the 2001 cropping season but not in the 2000 cropping season (Table 1). PR40-1-4-1c had the highest yield (3.5 t ha^{-1}), while PR15-5-1-7-7-3aGL had the lowest (2.5 t ha^{-1}) across seasons. PR40-1-4-1c had a growth duration of 124 d, a height of 150 cm (Table 2), and was tolerant of lodging. Its 1,000-grain weight was higher than the minimum required (30 g). Its grains were long and slender. It showed the highest volume of expansion at cooking, a trait desired by consumers. It was resistant to brown leaf spot and leaf scald and moderately susceptible to leaf blast. Because of these attributes, it was released as Lienge to replace IRAT2.

First semidwarf boro rice (*Oryza sativa*) germplasm collected in eastern Uttar Pradesh, India, breeds true

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Traditional boro rice is a unique type of *Oryza sativa* grown during the winter season (minimum temperature around 4 °C) in the depressions around rivers and lakes. A project funded by the Uttar Pradesh (UP) Council of Agricultural Research was undertaken to collect and conserve this type of rice. Twelve districts were explored and 570 accessions were collected. A semidwarf accession of traditional boro rice was spotted in the field of farmer Ram Briksha of Jhungiya village in the Baghauli block of Sant Kabir Nagar District, eastern UP, India. Collected in May 2000, this was given accession number 52. Plant height appeared to be about half that of a normal traditional boro plant. The average plant height of the semidwarf accession is 54.6 cm, while a tall plant without fertilizer is above 119 cm. The semidwarf plant has the same number of internodes, but the internode length was reduced. The lower internodes were much shorter than normal.

From October 2001 to May 2002, the entire collection was grown for categorization and cataloguing using the traditional package of practices. Observations on 22 morphoagronomic characters were recorded. Accession number 52 had 50 plants and all plants were semidwarf—i.e., they bred true. IRRI's *Standard evaluation system for rice* was used to describe the accessions:

Plant height	54.6 cm
Panicle length	16 cm
No. of grains per panicle	57
Days to 50% flowering	158
Days to maturity	188
Vegetative vigor	5 (normal)
Seedling height	13.16 cm
Cold tolerance	3 (seedlings light green)
Leaf blade color	2 (green)
Leaf blade pubescence	2 (intermediate)
Leaf length	26.0 cm
Leaf width	0.72 cm
Basal leaf sheath color	3 (light purple)
Tillering ability	5 (medium, 10–19 tillers $plant^{-1}$)
Awn color	3 (brown, tawny)
Awning	5 (short and fully awned)
Apiculus color	3 (tawny)
Culm length	38.6 cm
Panicle exsertion	5 (just exserted)
Culm strength	3 (moderately strong)
Lemma and palea pubescence	3 (hairs on upper portion)
Lemma and palea color	9 (black)
Spikelet fertility	3 (fertile)
Heat tolerance	1 (<80% spikelet fertility)

The traditional boro rice plant is susceptible to lodging because of its poor culm strength and excessive culm length. Because of its short culm, the semidwarf plant does not lodge. Fearing lodging problems, farmers do not add fertilizers that will further increase the chances of lodging and thereby decrease yield. Thus, they continue to look for a semidwarf boro but with its grain character intact. There are numerous semidwarf rice varieties but none in traditional boro. This accession therefore has immediate agronomic application. We had grown about 50 plants, all of which were semidwarf. The grain characters were typically those of boro rice (see table). (International organizations may request the seed through NBPGR, New Delhi.)

Comparison between common traditional boro variety and semidwarf accession no. 52.

Character	Traditional boro	Accession no. 52 (semidwarf)
Vegetative vigor	Vigorous (3)	Normal (5)
Seedling height (cm)	24.7	13.16
Leaf length (cm)	36.9	26.0
Leaf width (cm)	0.94	0.72
Culm length (cm)	83.8	38.6
Culm strength	7 (weak)	3 (moderately strong)
Plant height (cm)	104	54.6

A new, high-yielding mutant aromatic rice variety, Khushboo 95

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Rice is grown on 2.5 million ha in Pakistan. The average yield is 2.1 t ha^{-1}. During the 1960s, with the introduction of semidwarf varieties IR6 and IR8, yields doubled and most of the traditional fine-grained aromatic varieties went out of cultivation. However, Basmati 370, a traditional scented variety, survived to a certain extent. Another local aromatic variety, Jajai 77, is very popular with consumers in the province of Sindh. This variety is tall, has weak stems, and is susceptible to lodging. The most logical approach to remove these defects without impairing grain quality is to reduce plant height through induced mutation, a technique that proved successful in improving various agronomic traits in rice (Mustafa et al 1997, Singh et al 1997, Wen et al 1996, Baloch et al 2001).

Pure and viable uniform seeds of Jajai 77 were irradiated with 200 Gy of gamma rays at the International Atomic Energy Agency, Vienna, Austria, in 1981 and the M_1 generation was grown at NIA. Plants were selected on the basis of synchronous early flowering, increased tillering, and reduced plant height in the M_2, M_3, and M_4 generations during 1982, 1983, and 1984, respectively. The high-yielding, short-culm mutant line Jajai 77-30 with aromatic characteristics was eventually selected in 1984. The mutant has the following characteristics: reduced plant height, highly productive tillers, early maturity, increased panicle length, more grains per panicle, good grain quality, and distinct aroma.

Station varietal trials were conducted at two locations—Tando jam and Rice Research Institute, in Dokri, Sindh Province. The results were pooled over locations and years and data for grain yield were analyzed. The pooled analysis indicated significant ($P \leq 0.05$) differences in grain yield when averaged over locations and years. The mutant Jajai 77-30 consistently outyielded (5.3 t ha^{-1}) all other entries. Its grain yield was 74%, 77%, and 81% higher than that of commercial variety Jajai 77, Basmati 370, and Lateefy, respectively.

Jajai 77-30, along with other promising genotypes, was evaluated in zonal trials over 10 locations in Sindh from 1988 to 1990. This mutant outyielded all other entries in these trials. In coordinated national uniform rice yield trials conducted by the Pakistan Agricultural Research Council (PARC), Islamabad, from 1989 to 1991, Jajai 77-30 was the top and second-best yielder over various locations in Pakistan (3.7–4.2 t ha^{-1}) and in Sindh (3,724–4,483 kg ha^{-1}), respectively.

Jajai 77-30, named Khushboo 95, was approved for general cultivation in the province by the Sindh Seed Council in 1996. Now a prominent rice variety, it is grown on large areas in Dadu, Sanghar, and Jacobabad districts of Sindh and in Hafizabad District of Punjab. Yields ranged from 3.7 to 5.0 t ha^{-1}, which were substantially higher than those of well-adapted local aromatic varieties. The grain chalkiness of Khushboo 95 was much lower than that of the parent (see table).

Agronomic characteristics of mutant variety Jajai 77-30 (Khushboo 95) and its parent Jajai 77.

Characteristic	Jajai 77-30 (Khushboo 95)	Jajai 77	Increase over parent (%)
Yield (t ha^{-1})	4.4	2.1	52
Productive tillers $plant^{-1}$ (no.)	14.45	10.68	26
Filled grains $panicle^{-1}$ (no.)	148	88	41
Length/breadth	3.24	3.07	5
Head rice (%)	44.0	41.5	6
Chalkiness (%)	25.0	68.83	64 (decrease)
Amylose content (%)	20.80	19.81	5
Plant height (cm)	130	160	19 (decrease)
Proportionate elongation	1.55	1.50	3

Basmati 2000—an extra long-grained aromatic rice variety in Punjab, Pakistan

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Basmati 385 and Super Basmati are the main Basmati varieties grown in Punjab Province. Basmati 385 is an early-maturing and high-yielding variety, but it has long grain, which cannot compete with the extra long-grained Indian varieties. Super Basmati, on the other hand, is not well liked by farmers because it is harder to thresh and gives a lower yield than Basmati 385. However, being an extra long-grained variety with excellent cooking quality, it fetches a high price in the domestic and international markets. Breeding efforts were thus directed to producing a high-yielding Basmati variety with stiff stems, extra long grains, and excellent cooking and eating qualities.

Basmati 385 was crossed with 4048-3 (Super Basmati) in 1987. The pedigree method of selection was used until 1992. Line PK4553-42-1-2 was selected and tested in 29 trials conducted from 1995 to 1999. The overall average yield of PK4553-42-1-2 was 4.0 t ha^{-1}, 17% higher than Super Basmati's 3.4 t ha^{-1} (Table 1). However, the yield of PK4553-42-1-2 was on a par with that of Basmati 385. This new variety, approved for general cultivation in 2000 as Basmati 2000, has stiff stems, medium maturity, extra long grains, and excellent cooking characteristics (Table 2).

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Table 1. Yields of PK4553-42-1-2 and check varieties Basmati 385 and Super Basmati.

Trial	Trials (no.)	Yield (t ha^{-1})			Percent increase/ decrease over	
		Basmati 385	Super Basmati	PK4553-42-1-2	Basmati 385	Super Basmati
Varietal Yield Trial (1995-99)	5	3.09	2.58	3.15	+2	+22
Micro-plot Yield Trial (1996-99)	11	4.35	3.60	4.48	+3	+24
National Uniform Yield Trials (1994-96)	13	4.54	4.06	4.36	-4	+7
Av	29	3.99	3.41	4.00	–	+17

Table 2. Agronomic and grain quality characteristics of PK453-42-1-2 and check varieties Basmati 385 and Super Basmati.

Character		Basmati 385	Super Basmati	PK4553-42-1-2
General	Plant height (cm)	130	115	135
	Productive tillers plant^{-1} (no.)	13	15	13
	Grains panicle^{-1} (no.)	127	117	124
	Maturity (d from transplanting)	112	117	115
Grain	Thickness (mm)	9.50	10.99	10.89
	Length (mm)	2.00	2.10	1.97
	Width (mm)	1.85	1.86	1.96
Kernel	Length (mm)	6.80	7.45	7.68
	Width (mm)	1.72	1.72	1.83
	Thickness (mm)	1.57	1.62	1.64
	Length/width	3.95	4.33	4.19
	Shape	Slender	Slender	Slender
Boiled kernel	Length (mm)	13.0	13.9	14.5
	Width (mm)	2.32	2.20	2.30
	Thickness (mm)	2.20	2.00	2.20
Milling results (%)	Husk	22.5	22.5	22.0
	Bran	9.0	9.0	8.5
	Total recovery	68.5	68.0	69.5
	Head rice	52.0	50.5	53.0
	Broken	16.5	17.5	16.5
Cooking characters	Proportionate elongation	1.91	1.86	1.88
	Bursting (%)	9.0	7.0	6.0
	Aroma	Present	Present	Present
Chemical characters	Amylose (%)	24.6	24.4	23.2
	Gel length (mm)	75.0	78.0	77.0
	Alkali spreading value	3.5	5.1	5.0
	Protein (%)	8.1	8.5	8.2

Determinants of a premium-priced, special-quality rice

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Thai Jasmine or Thai Hom Mali is Thailand's special-quality rice for which local consumers and export markets are willing to pay a premium price. Thai Jasmine rice does not always receive a premium price from buyers. The price varies, depending on where the crop is grown. For example, milled rice (special grade, 100% head rice) from Prao is sold at a retail price of 22 baht kg^{-1} (US$1 = 43 baht), that from Sanpatong costs 20 baht kg^{-1}, whereas Mae Chan rice fetches 16 baht kg^{-1}. Milled rice from Prao with 5% broken grain is priced at 17 baht kg^{-1}. In this paper, we examined the relationship between quality parameters used by commercial rice buyers and the price they pay for KDML 105.

Twenty-seven 500-g samples of unhusked KDML 105 were collected from farmers' fields in Chiang Mai in the upper part of northern Thailand, as well as 20 samples from Nakornsawan in the lower north. The samples were priced and rated for quality characteristics by a commercial rice buyer (Chiangmai Chaiwiwat Ricemill Co., Ltd.). The quality characteristics evaluated were grain moisture, percentage head rice yield, aroma, vitreousness, and translucency. Grain moisture was measured by a Riceter series L grain moisture tester (Kett Electric Laboratory). A small sample (20–30 g) of rice was unhusked on a board with a roller. An experienced rice buyer rated percentage head recovery, vitreousness, translucency, and aroma, using a 0–3 scale.

All 27 samples from Chiang Mai were priced above 7,000 baht t^{-1} (US$162). In contrast, samples from Nakornsawan were more varied and received prices ranging from less than 5,500 to more than 7,000 baht t^{-1}. Only 10% of the samples from Nakornsawan were judged to be of premium quality and priced at more than 7,000 baht t^{-1}; 40% were priced at less than 5,500 baht t^{-1}. Grain moisture did not exceed the standard 14% in any of the samples—those from Chiang Mai ranged from 13.3% to 14.0%, while the Nakornsawan samples had 11.2–12.0%. The prices of Nakornsawan samples were determined primarily by their aroma and vitreousness scores, with percentage head rice and translucency having relatively minor effects (equation 1).

$$P = 3,259.7 + 28.8X_1^{*} + 403.5X_2^{*} + 357.1X_3^{*} + 71.9X_4^{ns} \quad r^2 = 0.82^{***} \quad (1)$$

where P = sample price, X_1 = percentage head rice, X_2 = aroma score, X_3 = vitreousness, score, and X_4 = translucency score.

All 27 samples from Chiang Mai received the full score of 3 for vitreousness, translucency, and aroma. Price was determined by only one quality characteristic, percentage head rice (equation 2).

$$P = 6,969.4 + 11.3X_1^{***} \quad r^2 = 0.92^{***} \quad (2)$$

These results illustrate the effect of geographic differences on special-quality rice. The Chiang Mai samples represent areas that produce rice with high-quality characteristics in terms of aroma, grain translucency, and vitreousness. In such a situation, attention to factors that influence percentage head rice would ensure that farmers are paid premium prices for their harvest. Grain moisture at harvest and during application of N fertilizer has been shown to strongly affect head rice percentage (Nangju and De Datta 1970, Jongkaewattana et al 1993). The problem is much more complicated for farmers in areas where important quality parameters, such as aroma and vitreousness, are highly variable as we found in Nakornsawan. In such a situation, production of Thai Jasmine rice that will fetch premium prices will not be possible until environmental factors governing these quality parameters are identified and controlled.

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Bhudeb, a new variety for the rainfed lowland ecosystem in eastern India

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The average yield of rice in the semideepwater ecosystem (41–75 cm) is less than 2 t ha^{-1} compared with 4 t ha^{-1} observed in the irrigated ecosystem. The State Variety Release Committee (SVRC) of West Bengal approved the release of a new variety, Bhudeb (CN1035-61), for the semideepwater ecosystem in November 2002. The F_2 seeds of IR57540 were received from IRRI in 1988 and these were grown for generation advance, assessment, and selection, following the method suggested by Mallik et al (2002) at RRS. In 1995, CN1035-61 (IET14496), one of the selections from IR57540, was nominated to the National Program Initial Variety Trial.

Bhudeb (Pankaj / IR38699-49-3-1-2//IR41389-20-1-5) has the genes of 25 parents originating from more than nine countries—one parent each from Sri Lanka (Babawee), Thailand (Gam Pai), and Vietnam (Tetep); two parents each from Taiwan (Tsai Yuan Chung and Dee-Geo-Woo-Gen), Malaysia (Siam 29 and Tangkai Rotan), Philippines (Tadukan and Sinawpagh); three parents each from the USA (Blue Rose Supreme, Marong Paroc, and Pa Chiam); Indonesia (Bayang, Benong, and Cina); seven parents from India (Gowdalu, Kitchili Samba, Latisail, Mudgo, *O. nivara*, Thekkan, and Vellaikar); and three parents from unknown places (Eravapandi, Pachchaperumal, and Vellai Illaankalayan). Some parents, such as Marong Paroc, Blue Rose Supreme, *O. nivara*, Tadukan, and Dee-Geo-Woo-Gen have been used more than once.

The All India Rice Workshop recommended large-scale testing and release of Bhudeb in 1999, considering its superior performance in the national trial (Table 1). Under semideepwater conditions in 1995–98, the mean yield of Bhudeb was 3.2 t ha^{-1} (Sabita, the national check, has 2.2 t ha^{-1}). In shallow water (<40 cm) in 2000, Bhudeb yielded 4.4 t ha^{-1}, which was 16% higher than the yield of check Savithri. Through the IRRI-ICAR shuttle breeding

Table 1. Performance of CN1035-61, national trial (semi-deep and shallow water), 1995–2000.[a]

Year	Trial/location	Yield (t ha^{-1})			CD (0.05)	Water depth (cm)
		CN1035-61	Check 1 (U. Prabha)	Check 2 (Sabita)		
1995	IVT-SDW[b]					
	Ghangraghat, UP	1.03	0.23	0.17	0.22	45
	Chinsurah, WB	2.08	0.67	2.50	0.29	77
	Ranital, Orissa	2.72	2.08	2.88	0.74	na[e]
	Faizabad, UP	1.60	1.41	1.08	0.36	40
1996	Bhubaneswar, Orissa	3.75(3)	1.67	1.81	0.63	40
	Pusa, Bihar	4.54(1)	3.00	2.09	1.22	40
	Canning, WB	2.60	NIL	NIL	0.92	na[e]
	Chinsurah, WB	1.85(4)	0.79	2.08	0.47	45
	Cuttack, Orissa	5.90	6.38	6.38	1.55	na[e]
	Mean (IVT)	2.90	1.80	2.11		
1997	AVT-SDW[c]		Local	Sabita		
	Sabour, Bihar	5.92(1)	NIL	NIL	0.82	na[e]
	Masodha, UP	4.59(2)	1.41	3.04	0.43	40
	Karimganj, Assam	3.89(4)	3.46	2.99	0.34	21
	Gosaba, WB	2.67	2.55	2.50	NS	48
	Chinsurah, WB	2.67(2)	2.31	2.85	0.35	68
1998			U. Prabha	Sabita		
	Chinsurah, WB	3.02(2)	2.05	2.89	0.46	59
	Canning, WB	2.89(4)	2.02	2.08	0.52	na[e]
	Gosaba, WB	1.79(5)	1.30	1.40	1.09	75
	Mean (AVT)	3.43	1.79	2.22		
	Grand mean	3.16	1.80	2.16		
2000	Advanced variety trial 1-Late (Shallow<40 cm)					
		CN1035-61	Savithri	Check[d]		
	Jeypore, Orissa	5.20	6.04	4.69	0.56	
	Patna, Bihar	5.00	4.06	5.37	NS	
	Hazaribagh, Bihar	4.38(2)	-	2.58	0.91	
	Faizabad, UP	1.54	0.61	0.84	0.18	
	Varanashi, UP	5.60	5.23	5.52	NS	
	Jagadalpur, MP	3.02	2.20	3.84	0.90	
	Karimganj, Assam	2.83(4)	2.78	2.91	0.18	
	Maruteru, AP	5.77	4.93	5.98	NS	
	Coimbatore, TN	6.30	6.48	6.31	0.06	
	Raipur, Chhattisgarh	4.47(3)	2.01	4.33	0.89	
	Mean	4.41	3.81	4.24		

[a]Figures in parentheses indicate ranking in the respective location. [b]IVT-SDW=initial variety trial semi-deepwater. [c]AVT-SDW=advanced variety trial semi-deepwater. [d]Pooja and Salivahan are the regional checks for eastern and other parts of India, respectively. [e]NA=not available.

program in 1998–99, the variety was tested under normal and delayed planting conditions. In normal planting, average yield was 3.47 t ha^{-1}, 16% and 39% higher than Sabita and Mashuri, respectively (Table 2). In late planting, the corresponding figures were 29% and 49%. In the 2000 multilocational adaptive trial over six locations in West Bengal, Bhudeb ranked first with a yield of 3.3 t ha^{-1}, which was 42% higher than Sabita's.

In 50 on-farm locations in seven districts of Bengal—Hooghly, Burdwan, Bankura, North 24 Parganas, South 24 Parganas, Uttar Dinajpur, and Dakshin Dinajpur—Bhudeb registered 3.5 t ha^{-1} yield in 2001 (RRS 2001). In front line demonstrations in the same year, it ranked first with 3.6 t ha^{-1} yield, which was 28% higher than Sabita's. On-farm testing in Assam showed that the variety was acceptable in two districts—Darrang and Kamrup. In Darrang, farmers named it *Ban Vijay* ("conquering the flood"), as it survives even after three floods in kharif. In Kamrup, Bhudeb had a yield of 4.2 t ha^{-1}, while the local variety had 3.2 t ha^{-1}. Farmers of Puri District in Orissa also accepted the variety as it manifested 63.9% yield increase over the local check in 2001. In Narangad, Khurda District, Orissa, Bhudeb survived even after 10–12 d of complete submergence, yielding 4.5 t ha^{-1} in 2001 kharif (CRRI 2002).

Bhudeb is a nonlodging, semitall (130–135 cm) variety with 150 d growth duration. It has deep green leaves, long erect flag leaf, and well-exserted panicles. Each panicle contains 160–170 grains with a panicle weight of 5.47 g. The potential yield of the variety is 6.2 t ha^{-1} (RRS 1999). Detailed characteristics are presented in Table 3. The variety is resistant to bacterial leaf blight (race 1), blast, brown planthopper (biotype 1), and gall midge (biotype 1), and is moderately resistant to sheath blight, sheath rot, and stem borers.

Table 2. Performance of CN1035-61 under the shuttle breeding program, 1998–99.

	Location	Yield (t ha^{-1})			CD (0.05)
		CN1035-61	Sabita	Mashuri	
1998 (N)[a]	CRRI, Orissa	4.03	4.80	1.98	1.24
	Rainital, Orissa	3.42	–	–	0.50
	Masodha, Uttar Pradesh	3.78	1.58	1.42	1.40
	Chinsurah, West Bengal	2.83	2.50	1.92	0.38
	Patna, Bihar	4.09	3.23	3.79	0.78
	Titabar, Assam	3.35	2.71	2.74	0.79
1999	Chinsurah, West Bengal	3.70	2.45	2.45	0.42
	CRRI, Orissa	2.54	1.50	1.67	0.44
	Mahsidh, Uttar Pradesh	3.32	3.05	3.62	0.52
	Raipur, Chattisgarh	3.61	4.14	3.11	0.89
	Titabar, Assam	3.04	3.07	2.37	0.47
	N. Lakhimpur, Assam	3.97	3.78	2.48	0.80
	Mean	3.47	2.98	2.50	
1998 (D)[b]	CRRI, Orissa	2.32	Nil	Nil	0.91
	Ranital, Orissa	2.92	–	–	0.44
	Masodha, Uttar Pradesh	1.79	0.78	0.90	0.17
	Chinsurah, West Bengal	3.20	3.50	1.80	0.38
	Patna, Bihar	2.88	2.53	2.78	0.84
	Titabar, Assam	1.47	1.31	1.70	0.46
1999	Chinsurah, West Bengal	2.05	2.05	1.90	0.18
	CRRI, Orissa	0.53	0.37	0.29	0.14
	Masodha, Uttar Pradesh	2.49	2.12	2.30	0.55
	N. Lakhimpur, Assam	2.80	2.93	1.68	0.30
	Titabar, Assam	2.25	1.75	1.79	0.25
	Mean	2.25	1.73	1.51	

[a]N = normal planting (middle of August). [b]D = delayed planting (first week of September).

Table 3. Agronomic and quality characteristics of variety Bhudeb (CN1035-61), IET14496.

Characteristic	Estimate
Plant height (cm)	Semitall (130–135)
Duration (d)	150–155
Plant type	Erect, compact, and non-lodging
Tillers plant^{-1} (no.)	6 to 7
Panicle type	Compact
Panicle exsertion (cm)	Complete, 3–4
Awn (mm)	Absent
Grains panicle^{-1}(no.)	160–170
Panicle weight (g)	5–5.5
Panicles m^{-2} (no.)	225–250
1000-grain weight (g)	22.70
Hulling (%)	72.32
Milling (%)	67.60
Length of grain (mm)	8.86
Breadth of grain (mm)	2.40
Thickness of grain (mm)	1.89
L/B (grain)	3.69
Kernel length (mm)	6.27
Kernel breadth (mm)	2.13
Kernel thickness (mm)	1.68
L/B (kernel)	2.94
Kernel color	White
Alkali value	4.0
Chalkiness	Absent
Elongation ratio	1.33
Volume expansion	3.5
Amylose (%)	25
Gelatinization temperature	Intermediate
Gel consistency	50

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Liboga, a new, short-duration upland rice variety released in Republique Democratique du Congo

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Two short-duration rice varieties, IRAT112 and Lioto, with average yields of 2.6 and 2.8 t ha^{-1}, respectively, have been released in the country since 1982. Farmers have shown great interest in cultivating short-duration rice varieties as these allow them to have food and money quickly. During the last 2 years, the Agronomic Research Centre of INERA at Yangambi has produced, in collaboration with some nongovernment organizations, a total of 75 t of short-duration variety rice seeds and distributed them to farmers in the eastern province of Congo. IRAT112 produces 8% less than Lioto and its short stature (100 cm) makes the common practice of hand harvesting difficult for tall farmers, who must stoop to harvest panicles. They prefer a medium-height (130–150 cm) variety that can tolerate lodging.

To identify more short-duration rice varieties for the country, we compared five lines with IRAT112 and Lioto as check varieties during two crop seasons in 1999-2000 at the Yangambi research center. The 2-year experiment was laid out in a randomized complete block design with four replications. Plots were 3 m × 5 m, in which 4–7 grains per hill were sown at 25 × 20-cm spacing.

The yields of the test entries, except that of PR43-90-7-2-2, were comparable with those of the check varieties (Table 1). Liboga gave the highest yield. It matured a few days earlier (Table 2). It was tall but resistant to lodging. Its grains were long and medium in shape. Its volume expansion was higher than that of the check varieties. It showed moderate resistance to brown leaf spot and leaf blast. Liboga was released as a new short-duration upland rice variety because of its high yield potential, good plant stature, and desirable grain characteristics.

Table 1. Yield of five selected breeding lines and check varieties at Yangambi, 1999-2000.

Breeding line/variety	Cross	Mean yield (t ha^{-1})[a]		
		1999	2000	Av
IRAT112 (check)	IRAT13/Dourado precoce	2.8 ab	2.3 a	2.6 a
Lioto (check)	R66/IRAT112 2.8 ab	2.7 a	2.8 a	
Liboga	Mutant IRAT112	3.1 a	2.7 a	2.9 a
PR43-63-21-9-3	OS6/IRAT112	3.0 a	2.2 a	2.6 a
PR43-90-7-2-2	OS6/IRAT112	2.4 b	1.1 b	1.8 b
PR50-13-3-3-11-2a	R66/IRAT13//R66/IRAT112	3.1 a	2.2 a	2.6 a
PR50-13-3-3 11-2b	R66/IRAT13//R66/IRAT112	2.9 a	2.3 a	2.6 a
Av		2.9	2.2	2.6
CV (%)		10.8	15.1	10.8

[a]In a column, means followed by the same letter do not differ significantly from each other at the 5% level by Duncan's multiple range test.

Table 2. Characteristics of five selected breeding lines and check varieties at Yangambi (av of 2 y).

Characteristic	IRAT112 (check)	Lioto (check)	Liboga	PR43-63-21-9-3	PR43-90-7-2-2	PR50-13-3-3-11-2a	PR50-13-3-3-11-2b
Days to 50% flowering	76	76	72	76	78	76	78
Duration (d)	104	104	100	104	108	105	108
Plant height (cm)	117	134	140	124	125	122	120
Lodging (score)[a]	2	3	2	2	2	2	2
Panicle exsertion	5	1	1	1	1	7	7
Grain length (mm)	9.95	9.42	9.21	9.74	9.06	9.83	10.01
Grain width (mm)	3.20	3.09	3.45	3.70	3.76	3.83	3.81
Length/width	3.10	3.05	2.67	2.63	2.40	2.56	2.63
Width/thickness	1.33	1.36	1.49	1.40	1.48	1.42	1.44
1,000-grain weight (g)	35.4	37.2	36.0	42.4	42.0	42.0	43.0
Translucency (%)	72	74	75	80	72	81	79
Volume expansion at cooking (mL 100 g^{-1})	372	372	389	389	398	385	377
Disease reactions[a]							
Brown leaf spot	MS	MR	MR	MS	MR	MS	MS
Leaf blast	MR	MR	MR	MR	MR	MR	MR
Leaf scald	MS	MR	MS	MS	MS	MS	MR

[a]Scored using the *Standard evaluation system for rice*, June 1988.

Efficacy of fungicides for control of rice tungro disease

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Tungro is considered an important disease of rice in Southeast Asia and in the southeastern states of India. Tungro virus disease can be managed through vector control (Bae and Pathak 1969, Shukla and Anjaneyulu 1980, Satapathy and Anjaneyulu 1984). Dubey (1980) reported that Bavistin, a fungicide, was effective in controlling leaf crinkle virus of urdbean. This prompted us to test fungicides for the therapeutic recovery of tungro on rice. We tested 12 fungicides (three granular, three EC formulations, and six wettable powders) under net-house conditions for therapeutic recovery of plants that were previously infected with tungro disease. One-month-old Jaya seedlings were planted in four rows of 10 seedlings per tray. Ten seedlings were healthy and 10 seedlings each of three replications were inoculated with three viruliferous hoppers per seedling in galvanized iron-mesh cages. The top of the cage was covered with muslin cloth and tightened with a rubber band. After symptoms were expressed (about 10–12 d after inoculation), each tray was sprayed with the fungicide at recommended doses at weekly intervals. Five such sprays were given. Virus quantification and symptomatology before the treatments showed a yellow color of the youngest leaf, which is a typical tungro symptom. After treatment with effective fungicides, the yellow color gradually fades away and the plant is able to recover. Two trays were not sprayed with fungicide (each tray has 20 healthy seedlings and 20 inoculated seedlings) and these served as a control. The height of the plants and number of tillers were observed and plant yield determined.

The fungicides tested were Oryzomate, Coratop, Kitazin, Hinosan, Tilt, Validamycin, Fongorene, Chlorothanil, Rovral, Topsin, Dithane M-45, and Bavistin. Of these, Coratop and Oryzomate resulted in plant recovery to the extent of a 10% reduction in height, 11.6 average number of tillers, and 14.8 yield per plant in grams. The corresponding figures in the control (inoculated) were 70%, 2.2, and 0.9, respectively. Kitazin and Fongorene showed moderate recovery (see table). The statistical design used in this experiment was a complete randomized design. ANOVA was calculated and it was found that the critical difference value for percent reduction in height was 25.4, 3.3 for average number of tillers, and 4.2 for yield per plant, values that are significantly different from those observed in Oryzomate and Coratop. It was difficult to make a group comparison of fungicides, even though a significant difference exists between granular insecticides and EC formulations. Among the wettable powders, Fongorene, Topsin, Dithane, and M-45 were more effective than other fungicides. The reason for comparing Oryzomate and Coratop with the healthy control is to show how effective these

Evaluation of fungicides in terms of ability to control rice tungro disease.

Fungicide	Dose (1 g or 1 mL ai L^{-1})	% reduction in height compared with healthy plant	Tillers $plant^{-1}$ (av no.)	Yield $plant^{-1}$ (g)
Granular				
Oryzomate	1 g $tray^{-1}$	10	11.6	14.8
Coratop	1 g $tray^{-1}$	10	11.4	14.6
Kitazin	1 g $tray^{-1}$	25	7.2	8.8
EC formulations				
Hinosan	1 mL L^{-1}	60	3.1	1.8
Tilt	1 mL L^{-1}	65	2.9	1.9
Validamycin	2 mL L^{-1}	70	2.6	1.6
Wettable powders				
Fongorene	1 g L^{-1}	25	7.8	8.2
Chlorothanil	1 g L^{-1}	60	2.4	2.0
Rovral	1 g L^{-1}	65	2.7	1.4
Topsin	1 g L^{-1}	25	8.0	7.8
Dithane M-45	1 g L^{-1}	25	7.4	8.6
Bavistin	1 g L^{-1}	65	2.8	1.5
Control (healthy)	–	–	11.8	15.4
Control (diseased)	–	70	2.2	0.9
CD (5%)		25.4	3.3	4.2

treatments are. They were significantly different from the diseased control.

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Trapping the adult whorl maggot *Hydrellia philippina* Ferino with baits

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The whorl maggot, *Hydrellia philippina* Ferino (Diptera: Ephydridae), attacks rice seedlings at transplanting (Reissig et al 1986). As the larva feeds on the tissues of unopened leaves, white or transparent patches become evident near the edges when they unfold. Pinholes on leaves, which break from the wind, are other symptoms of attack. The damaged plants remain stunted with a few tillers. Ephydrids cause a 10–20% yield loss in rice (Foote 1995). The adults are active during the day, with limited migration, and they are highly attracted to fishmeal bait (Reissig et al 1986). However, the strong odor of decomposing fishmeal is not acceptable to all human beings. Since behavioral approaches are key elements in integrated pest management (Foster and Harris 1997), we evaluated the attractiveness of two selected food attractant admixtures involving banana, soybean hydrolysate, vinegar, and palm oil.

Relative efficacy of baits in luring adult *H. philippina* in two locations.

Attractant admixture (95:4:1)	Traps (no.)	Flies captured (no. trap^{-1} d^{-1})		Pooled mean[c]
		Location 1[a]	Location 2[b]	
Banana pulp + vinegar + palm oil	10	24.8 (4.9)	16.1 (4.0)	20.4 (4.4)
Soybean hydrolysate + vinegar + palm oil	10	19.9 (4.4)	9.0 (3.0)	14.5 (3.7)

[a]Significant difference (P<0.01), Student's t = 4.1. [b]Significant difference (P<0.01), Student's t = 2.6. [c]Significant difference (P<0.01), Student's t = 3.5. Numbers in parentheses are $\sqrt{x + 0.5}$ transformed values.

Two 5-d-long field experiments were conducted in two locations (AC and RI, Killikulam, and a nearby farmer's field in Tamil Nadu, India) in 2000-01 using irrigated lowland rice variety ADT36 immediately after transplanting. On each 0.4-ha site, fly traps were set up 1 m above the ground. Two attractant admixtures—banana pulp / soybean hydrolysate + vinegar + palm oil (95:4:1), selected after a preliminary round of evaluation with a few others—were each placed in 10 traps that were arranged at 10-m spacing in a row. The two rows were 20 m apart. The baits were placed in Horlicks® bottle lids (6 cm diameter) at 20 g (banana pulp) or 20 mL (soybean hydrolysate) per trap. Palm oil was added to the baits to prevent them from drying because of the high temperature (33.0 ± 4.5 °C; 74.5 ± 13.5% relative humidity). Each day, the attractant admixtures were placed in the bait chamber of the trap at 0600 and the trapped flies were counted at 1800. The fly-catch data were compared by a paired t-test after $\sqrt{x + 0.5}$ transformation.

The results indicated that banana pulp + vinegar + palm oil (20.4 flies trap^{-1} d^{-1}) was 29% significantly (P< 0.01) more attractive to adult *H. philippina* than soybean hydrolysate + vinegar + palm oil (9.0–19.9 flies trap^{-1}d^{-1}).

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Effects of two potent biocontrol agents on water hyacinth

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Water hyacinth [*Eichhornia crassipes* (Mart.) Solms] is a noxious aquatic weed in rice fields. Farmers are compelled to erect barricades to prevent these weeds from entering their fields through irrigation canals. Mechanical removal and chemical methods are advocated, but, for one reason or another, none of the methods proved successful in controlling the weed. In recent years, biological control has received great attention.

Bowers (1986) described a procedure for field application of Collego, a water-suspendible dried spore preparation of the fungus *Colletotrichum gloeosporioides* f. sp. *aeschynomene* for the control of Northern jointvetch in rice and soybean fields. Abbot Laboratories-USA developed an experimental formulation of *Cercospora rodmanii* (named ABG-5003) against *E. crassipes* (Te Beest 1991).

A survey was carried out from Feb 2000 to Feb 2001 at quarterly intervals in rice fields of Kerala State, India, to identify fungal pathogens of water hyacinth with biocontrol potential. A number of fungi were isolated from plant parts showing disease symptoms. Pathogenicity tests revealed that seven out of 14 fungi were pathogenic to the weed plant: *Fusarium pallidoroseum*, *Myrothecium advena*, *F. oxysporum*, *F. moniliforme*, *Alternaria eichhorniae*, *Colletotrichum gloeosporioides*, and *Curvularia* sp. Of these pathogenic fungi, *F. pallidoroseum* and *M. advena* caused the drying up of water hyacinth plants. The other pathogenic isolates induced necrosis of leaf tissues around the site of inoculation, spreading 3–5 mm from the wound.

An experiment was conducted to test the host susceptibility of two efficient pathogenic fungi—*F. pallidoroseum* and *M. advena*—on 53 cultivated plants and 55 commonly occurring weeds under glasshouse conditions. Ten-day-old *F. pallidoroseum* culture grown on rice bran (Thara and Naseema 1998) was used to artificially inoculate leaves and stems of host plants. In the case of *M. advena*, the fungus was grown in Czapek's broth. After 10 d, the broth was shaken and the spore suspension thus obtained was sprayed on the host plants using an atomizer. Control plants were also maintained for each host plant.

F. pallidoroseum was found to be pathogenic to seven cultivated plants and six weed plants. Even though *F. pallidoroseum* was pathogenic to some cultivated plants such as cashew, papaya, banana, sweet potato, amaranthus, and tomato, it produced only small isolated spots at the point of inoculation and it did not spread. In water hyacinth, it caused complete blighting and drying up of the entire plant within 7 d. The fungus was found to be pathogenic to weed plants that are common in rice fields: *Hydrocotyl asiatica*, *Alloteropis cimicina*, *Monochoria vaginalis*, *Brachiaria ramose*, *Commelina benghalensis*, *C. jacobi*, *Eclipta alba*, *Cynodon dactylon*, and *Phyllanthus niruri*. On the other hand, *M. advena* was not pathogenic to any of the cultivated plants tested, whereas it was pathogenic to weeds such as *Marselia marcescens*, *Pistia stratiotes*, and *Limnocharis flava* in rice fields.

Since water hyacinth is a troublesome weed in rice fields, entailing much labor cost, the possibility of using *F. pallidoroseum* and *M. advena* as mycoherbicides must be exploited. Aside from being a rice weed, water hyacinth is also a problem in waterways where herbicide cannot be used as the water is used for drinking and other household purposes. Preliminary studies showed no harmful effects of these fungi on aquatic fauna. Our study revealed that *F. pallidoroseum* and *M. advena* could be used for biological control of water hyacinth as they are not expected to create problems for plants of economic and ecological importance.

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Sheath rot management in rice with fungicides and biopesticides

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Sheath rot disease of rice, caused by *Sarocladium oryzae*, inflicts damage to the uppermost flag-leaf sheath by infecting the sheath covering the young panicles at the booting stage. The young panicles are generally affected, leading to an increase in the number of chaffy, discolored, and shriveled grains and a reduction in weight and number of healthy grains. Because the disease inoculum increases in proportion from year to year, appropriate management of this disease under field conditions with fungicides and biopesticides is essential.

To assess the field efficacy of different fungicides and biopesticides, an experiment was conducted at the experimental farm of the Department of Plant Pathology, IGKV, Raipur, in 1997. The experiment was laid out in a randomized block design with 10 treatments replicated thrice. The test rice variety, Kranti, was grown in 3 × 2-m plots at a spacing of 20 cm × 15 cm. A uniform dose of 120 kg N, 22 kg P, and 24.9 kg K ha^{-1} was applied as basal in all treatments at transplanting. At the booting stage, each tiller was inoculated with four to five half-cooked rice grains coated with spores of *S. oryzae* culture. These nine formulations—Hinosan (0.1%), Antracol (0.05%), Baynate (0.1%), Octave (0.1%), Tilt (0.1%), Bavistin (0.1%), neem gold (2.0%), neem azal (0.3%), and Raze (1.0%)—were evaluated in the experiment.

The effectiveness of the treatments was compared on the basis of severity after application of two chemical sprays using the following formulas:

$$\text{Disease incidence (\%)} = \frac{\text{No. of plants infected}}{\text{Total no. of plants}} \times 100$$

$$\text{Disease severity (\%)} = \frac{\text{Area of leaf sheath infected}}{\text{Total leaf sheath area}} \times 100$$

The disease was observed in all treatments at varying severity levels (see table). All formulations were more effective in reducing disease severity than the control. There was less variation in percent incidence and this was recorded from 54.95% (Octave) to 66.28% (control). The fungicides Tilt, Bavistin, and Antracol were found to be superior in reducing the severity of sheath rot disease.

All the chemical fungicide and biopesticide formulations effectively and significantly reduced the severity of the disease over the untreated control. The fungicides Tilt, Bavistin, and Antracol were the most effective of all treatments. Singh and Raju (1981), Thrimurty (1986), and Karmakar (1992) had also reported the efficacy of carbendazim (Bavistin) in reducing disease severity and the present finding confirms these reports. Lewin and Vidhyasekaran (1987), however, reported that fungicides could be effective in vitro but failed to reduce disease severity under field conditions.

Effects of fungicides and biopesticides on sheath rot severity.

Fungicide/biopesticide (group)	Concentration (%)	Disease incidence (%)	Disease severity (%)
Hinosan (edifenphos)	0.1	58.07	62.95[a](52.52)[b]
Antracol (propineb)	0.05	59.50	59.25(50.32)
Baynate (thiophanate methyl)	0.1	59.83	64.81(54.09)
Octave (prochloraz)	0.1	54.95	66.66(54.84)
Tilt-25 E.C. (propiconazole)	0.1	55.56	47.14(43.90)
Bavistin (carbendazim)	0.1	57.89	55.55(48.23)
Neem gold (neem-based)	2.0	60.84	64.81(53.68)
Neem azal (neem-based)	0.3	62.31	66.66(54.88)
Raze (*Lantana camara*-based)	1.0	59.84	64.81(53.84)
Control	–	66.28	85.18(67.43)
CD at 5%	–	–	10.88

[a]Av of three replications. [b]Numbers in parentheses are angular transformations.

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Integrated weed control in drum-seeded wet-seeded rice

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Transplanting of rice is a traditional practice in India, but cultivation of wet-seeded rice is gaining momentum because of the high labor demand for transplanting during the peak season. The weed menace is greater in wet-seeded rice because the weeds and rice seedlings emerge at the same time. Though manual weeding is widely used, herbicides are considered more efficient in controlling weeds in wet-seeded rice. The integration of chemical and manual weeding is essential for the effective management of weeds without affecting the environment. This experiment was conducted to test the efficacy of the following herbicides along with manual weeding: a presowing herbicide (glyphosate), a preemergence herbicide (pretilachlor with safener), and a new postemergence herbicide, butanil (butachlor + propanil mixture).

Field experiments were conducted during the 1998-99 and 1999-2000 monsoon seasons at ACRI, TNAU, Madurai (9° 54′ N, 78° 54′ E, 147 m altitude). The field was puddled using a country plow and leveled uniformly using a bullock-drawn wooden plank. Gross plot and net plot sizes were 5×4.8 m^2 and 4.6×4.4 m^2, respectively. Soil at the test site was a silty clay loam, with pH 7.6, 0.8% organic C, 225 kg available N ha^{-1}, 17 kg available P ha^{-1}, and 272 kg available K ha^{-1}. The seeds were soaked in water overnight and incubated for 24 h. Sprouted seeds of rice cultivar ADT36 were sown at 80 kg ha^{-1} using an IRRI drum seeder (manually operated with a row spacing of 20 cm) onto puddled soil on 25 Nov 1998 and 18 Nov 1999. The total width of the drum seeder is 1.6 m, and eight rows could be sown in a single run. A single dose of 38 kg P ha^{-1} and 38 kg K ha^{-1} as basal with four splits of 120 kg N ha^{-1} (basal dressing, ¼ at tillering, ¼ at active tillering, and ¼ at panicle initiation) were applied. The weed control treatments (see table) were applied in a randomized block design with three replications. The data were analyzed by standard analysis of

Effects of integrated weed control on weed dry weight, panicles m^{-2}, panicle weight, and grain yield of drum-seeded wet-seeded rice.

Treatment	Time of application (DAS)[a]	Dose (kg ai ha^{-1})	1998-99 Weed dry weight (g m^{-2})	1998-99 Panicles No. m^{-2}	1998-99 Panicles Weight (g)	1998-99 Grain yield (t ha^{-1})	1999-2000 Weed dry weight (g m^{-2})	1999-2000 Panicles No. m^{-2}	1999-2000 Panicles Weight (g)	1999-2000 Grain yield (t ha^{-1})
Pretilachlor with safener + one HW[b]	3 + 25	0.4	1.68 (45.2)	412	1.67	4.2	1.65 (42.4)	422	1.69	4.3
Butanil + one HW	10 + 25	3	1.72 (50.6)	408	1.65	4.1	1.70 (48.6)	411	1.64	4.1
Glyphosate + one HW	15 DBS[c]	1.5	1.74 (53.3)	382	1.58	3.7	1.75 (54.6)	395	1.55	3.9
Pretilachlor with safener + two HW	3 + 25 and 45	0.4	1.35 (20.2)	460	1.75	5.2	1.31 (18.2)	375	1.73	5.4
Butanil + two HW	10 + 25 and 45	3	1.44 (25.3)	437	1.71	4.9	1.41 (23.8)	445	1.69	5.1
Glyphosate + two HW	15 DBS + 25 and 45	1.5	1.42 (24.0)	428	1.69	4.7	1.39 (22.9)	442	1.67	5.0
HW twice	25 and 45	–	1.79 (59.6)	356	1.55	3.4	1.76 (55.6)	359	1.49	3.6
Weed-free check	–	–	1.06 (9.6)	471	1.78	5.3	1.09 (10.2)	482	1.75	5.6
Unweeded control	–	–	2.38 (236.5)	220	1.38	1.8	2.39 (243.2)	234	1.31	2.1
LSD 5%			0.04	22	0.09	0.3	0.05	28	0.11	0.4

[a]DAS = days after sowing, [b]HW = hand weeding, [c]DBS = days before sowing. Numbers in parentheses are original values; weed dry weight values are log $\times$ + 2 transformed values.

variance and treatment means were compared using the LSD test at the 5% level of significance.

Weed samples were taken at 60 d after seeding (DAS) in each plot at four randomly selected spots using a quadrant of a 0.25-m^2 area. These were oven-dried at 70 °C for 48 h, and their dry weight recorded. The common weeds found were *Echinochloa colona*, *E. crus-galli*, *Cyperus difformis*, *C. iria*, *Fimbristylis miliacea*, *Eclipta alba*, *Ammannia baccifera*, and *Ludwigia parviflora*. Plant samples from a 0.5-m^2 area were taken at harvest and the yield components noted. Grain yield was recorded from the net plot area.

Phytotoxicity was observed with butanil treatment 10 DAS, but the rice plants were able to recover at the later stages. Pretilachlor with safener at 0.4 kg ai ha^{-1}, followed by two hand weedings (25 and 45 DAS), was shown to be a promising combination for effective weed control and good yield. Grain yield was statistically on a par with that of the weed-free check and significantly higher than that of the crop that received two hand weedings.

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Announcement

A new botanical insecticide for managing rice bug

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Rice bug, *Leptocorisa acuta* (Thurnberg), is a serious pest of rice during the crop's reproductive stage. Many synthetic insecticides are used to manage the pest and this resulted in the accumulation of insecticide residues in the harvested produce (Chinniah et al 1998). To identify alternatives to synthetic insecticides, the efficacy of five plant products (see table) against rice bug was tested in irrigated rice (variety ADT36) under field conditions from 1999 to 2002. The experiment used a complete randomized block design with three replications. Fenthion 100 EC 500 mL ha^{-1} was the check. Plot size was 5 m × 4 m.

Dust formulations of the plant products were prepared by mixing pulverized shade-dried plant with fly ash. Fly ash is a waste product generated from a thermal power station that uses lignite or coal as fuel. It is an amorphous silicate mineral with major matrix elements such as Si, Ca, K, and Na (Jambagi et al 1995). The dust formulations were then applied using a rotary duster during the milky stage when the bug population reached 8 m^{-2}. The rice bug population was recorded 3, 7, and 14 d after treatment—i.e., the number of nymphs and adults present in a 1-m^2 area per plot was observed. The mean population per area and the percentage reduction over the control were determined. Yields were recorded from the entire plot and adjusted to 14% moisture. Among the plant products, *Acorus calamus* 10 D recorded the smallest bug population (3.56 m^{-2}), followed by *Nicotiana tabacum* 50 D (4.56 m^{-2}) and *Ocimum basilicum* 50 D (4.67 m^{-2}) (see table). There was a 72.43% reduction in bug population over the check (fly ash control) in *A. calamus* 10 D-treated plots. The same plots recorded a grain yield of 4.5 t ha^{-1}, which was on a par with Fenthion 100 EC 500 mL ha^{-1} (4.5 t ha^{-1}). The results showed that *A. calamus* 10 D can effectively control the rice bug.

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Effects of selected plant products on rice bug population (mean of three seasons).[a]

Treatment	Bug population					Grain yield (t ha^{-1})
	Days after treatment				Percent decrease over control	
	3	7	14	Mean		
Vitex negundo leaf powder at 25 kg ha^{-1}	8.44 (2.89) d	6.67 (2.56) d	5.54 (2.32) d	6.85 (2.59) d	47.00	3.9 b
Prosopis juliflora leaf powder at 25 kg ha^{-1}	8.78 (2.96) d	7.11 (2.65) d	5.44 (2.28) cd	7.11 (2.63) d	45.00	3.9 b
Nicotiana tabacum 50 D at 25 kg ha^{-1}	6.56 (2.54) c	5.33 (2.30) c	4.56 (2.12) c	4.56 (2.12) c	64.70	4.1 b
Acorus calamus 10 D at 25 kg ha^{-1}	4.00 (1.97) b	3.56 (1.86) b	3.56 (1.84) b	3.56 (1.84) d	72.43	4.5 a
Ocimum basilicum 50 D at 25 kg ha^{-1}	6.00 (2.43) c	5.00 (2.20) c	4.67 (5.22) c	4.67 (5.22) c	63.85	4.1 b
Fenthion 100 EC at 500 mL ha^{-1}	1.56 (1.22) a	1.44 (1.16)	1.41 (1.16) a	1.41 (1.16) a	89.05	4.5 a
Check (fly ash)	13.78 (13.11) e	13.11 (3.60)	12.93 (3.56) e	12.93 (3.56) e		3.8 b

[a]Numbers in parentheses are square root-transformed values. Numbers followed by the same letters are not significantly different by LSD (P = 0.05).

Response of rice plants to rat damage at the reproductive phase

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Rats are the most important among the vertebrate pests of rice. They attack stored grain and rice plants growing in the field. More than 20 species of rats attack rice. The most important rodent pest species belong to the genera *Rattus, Mus,* and *Bandicota.* Their distribution depends on geographic location and agroecological situation. Rats can attack rice plants throughout their growth period. However, the attack intensifies during maximum tillering, when the rice canopy becomes dense. The rats cut the rice tillers and panicles, store the panicles inside their burrows, and eat the grains. Damage at the reproductive phase is generally considered to result in a total loss of yield because there is insufficient time for compensation to occur. A few stem-cutting experiments in deepwater rice (Poche et al 1980, Haque et al 1986) failed to provide evidence to support this hypothesis. Recent studies have also indicated that plants probably respond more strongly to artificial than to actual pest damage (Islam and Karim 1999).

We evaluated the impact of actual rat damage to a modern rice variety at the reproductive phase. The field experiment under controlled conditions was conducted at the BRRI experimental farm during the boro (dry) season in 2000 in a randomized complete block design with three replications. The treatments were severe rat damage at booting, heading, flowering, and dough stages. Unit plots were 2 × 2 m, with a 100-cm clear footpath separating the plots and blocks. Modern rice variety BRRI dhan 29 was used. The crop was established by transplanting 5-wk-old seedlings with 20 × 20-cm hill spacing. Standard fertilizer, irrigation water, and weed management procedures were adopted; pesticide was not used.

Bandicota bengalensis and *Rattus rattus* were caught from the farm by using live rat traps. One rat was confined in each plot by using a metal mesh cage measuring 120 × 120 × 120 cm, covering 6 × 6 (= 36) rice hills. Cages without a rat were placed in the control plots. Rats were kept confined in the plot until the desired level of damage was achieved. The field was kept flooded to prevent rat escape by burrowing through the paddy soil. Some kind of refuge (raised land) and food (snails) were provided inside the cage. All the rice tillers within the caged area were counted before rat confinement, and the healthy and damaged tillers were counted at cage removal. At crop maturity, all the mature and immature panicles and tillers without panicles within the caged area were counted. The mature panicles were harvested. Three weeks after harvest, panicles and tillers without panicles of the compensatory crop were counted and the ripe panicles harvested. Panicle length was measured, filled and empty grains were counted, and grain yields were adjusted at 14% moisture content.

On average, rat-damaged (cut or broken) tillers were 42.2% at booting, 65.5% at heading, 32.3% at flowering, and 47.3% at the dough stage (Table 1). Plots attacked by rats had significantly

Table 1. Influence of rat damage at different stages of reproductive growth phase on grain yield and yield components and plants' response observed at harvest, Gazipur, Bangladesh, 2000 boro season.

Characteristic	Booting	Heading	Flowering	Dough	Undamaged control	Mean of damage treatments	*P*<
Tillers damaged (%)	42.18	65.45	32.27	47.26	0	46.79	–
Mature panicles (no. plot^{-1})[a]	161.67 b	113.33 b	232.25 b	203.67 ab	368.67 a	269.90	0.05
Panicle reduction (%)	56.15	69.26	37.00	44.75	0	51.79	–
Compensatory tillers (no. plot^{-1})							
With immature panicles	143.00 a	67.00 b	9.33 c	4.00 c	00 c	55.83	0.01
Without panicles	69.83 b	183.17 a	80.25 b	81.00 b	28.67 b	103.56	0.01
Panicle length (cm)	23.53	24.15	22.12	19.22	24.00	22.26	ns
Grain sterility (%)	29.83	30.89	27.27	27.50	33.94	28.80	ns
Filled grains (no. panicle^{-1})	89.29	98.12	95.92	93.47	92.87	94.20	ns
Panicle weight (g panicle^{-1})	2.02	2.25	2.14	2.09	1.96	2.13	ns
Grain yield (g plot^{-1})	306.43	230.95	506.32	388.29	732.76	358.00	–
Yield loss (%)	58.15	68.48	30.90	47.01	–	51.14	–

[a]Plot was 1.44 m^2 with 36 rice hills. Data in a row followed by a common letter do not differ significantly at the 5% level by Duncan's multiple range test.

fewer mature panicles than undamaged control plots ($P<0.05$). On average, rats damaged 46.8% of the tillers, which resulted in a reduction in panicles by 51.8% and in grain yield by 51.1%. Haque et al (1986) reported that 40% of deepwater rice stem cutting at flowering caused a 59% yield loss. This may have been possible under three situations—basal tillers that bear larger panicles were cut selectively, the cutting operation also damaged some other stems, and stem cutting made plants vulnerable to other pests or diseases. Panicle reduction of 56.2%, 69.3%, 37.0%, and 44.8% at booting, heading, flowering, and dough stages, respectively, resulted in a corresponding grain yield reduction of 58.2%, 68.5%, 30.1%, and 48.0%. However, panicle length, number of filled grains per panicle, and panicle weight were not affected.

Rat damage at the reproductive phase boosted compensatory tiller production (Tables 1, 2). Three weeks after the harvest of the main crop, there were, on average, 260 tillers per 1.44 m^2, of which about 30% contained mature panicles, 22% had immature panicles, and the rest (48%) had no panicles. Plants damaged earlier had more mature compensatory panicles than those damaged later. However, the panicles were smaller, with 60–84% sterile grains and fewer filled grains per panicle. These panicles contributed 15.8%, 13.0%, 5.1%, and 0.2% to total grain yield when damage occurred at booting, heading, flowering, and dough stages, respectively. Thus, the compensatory crop reduced the respective yield loss from 58.2% to 42.4%, 68.5% to 55.5%, 30.9% to 25.8%, and 47.0% to 46.8% when damage was done at booting, heading, flowering, and dough stages.

Table 2. Compensation of rice crop for rat damage observed 3 wk after harvest of the main crop (BRRI dhan 29), 2000 boro season, Gazipur, Bangladesh.

Characteristic	Booting	Heading	Flowering	Dough	Mean of damage treatments
Compensatory tillers (no. plot^{-1})	320.17	302.34	198.09	219.52	260.03
With mature panicles	170.33	114.17	21.67	4.75	77.73
With immature panicles	18.17	99.50	67.67	38.60	55.99
Without panicles	131.67	88.67	108.75	176.17	126.32
Panicle length (cm)	19.24	18.37	18.68	15.69	18.00
Grain sterility (%)	60.05	70.06	67.54	84.28	70.48
Filled grains (no. panicle^{-1})	26.67	19.13	21.82	10.73	19.57
Panicle weight (g panicle^{-1})	0.51	0.33	0.41	0.23	0.37
Compensatory grain yield (g plot^{-1})	116.00	95.03	37.24	1.25	62.38
Contribution to grain yield (%)	15.83	12.97	5.08	0.17	8.51

The results show that rice plants suffered yield losses proportional to the loss of panicles or panicle-bearing tillers as a result of rat damage at the reproductive phase. Other yield components—panicle size, grains per panicle, and panicle weight—were not affected and had no influence on yield loss. Although plants respond strongly to damage and produce many tillers before flowering, plants can only compensate for some of the losses. Plants can contribute 13–16% to total grain yield, provided the compensatory crop is protected and harvested later. The extent of compensation depends on the timing and level of rat damage and agroecological conditions—soil fertility, soil moisture, and incidence of pests after the harvest of the main crop. Farmers can make a second harvest only if the compensatory crop is worthwhile. In cases of minor to moderate levels of rat damage, farmers may not be interested in the compensatory crop. But, in situations of severe damage (40% or more), they may be motivated enough if the compensatory crop can provide a sizable yield. However, the compensatory crop must be protected from pests. An important question is How long can a farmer wait for compensatory yield? Considering the flush of maturity of the first-generation compensatory panicles and the odds a farmer has to face, a cut-off date for the second harvest was set at 3 wk after the main crop harvest. Further delay would be impractical.

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Growth stage preference of pink stem borer *Sesamia inferens* (Walker)

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Considered a minor pest of rice, *Sesamia inferens* has been reported to cause severe damage to rice crops in the Punjab (Singh and Shera 2001). Because of the pest's late appearance in the season, the Basmati crop, which is planted late, suffers the most from this pest. To observe the growth stage preference of the pink stem borer (PSB), two different experiments were set up. In the first experiment, 100 deadhearts or whiteheads from two rice varieties—PR114 and Basmati 386—were selected at random (Table 1). In the second experiment, 11 different rice varieties planted in two replications were studied for their reaction to different species of stem borer (Table 2). Twenty-five hills per rice variety per replication were selected at random to calculate percent whiteheads. Further, to record the extent of damage caused by the different stem borers, 20 whiteheads were taken from each rice variety. The deadhearts and whiteheads collected from these two experiments were split open to calculate the damage done by each stem borer species.

Table 1. Growth stage preferences of different species of stem borers.[a]

Date	Stage	PR144				Basmati 386			
		YSB	WSB	PSB	SF	YSB	WSB	PSB	SF
13 Aug 2002	Tillering (3)[b]	68.89	20.00	2.22	8.89	–	–	–	–
28 Aug 2002	Booting (5)	13.04	26.08	13.04	47.80	–	–	–	–
12 Sep 2002	Tillering (3)	–	–	–	–	50.00	50.00	0.00	0.00
29 Sep 2002	Booting (5)	–	–	–	–	45.76	35.59	18.64	0.00
	Dough (8)	28.57	17.86	53.57	0.00	–	–	–	–
14 Oct 2002	Stem elongation (4)	–	–	–	–	66.67	33.33	0.00	0.00
	Booting (5)	–	–	–	–	66.67	33.33	0.00	0.00
	Heading (6)	–	–	–	–	71.42	14.28	14.28	0.00
	Milk (7)	–	–	–	–	43.07	6.15	50.76	0.00
18 Oct 2002	Dough (8)	–	–	–	–	7.14	0.00	92.86	0.00

[a]YSB = yellow stem borer, WSB = white stem borer, PSB = pink stem borer, SF = shoot fly. – stage not available. [b]Indicates growth stage of rice crop as per the 1–9 scale of the *Standard evaluation system for rice*.

Table 2. Growth duration and stem borer damage in some rice varieties.[a]

Variety	Growth duration (d)	Whiteheads (%)	Percent damage because of		
			YSB	WSB	PSB
PR115	125	0.56	75.00	0.00	25.00
Pusa Sugandh 3	126	1.94	100.00	0.00	0.00
Pusa RH 10	127	2.24	75.00	25.00	0.00
Pusa Sugandh 2	130	3.36	50.00	0.00	50.00
PR111	138	2.40	0.00	0.00	100.00
Pusa Basmati 1	140	9.24	13.30	6.67	80.00
RYT2492	142	4.56	0.00	0.00	100.00
IET15391	142	7.27	0.00	11.11	88.89
RYT2610	143	6.79	0.00	0.00	100.00
PR116	144	8.57	0.00	8.33	91.67
PR114	145	9.48	35.71	28.57	35.71
Mean	–	5.13	31.73	7.24	61.02

[a]Mean of two replications. Correlation coefficient (r) value for duration and percent whiteheads = 0.85; that for duration and percent damage because of PSB = 0.79.

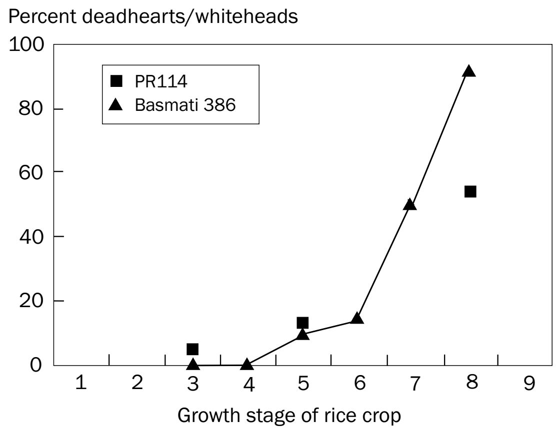

Fig. 1. Growth stage preference of pink stem borers.

PSB seemed to prefer a particular growth stage of the crop. The same observation was made within a crop variety as well as on the different varieties on the same day of the year (Table 1, Fig. 1). The damage caused by PSB on rice cultivar PR114 was less (2.22% and 13.04%) during tillering and booting stages of the crop than in the later dough stage (53.57% whiteheads).

Similarly, in Basmati 386, a low incidence of PSB was observed during the initial growth stages (tillering, stem elongation, and booting), in which damage was 0.0%, 0.0%, and 9.32%, respectively, the latter being the mean of two dates, 29 Sep 2002 and 14 Oct 2002. During later growth stages (heading, milk, and dough), damage attributed to PSB was 14.28%, 50.76%, and 92.86%, respectively.

When observations were taken on the same date (29 Sep 2002), PSB incidence was much higher (53.57%) in the dough stage of PR114, whereas only 18.64% deadhearts were observed on Basmati 386, which was at the booting stage. On 14 Oct 2002, damage caused by PSB was negligible in plants of Basmati 386, which were at the stem elongation and booting stages, whereas plants of the same cultivar at heading, milk, and dough stages (observed on 18 Oct 2002) showed 14.28%, 50.76%, and 92.86% damage. Perhaps, the much higher incidence of PSB during the later growth stages may be due to the presence of physical barriers such as a tight leaf sheath affecting egg laying at earlier stages.

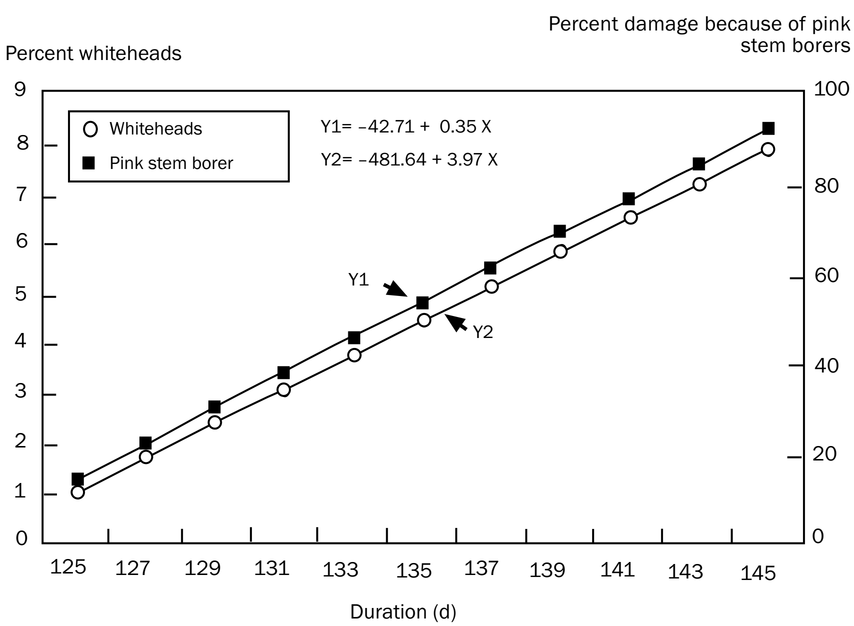

Fig. 2. Incidence of pink stem borer in relation to crop growth duration.

Incidence of rice stem borers on different rice varieties also reflected the particular growth stage preference of PSB (Table 2, Fig. 2). The data indicated 31.73%, 7.24%, and 61.02% whiteheads caused by YSB, WSB, and PSB, respectively. Out of the 5.13% damage, 1.63%, 0.37%, and 3.13% whiteheads were caused by YSB, WSB, and PSB, respectively, an indication that PSB is a major loss contributor at the postvegetative stage. High positive correlations existed between growth duration of the rice crop and whiteheads (r = 0.85) and between growth duration and PSB damage (r = 0.79), showing late occurrence of the pest because of growth preference.

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Control of rats at the ripening stage of a rice crop

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Rats are serious pests of rice in Bangladesh. In flood-prone environments, *Bandicota bengalensis* (Gray and Hardwicke) and *B. indica* (Bechstein) are dominant (Catling and Islam 1999, Islam and Karim 1995), whereas, in nonflood-prone areas, *Rattus rattus* Linnaeus and *B. bengalensis* dominate. Rat damage is usually concentrated in the rice tiller/stem cutting at maximum tillering and damage intensifies during ripening (Islam et al 1993). If water is absent, rats make burrows in the field, in bunds, or in nearby nonflooded land. Rats cut the ripened rice panicles, carry them to the burrows, and store them inside. In some cases, breeding coincides with the rice harvest. Damage varies, depending on the rat population, but a few rats can cause considerable damage (Islam et al 1993). Rat control at the ripening stage is very difficult because rats avoid traps and poison baits inasmuch as food is abundant. Under such situations, farmers do not have an effective option for rat control to save their ripened rice crop.

We decided to concentrate on targeting active burrows, that is, burrows with rats. An active burrow is identified by the presence of fresh (moist) soil at its opening. When rats go inside a burrow, they push the moist soil outside. Such evidence is more pronounced in the case of bandicoot rats. We tested two options: use of the chronic poison bait Lanirat (bromadiolone 0.005) and use of Phostoxin pellets that release lethal aluminum phosphide gas when exposed to moisture. Three tests were carried out at the BRRI experimental farm. A few grams of bait were loosely wrapped in paper and placed about 20–25 cm inside one set of active burrows. Phostoxin pellets (one per burrow) were placed about 20–25 cm inside another set of active burrows. The openings of all active burrows and other nonactive openings nearby were sealed tightly by soil. All the openings of another active burrow system were likewise sealed (this served as a control treatment). The efficacy of the poison bait and gas was evaluated in two tests in the aman (monsoon rice) season. A third test was carried out in the 2001 boro (dry-season rice) and, this time, only poison gas was used. The reopening of sealed burrows or creation of new openings was done at different days after treatment and data were compared with those obtained from the untreated control. Estimated rat mortality was adjusted by the use of Abbot's formula.

In the first test, up to 16 d after treatment, seven out of nine (77.8%) control burrows were reopened. None were reopened in the case of Phostoxin and only three out of 12 (25%) were reopened in the case of Lanirat bait (see table). The estimated mortal-

Efficiency of a chronic poison bait (Lanirat) and aluminum phosphide gas (Phostoxin pellets) used in active burrows, Gazipur, Bangladesh, 2000-01.

Attribute	Treatment		
	Phostoxin	Lanirat	Untreated control
Test I: 2000 aman (monsoon rice)			
Total burrows treated (no.)	8	12	9
Burrows reopened (no.) at			
3 d after treatment	0	1	7
6 d after treatment	0	3	7
11 d after treatment	0	3	7
16 d after treatment	0	3	7
Rat mortality (%)[a]	100.0	67.8	–
Test II: 2000 aman (monsoon rice)			
Total burrows treated (no.)	20	20	19
Burrows reopened (no.) at			
3 d after treatment	2	15	17
7 d after treatment	7	15	17
14 d after treatment	7	15	17
21 d after treatment	7	15	17
Rat mortality (%)	60.9	16.2	–
Test III: 2001 boro (dry-season rice)			
Total burrows treated (no.)	32	–	18
Burrows reopened (no.) at			
2 d after treatment	0	–	18
6 d after treatment	5	–	18
11 d after treatment	5	–	18
Rat mortality (%)	84.4	–	–

[a]Corrected by Abbot's formula.

ity was 100% for Phostoxin and 67.8% for Lanirat. In the second test, up to 21 d after treatment, 17 out of 19 (89.5%) control burrows were reopened. Seven out of 20 (35%) and 15 out of 20 (75%) Phostoxin- and Lanirat-treated burrows were reopened, respectively. Rat mortality was estimated at 60.9% for Phostoxin and only 16.2% for Lanirat. In the third test, up to 11 d after treatment, 100% of the control burrows were reopened, while five out of 32 (15.6%) Phostoxin-treated burrows were reopened. Rat mortality because of the Phostoxin treatment was estimated at 84.4%.

On average, Phostoxin pellets that produce lethal aluminum phosphide gas achieved 81.8% rat control, whereas the chronic poison Lanirat (bromadiolone) achieved 42%. The test revealed that targeting rats in the burrows during ripening, when most other traditional techniques are ineffective, is a good option. However, of the two chemical rodenticides tested, Phostoxin was much better than Lanirat in achieving immediate population knockdown. The technique of placing the bait or gas-releasing pellets inside the rat burrows should have the least effect on nontarget organisms and on the environment. Therefore, such a technique could be used in integrated or ecological rodent management programs, if needed.

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First report of sheath brown rot of rice in China and characterization of the causal organism by phenotypic tests and Biolog

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A bacterial disease of rice was observed in autumn of 1998-99 in the fields of Jiaxing and Yuhang, Zhejiang Province, China. Oblong to irregular dark green and water-soaked lesions occurred on the sheath, which later became gray-brown or brown surrounded by an effuse dark brown margin. With severe infection, the entire leaf sheath became necrotic and dried out. The panicles withered. Glumes of panicle emerging from the infected sheath exhibited water-soaked lesions that turned light brown. Grains of infected panicles were discolored, deformed, or empty. No bacterial ooze was produced from any part of the infected plant. The disease was first discovered in Japan in the 1950s. Since then, it has been reported in Southeast Asia, South America, and Africa, but not previously in China (Tanii et al 1976, Xie 1996). However, an epiphytic bacterium isolated from a weed was identified as *Pseudomonas fuscovaginae* in central China in 1986 but not from rice (Duan and Fang 1986). We therefore determined the causal organism and compared it with *P. fuscovaginae*, the causal organism of sheath brown rot of rice, and other related bacteria.

Six and 12 samples of rice grains and plants (5–6 g sample^{-1}) with sheath brown rot were collected from Jiaxing and Yuhang, respectively, in 1998-99. Isolations were done by plating serial dilution of seed washes (10^{-3}–10^{-5} g^{-1}) on King's medium B (KMB). Colony morphology was described and phenotypic and pathogenicity tests were performed (Mew and Misra 1994, Xie 1996). Six standard reference strains (I06235 *P. fuscovaginae*, I7007 *P. fuscovaginae*, I9801 *P. fuscovaginae*, I11332B *P. fluorescens* A, I04937 *P. fluorescens* C, and I10278 *P. putida* A1) were provided by IRRI. Additionally, Biolog (Biolog Inc., Hayward, USA) with software version 3.5 was used to further characterize the isolates.

Ten bacterial isolates from samples with sheath brown rot showed characteristics similar to those of the reference strains of

Table 1. Major bacteriological characteristics of causal organism of rice bacterial sheath brown rot compared with related bacteria.[a]

Bacteriological test	Strains tested			Reference strains		
	JX	YH	*Fus*	*Flu A*	*Flu C*	*Puti*
Gram staining	–	–	–	–	–	–
Polar flagellum	+	+	+	+	+	+
Motility	+	+	+	+	+	+
Production of endosporum	–	–	–	–	–	–
Fluorescent pigment	+	+	+	+	+	+
Growth at 41 °C	–	–	–	–	–	–
Oxidation of glucose	+	+	+	+	+	+
Gelatin liquefaction	+	+	+	+	+	–
Nitrate reduction	–	–	–	–	+	–
Levan formation from sucrose	–	–	–	+	–	–
β-glucosidase	–	d	–	–	–	–
Arginine dihydrolase	+	+	+	+	+	+
Lecithinase	d	d	d	+	+	–
Tween 80 lipolysis	d	d	d	+	d	d
Starch hydrolysis	d	d	d	–	–	–
Use of						
L-arabinose	+	+	+	+	–	+
Trehalose	+	+	+	+	+	–
2-ketogluconate	–	–	–	+	+	+
Inositol	–	–	–	+	+	–
Sorbitol	–	–	–	+	+	–
Adonitol	–	–	–	+	+	–
Polygalacturonic acid	–	–	–	–	–	–
Acid production from						
Inulin	–	–	–	–	–	–
Glucose	+	+	+	+	+	+
Mannitol	+	d	+	+	+	+
Salicin	–	–	–	–	–	–
Raffinose	–	–	–	–	–	–
Maltose	–	–	–	–	–	–
Sucrose	–	–	–	–	–	–
Dextrin	–	–	–			
Mannose	+	+	+			
Hypersensitivity of tobacco	+	+	+			
Total strains tested	5	5	3	1	1	1

[a]*Fus*= *P. fuscovaginae*, *Flu A* = *P. fluorescens A*, *Flu C* = *P. fluorescens C*, *Puti* = *P. putida A1*. JX = isolated from rice grains collected from Jiaxing;YH = isolated from rice grains collected from Yuhang. + = 80% of the strains were positive; d = 20–80% of the strains were negative; – = means 80% of the strains were negative.

P. fuscovaginae in the phenotypic, pathogenicity, and Biolog tests. The bacterium has the bacillus form, was Gram-negative with 1–4 polar flagella and aerobic, and it produced a green-fluorescent diffusible pigment on KMB. Colonies on nutrient agar medium were white to cream-white and translucent. Table 1 shows 32 phenotypic characteristics of the isolates, which are similar to those of the reference strains of *P. fuscovaginae.* Gelatin liquefaction, nitrate reduction, levan formation from sucrose, and the use of L-arabinose, trehalose, 2-ketogluconate, inositol, sorbitol, and adonitol differentiated the test strain from *P. fluorescens* and *P. putida.* The 10 selected strains isolated from rice grains and plants with sheath brown rot were identified as *P. fuscovaginae* by Biolog, which conformed with the three reference strains of *P. fuscovaginae* having a similarity of 0.819–0.903 (Table 2).

The causal organism of sheath brown rot of rice in Zhejiang Province has been phenotypically identified as *P. fuscovaginae.* It was the same organism reported in Japan in 1976 (Tanii et al 1976) but was different from bacterial sheath rot of rice caused by *P. syringae (P. oryzicola),* which occurred in the province in the 1960s (Fang and Ren 1960).

Table 2. Biolog identification and pathogenicity test for the causal organism of sheath brown rot of rice.

Strain code	Original identification	Biolog identity	Biolog similarity	Incidence at booting stage[a] (%)
I06235	*P. fuscovaginae*	*P. fuscovaginae*	0.884	100
I7007	*P. fuscovaginae*	*P. fuscovaginae*	0.819	100
I9801	*P. fuscovaginae*	*P. fuscovaginae*	0.903	100
I11332B	*P. fluorescens* A	*P. fluorescens* A	0.837	0
I04937	*P. fluorescens* C	*P. fluorescens* C	0.982	0
I10278	*P. putida* A1	*P. putida* A1	0.910	0
CB 97801		*P. fuscovaginae*	0.794	100
CB 97803		*P. fuscovaginae*	0.604	100
CB 97805		*P. fuscovaginae*	0.907	100
CB 97806		*P. fuscovaginae*	0.741	100
CB 97815		*P. fuscovaginae*	0.981	100
CB 98801		*P. fuscovaginae*	0.979	100 (80)
CB 98814		*P. fuscovaginae*	0.845	100 (80)
CB 98817		*P. fuscovaginae*	0.939	100 (70)
CB 98818		*P. fuscovaginae*	0.926	100 (60)
CB 98820		*P. fuscovaginae*	0.837	100 (90)
Distilled water	–	–	–	0

[a]Injection inoculation was used at booting stage; 10 rice plants per strain. Numbers in parentheses are results of spray inoculation with 10 rice plants per strain.

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Disappearance of the symbiont *Anabaena azollae* in *Azolla* subjected to high phosphorus

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Azolla is an aquatic fern that easily grows in rice fields. It has a symbiont N_2-fixing blue-green algae, *Anabaena azollae*, that lives in its cavity. *Azolla* is generally applied as a dual crop with rice and, on average, contributes 30–40 kg N ha^{-1} (Singh 1977). It is an essential nutrient for *Azolla* growth. Phosphorus is also applied to the rice crop in the form of single superphospate (SSP). Dawar and Singh (2002) observed soil-based cultures of *Azolla* and noted that a double dose of P (300 ppm) given to *Azolla* proved toxic to the algal partner. A few days' to week's incubation in high-P soil medium led to stunted *Azolla* growth. The fronds became small and, when examined for nitrogenase activity, no acetylene reduction activity was found. Light microscopy confirmed the disappearance of *Anabaena azollae* from the leaf cavities of the fronds.

A greenhouse study was conducted to quantify the effect of high P on two species of *Azolla*. Two accessions of *A. microphylla*—MI 4018 from IRRI and one from Pusa (NCCUBGA, IARI) —and two accessions of *A. pinnata*—PI 0519 from IRRI and one from Pusa—were used. Wide-mouth beakers (8 cm diam, 12 cm deep) were filled with 150 g soil (sandy loam Typic-Haploslept; total N, 22.4%; total carbon, 0.8–1.0%; Olsen P, 94.08 ± 0.023 kg ha^{-1}; available K, 227.2 ± 0.012 kg ha^{-1}) mixed with 5 g SSP (equivalent to 300 ppm P). Seven-cm-deep water was added to the beakers. When the soil settled, 0.5 g of soil-grown fresh *Azolla* was added to the beakers. Normal soil (without SSP) served as the control. The increase in biomass in terms of g fresh weight (Fig. 1) and nitrogenase activity in terms of acetylene reduction activity (Fig. 2) were recorded at weekly intervals. Nitrogenase activity was measured (Jewell and Kulasooriya 1970) using a gas chromatograph (GC) (Nucon model EC 5700) with a Porapak R column. *Azolla* plants were incubated for 1 h under an atmosphere of 10% C_2H_2 and 0.03% CO_2 in argon-sealed vials using the media at the designated pH and temperature. One mL of the sample was injected into the GC column and the ethylene (C_2H_4) formed was measured in terms of number of moles of ethylene mg^{-1} chl h^{-1} using a flame ionization detector. The disappearance of algae was also confirmed by examining crushed *Azolla* leaves under a Nikon light microscope at 40X and 100X magnifications.

In our studies, high P reduced biomass and eliminated the symbiont *A. azollae* from the leaf cavities of both species. Actylene reduction activity was found to be nil on the 21st day (Fig. 2). The absence of ARA could be attributed to the disappearance of the symbiont, as confirmed by light microscopy. Previous studies also found that *Azolla* can be grown in soil medium with less than 300 ppm P (Dawar and Singh 2002) and that P loading capacity differed among various species of *Azolla*. Saha et al (1982) reported that soils with *Azolla* release P to

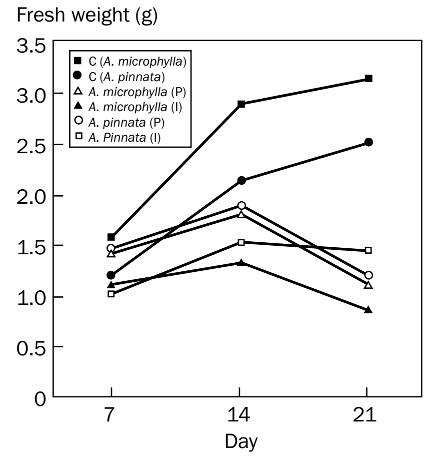

Fig. 1. Growth of *Azolla* (g fresh weight) at different times of incubation (means of three different sets).

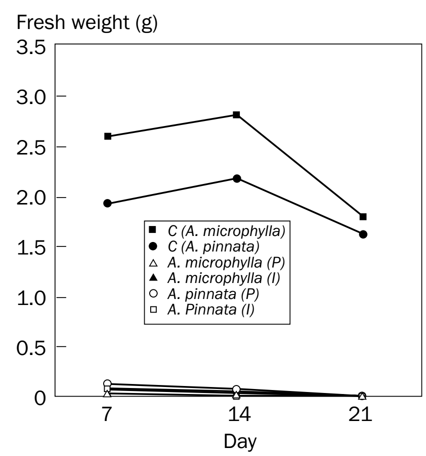

Fig. 2. Nitrogenase activity (n mole ethylene mg^{-1} ch h^{-1}) of *Azolla* at different times of incubation (means of three different sets).

the medium. They correlated this to the solubilizing effect of organic acids produced as a result of *Azolla* decomposition. Moreover, during *Azolla* decomposition, organic P is released to the soil solution. High P is also known to react with other nutrients (e.g., Zn) and it also changes the soil pH. The continuous use of acid-forming or base-forming fertilizers can gradually shift the soil pH and this might be one of the causes of algal disappearance. Soluble fertilizers, if present in large amounts, burn the crops, too (www2.ctahr.Hawaii.edu); the decrease in biomass could be attributed to the same factor. Watanabe and Ramirez (1984) calculated a partial correlation coefficient of P for different types of soils and concluded from the bioassays and soil analyses that *Azolla* growth is good if the soil has a high available P content and low P sorption capacity.

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Critical concentration of saline water for rice cultivation on a reclaimed coastal soil in Korea

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Reclaimed tidal areas for rice cultivation in Korea are irrigated with saline water when drought is severe or when fresh water is not available. Determining the critical saline concentration of irrigation water for different soil salinity levels is important to optimize water use and yield. In this study, we identified the concentration of saline water critical to rice growth on a reclaimed saline soil in Korea. The experiment was conducted at the Kyehwa substation of the NHAES during 2001-02.

Two experimental fields with low (0.1–0.2%) and medium (0.3–0.4%) soil salinity were used. The experiment involved four levels of salt solution mixed with sea water (0.1%, 0.3%, 0.5%, and 0.7%) and a control (tap water) in a split-plot design with three replicates. Saline solution was applied twice at the seedling stage (10 DAT and 25 DAT) for 5 d. Segyehwa, a japonica rice variety common in the reclaimed area, was grown.

Plant height and number of tillers decreased sharply when low-salinity soil was treated with 0.7% salt solution. The same trend was observed with medium-salinity soil treated with 0.1% salt solution (see table). Panicle num-

Some agronomic characteristics, yield components, and yield of rice grown on reclaimed saline soil given saline water treatments at the seedling stage, Kyehwa, Korea, 2001-02.[a]

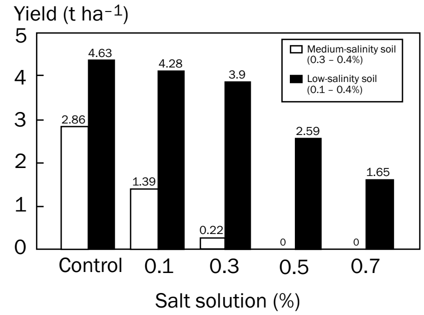
Treatment		Plant height (cm)	Tillers m^{-2} (no.)	Panicles m^{-2} (no. × 1,000)	Ripened grain (%)	1,000-grain weight (g)
Salinity level	Salt solution (%)					
Low-salinity soil (0.1–0.2%)	Control	75	473	384 a	93.4 a	24.2 a
	0.1	75	473	337 b	92.2 a	24.3 a
	0.3	73	462	323 b	90.5 a	23.0 a
	0.5	69	398	228 c	60.5 c	19.6 c
	0.7	27	209	159 e	42.8 e	10.9 d
Medium-salinity soil (0.3–0.4%)	Control	63	334	303 bc	85.2 b	21.6 b
	0.1	52	275	184 de	55.2 cd	18.5 c
	0.3	21	120	92 f	35.1 f	9.3 e
0.5	–	–	–	–	–	
0.7	–	–	–	–	–	

[a]Means followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test.

ber per unit area and percentage of ripened grain decreased dramatically with 0.5% saline water in low-salinity soil and with 0.1% saline water in medium-salinity soil. However, the 1,000-grain weight of brown rice decreased sharply with 0.7% saline water in low-salinity soil and 0.3% saline water in medium-salinity soil, indicating that this component, unlike other yield components, was less affected.

Milled rice yield decreased significantly with increasing saline water level in both low- and medium-salinity soil. In low-salinity soil with 0.7% salt solution, the yield index was only 36% compared with the control. In medium-salinity soil, even the control plot showed a yield index of only 62% compared with the control in the low-salinity soil treatment (see figure).

The results demonstrated that the critical concentration of saline water for rice growth was 0.5% salt in low-salinity soil and 0.0% salt in medium-salinity soil. Therefore, to avoid severe salinity stress on yield, less than 0.5% salt in the irrigation water could be applied on low-salinity soil.



Performance of milled rice based on different salt solutions and levels of salinity on a reclaimed saline soil, 2002-03.

The use of salt-tolerant varieties is recommended, especially in medium-salinity soil, to allow application of saline irrigation water.

Manuring option for maximizing the yield of quality rice

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Much interest exists in ways to exploit renewable N sources that not only sustain soil fertility but also improve yield. The use of both organic and inorganic fertilizers is a way to save on costs and maintain soil health. An experiment was conducted to maximize rice yield by applying green manure in combination with inorganic fertilizers. It was carried out in sandy clay loam soil with pH 7.1, 0.42% organic carbon, 232 kg N ha^{-1}, 5.81 kg P ha^{-1}, 240.7 kg K ha^{-1}, and electrical conductivity of 0.5 dS m^{-1}. Two-year data from the same season (September 1997 and September 1998) were obtained. The experiment was in a randomized block design replicated thrice.

The treatments consisted of 100%, 75%, and 50% application of the recommended doses of inorganic N and K fertilizers with and without the green manure *Sesbania aculeata* (Table 1). *S. aculeata* was sown at 60 kg ha^{-1} prior to the planting of rice in the respective treatments and incorporated *in situ* 45 d after sowing (DAS). The entire dose of P was applied basally. N was applied in four equal splits (basal, active tillering, panicle initiation, and flowering) and so was K (10, 25, 40, and 55 d after transplanting, DAT). White Ponni, a medium-duration variety, was planted at 20 × 10-cm spacing, for which the blanket recommendation is 75-16.1-31.1 kg NPK ha^{-1}. In both years, nutrient content of *Sesbania* varied from 2.6% to 2.7% N and from 0.8% to 0.9% K on a dry-weight basis. In both years, higher grain and straw yields were observed in treatments given 100% N and K fertilizers and green manure. The net return and benefit-cost ratio were also

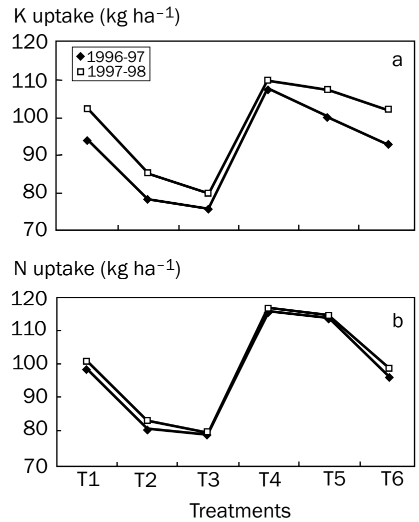
Table 1. Influence of green manure on grain and straw yield (t ha^{-1}) of rice.

Treatment	Grain yield		Straw yield	
	1996-97	1997-98	1996-97	1997-98
100% N and K (T1)	4.9	5.2	8.8	9.5
75% N and K (T2)	4.7	5.0	8.4	8.9
50% N and K (T3)	4.5	4.7	8.0	8.5
Green manure + 100% N and K (T4)	5.3	5.6	9.6	10.0
Green manure + 75% N and K (T5)	5.1	5.4	9.2	9.7
Green manure + 50% N and K (T6)	4.9	5.2	8.7	9.3
CD (P = 0.05)	0.16	0.17	0.31	0.30

Table 2. Influence of green manure on economics of rice.

Treatment	Net return (Rs ha^{-1})		Benefit-cost ratio	
	1996-97	1997-98	1996-97	1997-98
100% N and K (T1)	23,165	23,950	3.51	3.58
75% N and K (T2)	22,578	23,363	3.55	3.62
50% N and K (T3)	21,126	21,912	3.40	3.50
Green manure + 100% N and K (T4)	27,701	27,970	3.67	3.72
Green manure + 75% N and K (T5)	25,476	26,261	3.58	3.65
Green manure + 50% N and K (T6)	23,688	24,474	3.42	3.48

higher in those treatments (Table 2). Green manure with 50% of the recommended N and K produced an economic yield comparable with that of 100% recommended N and K only. Similarly, N and K uptake by rice was also higher in plots with green manure and 100% N and K fertilizers (see figure). Lodging was noted in all treatments, except for the treatment with green manure and 100% N and K.



Influence of green manure on K (a) and N (b) uptake of rice.

Effects of organic and inorganic P fertilizers on soil fertility and grain yield in a rice-pulse system

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The amount of indigenous rock phosphate (RP) deposit used in India was estimated to be about 260 t (Narayanasamy and Biswas 1998). It was equally effective as a water-soluble P fertilizer in suitable environments (Khasawnch and Doll 1986). Rock phosphate is applied more for its residual effect because its availability increases slowly and continuously when in contact with the soil. The relative effectiveness is two to three times more than that of superphosphate (Chien and Hammond 1988).

The application of RP, together with organic manure, enhances the dissolution of RP in the soil, thereby increasing the availability of P to the plant. The organic acids produced during decomposition of organic manure supply the photons (H^+) needed for RP dissolution (Bagavathiammal and Mahimairaja 1999). In association with phosphate-solubilizing microorganisms and organic manure, RP can be used as a P source in many crops and the mechanism that enables solubilization of P from RP by microorganisms was found to be the production of organic acids and chelating substances (Datta et al 1982). The residual effect of RP was more pronounced in the presence of organic manure in the rice-rice cropping system (Panda 1989). Roy et al (1997) found that in Udic Ustochrepts, the yield of rice increased, while leaving the soil enriched with essential plant nutrients by using Mussoorie RP incorporated with legume straw and phosphobacteria (*Bacillus polymyxa* and *Pseudomonas striata*) in neutral to slightly alkaline soils.

Rajphos (Uadipur RP, a product of Rajastran Mines and Minerals Ltd., Uadipur, India) is a source of P but little was known about its effectiveness. We carried out a study to evaluate the agronomic effectiveness of Rajphos vis-à-vis other sources of P, to determine the effect of organic manures and biofertilizer on its effectiveness, and to examine its residual effect on the soil. The study assessed the effects of different inorganic P fertilizers and organic manures (green leaf manure such as pungam leaf [*Pongamia glabra*] and biofertilizer such as phosphobacteria) on the yields of rice and blackgram and on soil fertility.

We conducted field experiments during 1996-97 in the Soil Science Department in Coimbatore. The soil is a clay loam alluvial, with pH 7.86, EC 0.48 dS m^{-1}, 0.42% organic C, and 183 kg $KMnO_4$-N ha^{-1} and 543 kg NH_4OAcK ha^{-1}. The average total P (on a dry-weight basis) was 7.2%, 8.3%, 20.1%, and 0.17% in Rajphos, Mussoorie RP, diammonium phosphate (DAP), and green leaf manure, respectively. The treatments were replicated three times in a randomized block design. Short-duration variety ADT36 (110 d) was planted during the first week of December every year at 15 × 10-cm spacing. The freshly collected leaves of pungam were incorporated at 6.25 t ha^{-1} (equivalent to 1.875 t ha^{-1} [dry-weight basis]) into the field 1 wk before transplanting. The phosphobacteria was applied basally 3 d before transplanting. The recommended doses of N (120 kg N ha^{-1}) as urea and potassium (50 kg K_2O ha^{-1}) as muriate of potash were applied in four equal splits at the initial, tillering, panicle initiation, and flowering stages. Plots were irrigated and 25-d-old rice seedlings were transplanted in the puddled field. The usual cultivation practices such as weeding (four times) and plant protection (two times) were carried out.

The crop was harvested at maturity and its yield recorded. The postharvest soil samples after rice were analyzed for Olsen P with 0.5 M $NaHCO_3$ (pH 8.5) as extractant (Olsen et al 1954). Representative soil samples were collected at 0–15-cm depth, air-dried, passed through a 2-mm sieve, and analyzed.

Initially, the highest grain yield of rice was obtained with DAP, followed by RPs (Table 1). Though Mussoorie RP had a relatively higher total P content (8.3% P) than Rajphos (7.2% P), the latter performed better in rice soil. However, Mussoorie RP and Rajphos were on a par at the 5% level. This may be due to the differences in chemical composition and varying dissolution patterns of P from these two RPs. Rajphos, up to 32.73 kg P ha^{-1}, performed as well as DAP, but it gave a higher rice yield than Mussoorie RP at all levels. The addition of green manure at 6.25 t ha^{-1} and phosphobacteria at 2 kg ha^{-1}, along with different sources of P, considerably increased the yield, mainly by improving the dissolution and availability of P from RPs. The combination of Rajphos (at two P levels, 21.82 and 32.73 kg ha^{-1}), green leaf manure, and phosphobacteria gave higher grain yields, which were comparable with the sole application of DAP (at 21.82 kg P ha^{-1}) in the cropping sequence.

The application of Rajphos at 32.73 kg P ha^{-1}, along with green leaf manure and phosphobacteria, recorded the highest benefit-cost ratio of 2.7. This was followed by DAP at 32.73 kg P ha^{-1} + green leaf manure + phos-

Table 1. Effect of different sources and levels of P on yield (kg ha^{-1}) of ADT36 (av of 2-y data).[a]

Level (L) (P kg ha^{-1})	Sources (P)[b]				
	RP	MRP	DAP	L mean	O mean
P alone					
10.91	4,051 c	3,955 c	4,241 c	4,082 C	
21.82	4,502 b	4,457 b	4,661 b	4,540 B	
32.73	4,952 a	4,757 ab	5,006 ab	4,905 A	
43.64	4,627 ab	4,907 a	5,302 a	4,945 A	
Mean	4,533 B	4,519 B	4,803 A		4,618 C
P + GLM (0)					
10.91	4,727 c	4,613 b	4,902 c	4,747 C	
21.82	5,066 bc	4,989 b	5,222 bc	5,092 B	
32.73	5,490 a	5,384 a	5,524 ab	5,466 A	
43.64	5,163 ab	5,569 a	5,579 a	5,510 A	
Mean	5,122 B	5,139 B	5,362 A	5,362 A	5,204 A
P + GLM + PB (0)					
10.91	4,455 c	4,327 b	4,611 b	4,464 C	
21.82	4,817 bc	4,660 b	4,956 b	4,811 B	
32.73	5,277 a	5,060 a	5,377 a	5,238 A	
43.64	4,952 ab	5,192 a	5,514 a	5,219 A	
Mean	4,875 b	4,810 b	5,115 a		4,933 B

	SED	LSD (5%)
P	56	113
O	56	113
L	65	130
P × L	113	225
O × P	98	195
P × L × O	95	389

[a]Means followed by small letters are compared within the column. Means followed by capital letters are compared within the column (L and O) and across the row (P). [b]RP = Rajphos; MRP = Mussoorie rock phosphate; DAP = diammonium phosphate; L = levels of P; O = organic – green leaf manure (GLM)/ phosphobacteria (PB).

phobacteria (2.5). The P buildup in the soil increased significantly (at the 5% level) as a result of using phosphatic sources in combination with green leaf manure/phosphobacteria. The application of organic manure, along with Rajphos, improved P availability at the later stages of crop growth and thus increased grain yield. This is attributed to the enhanced solubility of Rajphos brought about by the production of organic acids. The lower yield obtained by Rajphos alone might be ascribed to the slow release and less amount of P produced from Rajphos in available form (Rabindra et al 1986).

To examine the residual effect of Rajphos, a rice fallow summer crop of black gram (variety Co 5 of 75-d duration) was sown on the same plots without further application of nutrients. Application of Rajphos at 32.73 kg P ha^{-1}, along with green leaf manure applied to rice, gave the highest residual blackgram yield of 480 kg ha^{-1}, which was followed by Rajphos + green leaf manure + phosphobacteria (Table 2).

These results suggest that the combined application of Rajphos (up to 32.73 kg P ha^{-1}), green leaf manure (6.25 t ha^{-1}), and phosphobacteria (2 kg ha^{-1}) could adequately substitute for inorganic phosphatic fertilizers (particularly DAP) in a rice-pulse cropping system.

Table 2. Residual effect of different sources and levels of P on grain yield of blackgram (variety Co 5) (av of 2-y data).[a]

Level (L) (P kg ha^{-1})	Sources (P)				
	RP	MRP	DAP	L mean	O mean
P alone					
10.91	240 c	290 a	275 a	268 C	
21.82	323 b	215 b	170 c	236 D	
32.73	320 b	310 a	230 b	287 B	
43.64	385 a	297a	280 a	321 A	
Mean	317 A	278 b	239 c		9.71 B
P + GLM (0)					
10.91	260 c	260 b	220 c	240	
21.82	360 c	270 b	320 b	317	
32.73	480 a	330 a	360 a	390	
43.64	365 b	310 a	320 b	332	
Mean	366 ns	293 ns	305 b		10.29 A
P + GLM + PB (0)					
10.91	230 c	270 b	280 c	260	
21.82	315 b	270 b	290 b	288	
32.73	390 a	360 a	310 b	353	
43.64	325 b	275 b	355 a	318	
Mean	315 ns	294 ns	309 ns[b]		306 B

	SED	LSD (5%)
P	0.47	0.94
O	0.47	0.94
L	0.54	1.09
P × L	ns	
O × P	ns	
P × L × O	11	22

[a]Means followed by small letters are compared within the column. Means followed by capital letters are compared within column (L and O) and across the row (P). RP = Rajphos; MRP = Mussoorie rock phosphate; DAP = diammonium phosphate; L = levels of P; O = organic – green leaf manure (GLM)/ phosphobacteria (PB). [b] ns = not significant.

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Managing pressmud cake for nitrogen and phosphorus nutrition of crops in a rice-wheat rotation

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Rice-wheat is a nutrient-exhaustive cropping system that requires heavy inputs of fertilizers to obtain high yields. Application of organic materials to agricultural land has been viewed as an excellent way to recycle nutrients and organic matter that can support crop production and maintain or improve soil quality. Over the years, Asian farmers have used several types of organic materials. One of these is pressmud cake (PMC). PMC is produced annually from India's sugar industry. PMC is an important by-product when sugarcane is converted into crystalline sugar using two main processes: carbonation and sulphitation. Carbonation PMC contains high amounts of $CaCO_3$ and is therefore not recommended for alkaline soils. PMC produced from sugar factories using sulphitation contains about 2% N and 1% P, in addition to several other plant nutrients (2.5 g Fe kg^{-1}, 1.5 g Mn kg^{-1}, 0.27 g Zn kg^{-1}, and 0.13 g Cu kg^{-1}) (Kumar and Mishra 1991). This valuable organic material has great potential as a source of nutrients for the rice-wheat system in the Indo-Gangetic Plains. No precise information is available on the availability of N and P from the PMC in the rice-wheat rotation. Similarly, there is a dearth of agronomic strategies for the efficient use of PMC in the rice-wheat system.

We conducted a 4-year field experiment from 1998 to 2002 on loamy sand soil (Typic Ustipsamment) at the experimental farm of PAU. The soil has the following characteristics: 89 g clay kg^{-1}; 825 g sand kg^{-1}; pH 7.3 (1:2 soil-to-solution ratio); electrical conductivity, 0.19 dS m^{-1} (soil-to-solution ratio); organic carbon, 3.2 g kg^{-1}; total N, 0.40 g kg^{-1}; and cation exchange capacity, 7.8 cmol kg^{-1}. The soil contained 3.8 mg Olsen P kg^{-1} and 36 mg NH_4OAc-extractable K kg^{-1} in the 0–15-cm layer. A randomized complete block design with three replications was used. PMC containing 2.1% N, 1.3% P, and 0.5% K (av of 4 y) was applied to rice at 5 t ha^{-1} (dry-weight basis), which supplied 105 kg N, 65 kg P, and 25 kg K ha^{-1} each year. A known quantity of PMC (sulphitation) was uniformly distributed in the respective treatment plots and incorporated into the soil 2–3 d before transplanting of rice seedlings. The nine treatments used different combinations of PMC, N, and P rates:

T1-PMC (0) + 120 kg N ha^{-1} to rice and 120 kg N + 26.2 kg P ha^{-1} to wheat (recommended)

T2- PMC (5 t ha^{-1}) + 60 kg N ha^{-1} to rice and 80 kg N + 13.1 kg P ha^{-1} to wheat

T3- PMC (5 t ha^{-1}) + 60 kg N ha^{-1} to rice and 80 kg N + 26.2 kg P ha^{-1} to wheat

T4- PMC (5 t ha^{-1}) + 60 kg N ha^{-1} to rice and 120 kg N + 13.1 kg P ha^{-1} to wheat

T5- PMC (5 t ha^{-1}) + 60 kg N ha^{-1} to rice and 120 kg N + 26.2 kg P ha^{-1} to wheat

T6- PMC (5 t ha^{-1}) + 80 kg N ha^{-1} to rice and 80 kg N + 13.1 kg P ha^{-1} to wheat

T7- PMC (5 t ha^{-1}) + 80 kg N ha^{-1} to rice and 80 kg N + 26.2 kg P ha^{-1} to wheat

T8- PMC (5 t ha^{-1}) + 80 kg N ha^{-1} to rice and 120 kg N + 13.1 kg P ha^{-1} to wheat

T9- PMC (5 t ha^{-1}) + 80 kg N ha^{-1} to rice and 120 kg N + 26.2 kg P ha^{-1} to wheat

A basal dose of 25 kg K ha^{-1}, along with fertilizer P, was drilled during wheat sowing. Fertilizer N (as urea) was applied to rice in three equal split doses at 5, 21, and 42 d after transplanting. Fertilizer N was applied to wheat in two equal split doses—at sowing and 3 wk after sowing along with the onset of irrigation. All other recommended soil, water, and crop management practices were followed in both rice and wheat.

To explain the results obtained from the field study, the dynamics of N and P release from PMC was also investigated in the laboratory. PMC at 3 g kg^{-1} (dry-weight basis) was uniformly incorporated into the loamy sand soil and moisture was adjusted to 75% of field capacity. Amended and nonamended soil samples (400 g) were weighed into 500-mL plastic containers in three replicates and incubated at 30 ºC for up to 60 d. The plastic containers were weighed every third day during incubation and the loss in weight during incubation was made up through regular addition of distilled water. Soil samples were extracted from the containers at 10, 20, 30, 45, and 60 d after incubation to assess N and P mineralization. Mineral N (NH_4^+-N + NO_3^--N) was determined in 2 M KCl extracts (1:10 soil:extractant) and measured by micro-Kjeldahl steam distillation using MgO and Devarda's alloy. Available P was measured in 0.5 M $NaHCO_3$ soil extracts colorimetrically.

Application of PMC along with 80 kg fertilizer N ha^{-1} (T6-T9) produced rice grain yield equivalent to that produced with the recommended fertilizer treatment of 120 kg N ha^{-1} (T1) during 1998 and 1999 (Table 1). In 2000 and 2001, application of 60 kg N ha^{-1} on PMC-amended plots (T2-T5) produced yields similar to those obtained with 120 kg N ha^{-1} on nonamended (T1) plots. Increasing the fertilizer N dose to 80 kg ha^{-1} (T6-T9) significantly increased the rice yield over treatments with 60 kg N ha^{-1} on PMC-amended plots (T2-T5) or 120 kg N ha^{-1} on nonamended plots (T1). This was possibly due to increased soil N resulting from continuous application of the organic material.

Application of 80 kg N ha^{-1} and 13 kg P ha^{-1} to PMC-amended plots (T2 and T6) produced wheat yields equivalent to those obtained with 120 kg N ha^{-1} and 26 kg P ha^{-1} on nonamended plots (T1). There was no further increase in wheat yield with the application of 120 kg N ha^{-1} and 26 kg P ha^{-1} over 80 kg N ha^{-1} and 13 kg P ha^{-1} on PMC-amended plots. The residual effect of PMC in the following wheat crop was thus equivalent to 40 kg N and 13 kg P ha^{-1} to the rice-wheat system. No significant residual effect of N and P treatments applied to wheat was observed on the grain yield of rice. Similarly, N rates applied to rice showed no residual effect on the yield of the following wheat crop. Regular application of PMC during the 4-year period significantly increased organic carbon and available P content of the soil. The average increases in organic carbon and available P in PMC-treated soil (av of T2-T9) as compared with nonamended (T1) soil were 23% and 156%, respectively (Table 1).

N mineralization in the PMC-amended soil occurred in three phases. In the first phase, mineral N concentration decreased during the first 10 d after incubation, possibly because of the greater rate of N immobilization compared with mineralization (Table 2). The second phase was observed between day 10 and day 30, when mineral N in the PMC-amended soil increased significantly over the nonamended soil. During this period, 25.6% of the total PMC-N applied was mineralized. The third phase, covering the period between day 45 and day 60, had the maximum rate of N. During this time, 29.5% of the total PMC-N applied was mineralized.

Table 1. Effect of pressmud cake and N and P fertilizers on crop yield, organic carbon, and available P content of soil in the rice-wheat rotation, PAU, Ludhiana, Punjab, India.

Treatment[a]	Av grain yield (t ha^{-1})			Organic C (g kg^{-1})	Available P (mg kg^{-1})
	Rice		Wheat (1998- 2000)	After rice 2001	After rice 2001
	1998-99	2000-01			
T1	5.5	5.8	5.3	3.2	4.9
T2	5.3	5.8	5.2	3.7	12.4
T3	5.3	5.9	5.3	3.9	13.1
T4	5.2	5.8	5.4	3.7	11.4
T5	5.2	5.7	5.6	3.8	12.3
T6	5.5	6.3	5.2	3.9	12.1
T7	5.7	6.4	5.3	3.8	13.6
T8	5.6	6.2	5.4	4.0	12.3
T9	5.6	6.4	5.3	3.8	14.0
LSD (0.05)	0.33	0.41	ns[b]	0.32	3.15
Treatment means					
T2-T5	5.2	5.8	5.4	3.8	12.3
T6-T9	5.6	6.3	5.3	3.9	13.0

[a]See text for description of individual treatments [b]ns= not significant.

Table 2. N and P dynamics in loamy sand soil amended with pressmud cake (PMC) (3 g kg^{-1}) and incubated for 60 d at 30 °C under 75% field-capacity moisture regime.[a]

Treatment	Incubation period (d)				
	10	20	30	45	60
	Mineral N (mg kg^{-1})				
Nonamended	38.2	46.2	52.7	61.6	70.1
PMC-amended	33.6*	63.0*	68.0*	71.8*	105.0*
	Available P (mg kg^{-1})				
Nonamended	14.2	13.1	12.6	14.2	10.8
PMC-amended	20.3*	23.0*	19.2*	20.3*	19.5*

[a]* = Values within a column differ significantly at P = 0.05.

Available P concentration in the PMC-treated soil increased mainly during the first 20 d after incubation (Table 2). The increase in available P in PMC-amended soil was about 70% relative to the nonamended soil. The increase in available P in the amended soil represented 31.4% of the total P in PMC.

Laboratory results show that a significant portion of N from PMC mineralized 20–30 d after application, meeting part of the crop N demand during the early period. The second phase of N release, appearing between 45 and 60 d, provided sufficient N to rice, thus eliminating the need to apply fertilizer N at this crop stage. In PMC-amended fields, supplemental application of fertilizer N may be more critical during the first 3 wk of rice growth. However, there is a need to study the optimum fertilizer N schedule for rice on PMC-amended fields to further increase the efficiency of N from both PMC and fertilizer. The sharp increase in P availability in PMC-amended plots and the maintenance of high P levels over a long period will help meet the crop's P requirements. Long-term application of PMC may even cover the whole fertilizer P needs of the rice-wheat system.

In conclusion, PMC is an excellent source of plant nutrient for increasing crop yield and improving soil fertility. The efficient use of PMC could supply a large amount of N and P fertilizer needed in the rice-wheat rotation and thereby increase farmers' profits. This sugar by-product is available locally at minimal rates. It is easy to use and no additional land preparation is required. The data show that N and P are quickly released in PMC-amended soil, contributing to improved nutrition and higher crop yield. In the rice-wheat rotation, the application of 5 t PMC ha^{-1} could save 33–42% of fertilizer N cost and 50% of fertilizer P cost, with no loss in yield.

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Phosphorus input-output on an Ultisol cropped to upland rice in West Africa

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Phosphorus (P) deficiency is a major constraint to crop production on highly weathered, low-activity clay soils in the humid tropics (Sanchez and Salinas 1981). Soils in the humid tropics of West Africa are no exception, and P is the most limiting nutrient, affecting crop production and productivity. Not only are these soils low in available P, but the applied P is quickly converted into insoluble forms (Sahrawat et al 2001a). In West Africa, 70% of upland rice is grown in the humid zone, mostly on Ultisols and some Alfisols and Oxisols.

There is a lack of information on the long-term effects of P fertilizer on its recovery and balance in an upland rice production system. We present results from a 6-year experiment on P input-output using improved upland rice cultivars. A long-term (1993-98) experiment was conducted at the Centre National de Recherche Agricole (CNRA) station at Man (7.2°N, 7.4°W; 500 m altitude), Côte d'Ivoire, West Africa, to study the response of four improved upland rice cultivars to direct P in 1993 and to residual P in 1994, 1995, 1996, and 1998, applied at five rates (0, 45, 90, 135, and 180 kg P ha^{-1}) only once in 1993 (Sahrawat et al 2001b). The experimental site receives an average annual rainfall of about 2,000 mm in a monomodal season. The rainfall received during the growing season (June to October) was highly variable during 1993-98, varying from 684 to 1,668 mm. The experimental site was under bush fallow for the last 3 years before the start of the study. The soil at the site in the humid forest zone is an Ultisol with acidic pH (pH water 4.9; pH KCl 4.0), low available P (2.7 mg Bray 1 P kg^{-1} soil) and total P (155 mg P kg^{-1} soil), and moderate organic C (14.7 g kg^{-1} soil) and total N (950 mg kg^{-1} soil). The soil was high in exchangeable acidity (19.5 g kg^{-1}), dithionite-citrate extractable Fe (3.3 g kg^{-1}), and oxalate extractable Fe (2.3 g kg^{-1}).

The four rice cultivars (WARDA-bred cultivars WAB56-125, WAB56-104, and WAB56-50 and check IDSA6) with five rates of P fertilizer, applied as triple superphosphate, were arranged in a randomized complete block design with four replications. The cultivars were sown in rows at a spacing of 0.25 m in plots measuring 5 m × 3 m. Each year, all plots received a uniform application of N (applied as urea at 100 kg ha^{-1} in three splits) and K (applied as KCl at 100 kg ha^{-1}).

Rice crops were grown in 1993, 1994, 1995, 1996, and 1998; P fertilizer was applied only in 1993. At harvest, grain and straw yields were recorded and total P uptake in rice biomass was computed by analyzing the P content of the grain and straw samples.

The P input-output values (input is the amount of P fertilizer applied and output is the amount of P taken up in the grain plus straw in five crops), averaged over four rice cultivars, are summarized in Table 1. The recovery of applied P was calculated by subtracting P uptake in the no-P control from the P uptake in the plus-P treatment. Input-output was negative in the no-P treatment but positive in treatments where P fertilizer was added. The results show that in five crops, only a small fraction of the applied P fertilizer was removed by the rice crop, which varied from 5.5% to 9.4%, and this value decreased with the increase in the rate of P applied. In 1998, however, after 5 years of successive cropping, available P in the soil (Bray 1) was found to be similar and not affected by the rate of P fertilizer applied in 1993 (Table 2). This indicates that the applied soluble P was rendered insoluble during a reaction with sesquioxides in the soil (Abekoe and Sahrawat 2001). However, total P content in the soil at the end of the experiment in 1998 was affected by the rate of P fertilizer applied. Total P content in the soil was highest in the treatment that received P fertilizer at 180 kg P ha^{-1} and lowest in the no-P treatment. Cropping did not affect total soil P content in the control treatment without P application.

The results of this study show that P input-output was negative in the treatment that did not receive P fertilizer but positive in the treatments that received added P. Available P was similar in all treatments receiving a range of applied P, although total P was higher in the treatments that received higher rates of fertilizer P. This also indicates that only a small fraction of the applied P was recovered from 5 years of continuous cropping; the rest of the P was rendered unavailable and became part of the soil P (indicated by total P content in the soil). The reversion of soluble P to insoluble forms is caused by phosphate reactions with iron and aluminum oxides (Abekoe and Sahrawat 2001).

Table 1. Phosphorus input-output, recovery, and balance on an Ultisol, Côte d'Ivoire, 1993-98.[a]

P input (kg ha^{-1})	P output (kg ha^{-1})	P balance (kg ha^{-1})	Fertilizer P recovered in crop (%)
0	9.1	–9.1	–
45	13.5	31.5	9.4
90	16.8	73.2	7.2
135	19.5	115.5	6.8
180	19.5	160.5	5.5
LSD (0.05)	1.04		

[a]Fertilizer P applied at five rates only once in 1993. Each value is average of four rice cultivars. P input is the amount of fertilizer P applied; P output is the amount of P removed by the crop in 1993-98. P recovery in a treatment is calculated by subtracting P uptake in the no-P control from the P uptake in the plus-P treatment.

Table 2. Extractable and total P in soil samples at the start and end of 6 years (1993-98) of cropping of an Ultisol.

	P rate (kg ha^{-1})[a]	Extractable P (mg kg^{-1} soil)	Total P (mg kg^{-1} soil)
1993	0	3	155
1998	0	3	150
	45	4	188
	90	4	213
	135	4	245
	180	4	267

[a]Fertilizer P was applied only once in 1993.

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Leaf color chart-based N management in wet-seeded rice

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When blanket N recommendations are adopted, the crop demand for N and fertilizer N application are usually not matched properly. To avoid underfertilization or overfertilization of N to the rice crop, IRRI introduced the leaf color chart (LCC) to help farmers measure leaf color intensity, an indicator of the crop's need for N. This leads to a crop need-based, variable rate of N application to rice. Hegde et al (2001) pointed out the advantage of using the LCC to effectively manage blast incidence in rainfed rice culture. Although transplanting of rice is traditionally practiced in India, direct wet seeding of rice is becoming popular because of higher profit and greater savings on labor. An experiment was conducted to study LCC-based N management in wet-seeded rice.

Two field experiments were conducted at the RRS on red sandy loam soil during the 2000 wet season (December to March) and 2002 summer season (February to May). The experimental design was a split plot with three replications. Five N management practices constituted the main plots: control (no N), use of threshold (LCC) values 3, 4, and 5; and use of the recommended N dose. Four short-duration varieties (110 d) formed the subplots: ADT43, ADT36, ASD18, and MDU5. The recommended N rate was 120 kg ha^{-1}, applied in three splits (50% at the time of seeding, 25% at active tillering, and 25% at panicle initiation). The recommended dose of P (38 kg ha^{-1}) was applied basally at the time of seeding and K (38 kg ha^{-1}) was applied in three equal splits at seeding, active tillering, and panicle initiation. Disease, insect, and weed control measures were implemented as needed. The pregerminated seeds were sown using a drum seeder. Periodically, LCC readings were taken from 10 randomly selected plants using the topmost fully expanded leaves. Whenever the leaf color fell below a critical value, N was applied at 30, 45, and 30 kg ha^{-1} at the early, rapid, and late growth stages (CREMNET 1998). The time and amount of N applied at the different growth stages are given in Table 1.

LCC-based N management and variety significantly influenced grain and straw yields (Table 2). Application of N at 135 kg ha^{-1} in four splits at seedling (30 kg ha^{-1}), active tillering (45 kg ha^{-1}), panicle initiation (30 kg ha^{-1}), and flowering (30 kg ha^{-1}) based on an LCC value of 4 recorded the highest grain yield in both years. However, it was on a par with yields of N treatment with LCC 5, in which N at 165 kg ha^{-1} was applied in five splits—at seedling, active tillering, maximum tillering, panicle initiation, and flowering stages. On the other hand, the recommended N application in three splits recorded a lower yield than the LCC-based N treatments. Among the varieties, ADT36 gave a significantly higher yield than ASD18 and ADT43, but it was on a par with MDU5. The interaction between N and variety was not significant. The highest net income and benefit-cost ratio were noted in the LCC 4-based N treatment. Agronomic efficiency of applied N (AEN) values, defined as the increase in grain yield beyond the control per kg of N applied, were the highest for the LCC 4-based N treatment. Grain yields and AEN values were low in 2002 because of the high temperature and water stress that occurred during flowering and ripening.

Thus, N application based on an LCC value of 4 will help farmers realize high yield and achieve higher N-use efficiency with short-duration rice varieties. The use of the LCC can prevent un-

Table 1. Total quantity of N applied (kg ha^{-1}) under different treatments.

Treatment	Basal (seeding)	Seedling	Active tillering	Maximum tillering	Panicle initiation	Flowering	Total
Control–no N	–	–	–	–	–	–	0
LCC value 3	–	30	45	–	30	–	105
LCC value 4	–	30	45	–	30	30	135
LCC value 5	–	30	45	30	30	30	165
Recommended N	60	–	30	–	30	–	120

Table 2. Effect of N and variety on yield and economics of wet-seeded rice.

Treatment	Rate of N applied (kg ha^{-1})	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Agronomic efficiency of applied N		Net income (Rs ha^{-1})		Benefit-cost ratio	
		2000	2002	2000	2002	2000	2002	2000	2002	2000	2002
N management											
Control–no N	0	3.0	2.6	4.8	4.4	–	–	4,001	3,428	1.32	1.28
LCC value 3	105	4.6	3.2	6.6	4.5	15	6	10,646	4,702	1.79	1.35
LCC value 4	135	5.8	4.3	7.7	6.3	21	13	16,152	11,164	2.17	1.81
LCC value 5	165	5.5	3.8	7.6	5.5	15	7	14,489	7,898	2.02	1.56
Recommended N	120	4.2	2.9	6.6	4.5	10	3	9,123	3,394	1.66	1.25
CD (P = 0.05)	–	0.3	0.6	0.8	0.8	na[a]	na	na	na	na	na
Variety											
ADT43	–	4.3	2.9	7.0	5.5	–	–	9,986	4,738	1.74	1.35
ADT36	–	5.1	3.7	6.3	5.1	–	–	12,540	4,869	1.93	1.56
ASD18	–	4.4	3.4	5.6	4.2	–	–	9,187	5,504	1.68	1.40
MDU5	–	4.6	3.4	7.8	5.3	–	–	11,813	6,810	1.87	1.50
CD (P = 0.05)		0.6	0.5	0.6	0.5	na	na	na	na	na	na

[a]*na* = not analyzed.

der- or overfertilization of direct-seeded rice crops. By using the LCC, farmers can apply N at the right time, thereby increasing the productivity and profitability of direct wet-seeded rice.

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Chlorophyll meter-based N management for rice grown in soils amended with organic manure

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To ensure high yields, rice farmers tend to apply N in excess of the requirements. This often leads to low N-use efficiency as it does not account for large field-to-field variability of soil N supply. Synchronization of N supply with crop demand is crucial to achieving high yield and N-use efficiency. The chlorophyll meter, also known as the SPAD (soil plant analysis development) meter, can quickly and reliably assess the leaf area-based N status of a crop and can guide need-based N fertilizer applications in rice. Although the SPAD meter can be advantageously used to explore N management strategies, cheaper alternate gadgets such as the leaf color chart are already available for use by farmers. An approach based on the application of N when the sufficiency index (defined as SPAD value of the plot in question divided by that of an overfertilized reference plot or strip) falls below 0.90 (Hussain et al 2000) was used to determine the fertilizer N requirement of rice grown in soils amended with farmyard manure (FYM) and green manure (GM).

Field experiments were conducted in 1999-2001 on a Typic Ustipsamment at Ludhiana, northwestern India. Surface soil samples from the field locations contained 653–701 g sand kg^{-1}, 113–140 g clay kg^{-1}, 2.1–3.0 g organic C kg^{-1}, and a pH of 7.3–8.0. Experiments were laid out in a completely randomized block design with three replications. Treatments consisted of a zero-N control; recommended fixed split application of 120 kg N ha^{-1} in three equal doses at transplanting, mid-tillering, and panicle initiation; and N fertilizer applied on the basis of a chlorophyll meter reading following a sufficiency index approach in plots amended with 15 t FYM ha^{-1} or 20 t GM ha^{-1} (fresh-weight basis). Total N additions from organic manure are reported in the table. SPAD readings were taken weekly starting from 2 wk after transplanting and N was applied (doses varied in different years, see table) whenever a SPAD reading was below 90% of the value recorded in the overfertilized plot established by applying 240 kg N ha^{-1} in four splits.

Rice yield, total fertilizer N applied, and total N uptake in nonamended and organic manure-amended soils following the sufficiency index approach (SPAD<90% of overfertilized reference, OFR) using a SPAD meter, PAU, Ludhiana, India.[a]

Treatment	N applied (kg ha^{-1}) through		Yield (kg ha^{-1})	N uptake (kg ha^{-1})
	Fertilizer	Organic manure		
1999				
Nonamended; zero N (control)	0	–	3.38 c	37 d
Nonamended; recommended splits, N_{120}	120	–	5.78 b	89 c
Nonamended; N[b] at SPAD<90% of OFR	80	–	5.93	85 c
GM amended; N[b] at SPAD<90% of OFR	30	92	6.89 a	111 a
FYM amended; N[b] at SPAD<90% of OFR	75	106	6.44 a	92 b
2000				
Nonamended; zero N (control)	0	–	4.48 c	45 c
Nonamended; recommended splits, N_{120}	120	–	8.11 b	100 a
Nonamended; N[b] at SPAD<90% of OFR	100	–	8.20 b	97 a
GM amended; N[b] at SPAD<90% of OFR	30	84	8.62 a	104 a
FYM amended; N[b] at SPAD<90% of OFR	100	115	8.65 a	105 a
2001				
Nonamended; zero N (control)	0	–	3.90 b	42 c
Nonamended; recommended splits, N_{120}	120	–	6.20 a	93 a
Nonamended; N[b] at SPAD<90% of OFR	90	–	6.39 a	84 b
GM amended; N[b] at SPAD<90% of OFR	30	108	6.48 a	99 a
FYM amended; N[b] at SPAD<90% of OFR	90	130	6.66 a	89 b

[a]Within a column, means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's multiple range test. [b]30 kg N ha^{-1}, except during 29–49 DAT, when 45 and 40 kg N ha^{-1} were applied in 1999 and 2000, respectively, when SPAD reading was <90% of overfertilized reference treatment.

Need-based N management using the chlorophyll meter following a sufficiency index approach resulted in a savings of 25–40 kg N ha^{-1} in contrast to recommended splits for comparable rice yields in all 3 years (see table). The application of 30 kg N ha^{-1} was adequate on GM-amended plots in all years. In these plots, a depression in SPAD values was observed from 45 to 52 d after transplanting. Application of one or two doses of urea N at this stage possibly resulted in higher grain yield of rice in 2 out of 3 years. When soils were amended with FYM containing varying amounts of total N in different years, the amount of N fertilizer needed to achieve rice yields equivalent to those produced by recommended splits varied accordingly. In 1999 and 2001, need-based N application indicated substantial savings (40–45 kg N ha^{-1}) in N fertilizers. In 2000, savings in N were low probably because of the quality of FYM used in the study. GM- and FYM-amended plots produced significantly higher yields than nonamended plots during 1999-2000.

Two conclusions emerge from this study: (1) Plant need-based N management with a chlorophyll meter using the sufficiency index approach can quantitatively take into account increased N supply as a result of manure application and provide rational estimates of how much N fertilizer may be applied to rice; and (2) Organic amendments to such soils, in combination with organic fertilizers, consistently increase rice yields over that achieved with chemical fertilizers alone in the short run. Thus, organic amendments only serve as an alternative source of nutrients (N) for rice in these coarse-textured soils.

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OUR MAN IN CHINA

Dr. Zhikang Li, member of the IRRN Editorial Board, has been designated as IRRI molecular geneticist and coordinator of the International Network for Molecular Breeding and, at the same time, chief scientist of the Chinese Academy of Agricultural Sciences (CAAS). He will be based in China. Dr. Li has agreed to continue serving in the Editorial Board, handling submissions related to plant breeding and cell/molecular biology sent in by Chinese scientists. (See page 43 for guidelines on submitting electronic files to IRRN.)

Use of microplot technique to evaluate the effect of herbicide and organic fertilizer on dehydrogenase activity in lowland rice soil

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Assessment of soil microbial activity is necessary to understand the nutrient fluxes in a given ecosystem. Soil dehydrogenase activity is one of the measures of microbial activity of a large part of the microbial community in the soil (Alef 1995). In this study, we used a microplot technique to evaluate the effect of herbicide and organic fertilizer application on soil dehydrogenase activity based on the microbial electron transport system (ETS) activity assay.

Two experiments were conducted at PhilRice (longitude 120°56′E; latitude 15°45′N) in November and December 2001 in Maligaya clay soil. Microplots (2 × 2 m) were constructed in a well-puddled soil. The treatments for Experiment 1 were with and without herbicide application (cyhalofop butyl) at 1 L ha^{-1}. For Experiment 2, the treatments were a control (no application), application of 60-40-40 kg NPK ha^{-1}, and 5 t organic fertilizer ha^{-1}. The organic fertilizer contained 0.147% N, 0.152% P, and 8.45% K.

In each experiment, the treatments were replicated four times and laid out in a randomized complete block design. Soil samples (0–15 cm) were collected from the mixture of five random sites in each plot at 0, 2, 4, 6, and 8 d after herbicide application (Experiment 1) and at 1, 10, and 20 d after fertilizer application (Experiment 2) using a PVC (30-cm length, 15-cm diameter) sampler. The ETS activity assay was done by mixing 0.5 g of homogenized soil sample, 2 mL 0.1 M Tris-HCL buffer (pH 7.7), and 1 mL iodonitrophenyltetrazolium (INT) solutions and incubating the mixture for 15 min at 30 °C. The reaction was determined by adding 0.5 mL of 37% formaldehyde. The tubes were centrifuged at 3,000 xg for 15 min. The photometric absorbance of the supernatant was read at 480 nm (IRRI 1998). Statistical analysis and comparison of means were done using IRRISTAT for Windows software.

In Experiment 1, microbial activity in microplots without herbicides was lower than in those with herbicides at 2 and 4 d after application (DAA). However, herbicides had no significant effect on microbial activity at 6 and 8 DAA (Fig. 1). These results indicate that the application of cyhalofop butyl induced a short-term stimulation of microbial activity in lowland Maligaya clay soil. The increase in microbial activity could be attributed to the rapid degradation of cyhalofop butyl (http://cdpr/ca.gov/docs/publicreports/5748.pdf) into organic compounds that may become carbon and energy sources for the microorganisms. Although the result of this study implies that the herbicide could be relatively safe for nontarget organisms in the soil, the effect of continuous application of this pesticide needs further study.

In Experiment 2, organic fertilizer increased microbial activity at 10 and 20 DAA. Moreover, microbial activity in plots with inorganic fertilizer (60-40-40) did not differ from that in untreated plots (Fig. 2). The increase in microbial activity may be one of the causes of the significant increase in rice yield when the soil was treated with the same source of organic fertilizer in a previous

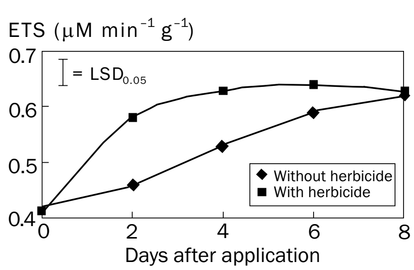

Fig. 1. Dehydrogenase activity in lowland rice soil as affected by application of herbicide cyhalofop butyl. PhilRice, Maligaya, Muñoz, Nueva Ecija, Philippines, November 2001.

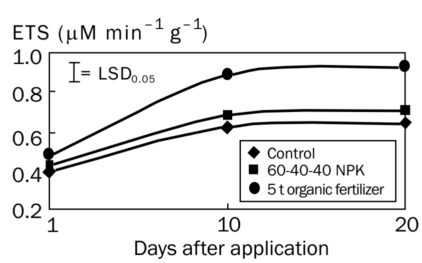

Fig. 2. Soil dehydrogenase activity in microplot as affected by fertilizer application. PhilRice, Maligaya, Muñoz, Nueva Ecija, Philippines, December 2001.

study. This organic fertilizer was produced from kitchen garbage, crop residues, and tree trimmings that were rapidly decomposed by applying effective microorganism inoculants.

Ecotoxicological studies conducted at PhilRice are done in bigger plots that require more inputs. The treatment application is also difficult. This is our first attempt to use the microplot method and it minimized our problems in using bigger plots. However, this study will be repeated on planted plots to be able to relate the changes in microbial activity to nutrient availability and rice yield.

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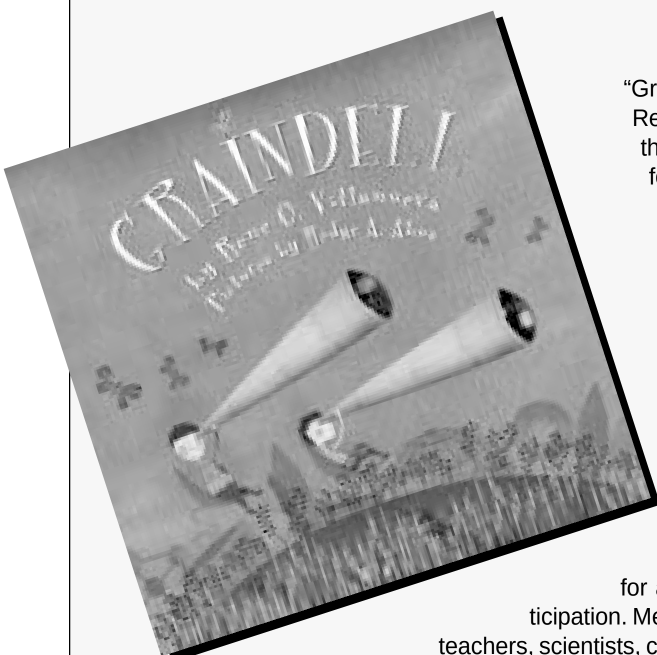
IRRI launches first children's storybook



"Graindell" is a children's storybook published by the International Rice Research Institute (IRRI). Written by renowned Filipino children's author Rene O. Villanueva, the book captures the organization's goal for all the children of the world—a "home for tomorrow," a progressive community where no one will go hungry. Through this first title in a series of children's publications, IRRI introduces its future stakeholders to important issues relating to rice, "the grain of life," food to half the world's population, especially in Asia.

Graindell, "the planetoid shaped like a little eye," tells the story of two friends, Abu and Thor, who share a common dream—to turn their home into the greatest place to live. The simple, yet moving, tale comes alive with the masterful renderings of Redge Abos, a young and talented artist from *Ilustrador ng Kabataan* (INK), in watercolor, combined with digital technology.

With the release of this first children's storybook, IRRI launches the "Graindell Community," which espouses the call for a dynamic, well-developed countryside through multisectoral participation. Membership is open to children and their stewards, including parents, teachers, scientists, children's storywriters and illustrators, and other concerned citizens. The members of the "Graindell Community" converge at the educational Web site, Graindell.com, where IRRI's own scientists lend their expertise to build a popular knowledge bank on rice, against the backdrop of science, food and nutrition, environment, arts and culture, literacy, and community participation. The site teaches children to "aspire, persevere, and achieve" through games, instructional materials, and interactive learning exercises with other children, as well as their stewards.

Graindell is IRRI's first project for the United Nations International Year of Rice to be celebrated in 2004.

The story of "Graindell" celebrates what IRRI is all about. It portrays the organization's endeavor to create a new generation of rice farmers and consumers who will embrace the traditional wisdom of farm life, understand the need for new and creative technology, and work together for a self-sufficient and well-developed society. By involving children now, they can march fearlessly into the future, knowing that "a home for tomorrow" is not only possible—it is achievable.

The "Graindell Community," the book, and the Web site were launched during National Children's Book Day, on July 15, at Museo Pambata in Roxas Boulevard, Manila, spearheaded by the Philippine Board on Books for Young People (PBBY) to promote international understanding through children's literature.

Please visit www.graindell.com <http://www.graindell.com> to sign up, get more information, and contribute content to the site.

Biochemical response of rice genotypes to exogenous gibberellic acid

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The most significant physiological effect of exogenous gibberellic acid (GA_3) on plants is to break dwarfism and stimulate the elongation of genetically dwarf genotypes, as these dwarf lines generally have a low level of endogenous GA_3 in their tissues (Singh et al 1978, Suge 1990). However, the same effects have not always been noted in all cases. Several dwarf genotypes of rice and wheat do not respond to exogenous application of GA_3 mainly because their tissues have high endogenous GA_3 (Singh et al 1981, Kumar et al 1992). The GA_3-induced elongation in dwarf genotypes is mainly attributed to greater cellular, biochemical, and physiological activities of the plants. This study looked at the biochemical effects of exogenous GA_3 on morphologically GA_3-responding and nonresponding rice genotypes.

Twenty-five-day-old seedlings of two dwarf rice genotypes, Dwarf mutant (a genotype that responds morphologically to GA_3) and Cigar (a genotype that does not respond to GA_3), were transplanted separately in a field at CARI at 40 × 20-cm spacing during the wet season. A full dose of NPK was applied before transplanting. Two lines each of both genotypes were sprayed with 100 ppm GA_3 solution, twice at 20 and 45 d after transplanting. Another two lines of each genotype were maintained as a control. Plants of both genotypes were sampled at flowering and thereafter separated into different parts. They were then dried in a hot-air oven at 70 °C for 48 h and ground for chemical analysis. The top three leaves were sampled for chlorophyll and enzyme assays. To estimate endogenous hormones (indole acetic acid [IAA] and GA_3), whole plants were cut from the base and washed thoroughly with tap water and finally rinsed with distilled water. Thereafter, plants were cut into small pieces, weighed, and preserved in brown bottles containing a sufficient amount of methanol at about 5 °C in the refrigerator. Chlorophyll, total sugar, starch, N, P, and Fe contents were determined following the methods of Yoshida et al (1976). Nucleic acid (RNA and DNA) and phytohormone (IAA and GA_3) contents and activity of various enzymes (catalase, peroxidase, nitrate reductase, ribonuclease, and succinate dehydrogenase) were measured using the procedure described by Mahadevan and Sridhar (1986).

Rice genotypes that showed distinct morphological and growth responses to exogenous GA_3 exhibited a differential biochemical response to GA_3 as well. Among the dwarf rice genotypes, Dwarf mutant, which showed marked growth and morphological response to GA_3, registered the maximum negative biochemical response to GA_3 for chlorophyll, nucleic acid (RNA and DNA), and endogenous IAA and GA contents in vegetative shoots. Cigar, which showed a smaller morphological and growth response to exogenous GA_3, registered little biochemical response also. Exogenous GA_3 caused a greater reduction in contents of protein and total organic N, P, and Fe in shoots of Dwarf mutant, whereas it markedly enhanced the level of total sugars and starch in the shoots of the same genotype (Table 1). The other genotype, Cigar, however, showed marginal biochemical changes in its shoots after GA_3 application. A further effect of exogenous GA_3 on rice genotypes was the stimulation and inhibition of the activity of different enzymes. Generally, GA_3 stimulated the activity of the hydrolytic enzymes (amylase, ribonuclease) and the respiratory enzyme (succinate dehydrogenase), while impairing the activity of nitrate reductase, IAA oxidase, catalase, and peroxidase to varying extents in the test genotypes (Table 2). The biochemical effect of exogenous GA_3 was invariably higher in Dwarf mutant than in Cigar. In general, the biochemical makeup of shoots of rice genotypes changed in accordance with their morphological and growth response to exogenous GA_3.

GA_3 induced a reduction in contents of inorganic nutrients (N, P, and Fe), chlorophyll, nucleic acids, and endogenous hormones in shoots of the most GA_3-responsive genotype, Dwarf mutant. This was perhaps due to their greater use, as their biomass was enhanced markedly by

Table 1. Effect of exogenous application of GA_3 on the organic and inorganic nutrient content in shoots of rice genotypes.

Genotype/ treatment	N (%)										Carbohydrates (%)			
	Protein N		Soluble N		Total N		P (%)		Fe (mg 100 g^{-1})		Total sugars		Starch	
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf
Dwarf mutant														
Control	1.2	3.2	0.4	0.3	1.5	3.5	0.4	0.4	53	95	1.0	0.7	4.0	1.0
GA_3	0.4	1.1	0.3	0.3	0.6	1.3	0.3	0.3	45	70	2.5	0.8	4.5	0.4
% of control	32	33	80	100	43	38	64	65	85	74	240	118	115	42
Cigar														
Control	1.2	2.8	0.3	0.3	1.5	3.1	0.4	0.4	80	63	0.4	1.1	1.6	0.3
GA_3	1.0	2.5	0.4	0.3	1.7	2.8	0.4	0.3	90	63	0.6	0.9	1.7	0.2
% of control	88	90	125	80	90	90	105	88	111	100	107	82	105	73

Table 2. Effect of exogenous application of GA_3 on the activity of different enzymes in rice genotypes.

Genotype/ treatment	Nitrate reductase (µmol NO_2 g^{-1} h^{-1})	Amylase (mg starch g^{-1} h^{-1})	Ribonuclease (mg P g^{-1} h^{-1})	Succinate dehydrogenase (OD g^{-1} h^{-1})[a]	IAA oxidase (mg IAA g^{-1} h^{-1})	Catalase (mg H_2O_2 g^{-1} h^{-1})	Peroxidase (OD g^{-1} h^{-1})
Dwarf mutant							
Control	0.97	2.80	0.18	0.27	1.22	24.5	0.66
GA_3	0.54	3.04	0.19	0.28	2.00	23.0	0.60
% of control	55	108	109	102	90	94	92
Cigar							
Control	2.14	2.80	0.09	0.24	1.15	22.3	0.64
GA_3	1.70	3.06	0.11	0.29	1.00	20.6	0.55
% of control	79	109	125	119	86	92	87

[a]OD = optical density.

GA_3 application (Singh and Ram 1997). However, the higher carbohydrate content, especially in the stem of the GA_3-responsive genotype, may be caused by the greater increase in photosynthetic production (shoot growth) as the leaf area of this genotype increased significantly after GA_3 application. A greater leaf area produces higher amounts of carbohydrates in rice plants (Yoshida 1972). Kim and Hue (1988) and Prakash and Prathapasenan (1990) have also reported the stimulation of hydrolytic and respiratory enzymes and suppression of catalase, peroxidase, nitrate reductase, and IAA oxidase by GA_3 in rice as shown in this study.

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Water management in direct-seeded lowland rice

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Lack of proper water management is probably the most widespread constraint to higher rice yields (Sharma and Sarkar 1994). Hence, a rice production method that inherently requires less water or is more water-efficient would have an advantage over the traditional transplanting system.

The water requirement can be reduced by changing the irrigation schedule and method of crop establishment (Kim et al 1992). Wet seeding, in lieu of transplanting, offers a significant opportunity for improved management of irrigation water (Bhuiyan et al 1995). The present study aimed to reduce the irrigation requirement and improve productivity in wet-seeded puddled lowland rice.

The experiment was conducted on the wetland farms of TNAU during kharif (dry season, Jun-Oct 1997) and rabi (wet season, Sep 1997-Jan 1998) on clay loam soil with pH (1:2 w/v water) 7.66, electrical conductivity 0.5 dS m^{-1}, field capacity 30%, organic carbon 0.73%, and bulk density 1.33 g cm^{-3}. Soil available NPK was 248, 6.6, and 456.5 kg ha^{-1}, respectively. The amount of rainfall received during kharif was 249 mm and that during rabi was 514 mm. Sprouted seeds of ASD18 (kharif) and IR20 (rabi) were sown using a drum seeder.

Details of the experiment—plot size, seeding date, transplanting date (for T_9), and harvest dates—which were the same in all treatments, are given in Table 1.

Table 1. Plot size and dates of sowing, transplanting, and harvesting, 1997 kharif and rabi.

Item	Kharif	Rabi
Plot size (m^2)	24	24
Date of sowing	27 Jun 1997	15 Sept 1997
Date of planting (T_9)	23 Jun 1997	18 Oct 1997
Date of harvesting	20 Oct 1997	23 Jan1998
Duration (d)	116	131

Land preparation and leveling were done 1 d after soaking the soil. Before sowing, the field was kept drained to keep it saturated to facilitate easy sowing and ensure early and uniform establishment of seedlings. After sowing, the field was kept moist, taking care not to flood it or have cracks form for the first 5 d by providing light irrigation and drainage. Because of slow establishment of seedlings, irrigation treatments were imposed 20 d after sowing (DAS). Up to 20 DAS, only light irrigation to a depth of 2 cm was given equally to all treatments and this was taken into account when total water use was computed. All the plots and replications were demarcated by buffer and irrigation channels. A plot was provided with buffer channels on all sides to arrest interplot seepage and hydraulic conductivity.

The experiment was laid out in a randomized block design with nine irrigation regimes: irrigation to 5 cm depth 1 d after disappearance of ponded water (DADPW) (T_1), irrigation to 5 cm depth 3 DADPW (T_2), continuous submergence in 2.5-cm-deep water throughout the crop period (T_3), irrigation to 2.5-cm depth 1 DADPW (T_4), irrigation to 2.5-cm depth 3 DADPW (T_5), saturation throughout the crop period (T_6), maintaining 5-cm depth of water during critical stages and maintaining saturation during other stages (T_7), maintaining 2.5-cm depth of water during critical stages and maintaining saturation during other stages (T_8), and irrigation of transplanted rice to 5-cm depth 1 DADPW (T_9). All treatments were replicated three times. In T_9, irrigation was given until water depth reached 5 cm (or 2.5 cm). Again, a water depth of 5 cm (or 2.5 cm) was provided either 1 or 3 DADPW, depending on the treatment.

The critical stages include active tillering (35–40 DAS), panicle initiation (55–60 DAS), and flowering (75–80 DAS). In treatments T_7 and T_8, irrigation to either 5- or 2.5-cm depth was imposed during the critical stage + 1 d each, before and after the start of the critical growth stage (i.e., total of 8 d) only. Further, for treatments T_6 (entire growth period), T_7, and T_8 (growth period other than critical period), saturation was maintained by applying 2 cm of water when required. Excess/standing water was not present and hairline cracks did not develop.

A fertilizer schedule of 120:16.3:31.5 kg NPK ha^{-1} for ASD18 (kharif) and 150:21.5:41.5 kg NPK ha^{-1} for IR20 (rabi) was followed uniformly in all plots.

The quantity of water applied to both the nursery and main field was measured by using a 90° V notch. Effective rainfall was worked out by the evaporation / precipitation ratio and taken into account in the determination of total water use. Hand weeding was done twice. Grain yield (rough rice) was measured from a net plot area (7.2 + 2.6 m^2) and expressed at 14% moisture level.

Irrigation to 5-cm depth 1 DADPW in direct-seeded rice (T_1) and in transplanted rice (T_9) recorded the highest grain yield of 5.5 and 5.3 t ha^{-1} during kharif and rabi, respectively. The highest growth and yield-attributing characters observed in these irrigation regimes (data not presented) resulted in more grain yield. However, continuous submergence of rice at 2.5-cm depth throughout the crop-growing period did not give a significantly different yield. In both seasons, T_5 recorded the lowest grain yield because rice plants experienced moisture stress and cracks developed in this irrigation regime (Table 2).

The quantity of water applied decreased with an increase in the interval between irrigations. The maximum amount of water use was recorded with transplanted rice (T_9) due to extended land preparation and nursery establishment, which resulted in the lowest water productivity (WP). T_3 recorded the highest WP (0.506 and 0.514 g rice per kg of water applied during kharif and rabi, respectively) because higher grain yield was obtained with a minimum amount of water (Table 2). Flooding the soil to 1- or 10-cm depth has no effect on rice yield (Greenland 1997).

With T_3, savings of irrigation water—about 340 and 308 mm ha^{-1} (24.5% and 23.8% over transplanted rice in kharif and rabi, respectively)—were realized without impairing productivity and net returns (Table 2). Therefore, it can be concluded that continuous submergence of the rice crop in 2.5 cm of water (instead of 5 cm) is a desirable practice to achieve higher grain yield and WP.

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Table 2. Grain yield and water productivity of direct-seeded rice, Tamil Nadu, India, 1997 kharif and rabi.

Treatment[a]	Kharif			Rabi		
	Water use (mm)	Grain yield (t ha^{-1})	Water productivity (g rice kg^{-1} water)	Water use (mm)	Grain yield (t ha^{-1})	Water productivity (g rice kg^{-1} water)
T_1	1,108	5.5	0.497	1,045	5.1	0.489
T_2	998	4.9	0.496	971	4.8	0.489
T_3	1,045	5.3	0.506	985	5.1	0.514
T_4	1,012	5.1	0.500	967	4.8	0.501
T_5	952	4.3	0.456	937	4.2	0.444
T_6	956	4.5	0.468	933	4.2	0.454
T_7	972	4.8	0.489	955	4.5	0.475
T_8	964	4.7	0.483	945	4.4	0.469
T_9	1,385	5.4	0.392	1,293	5.3	0.409
CD at 5%	49.1	0.23	0.23	47.1	0.023	0.203

[a]For treatment details, refer to text.

Farmer categorization based on farmer performance index: identifying the targets of agricultural extension

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Careful identification of target groups is essential in any effective agricultural extension program. Since one of the objectives of agricultural extension is to increase crop yield, efforts should be exerted to clearly identify the target audience. Blanket recommendations have given marginal returns to investments. In this context, the farmer performance index (FPI) can be used to categorize farmers who can be targeted as recipients of extension programs. Pingali et al (1990) have defined FPI as the ratio of farmers' actual yield to location-specific yield (LSY) potential. The main advantage of using FPI in agricultural extension programs is the assurance that extension targets can be identified for different technological packages.

An investigation was carried out in Shrawasthipura and Rambewa villages of Anuradhapura District (dry zone), Sri Lanka. The two villages are dominated by tank-fed rice culture. A field survey was done just after the major rice-growing season in 2001-02 (*maha*, Oct-Feb) and 25 farmers from each village were selected randomly. Pretested questionnaires were used to gather data on yield performance.

LSY was calculated by taking the average rice yield in the last 5 years. This was found to be 4.3 t ha^{-1}. The FPI values were calculated for the farmers selected in the two villages (see figure). The results indicate that, in Shrawasthipura and Rambewa, 44% and 36% of farmers had yields below LSY, respectively. Farmers were then categorized according to actual yields that they obtained. The table illustrates the farmer categorization.

Farmer categorization on the basis of FPI.

Yield category	Percentage of farmers	
	Shrawasthipura	Rambewa
Low (below 4 t ha^{-1})	28	16
Medium (4–5 t ha^{-1})	52	64
High (above 5 t ha^{-1})	20	20

This type of farmer categorization characterizes the targets of agricultural extension programs with further identification of farmers' needs. For example, the low yielders are represented by 28% and 16% of farmers in Shrawasthipura and Rambewa, respectively. To reduce the gap between LSY and actual yield, major limitations encountered in this category should be identified and extension interventions be directed to remove such limitations.

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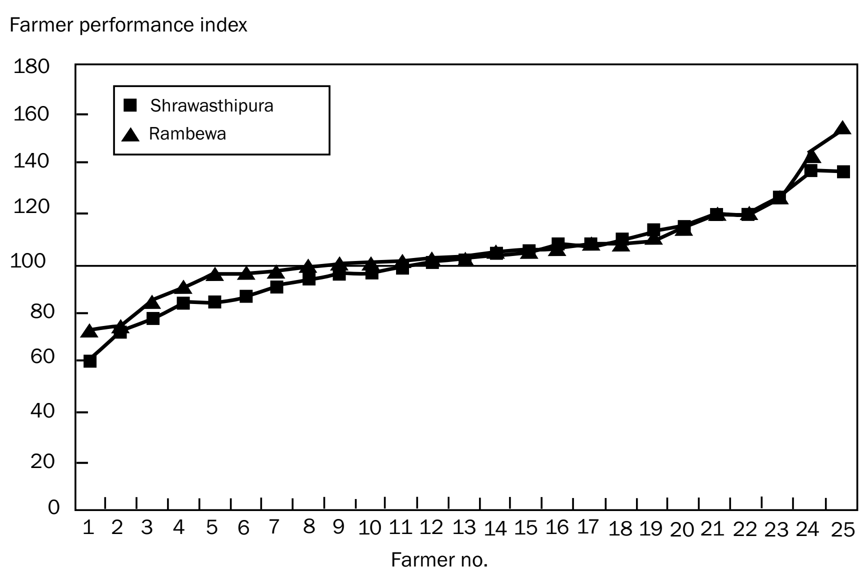

Farmer performance index of farmer-respondents in Shrawasthipura and Rambewa, Anuradhapura, Sri Lanka, 2001-02.

Front-line demonstration performance of salt-tolerant rice varieties in coastal saline soils

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A front-line demonstration (FLD) is one of the approaches used to discriminate technology generated through research. This unique program directly involves scientists, enabling them to have first-hand information. Considering the demand for salt-tolerant rice varieties in the coastal saline soils (Khar land) of Maharashtra, an FLD was launched by the Khar Land Research Station in nearby villages from 1997 to 1999.

Of the 8.6 million ha of salt-affected soils in India, 65,465 ha are covered by coastal saline soils in Maharashtra (GOM 1990). Farmers in this region generally grow conventional rice varieties using suboptimal input levels. Because they lack knowledge of rice production technology, their farms are not productive. The Khar Land Research Station, Panvel, has released improved, salt-tolerant rice varieties Panvel 1, Panvel 2, and Panvel 3 (Ingale et al 1993, Sawardekar et al 2000). However, the spread of these varieties has been limited because of weak extension activities and poor information dissemination programs. Moreover, the area devoted to seed production of these varieties at the research station is limited. With financial and technical assistance of the Indian Council of Agricultural Research, New Delhi, an FLD of salt-tolerant improved rice varieties was conducted in farmers' fields. Cultivated were the salt-tolerant varieties listed in Table 1.

The farmer participants came from Koproli, Chirner, and Jui villages of Uran Tahasil District, Raigad. The experiment, conducted in 1997-99 kharif, aimed to study the technology gap, extension gap, technology index, and economics of rice production. Each demonstration farm was 0.20 ha. Soil types were clay loam, with low to medium N, and high to very high available P and K (Table 2). Salinity levels were from 6.3 to 9.3 dS m^{-1}. Rainfall distribution was uniform throughout the crop-growing period.

Production and economic data, as well as data on local practices, were collected.

The technology gap, extension gap, and technology index were calculated using the following formulas (Samui et al 2000):

Technology gap = potential yield – demonstration yield
Extension gap = demonstration yield – farmers' yield
Technology index = potential yield – demonstration yield / potential yield $\times$ 100

A comparison of productivity levels, yield gaps, technology gaps, and extension gaps between improved salt-tolerant rice varieties and local checks is shown in Table 1. Variety Panvel 1 recorded the highest rice yield (4.4 t ha^{-1}) in the 1998 kharif season. The results indicate the good impact of FLD trials on farming communities with coastal saline soils. Farmers were motivated by agrotechnologies applied in the

Table 2. Characteristics of soil in demonstration blocks (av data).

Soil parameter	Koproli	Chirner	Jui
pH	6.5	6.7	6.5
EC (dS m^{-1})	6.3	7.1	9.3
Organic C (%)	0.48	0.49	0.47
Available P_2O_5 (kg ha^{-1})	68	72	71
Available K_2O (kg ha^{-1})	1,300	1,200	1,500

Table 1. Yield, technology gap, extension gap, and technology index of improved salt-tolerant rice varieties.

Year	Variety	Demonstrations (no.)	Yield (kg ha^{-1})			% increase over local check	Technology gap (kg ha^{-1})	Extension gap (kg ha^{-1})	Technology index (%)
			Potential	Demonstrations	Local check				
1997	CSR10	15	4,500	4,020	3,515	14.37	480	505	10.66
1998	Panvel 1	20	4,500	4,429	3,520	25.82	71	909	1.57
1999	Panvel 1	20	4,500	4,247	3,023	40.48	253	1,224	5.62

FLD trials and they adopted these in the succeeding years, resulting in enhanced productivity. The yield of rice, however, varied because of climate changes during the experimental period and the use of different varieties.

The observed technology gap may be attributed to dissimilarities in soil fertility, salinity, and weather conditions. Hence, a location-specific recommendation appears to be necessary to close the gap. The wide extension gap emphasizes the need to educate farmers. The technology index reflects the feasibility of using the evolved technology in farmers' fields. The lower the value of the technology index, the more feasible the use of the technology is. The highest technology index, noted in 1997 kharif with variety CSR10, clearly indicates the existence of a wide gap between technologies developed at research stations and those used in farmers' fields.

Additional costs, mainly for inputs, were noted in the FLD trials, thus increasing the cost of cultivation over that of the local check. But gross returns and net returns were still substantial in the FLD trials. Higher benefit-cost ratios were seen with improved varieties than with local checks (Table 3).

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Table 3. Economics of rice cultivation.

			Cost of cultivation (Rs ha^{-1})			Gross return (Rs ha^{-1})		Net return (Rs ha^{-1})			Benefit-cost ratio	
Year	Variety	Input cost for demonstration (Rs ha^{-1})	Demonstration	Local check	Additional cost of cultivation in demonstration (Rs ha^{-1})	Demonstration	Local check	Demonstration	Local check	Additional return (Rs ha^{-1})	Demonstration	Local check
1997	CSR10	2,372	9,768	8,525	1,243	17,300	13,115	7,532	4,590	2,942	0.77	0.53
1998	Panvel 1	2,372	8,883	7,900	983	18,800	14,400	9,917	6,500	3,417	1.11	0.82
1999	Panvel 1	2,372	12,166	10,900	1,266	20,900	17,200	8,699	6,300	2,309	0.71	0.57

Extent of women's involvement in Indian rice cultivation

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As in other countries, nearly half of the available human resources in India are women. In traditional village communities, women are primarily involved in all stages of crop cultivation, from field preparation to harvesting of grains. In rural areas of India, most female workers help the men in farm operations, especially in the agricultural sector (Sherwani 1983). In general, women provide 60–70% of labor input. For rice, this proportion reaches 80%. Gautam and Meenakshi (1992) indicated that the proportion of women in the agricultural labor force was more and their contribution to agriculture was greater than men's.

In 2000, we conducted a study at the Regional Research Station, Paiyur, to find out the extent of women farmers' involvement in rice cultivation. The data were collected at Palacode and Krishnagiri taluks of Dharmapuri District in Tamil Nadu, India. Agriculture is the source of livelihood of the people in this area, with a wide variety of crops grown—cereals, millet, pulses, oilseeds, tomato, and mango. In this district, rice is grown on about 57,000 ha of land during the wet (Jul-Nov) and dry seasons (Dec-Mar). Canal and well-irrigation systems are fairly common.

One hundred and twenty women farmers were selected randomly from six villages in these two taluks (20 from each village). Most of the women farmers cultivate relatively small farms (0.1–1 ha); some who have more land (>1 ha) live in clusters. Through a well-structured interview schedule, data on the involvement of women in each cultivation practice were collected. The extent of involvement of women farmers was categorized into three groups: doing the work herself, assisting, and supervising.

Women farmers were actively involved in all rice cultivation practices, except in the preparation of the field for transplanting (22% reporting) and raising seedlings in nurseries (34% reporting) (see table). These practices are considered risky and therefore involve only men. Similarly, spraying of pesticides and fungicides to protect the crop is regarded as an all-male activity. Women farmers did not want to be involved as they perceived this activity to be risky (100%). Women were highly involved in transplanting (79.2%), intercultivation (59.8%), harvesting (82.7%), and postharvest (89.6%) operations.

Extent of women's involvement in rice cultivation, Dharmapuri District, Tamil Nadu, India.

Cultivation practice		Doing the work herself		Assisting		Supervising		Others[a]	
		No.	%	No.	%	No.	%	No.	%
Main field preparation									
Collecting stubbles		15	12.5	–	–	30	25.0	75	62.5
Cleaning field boundaries		10	8.3	–	–	15	12.5	95	79.2
Applying farmyard manure		–	–	15	12.5	20	16.7	85	70.8
Plowing and leveling		–	–	–	–	–	–	120	100
	Subtotal	25	5.2	15	3.1	65	13.6	375	78.1
Nursery preparation									
Seed cleaning		–	–	28	23.3	32	26.7	60	50.0
Seed treatment		–	–	5	4.2	18	15.0	97	80.8
Sowing		10	8.3	–	–	30	25.0	80	66.7
	Subtotal	10	2.8	33	9.2	80	22.2	237	65.8
Transplanting									
Pulling out seedlings		62	51.7	13	10.8	22	18.3	23	19.2
Transporting seedlings		58	48.3	17	14.2	–	–	45	37.5
Transplanting in main field		58	48.4	25	20.8	30	25.0	7	5.8
	Subtotal	178	49.5	55	15.3	52	14.4	75	20.8
Intercultivation									
Gap filling		42	35.0	5	4.2	35	29.2	38	31.6
Weeding		48	40.0	10	8.3	40	33.3	22	18.4
Applying herbicides		–	–	15	12.5	32	26.7	73	60.8
Topdressing fertilizers		–	–	20	16.7	40	33.3	60	50.0
	Subtotal	90	18.8	50	10.4	147	30.6	193	40.2
Plant protection									
Spraying pesticides/fungicides		–	–	–	–	–	–	120	100
	Subtotal	–	–	–	–	–	–	120	100
Harvesting									
Harvesting		60	50.0	24	20.0	36	30.0	–	–
Bundling		48	40.0	–	–	60	50.0	12	10.0
Transporting to yard/thrashing floor		28	23.3	10	8.3	–	–	82	68.4
Heaping		60	50.0	18	15.0	40	33.3	2	1.7
Thrashing		52	43.3	12	10.0	48	40.0	8	6.7
	Subtotal	248	41.3	64	10.7	184	30.7	104	17.3
Postharvest									
Winnowing		40	33.3	5	4.2	60	50.0	15	12.5
Bagging		38	31.7	12	10.0	60	50.0	10	8.3
Stacking		40	33.3	18	15.0	45	37.5	17	14.2
Storing		112	93.3	–	–	–	–	8	6.7
	Subtotal	230	47.9	35	7.3	165	34.4	50	10.4
	Total	781	27.1	252	8.8	693	24.1	1,154	40.0

[a]Reasons given for not being involved in rice cultivation: no time to get involved, hired laborers to do the job, considered it risky, and regarded it as man's job.

Sixty percent of the women farmers were directly involved in rice cultivation, distributed in each category as follows: doing the work herself (27.1%), assisting (8.8%), and supervising (24.1%). They played a distinct and well-accepted role in such activities as pulling out seedlings (80.8%), transporting (62.5%), transplanting seedlings (94.2%), harvesting (100%), bundling (90%), heaping the bundles (98.3%), thrashing (93.3%), winnowing (87.5%), bagging (91.6%), and storing of grains (93.3%). Women farmers with small land did the activities themselves to reduce cultivation costs and thereby increase net income. On the other hand, women farmers with big farms often paid others to assist in and supervise the process of cultivation.

The results imply that technology development and transfer should consider specific characteristics and needs of women in the conduct of rice production activities. This will enhance efficiency in different farming operations and boost farm productivity and net profit.

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Farmers' participatory evaluation of BRRI hybrid dhan 1 in Bangladesh

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Farmers' participatory evaluation of rice varieties refers to the active involvement of farmers in the process of selecting varieties. It enables one to understand the criteria and approaches used by farmers in deciding what variety to grow (Hawlader 2001). BRRI hybrid dhan 1, the first hybrid rice variety developed by the BRRI and released in 2001, was evaluated using a participatory approach at on-station (BRRI Regional Station, Bhanga, Faridpur) and on-farm (13 villages of Faridpur District) trials in 2002 boro *(*dry season). In many countries, this approach is commonly used to identify farmers' preferred varieties. In Nepal, varieties selected through participatory evaluation yielded 15–18% more than existing varieties (Sthapit et al 1996). In view of the very little work done on participatory evaluation of hybrid rice in Bangladesh, this study used a participatory approach to learn farmers' preferences and opinions about hybrid rice.

On-station trials evaluated BRRI hybrid dhan 1, three imported hybrids (Sonar Bangla, Alook, and Jagoron), two popular inbred varieties (BINA dhan 5 and BINA dhan 6), and one popular inbred check variety (BRRI dhan 29). All the test varieties were grown side by side with the check variety. Plot size was 20 m $\times$ 10 m. The on-farm experiment used BRRI dhan 29, a popular boro rice variety, as a check for comparison with BRRI hybrid dhan 1. Plot size was 20 m $\times$ 20 m. Forty-day-old seedlings of each variety were transplanted at a spacing of 20 cm $\times$ 15 cm with 1–2 seedlings per hill. Standard agronomic practices were followed.

Field evaluation of crop cuts of test and check varieties was done at crop maturity. Farmers, officials of the Directorate of Agricultural Extension and Seed Certification Agency, BRRI scientists, newspaper reporters, and local leaders were present at the occasion. Through brainstorming sessions, group discussions, and matrix rankings, 200 participating farmers identified the characters of a rice hybrid that they preferred.

Results of on-station trials revealed that BRRI hybrid dhan 1 took 163 d to mature and its grain yield was 8.2 t ha^{-1} (Table 1). BRRI hybrid dhan 1 exhibited the highest productivity (50.3 kg ha^{-1} d^{-1}), followed by BRRI dhan 29 (44.6 kg ha^{-1} d^{-1}), Sonar Bangla (44.5 kg ha^{-1} d^{-1}), and Alook (38.4 kg ha^{-1} d^{-1}). BRRI hybrid dhan 1 showed a 12.8% increased productivity over BRRI dhan 29.

Table 1. Performance of some hybrid and inbred rice varieties, BRRI Regional Station, Bhanga, Faridpur, during 2002 boro.

Hybrid/inbred variety	Plant height (cm)	Panicles m^{-2} (no.)	Filled grains $panicle^{-1}$ (no.)	Grain sterility (%)	Days to maturity	Grain yield ($t\ ha^{-1}$)	Productivity ($kg\ ha^{-1}\ d^{-1}$)	Increased productivity over check (%)
BRRI hybrid dhan 1	102.7	285	136.4	20.1	163	8.2	50.3	12.8
Sonar Bangla	85.3	260	130.0	7.4	155	6.9	44.5	–0.2
Alook	84.8	272	123.4	22.3	151	5.8	38.4	–13.9
Jagoron	83.0	220	127.0	17.3	155	5.9	38.1	–14.8
BINA dhan 5	99.5	192	99.8	14.4	156	5.4	34.6	–22.4
BINA dhan 6	107.0	208	126.0	17.1	172	6.3	36.6	–17.9
BRRI dhan 29 (check)	99.6	255	132.0	15.5	166	7.4	44.6	–
Mean	94.6	227.4	124.9	16.3	159.7	6.6	41.0	–
CV (%)	10.5	15.3	9.5	29.2	4.7	15.1	14.4	–

Table 2. Comparative productivity of BRRI hybrid dhan 1 and BRRI dhan 29 grown in 13 villages of Faridpur District, 2002 boro.

Location (village)	BRRI dhan 29			BRRI hybrid dhan 1			Increased productivity over BRRI dhan 29 (%)
	Days to maturity	Grain yield ($t\ ha^{-1}$)	Productivity ($kg\ ha^{-1}\ d^{-1}$)	Days to maturity	Grain yield ($t\ ha^{-1}$)	Productivity ($kg\ ha^{-1}\ d^{-1}$)	
Tuzarpur	165	8.5	51.5	157	9.0	57.7	12.0
Khapura	162	7.0	43.2	158	7.4	46.8	8.3
Brahmankanda	161	8.0	49.7	157	8.5	54.1	8.9
Mansurabad	164	8.6	52.4	159	9.5	59.7	13.9
Poranpur	162	6.8	42.0	156	7.0	44.9	6.9
Laxmipur	160	7.0	42.4	159	7.3	45.9	8.3
Deora	161	7.5	46.6	160	7.5	47.8	2.6
Nidhirampur	160	7.3	45.6	158	8.0	50.6	11.0
Gongadhardi	162	7.5	45.5	159	8.8	55.3	21.5
Sadardi	163	8.3	50.9	157	9.4	59.9	17.7
Mansurabad	164	8.0	48.8	159	9.0	56.6	16.0
Maligram	160	8.2	51.3	157	8.6	54.8	6.8
Hazrakanda	162	7.8	48.1	159	8.0	50.3	4.6
Mean	162	7.8	47.5	158.1	8.3	52.6	10.7
CV (%)	1.7	7.1	7.3	3.0	10.0	9.6	–

On-farm results showed that BRRI hybrid dhan 1 took 158.1 d to mature; grain yield was 8.3 t ha^{-1} (Table 2). The increased productivity of BRRI hybrid dhan 1 over BRRI dhan 29 ranged from 2.6% to 21.5% (the mean was 10.7%). Similarly, Hawlader et al (2002) reported 7 d earliness and a 14.2% increase in grain yield of BRRI hybrid dhan 1 over BRRI dhan 29 during on-farm trials in 2000-01 boro.

BRRI hybrid dhan 1 was preferred because of its uniformity, high grain and stover yield, long panicles, high filled grains/panicle, and low grain sterility and shattering. The farmers did not consider grain yield as the sole criterion for varietal selection. Also considered important were the production of sufficient straw, less grain shattering in the field, cold tolerance at the seedling stage, good market value, easy threshing quality, and lower seed price (Hawlader 2001). The farmers also wanted the cost of hybrid seed to be reasonable; the hybrid variety to fit into their cropping patterns, to adapt to the local environment, and to meet household requirements; and the required management practices to be affordable. The adoption rate of BRRI hybrid dhan 1 may be increased if farmers participate in its evaluation.

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Each note may include up to two tables and/or figures (graphs, illustrations, or photos). Refer to all tables and figures in the text. Group tables and figures at the end of the note, each on a separate page. Tables and figures must have clear titles that adequately explain contents.

Apply these rules, as appropriate, to all research notes:

Methodology

- Include an internationally known check or control treatment in all experiments.
- Report grain yield at 14% moisture content.
- Quantify survey data, such as infection percentage, degree of severity, and sampling base.
- When evaluating susceptibility, resistance, and tolerance, report the actual quantification of damage due to stress, which was used to assess level or incidence. Specify the measurements used.
- Provide the genetic background for new varieties or breeding lines.
- Specify the rice production systems as irrigated, rainfed lowland, upland, and flood-prone (deepwater and tidal wetlands).
- Indicate the type of rice culture (transplanted, wet seeded, dry seeded).

Terminology

- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
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Mini reviews should address topics of current interest to a broad selection of rice researchers, and highlight new developments that are shaping current work in the field. Authors should contact the appropriate editorial board member before submitting a mini review to verify that the subject is appropriate and that no similar reviews are already in preparation. (A list of the editors and their areas of responsibility appears on the inside front cover of each IRRN issue.) Because only 1-2 mini reviews can be published per issue, IRRN will require high quality standards for manuscripts accepted for publication. The reviews should be 2000-3000 words long, including references. Refer to the guidelines for research notes for other aspects of writing and content.

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Notes from the field should address important new observations or trends in rice-growing areas, such as pest outbreaks or new pest introductions, or the adoption or spread of new crop management practices. These observations, while not the result of experiments, must be carefully described and documented. Notes should be approximately 250 words in length. Refer to the guidelines for research notes for other aspects of writing and content.

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International Year of Rice

Last year, the United Nations General Assembly declared 2004 as the International Year of Rice. The International Year of Rice aims to "promote the ecological, social, and cultural diversity of rice-based production systems as a prism through which key global concerns can be addressed, such as poverty and hunger alleviation, undernourishment, food safety, environmental protection, and other important issues."

The Food and Agriculture Organization (FAO) of the UN will facilitate the implementation of activities related to the celebration through a network of stakeholders that include donors, a global working group, regional working groups, national working groups, and community working groups including farmers' groups, nongovernment organizations, and the private sector.

The initiative for the celebration was spearheaded by a Philippine-led resolution cosponsored by 43 member countries to promote awareness on sustainable development of this staple food for more than half of the world's population. Through increased awareness of the rice system, food and agricultural policy and technical, economic, social, and development goals will be better focused by all stakeholders involved in the sustainability of food systems.

The International Year of Rice logo—Rice is life—aptly captures the essence of this important staple food. The official launching of the event will be held on October 31 in New York.

As a member of the International Year of Rice Committee, IRRI is already initiating several projects that involve all rice sectors in the celebration, starting with the *IRRN* Best Article Awards (see below) and the publication of *Graindell*, a children's storybook (see related story on page 67).

IRRN Best Article Awards

What better way to celebrate the International Year of Rice (IYR) than to honor the people who help make it happen. Rice researchers work quietly in the fields and laboratories, conducting studies that they hope will make a difference in the lives of millions of rice producers and rice consumers all over the world. In its 28-year existence, the *International Rice Research Notes* (*IRRN*) has been an active partner in bringing the fruits of their labor to the scientific community. To commemorate 2004 as IYR, the Best Article Award is being established to recognize the contributions of rice researchers from national agricultural research and extension systems (NARES) in developing countries toward the advancement of rice-related knowledge and technology.

Beginning in August 2003, papers submitted for publication in the *IRRN* will be evaluated on the basis of scientific content, originality, relevance, and organization. There will be up to six winning papers from the six sections of *IRRN*—plant breeding; genetic resources; pest science and management; soil, nutrient, and water management; crop management and physiology; and socioeconomics. The winners will be chosen by the *IRRN* Editorial Board and invited reviewers. The winning entries will be announced in the October 2004 issue of *Rice Today* and will be published in the December 2004 issue of *IRRN*.

The competition is open to all NARES rice researchers. The Award will be given to the first author of each paper. Additional authors may come from any organization. Research for all categories must have been conducted in a developing country. Each winner will receive a $500 cash prize.

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