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IRRI
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International Rice Research Notes

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 three times a year in April, August, and December by the International Rice Research Institute.

Focus on hybrid rice

Achieving self-sufficiency in rice production and maintaining price stability are important in countries where rice provides food security and generates employment and income for people. In the past three decades, most rice-growing countries, particularly in Asia, have done remarkably well in meeting their rice needs. But by 2030, the world must produce 60% more rice than it produced in 1995 to meet the demand created by increasing population and rising income. This increase must be achieved using less land, less labor, less water, and fewer pesticides, and it must be sustainable. To meet this challenge, increasing the yield potential of rice beyond that of the semidwarf varieties is an important strategy.

Hybrid rice is a technology for meeting this challenge. This technology has enabled China to increase its rice production significantly during the past 20 years. IRRI, in collaboration with several national agricultural research systems, has developed rice hybrids for the tropics and helped India, Vietnam, and the Philippines to begin commercializing them. By the 21st century, about 3 million hectares are expected to be covered with hybrid rice, which should produce about 3 million tons of extra rice (worth $450 million) annually.

The Third International Symposium on Hybrid Rice Research was held 14-16 November 1996, at the Directorate of Rice Research in Hyderabad, India. The key papers presented are being published as an IRRI-Indian Council of Agricultural Research book. The posters displayed at the symposium appear as notes (in a modified format) throughout this issue of the IRRN. They are denoted by the symbol.

We hope that you find these notes to be a valuable source of information.

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Germplasm improvement

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 16 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is cosponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP). Its membership comprises donor countries, international and regional organizations, and private foundations.

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Germplasm improvement

Genetic resources

International testing of rice hybrids for yield and adaptability by INGER: prospects and problems

R. C. Chaudhary and S. S. Virmani, IRRI

Because of the potential of hybrid rice and its commercial success in China, many countries in Asia, Africa, Latin America, and the Caribbean showed a keen interest in developing and using this technology. The first International Hybrid Rice Observational Nursery (IRHON) was put together in 1994 with 44 hybrids (H), 36 restorers (R), and 5 maintainers (B) developed at IRRI. This nursery was evaluated in Bangladesh (Gazipur), China (Changsha, Hangzhou), India (Coimbatore, Faizabad, Hyderabad, Kapurthala, Karnal, Mandya, Maruteru, Pantnagar), Myanmar (Yangon, Yezin), the Philippines (Los Baños, Maligaya), and Sri Lanka (Batalagoda). A number of hybrids that could be adapted in most of these countries were identified. Hybrids IR67693H, IR69672H, IR69684H, IR69686H, and IR69689H were identified as superior and widely adapted. In the second IRHON conducted at 29 locations in 13 countries, 33 hybrids, 3 B lines, and 25 R lines developed in IRRI, China, India, and Myanmar were tested. Hybrids IR67693H, IR64616H, IR68284H, IR68877H, IR69679H, and IR70402H were identified as superior. In the third IRHON, three hybrids from a private company were also included. This nursery is now undergoing testing at 45 locations in 16 countries in Asia, Africa, and Latin America.

Superior hybrids in earlier tests produced up to 3 t ha^{-1} more grain than the best locally adapted check varieties. Genotype x environment (G×E) interaction analysis and superiority analysis helped identify the stability of the hybrids and forecast their adaptability to untested locations. The G×E analyses did not show a wider adaptability of the hybrids when compared with their parents or checks. INGER, through its global access to hybrids, some parental material, and test sites, can support the testing and use of hybrids and available parents in interested national agricultural systems. INGER can thus help realize the dream of interdependence, exchange, reciprocity, and sharing in a network where no country is too poor to give and no country is too rich to receive. But reservations of some breeders in sharing parental lines and seedborne problems like kernel smut (*Tilletia*) and nematodes impose restrictions. The cost of testing, breeders' rights, and intellectual property rights are some problems that still loom over the scientific community. All these problems could affect the evaluation of hybrids through the INGER mechanism. ■

Screening rice hybrids for quality traits

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In rice hybrids, characters such as lemma and palea, seed size and shape, and pericarp color do not segregate because they are inherited through maternal tissue. Endosperm translucency, chalkiness, and cooking and eating quality traits generally show genetic segregation. Rice is the only cereal consumed as unprocessed whole grain and consumers value specific appearance, taste, and cooking quality traits. Therefore, the effect of heterozygosity of F_1 hybrids on grain quality is more important.

We evaluated 27 hybrids in two replications for 13 physicochemical characteristics in the 1995 wet season harvest and using standard procedures, including physical parameters such as grain shape and size, endosperm appearance, milling, and head rice recovery (HR%). Among cooking and eating quality traits, we studied amylose content (AC%), gelatinization temperature (GT), water uptake (WU), volume expansion ratio (VER), kernel length after cooking (KLAC), and elongation ratio (ER).

Of the 27 hybrids tested, 17 belonged to long slender, 4 to long bold, 5 to medium slender, and 1 to short bold grain type. Four hybrids—URH1, IR58025A/IR54742, IR58025A/IR34686, and IR58025A/IR32809—possessed extra long grains. Except for URH1, the other three hybrids showed intermediate AC (23.6 and 25.4%). IR58025A/IR34686 exhibited a high VER (5.3). Six hybrids—IR58025A/IR29723, 3RI-086, MTURH2020, 2RI 158, MTURH2015, and MPH517—recorded a high HR (ranging from 60.3 to 63.9%).

Eleven hybrids were in the most desirable AC range (20-25%) preferred in the Indian subcontinent. IR58025A/IR48751 and IR58025A/IR21567 had typical intermediate AC values (24.9 and 23.3%) with long slender and attractive translucent grains. Other hybrids that possessed an intermediate AC and long slender grains, but with occasional chalkiness, were PA112, HKRH1002, and IR58025A/IR48749.

Hybrids MPH517, 3RI 160, and PMS1OA/IR48725 possessed endosperm translucency and high HR. Hybrids with desirable starch properties (intermediate AC) and translucent grains with moderate HR were IR58025A/IR29723, IR58025A/IR34686, IR58025A/IR55838, and

IR58025A / IR21567. But the last two hybrids also possess long slender and attractive grains, moderate HR, and a high VER, a good combination of quality traits. ■

Studying comparative suitability of CMS lines

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Parental lines constitute the first and foremost step in a hybrid breeding program. In this context, developing a commercially viable cytoplasmic male sterile (CMS) line is considered to be a highly cumbersome process. In fact, the belated success of hybrid rice technology in India was basically due to the nonavailability of a CMS line suited to the tropics. Over the years, a large number of male sterile lines with different cytosterility sources have been developed in India and elsewhere. Only a few—such as IR58025A and IR62829A—are now used commercially in India. They possess all the essential traits—complete and stable male sterility, high outcrossing rate, better grain quality, easy restorability, good combining ability, and adaptability—of a commercially viable CMS line. Some 64 CMS lines from India, China, Malaysia, and IRRI were evaluated along with IR58025A, IR62829A, and standard checks in the wet season of 1995 and 1996 and dry season of 1994 and 1995 to assess their comparative suitability for commercial use. The CMS lines, along with their corresponding maintainers, were grown for maintenance and evaluation for their floral traits such as pollen sterility, panicle and stigma exsertion, outcrossing rate, duration and angle of glume opening, growth duration, number of effective tillers, spikelets panicle^{-1}, grain type, adaptability, and pigmentation (if any). Each CMS line was characterized for all the traits individually. The final value was obtained by adding together the weighted score allotted to a CMS line for all these traits. This single final value on a 1 to 9 scale indicated the line's practical utility.

Only 11 lines were found to be equally better for all the characters studied than IR58025A and IR62829A: four CMS lines (IR68280A, IR68897A, IR68899A, and IR69628A) from IRRI, two (DRR2A and DRR3A) from the Directorate of Rice Research, and one each from China (9601A), Malaysia (MH-841A), IARI (Pusa 5A), Cuttack (CRMS 31A), and Faizabad (NDCMS 7A). Some of the promising CMS lines were IR67684A, IR68890A, IR68902A, IR68279A, IR68895A, and CRMS 6A. About 31 lines possess one or two good characters and can be used for specific purposes. All Chinese lines, for example, are useful as cytosterility sources to convert promising maintainers into new CMS lines. The remaining 16 lines have one or more drawbacks and will need further improvement. The promising CMS lines are now being studied for their combining ability and use in breeding programs. ■

Identifying a new long-duration CMS line (APMS 5A) for coastal regions

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Several male sterile lines developed in India belong to the early- to medium-duration group. Hybrids developed using these male sterile lines are also of early to medium growth duration. These hybrids are not suitable for cultivation during the wet season, particularly in the coastal areas of Andhra Pradesh, where long-duration varieties are predominantly grown. We need to develop long-duration rice hybrids to increase rice productivity and fit them into the cropping system. An effort was made to develop long-duration (145-150 d) and stable local cytoplasmic male sterile (CMS) lines. Several testcrosses were made using local long-duration elite lines and IRRI CMS lines to screen the elite varieties for their maintaining or restoring ability. A few long-duration maintainer lines were identified based on pollen and spikelet sterility. MTU4870 was therefore selected and successfully converted into a local cytosterile line in the background of a wild abortive source of cytoplasm through the backcross breeding technique. This line was designated as APMS5A.

APMS5A is a long-duration (145-150 d) line with tolerance for brown planthopper, bacterial leaf blight, rice tungro virus, and sheath blight. It also possesses a sturdy culm. It has a comparable angle of spikelet opening duration (190 min), angle of spikelet opening (31°C), stigma exsertion, and natural outcrossing potential (12%) with the popular CMS line IR58025A. APMS5A, a 100% sterile line, is the first long-duration CMS line developed in India with desirable floral and agronomic traits. A few effective restorers were also identified. APMS5A will facilitate the development of long-duration rice hybrids suitable for cultivation in the coastal areas. ■

Wide hybridization for diversification of CMS in rice

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To identify new sources of male sterility-inducing cytoplasm within the A genome of genus *Oryza*, 132 interspecific crosses involving accessions of four wild (*O. rufipogon*, *O. nivara*, *O. barthii*, and *O. longistaminata*) and two cultivated species (*O. sativa* and *O. glaberrima*) were effected. Accessions possessing sterility-inducing cytoplasm were identified following reciprocal and F_2 backcross methods and advanced through substitution backcrossing to develop cytoplasmic male sterile (CMS) lines. Two indices were used: (1) pollen morphology and staining pattern and (2) type of interaction with a set of maintainers and restorers of wild abortive (WA) cytosterile stock. The newly developed CMS lines are grouped using these indices as follows: I. RPMS1 (*O. rufipogon*; VNI) and RPMS2 (*O. nivara*; DRW21039) are gametophytic types; II. RPMS3 (*O. nivara*; DRW21030) is similar to MS577A in pollen stainability, but the restoration and maintenance reactions are similar to those of the WA type; III. RPMS4 (*O. nivara*; DRW21018) is a sporophytic type, but restorers and maintainers are different from WA; IV. RPMS5 and RPMS6 (*O. nivara*; RPW21111) are sporophytic types with restorer and maintainer reactions similar to those of WA. All the new CMS lines possessed complete panicle exsertion essential for enhancing outcrossed seed yield.

For the two stable CMS lines, MS577A and IR66707A, no restorers are available in cultivated rice germplasm. A search for restorer sources for these CMS lines was made among the wild accessions of the A genome species. Although none of the accessions could restore fertility in IR66707A, three accessions of *O. rufipogon* (VN2, DRW22016, DRW220175) and one each from *O. sativa* f. *spontanea* (RPW20001) and *O. glaberrima* (DRGL 30090) did restore fertility in MS577A. Studies on the genetics of fertility restoration in these cross combinations indicated that two dominant genes act in an additive manner to restore fertility. ■

Krishna CMS lines in the background of four different cytoplasmic sources in rice

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Four cytoplasmic male sterile (CMS) lines of Krishna with sterile cytoplasm from four different sources (wild abortive [WA], *O. perennis*, Kalinga 1, and Lalruma from Mizoram) have been developed. The two CMS lines—Krishna A with WA and Krishna A with *O. perennis* as a source—were developed through conversion with CMS lines V20A (WA) and IR66707A (*O. perennis*), respectively, by subsequent backcrossing with common isonuclear maintainer Krishna A. But Krishna A with Kalinga 1 and Krishna A with Lalruma cytoplasmic sources were developed through indica/indica crosses. These four CMS lines are all dwarf in stature, are of medium duration, and have reduced white anthers that exhibit 80-90% unstained withered pollen grains.

To understand the nature of these four cytosterility sources, they were testcrossed with four maintainers—V20B (maintainer of WA), IR66707B (maintainer of *O. perennis*), Yar-Ai-ZhaoB (maintainer of Gambiaca), and MS577B (maintainer of *O. sativa* f. *spontanea*)—and the elite inbred lines SPR7210-1-3, IR48725-B-B-120-1, NDR30074, TTB150-61, and R657-93-869. The sterility of the four CMS lines was maintained by the four maintainers. The restorer SPR7210-1-3 of Krishna A (WA) was found to be a maintainer of the other three CMS lines—Krishna A (*O. perennis*), Krishna A (Kalinga 1), and Krishna A (Lalruma)—whereas the restorer IR48725-B-B-120-1 of Krishna A (WA) behaved as partial restorer of Krishna A (Kalinga 1) and Krishna A (Lalruma) and as a maintainer of Krishna A (*O. perennis*). Variety R657-93-869 was found to be a partial restorer of Krishna A (WA) and Krishna A (Lalruma) and a maintainer of Krishna A (Kalinga 1) and Krishna A (*O. perennis*). The restorer TTB150-61 for Krishna A (Lalruma) behaved as a partial restorer of Krishna A (WA) and Krishna A (Kalinga 1), and as a maintainer of Krishna A (*O. perennis*). ■

Characterizing thermosensitive genic male sterile lines of rice

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The cytoplasmic male sterility (CMS) system is widely used to develop rice hybrids. Although effective, this system is quite cumbersome to practice. Certain genic male sterile lines that revert to fertility under specific temperature are called thermosensitive genic male sterile (TGMS) lines. Deployment of the TGMS system to develop two-line hybrids has several advantages over the conventional CMS system, as it requires neither maintainers for seed multiplication nor restorers for producing hybrids. In addition, two-line hybrids may not suffer from possible negative effects of the sterility-inducing cytoplasm. For an effective use of TGMS lines, they have to be characterized for their critical sterility and fertility points. This information is essential for deciding on a suitable location and/or period for seed multiplication and hybrid seed production. Two IRRI-bred indica TGMS lines-IR68945-4-33-4-14 and IR68949-11-5-31-along with their japonica TGMS donor, were characterized under controlled conditions in the IRRI phytotron. These lines were subjected to eight constant temperatures (20-32 °C) and four day-night combination temperatures (27/21 °C-32/24 °C) for a period of 3 wk during the sensitive stage. The critical sterility point for both lines was 30 °C and above, whereas it was only 27 °C and above for Norin PL 12. The critical fertility points for the indica TGMS lines ranged between 24-28 °C (constant temperate) and 27/21 °C-28/22 °C (day-night combination temperature). Norin PL 12 was found to be very sensitive to higher temperature compared with the indica TGMS lines.

Comparative effects from treatments revealed that the maximum temperature in day-night combination temperatures was crucial in determining the sterility or fertility of TGMS lines. The effects of intervening fertility-inducing temperature (27 °C) during the sterility phase (32/24 °C) were studied in TGMS lines IR68945-4-33-4-14, ID24, and Norin PL 12. Even an exposure for 2 h at 27 °C could induce fertility in IR68945-4-33-4-14, whereas ID24 remained unaffected even after 10 h exposure at 27 °C. The behavior of Norin PL 12 was intermediate in this respect as 4 h of interruption could induce fertility. ■

Identifying and characterizing thermosensitive cytoplasmic male sterile lines

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In wheat, an alloplasmic line of Norin 26 (*Triticum aestivum*) with *Aegilops crassa* cytoplasm has been found to show male sterility under long-day (15.0 h) conditions and fertility under short-day (14.5 h) conditions with no influence of temperature. In the present study, a similar influence of temperature rather than photoperiod was observed in wild abortive (WA) cytoplasmic male sterile (CMS) line J24A (Pusa 33-16A). It was studied along with its maintainer line J24B (Pusa 33-16B) under different temperature regimes for fertility-sterility alterations. The pattern of their fertility-sterility transformation revealed them to be of high critical sterility point (CSP) and high critical fertility point (CFP) type. Yet they differed in their degree of transformation; the CSP was 33.8 °C in J24A and 35.1 °C in J24B. Although the CFPs of both fall in the same range (24 °C), a comparative study of the A and B lines for their temperature-influenced sterility-fertility behavior revealed the thermosensitive genic male sterility (TGMS) gene to be probably linked to the nuclear sterility gene (*rf*). Fertile cytoplasm (C gene) also possessed some degree of influence on fertility as well as on TGMS genes located in the nuclear genome. This was evident from the B line, which showed a relatively higher CSP and CFP than the A line. To have a stable CMS line, the nuclear genome should have the fertility gene *Rf* with the environment-sensitive male sterility gene (EGMS) in a dominant state, so that neither temperature nor daylength would affect its stability for pollen sterility. A CMS line having the EGMS gene in a recessive state can be deployed under high-temperature conditions for hybrid seed production. The A line in this state will be more stable for sterility because of the combined effect of both fertility and EGMS genes. Seed multiplication of the CMS line can be done with ease, taking advantage of fertility transformation under low-temperature conditions. To minimize the risk of temperature fluctuations, the CMS line can be planted in alternate rows with its B line. If high temperatures prevail during the seed multiplication phase and make the CMS line completely sterile, the B line as a maintainer can provide abundant pollen for outcrossing. If selfing does occur, it would help to further increase seed yield of the thermosensitive CMS line. ■

Screening rice germplasm for floral attributes that influence outcrossing

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A cytosterile line with high outcrossing potential would economize the cost of hybrid seed production in rice. We screened rice germplasm to identify genotypes with useful floral traits that could influence outcrossing. We used prospective maintainers and restorers in a testcross nursery program. Isolation of prospective maintainers with useful floral characteristics could lead to the development of cytosterile lines with high outcrossing potential through a backcrossing program. We evaluated 75 genotypes for floral and related traits: duration of opening of florets, angle of opened florets, percentage of exserted stigma, spikelet length, anther length, stigma length, panicle length, number of effective tillers plant^{-1}, grain yield plant^{-1}, and plant height. The analysis of variance recorded highly significant differences for all the traits, indicating the presence of a sufficient degree of variation for these traits for selection among cultivars. We identified genotypes Aditya, VL Dhan 63, IET10119, IET10115, IET10119, Shankar, VL Dhan 8, Pratibha, Kunti, Surajmukhi, and Vikas as possessing multiple floral traits that would enhance seed set. All these genotypes can therefore be used as parental lines to develop hybrids and enhance outcrossing. ■

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Comments. If you have comments or suggestions about the IRRN, please write to the editor.

Physical localization of *phyA* and *rbcS* genes in rice

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Phytochrome is an important photoreceptor and regulates many growth and development processes in plants (Thompson and White 1991, Furuya 1993, Terzaghi and Cashmore, 1995). Ribulose-1.5-bisphosphate carboxylase (Rubisco) small subunit genes (*rbcS*) are regulated developmentally by light (Tobin and Silverthorne 1985, Gilmartin et al 1990). Both genes (*phyA* and *rbcS*) coding for phytochrome and Rubisco SSU are functionally related. We tried to physically map onto the chromosomes by in situ hybridization rice genes related to photoperiod/light reception, signal transduction, and gene expression regulated by photoperiod, aiming to understand the relationship between the structure and function of the rice genome and between the genetic map and the physical map. The physical locations of CaM and Ca^{2+}-ATPase genes were reported (Bi et al 1996). The results of those of *phyA* and *rbcS* genes follow.

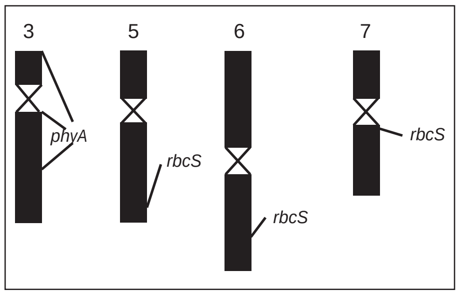
The rice *phyA* gene clone, pPHY1, and *rbcS* gene clone, pRR1, are genomic clones of 6.6 kb and 1.1 kb in size, kindly provided by Prof. Nam-Hai Chua of Rockefeller University and Prof. Ray Wu of Cornell University, USA. *Oryza sativa* L. subsp. *indica*, cv. Guang-lu-ai 4, was used for chromosome preparations. Clones pPHY1 and pRR1 were transformed into *E. coli* TGI. Plasmid amplification, extraction, labeling with biotin, in situ hybridization, and detection were performed with the procedures followed by Bi et al (1996). Chromosomes were identified according to data from Kurata (1986).

The results showed that the hybridization detection ratio was about 29.79% for *phyA* and 21.56% for *rbcS*. The *phyA* gene was located near the centromere of the long arm, at the end of the short arm, and in the middle of the long arm on chromosome 3. The *rbcS* gene was mapped near the centromere on the long arm of chromosome 7, at the end of the long arm of chromosome 5, and at the 2/3 distance of the long arm from the centromere in chromosome 6 (see table, figure).

Chromosome locations and detection ratios of *phyA* and *rbcS* genes in rice.

Clone name	Size (kb)	Chromosome location[a]		Average detection ratio (%)
phyA	6.6	3L	near centromere	14.89
		3S	end	12.77
		3L	middle	2.13
			Total	29.79
rbcS	1.1	7L	near centromere	8.62
		5L	end	6.90
		6L	2/3 distance from centromere	6.04
			Total	21.56

[a]L = long arm, S = short arm.



Chromosome maps of rice *phyA* and *rbcS* genes showing hybridized positions. Short arm is at the top, constriction represents the centromere, and the long arm is under the constriction.

The *phyA* gene was near RZ575 on chromosome 3 of the genetic map (Causse et al 1994), and RZ575 was on the long arm (Singh et al 1996). We also located the *phyA* gene on chromosome 3 and found three loci. This suggests that fragments for the *phyA* gene are dispersed on chromosome 3.

Kuozuka et al (1993) proved that the *rbcS* sequence of pRR1 (Xie and Wu 1988) showed 98.8% homology with the rice *rbcS* cDNA clone OSRUBPC1 (Matsuoka et al 1988). Wu et al (1986) indicated that two genes coding for rice *rbcS* share more than 95% DNA sequence homology in a sequenced 230 bp segment, and one of the two cloned genes (pOSrbcS-1) was probably located on three chromosomes. Matsuoka et al (1988) also thought that a few genes encoded *rbcS* in rice from the Southern blot results, with the pOSSS1139 cDNA insert as a probe. Therefore, our result of physically mapping multipositions of *rbcS* on chromosomes is consistent with the above results.

Rice chromosomes are small and very difficult to identify individually, and all chromosomes have deeply stained regions on both sides of the centromere (Kurata and Omura 1978). This different Giemsa staining pattern makes it difficult to locate the true ends of the chromosomes and the relative chromosomal location of probes (Jiang et al 1995). We are going to continue to map the *phyA* and *rbcS* genes by multicolor fluorescence in situ hybridization with both gene clones and centromere-specific random fragment length polymorphism markers for special chromosomes.

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Fertility restoration studies in four WA CMS lines of rice

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Fertility restoration studies involving four wild abortive (WA) cytoplasmic male sterile (CMS) lines—V20A, IR58025A, IR62829A, and IR54752A—resulted in the identification of 20 restorers. We studied segregation for fertility in the F_2 and backcross progenies of these CMS lines with four restorer lines—ARC11353, IR30864, IR13419-113-3, and IR9761-19-1. The results indicated that fertility restoration in WA CMS lines was controlled by two additive major genes. Their effect was sporophytic and they displayed differential gene interactions such as epistasis with complete dominance (12:3:1) or epistasis with incomplete dominance (9:6:1) depending on the parents involved in the cross.

We noticed differential segregation of the F_2 and backcross progenies in the crosses involving IR30864 and IR9761-19-1 depending on the female parent. This suggested that the performance and expressivity of the R genes varied according to the nuclear background of the female parent. The pattern of segregation in crosses involving IR54752A was different from that of other CMS lines, suggesting the involvement of certain minor genes for fertility restoration carried by this CMS line in deciding the fertility of the progenies. ■

Effect of minor genes in restoration of fertility in CMS lines of rice

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We evaluated 128 hybrids in the 1994 dry season and 135 hybrids in the 1995 wet season. The hybrids, involving varieties C29 and PMK2, with different wild abortive (WA) sources of cytoplasmic male sterile (CMS) lines—IR58025A, IR62829A, and PMS3A—showed marked differences in pollen and spikelet fertility. When C29 was crossed with IR62829A and PMS3A, it behaved as a partial restorer (21-90% pollen and spikelet fertility). But when crossed with IR58025A, it behaved as a maintainer (100% pollen and spikelet sterility). All three CMS lines, however, had WA cytoplasm. Similarly, PMK2 behaved as a restorer (>90% pollen and spikelet fertility) with PMS3A, while it maintained sterility (100%) with IR62829A. The minor or modifier genes present in the pollinator might have reacted with the CMS lines used and resulted in this type of variation. ■

Breeding for male fertility restoration incorporating Basmati rice quality

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Basmati is the most highly valued rice commodity in the world agricultural trade market. Pusa Basmati 1, released in India, combines both high yield and ideal Basmati quality. In Pakistan, semi-tall Pak 385 and Pak 386 are reported to be better yielding than Basmati 370. Results at IARI have demonstrated the possibility of developing hybrids with Basmati grain quality and a high level of heterosis. Such Basmati hybrids would raise yields further.

A major limitation to developing Basmati rice hybrids is the nonavailability of satisfactory restoration among Basmati cultivars or breeding lines. Some 90% of Basmati materials showed imperfect maintaining ability, 3%

showed good maintenance, and 7% showed partial restoration. But few showed 60-70% restoration ability. This situation led us to begin a systematic restorer breeding program incorporating ideal Basmati quality.

Testcrosses were made using cytoplasmic male sterile (CMS) lines Pusa 1127A (a new cytosterility source from Pusa 743), Pusa 3A wild abortive (WA), and IR58025A (WA) with the Basmati cultivar or breeding line that had shown high F_1 fertility (60-70%) in previous testcrosses. All the F_1s were raised. Seeds from the best fertile plants were harvested and subjected to grain and cooking quality tests. Only those hybrids that exhibited Basmati cooking characteristics in an appreciable proportion of grains were raised to the F_2 generation. Selections were made on the basis of spikelet fertility, grain shape, and grain appearance. They were subjected to cooking quality tests and only those possessing ideal Basmati characteristics were raised to the F_3. In the F_3, diverse-looking plants were selectively intermated and the entire process was repeated. Simultaneously, some of these selected plants were testcrossed with Pusa 3A. Pollen donor plants of hybrids showing improved restoration and ideal Basmati quality were advanced to the F_4. In the F_4 and later generations, the entire process was again repeated as in the F_3. Likewise, the material was advanced to the F_6 generation. The intermated lines were also advanced to further generations.

Testcrosses made between Pusa 3A and the selected lines revealed that nine lines—Sps95-694-2, Sps95-694-3, Sps95-81-1, Sps95-81-3, Sps95-81-4, Sps95-81-5, Sps95-81-6, Sps95-768, and Sps95-167-1—showed normal restoration. The grain quality of these hybrids was comparable with that of Pusa Basmati 1 and Karnal Local. Three of these lines are now used for Basmati hybrid seed production with Pusa 3A (Basmati CMS line). ■

Genetics of thermo-sensitive genic male sterile lines in rice

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Understanding the inheritance pattern and studying allelic relations among diverse thermosensitive genic male sterile lines (TGMS) were the objectives of this investigation. Lines F61, SA2, JP1, JP8-8-1s, ID24, and IC10, developed at the DRR, Hyderabad, and lines IR32364, IR68292, IR68294, IR68945, and IR68949, received from IRRI, Philippines, were crossed with a set of normal pollen parents, to study segregation patterns in the F_2, F_3, and backcross generations. The results indicated that sterility caused by the TGMS trait was governed by a single recessive gene. In segregating populations, however, individual TGMS progenies from the same F_2 showed different fertility levels. This indicated that some other genes modify the major gene and affect fertility.

Allelic relations were examined by studying direct crosses and backcrosses involving two different TGMS lines over seasons. The lines developed from Norin PL 12 (*tms2*) (IR68292, IR68294, IR68945, and IR68949) at IRRI were allelic to ID24 and JP1. The lines IR32364 (*tms3*), JP8-8-1s, and IC10 were also allelic. Lines SA2 and F61 were observed to be nonallelic to all other lines, and may possess different TGMS genes, including *tms1* from China. ■

Mitochondrial gene expression in cytoplasmic male sterile and fertile lines of rice

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In various plant species, rearrangements in the mitochondrial genome have been associated with cytoplasmic male sterility (CMS). These rearrangements could modify genome expression and thereby play a role in pollen abortion. In rice, investigations carried out in our laboratory have established some rearrangements in the genetic organization of mitochondrial DNA between male sterile and fertile lines. For example, the *cox1* locus was found rearranged in the CMS line compared with the fertile lines.

To establish the correlation, if any, in DNA organizational pattern with the expression of the male sterile phenotype, we conducted a Northern analysis on total RNA from the sterile and fertile lines. The blot, when probed with *atp6*, showed a single transcript in all the lines tested, whereas *atp9* and *cox3/orf25* showed five and two transcripts, respectively. On probing with *atp9*, we observed multiple transcripts of sizes 3.2 kb, 1.7 kb, 1.3 kb, 0.8 kb, and 0.6 kb, and 0.3 kb was the most abundant of the transcripts, probably representing the mature functional transcript. The cotranscribed genetic locus of *cox3/orf25* when used as a probe, yielded two transcripts of 2 kb and 1 kb. Even though *atp6* in Chinsurah Boro-type cytoplasm has been found to be differentially transcribed and edited, and hence implicated in CMS, we could not detect different transcripts of *atp6* in the rice lines used in our study bearing WA type cytoplasm. Work on putting more probes on the Northern blots and studying the gene-specific pattern of expression is in progress. ■

RAPD and PBR analysis of CMS maintainer and restorer lines in rice

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Recently developed molecular tools such as randomly amplified polymorphic DNA (RAPD) and polymerase chain reaction-based random fragment length polymorphism (PBR) are available for characterizing genetic variation and DNA typing of rice genotypes. DNA analysis of three cytoplasmic male sterile (CMS) lines with the respective maintainers (B) and two restorer lines (R) using 12 decamer primers from Operon (OPA-01 to OPA-12) revealed polymorphism only with primers OPA-03, OPA-07, OPA-09, and OPA-12. CMS lines IR67684A, IR58025A, and IR62829A have distinct RAPD markers in contrast to their B and R lines. DNA polymorphism of A, B, and R lines was also confirmed with PBR in 15 primer/enzyme combinations. PBR reaction amplified a 546-bp (OPA-12) fragment in IR58025A and an 872-bp (OPA-12) fragment in IR62829A lines in a genotype-specific manner. These markers are being developed for identifying genotype-specific DNA markers and mapping desirable genes for hybrid rice research. ■

Transferring wild abortive cytoplasmic male sterility through asymmetric fusion of protoplasts

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We attempted a one-step transfer of wild abortive cytoplasmic male sterility (CMS) through asymmetric fusion between the protoplasts of CMS and fertile maintainer lines. We established embryogenic cell suspensions from the calli obtained from mature seed scutella of a CMS line (V20A), fertile maintainers (RCPL1-2C and V20B), and restorer IR36 lines. We isolated and cultured protoplasts to produce protocalli that differentiated into plants. Pollen grains of the protoplast-derived plants of the CMS line were sterile, whereas those derived from the maintainer and restorer lines were fertile. To accomplish asymmetric fusion, the protoplasts of the CMS line and fertile maintainer lines were inactivated with 30 krad gamma ray and 10 mM iodoacetamide, respectively. Electrically fused protoplasts divided on a culture medium and formed micro-colonies that developed into calli. These calli also differentiated on transfer to a regeneration medium. We recovered 27 cybrid lines from the fusion product of V20A/RCPL1-2C and 23 lines from V20A/V20B. Pollen grains from all the cybrid lines were sterile.

Analyses of mitochondrial DNA of the fusion partners and cybrids were conducted by using *orf 156* as a probe. This revealed differences in polymorphism between the mitochondrial DNA of the CMS line and fertile maintainers. In the case of *Hin*dIII-digested DNA, the *orf 156* gene was located on a 1.3-kb fragment in the male sterile line, V20A, and on a 12-kb fragment in its fertile maintainers, RCPL1-2C and V20B. A DNA blot analysis of the *Hin*dIII-digested DNA of all five cybrids showed hybridization of *orf 156* to the 1.3-kb fragment. This demonstrated the transfer of mitochondrial DNA from the CMS line to the cybrids. ■

Breeding methods

Adaptability and yield of rice hybrids

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Heterosis in rice was reported in 1926. But commercial exploitation took almost 5 decades mainly because of problems in hybrid seed production. China was the only country to commercially exploit heterosis before 1994. Recently, a few rice hybrids were released in India for commercial cultivation. Although the yield advantage of rice hybrids is well documented, doubts regarding their yield gains and adaptability over locations still persist. Therefore, we present here the average yield gains obtained from hybrids and their adaptability to locations in India. We used data from 1991 to 1995 on various hybrids tested under different trials over 12 locations in the wet season (WS) and at six locations during the dry season (DS). The yearwise mean yields of hybrids over locations and over trials were calculated separately for both the WS and DS. We identified a hybrid as widely adaptable if it had an overall yield advantage of more than 0.7 t ha^{-1} over the high-yielding national check variety Jaya, and we calculated the frequency of such hybrids for each season and year. Percentage heterosis was computed for each year based on the highest yielding hybrid vs Jaya.

The results showed that the overall mean of experimental hybrids increased gradually during the WS from 4.5 t ha^{-1} in 1991 to 5.5 t ha^{-1} in 1995; during the DS, yields increased similarly from 5.0 to 6.0 t ha^{-1}. During the same period, the percentage of widely adaptable hybrids in the WS increased from zero to 17%. Similarly, in the DS, it increased from 1.75% (1991-92) to 17% (1994-95). The maximum yield gain obtained during the WS derived from the performance of hybrids vs Jaya was 544 kg ha^{-1} in 1991 and 1,522 kg ha^{-1} in 1995. Similarly, in DS, the yield gain in hybrid rice was 846 kg ha^{-1} in 1991-92 and 1,634 kg ha^{-1} in 1993-94. The heterosis for grain yield increased—from 14% (1991) to 31% (1995) in the WS, and from 8% (1991-92) to 27% (1993-94) in the DS. The results indicate that hybrids undoubtedly have a yield advantage over high-yielding varieties such as Jaya. The margin of yield gain increased over the years. The diversity of material added over time may be the reason for such gains. The hybrids are also as widely adaptable as Jaya. ■

Yield stability in rice hybrids

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Hybrid rice technology is considered to have the most potential and be readily exploitable to further raise the yield ceiling in the irrigated ecosystem. But successful exploitation over a large area depends on identifying stable hybrids. Yield heterosis is reported to be a variable trait, which depends not only on parent combinations but also on environmental conditions. Stability for yield of rice hybrids is therefore analyzed. We examined the stability of hybrids for yield in two sets of environments categorized as low and high. Grain yield data of 10 trials conducted between the 1994 wet season (WS) and 1995 WS were used. Locations with a mean yield lower than the grand mean yield were termed low environments, whereas those with a mean yield higher than the grand mean yield were identified as high environments. We analyzed grain yield data on eight hybrids in the 1994-95 WS and dry season tested along with inbred Jaya, Rasi, and IR36 at five locations. The mean yield and coefficient of variation over seasons and locations were calculated for both hybrids and inbreds to find environment-dependent heterosis.

The mean grain yield advantage of the best-yielding hybrid over Jaya was calculated for each environment. The results indicated that the stability of rice hybrids for grain yield is comparable with that of the best inbred check variety, Jaya. Some of the hybrids, such as IR58025A/IR34686 and IR58025A/IR29723, showed better yield stability over seasons compared with Jaya. But the yield heterosis of the hybrids was better expressed in environments categorized as high. ■

Exploiting heterosis using TGMS lines in intra- and intersubspecific hybridization

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The performance of various thermo-sensitive genic male sterile (TGMS) lines was assessed in order to use them in two-line intra- and intersubspecific hybridization with wide compatibility lines. Some 26 lines comprising TGMS lines, indica accessions, and japonica with wide compatibility (WC) gene(s) were used to make 65 hybrids: 31 were indica/indica and 34 were indica/japonica (WC). Standard heterosis was recorded up to 58%. Seed yield (g $plant^{-1}$) ranged from 2.3 to 31.3. The number of heterotic combinations was higher in intersubspecific cross combinations. Spikelet fertility ranged from 2.7 to 88.4% in intersubspecific crosses and from 3.6 to 96.0% in intrasubspecific crosses. The WC lines were not universally compatible in all combinations. The TGMS line ID/24 was completely compatible with all WC as well as with other indica accessions.

A molecular phylogenetic map was constructed involving all 26 lines based on the polymorphism generated by 10 random primers—OPD3, OPU7, OPU14, OPZ18, OPZ19, OPZ20, OPA7 + OPA6, and OPA12 + OPD5. By using the un-weighted pair-group method, arithmetic average (UPGMA), a dendrogram was made, taking into consideration the distance calculated based on Jaccard similarity indices. The genetic distances were from 0.2 to 0.88. The height in hybrids increased as the genetic distance between the parents widened. With genetic distance > 0.70 among parents, spikelet fertility and grain yield $plant^{-1}$ decreased considerably. Heterotic combinations were observed when the genetic distance ranged from 0.4 to 0.7 among parents. ■

Developing CMS and restorer lines of tropical rice hybrids

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The successful development and cultivation of hybrid rice in China in 1976 encouraged IRRI scientists and collaborating countries to intensify this research in 1980. Because the Chinese hybrids and parental lines were not adapted to the tropics, IRRI began collaborating with several tropical rice-growing countries to develop suitable parental lines and hybrids. By 1989, IRRI developed two commercially usable cytoplasmic male sterile (CMS) lines that, when combined with easily available restorers among elite tropical indica rice cultivars, produced hundreds of experimental rice hybrids. Some of these yielded about 1 t ha^{-1} more than inbred checks in national trials under irrigated conditions. By 1994, India, Vietnam, and the Philippines had released some promising rice hybrids for commercial cultivation by farmers. New and better CMS lines are now available in the genetic background of irrigated, rainfed, boro, and aromatic rice cultivars. The cytoplasmic base has been diversified to protect future rice hybrids from outbreaks of disease or insect pests. Breeding indica / tropical japonica hybrids has begun with the development of CMS lines in the background of tropical japonica. ■

Developing Pusa 3A, a Basmati CMS line

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Basmati rice occupies a significant place in India's rice economy on account of its high export potential. With the release of Pusa Basmati 1, the first high-yielding semidwarf Basmati variety meeting quality standards, India leaped ahead in Basmati rice production. Further improvement in Basmati yield may be possible with the adoption of hybrid rice technology.

Various Basmati rice lines were testcrossed with IR58025A. Pusa Basmati 1 showed complete sterility and proved to be a perfect maintainer of wild abortive (WA) cytosterility. The pollen sterility in the F_1 hybrid was 100%. The F_1 was backcrossed to Pusa Basmati 1 and a BC_1 population of about 600 plants was raised. All the plants showed 100% pollen sterility. Segregation was observed for various plant characters. Twenty BC_1 plants that were closer to Pusa Basmati 1 for various characters were backcrossed to Pusa Basmati 1. About 30 seedlings in each of the 20 BC_2 progenies showed 100% pollen sterility. Cooking quality of the 20 pollen donors was analyzed. The best five donors showing good cooking quality were selected on the basis of their similarity to Pusa Basmati 1 for various agronomic characters such as plant height, panicle length, spikelet morphology, and days to 50% flowering. These plants were again backcrossed to the selected five pollen donors, thus maintaining the identity of the pollen donors for the respective population. The BC_3 plants raised from the above crosses were screened for pollen sterility; all the plants were 100% sterile. Three plants were selected from each BC_3 progeny row and these were again backcrossed to their respective pollen parent from Pusa Basmati 1. Progenies from pollen plants No. 1 and 3 (Pusa Basmati 1-1 and Pusa Basmati 1-3) had all the morphological characters of Pusa Basmati 1. They were further backcrossed to their respective pollen plants—Pusa Basmati 1-1 and Pusa Basmati 1-3, both with excellent cooking quality traits. The CMS line derived from Pusa Basmati 1-3 has been named Pusa 3A. This line shows stable sterility under different environmental conditions at New Delhi and Aduthurai, Tamil Nadu, during the two different rice seasons. This line is now being used extensively for testcrossing with both Basmati and non-Basmati male parents. A few promising combinations with Basmati restorers have been identified. It was also found that heterosis with non-Basmati restorers was far greater than with Basmati restorers for various characters, including yield. ■

Screening rice genotypes for thermosensitive genic male sterility reaction

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Two-line rice hybrids were found to be more heterotic than three-line hybrids. Constraints of the three-line system can also be avoided in the two-line system. Any rice variety can be used as a pollen parent in the two-line system irrespective of the presence of a restorer gene. The two-line system also offers the advantage of easy seed production. For photoperiod-sensitive genic male sterility (PGMS) vs thermosensitive genic male sterility (TGMS), the TGMS system is more useful for the weather conditions that prevail in southern India. We therefore screened some diverse genotypes to identify potential lines. Staggered sowings and plantings were done during the 1995-96 wet and dry seasons. We carried out pollen studies on these lines and also recorded spikelet fertility. Data on pollen sterility were correlated with minimum, maximum, and daily mean temperatures during the critical period of sensitivity of the lines, that is, 10 d from the third day after panicle initiation.

During the 1995 wet season, one TGMS line—IR68949-5-31-34—exhibited complete pollen and spikelet sterility for a period of 51 consecutive d. The mean daily temperatures during this 51-d period were between 27.1 and 28.4 °C. The same line transformed to partial fertility when the average temperatures reached 26 °C and below.

During the 1996 dry season, a second TGMS line, IR68945-33-4-14-40, was found to be completely sterile for a period of 15 d. The mean daily temperature regimes at the critical period of sensitivity ranged from 23.5 to 26.5 °C. Later, this line transformed to partial or complete fertility. The two TGMS lines identified in this study may be used to develop new two-line rice hybrids for enhancing heterosis and thus production and productivity of the rice crop. ■

Identifying parental lines in hybrid rice by RAPD fingerprinting

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The commercial production of hybrid rice hinges on three-line breeding, male sterile, maintainer, and restorer lines. Developing and producing new parental lines are essential for the sustainability of hybrid rice. Characterizing these lines based on morphological and phenological characters consumes time, lacks sufficient resolving power, and is influenced by the environment. Therefore, we need to characterize parental lines, especially restorers, using biotechnological tools.

DNA was extracted from commonly used parental stocks (CMS lines IR58025A and IR62829A; their isonuclear maintainer (B) lines IR58025B and IR62829B; and elite restorer (R) lines IR40750, IR9761, IR34686, and IR10198. These extracted DNA samples were amplified by polymerase chain reaction using 20 arbitrary oligo-nucleotide primers. The amplified products were analyzed on agarose gel and scored for the presence or absence of bands. With selected primers (OPA-7, OPA-12, OPA-20, OPB-19, OPU-17, and OPW-4), sufficient polymorphism could be detected to allow identification of individual stocks. The isonuclear maintainer and the CMS lines were, however, indistinguishable. The randomly amplified polymorphic DNA (RAPD) analysis is a potentially simple, rapid, and reliable DNA finger-printing method for identifying parental stocks and determining the parentage of rice hybrids. As this molecular technique verifies the degree of dissimilarity between the parental lines, the RAPD analysis may also help in identifying new potential combina-tions based on genetic divergence. ■

Exploiting the in vitro ovary culture technique to breed rice hybrids

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The thermosensitive genic male sterility (TGMS) system has a high potential to develop two-line hybrids, which are more economical for seed production. The ovary culture technique can also help to improve or develop new lines for several economic traits. We therefore cultured unpollinated ovaries from plants of five crosses involving TGMS UPRI 95-140 (P1), the good ideotype UPRI 95-117 (P2), and maintainers UPRI 95-139 (P3) and UPRI 95-130 (P4). Quality rices—Basmati 385 (P5), Haryana Basmati 1 (P6), and UPRI 95-145 (P7)—were also cultured. The cultured ovary from hybrid plants P1/P2 pretreated at 8 °C for 14 d on an N6 medium supple-mented with 500 mg lactoprotein hydrolysate (LH) L^{-1}, 4 mg 2,4-D L^{-1}, 2 mg NAA L^{-1}, and 1 mg BA L^{-1} produced 0.5% calli. Regeneration of these calli on an MS medium containing 500 mg casein acid hydrolysate L^{-1}, 0.5 mg NAA L^{-1}, and 1.5 mg BA L^{-1} produced four clumps of completely green plantlets and one partially green plantlet. One of these green plantlets showed the TGMS trait. It was completely spikelet sterile during the panicle heading period between 15 Jun and 5 Sep, but was partially fertile and set seed after 18 Sep. Seed set was 0.5, 1.7, 4.8, 12.3, and 6.4% at heading on 18 Sep, 1 Oct, 12 Oct, 26 Oct, and 1 Nov 1995, respectively. The ovary culture-derived line was dwarf, with an intermediate plant type, and flag leaf and panicle length similar to those of the female parent. But this line produced more spikelets.

The unpollinated ovaries of F_1 plants derived from maintainer/quality rices cultured on an N6 medium supplemented with 0.5 mg 2,4-D L^{-1}, 4 mg NAA L^{-1}, and 1.0 mg BA L^{-1} produced calli. Callus induction was 3.33, 2.67, 1.33, and 2.00% for P5/P3, P3/P5, P6/P4, and P7/P4, respectively. But plantlets were regenerated only from P5/P3 (46.7%) and P3/P5 (50.0%) on an N6 regeneration medium supplemented with 500 mg LH L^{-1}, 0.5 mg NAA L^{-1}, and 2 mg kinetin L^{-1}. The performance of seven H1 clones of the former cross showed four clones with long, bold grain and a nontranslucent endosperm, whereas clones 6 and 7 had long, slender grains and a translucent endosperm free of an opaque area and were comparable in quality with Basmati 385. Exploitation of these lines to improve quality and yield potential in a hybrid rice breeding program is in progress. ■

Pest resistance — diseases

A variety with durable resistance to rice blast

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San-Huang-Zhan No. 2 (SHZ), a rice variety developed by the Guangdong Academy of Agricultural Sciences, was cultivated on 1,533 ha in 1986. It then spread from 8,000 ha in 1987 to 10,977 ha in 1995 and showed excellent resistance to blast in an environment favorable to blast in Guangdong, China. Therefore, we assumed that SHZ is a variety with durable resistance to blast.

Looking at the resistance performance of SHZ, we found that its resistance spectrum (RS) was more than 95% from 1985 to 1995 (Table 1). In 1995, the RS of SHZ was 99.5% under artificial inoculation with 220 isolates in Guangdong and 95.2% with 124 isolates of *Pyricularia grisea* from eight rice-growing zones in China. Furthermore, we screened a stable isolate (GD-V1) that is compatible to SHZ to investigate the reaction of SHZ compared with the reaction of the resistant check IR36 and the susceptible check B40. Entries were inoculated at the 5-leaf stage. Lesion density (LD) and lesion size (LS) were scored by the method of Roumen and diseased leaf area (DLA) was measured by the method of Notteghem. To make a better comparison, we converted the observed data (OD) of LD, LS, and DLA into relative value (RV) on the basis of B40, and computed the mean of LD, LS, and DLA. At the same time, resistance of the varieties was assessed in fields in eight rice-growing zones in China by the Standard of the National Blast Co-research Group. Results (Table 2) indicated that the resistance of SHZ and IR36 is different because SHZ

Table 1. Resistance spectrum (%) of San-Huang-Zhan No. 2 from 1985 to 1995 in Guangdong, China.

Year	1985	1986	1987	1989	1991	1992	1993	1994	1995
RS	100	100	98	95	96.5	98	98	98	99.5

Table 2. Qualitative and quantitative resistances of San-Huang-Zhan No. 2 (SHZ).

Cultivar	Resistance spectrum (%)		LD (lesions cm^{-1})		LS (mm)		DLA (%)		Field observation			
									LB[e]		PB[f]	
	Guangdong[a]	China[b]	OD[c]	RV[d]	OD	RV	OD	RV	Mean	Maximum	Mean	Maximum
SHZ	99.5	95.2	0.3	4	1.3	19	8.5	10	1.3	4	1	3
IR36 (check)	58.2	-	0.4	6	1.4	20	24.6	30	3.0	9	3.2	9
B40 (check)	-	-	6.6	100	6.9	100	82.0	100	-	-	-	-

[a]Including 220 isolates in Guangdong. [b]Including 124 isolates in China. [c]OD = observed data = mean of three experiments with 6 replications. [d]RV = relative value = tested data of cultivar/tested data of B40 × 100. [e]LB = leaf blast. [f]PB = panicle blast.

Table 3. Reaction to ZB13 blast isolate of F_1 and F_2 plants from crosses of San-Huang-Zhan No. 2 (SHZ).

Cross	F_1 reaction	F_2 reaction				
		R[a]	S	Expected ratio	χ^2	P
CO 39/SHZ	R	331	10	63:1	3.31	0.05-0.1
B40/SHZ	R	228	8	63:1	0.54	0.25-0.5
SHZ/CO 39	R	401	0			
SHZ/B40	R	601	0			

[a]R = resistant, S = susceptible.

exhibited a wide qualitative RS and a high quantitative resistance for three factors—LD, LS, and DLA—whereas IR36 appeared to have a narrow qualitative RS but high quantitative resistance under a wide range of populations of *P. grisea* in different latitudes of China. Quantitative resistance plays a key role in the durability of resistance.

The genetic experiment showed that three independently dominant genes control the blast resistance of SHZ and there is another gene present in the cytoplasm of SHZ as well (Table 3).

IR36 represents an indica variety with durable blast resistance under tropical irrigated conditions. Some researchers concluded that the partial resistance of IR36 is associated with blast durability. Other researchers showed that IR36 had at least three major genes for complete resistance to two Philippine blast isolates. The inheritance of partial blast resistance in IR36 is most likely polygenic. SHZ seemed to have three major genes for complete resistance to blast, but some questions remain. Is the durability of SHZ in China mainly due to major genes or not? What is the function of another gene present in the cytoplasm for blast durability? Further research is needed to answer these questions. ■

Multilocational evaluation of promising advanced breeding lines for resistance to rice tungro viruses

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An important objective of IRRI's breeding program for irrigated rice ecosystems is to develop varieties with resistance to rice tungro viruses in order to achieve durable resistance to tungro disease. We conducted this study to monitor tungro virus and leafhopper vector variability between test locations, based on the reaction of selected varieties and advanced breeding lines with different sources of resistance. The advanced breeding lines were IR68305-18-1 (IR64*4/Balimau Putih); IR71026-3-2-4-3-5-2 (IR1561-228-3-3*3/*Oryza longistaminata*); IR69705-1-1-3-2-1 (IR1561-228-3-3*2/Utri Merah); IR71030-2-3-2-1 (IR1561-228-3-3*6/ARC11554). IR64 was used as a susceptible check and IR62 as a vector-resistant check with field resistance to tungro.

The table shows locations, seasons, and years of tests. At each location, we used a randomized complete block design with four replications. The plot size was 8 m × 8 m with 2 m between plots. We transplanted 21-d-old seedlings at 20 cm × 20 cm spacing, with 2-3 seedlings $hill^{-1}$. The plants were exposed to natural infection with tungro viruses in the field. We assessed plants for disease symptoms and sampled leaves to detect tungro viruses by enzyme-linked immunosorbent assay (ELISA) at 30-35 and 55-60 d after transplanting (DAT). We recorded

Average[a] percentage infection with rice tungro bacilliform virus (RTBV), rice tungro spherical virus (RTSV), visual disease incidence, and number of green leafhoppers (GLH) in different varieties and advanced breeding lines planted in field trials in the Philippines, Indonesia, and India in 1995-96.

Test location/season	Varieties/lines	Infection (%)			GLH (no.)[c]
		BB[b]	SS	Visual	
Philippines					
Maligaya,	IR62	0.8	34.2	0.3	24.6
Nueva Ecija	IR64	27.0	67.3	23.1	169.5
1995 WS[d], 1996 WS	IR68305-18-1	2.0	55.2	0.1	145.4
	IR71026-3-2-4-3-5-2	0.9	28.5	0.1	134.8
	IR69705-1-1-3-2-1	2.3	3.4	0.2	174.8
	IR71030-2-3-2-1	0.6	11.1	0.1	52.1
Midsayap,	IR62	8.9	48.8	17.8	10.2
North Cotabato	IR64	80.8	89.1	92.2	100.7
1995 WS, 1996 DS,	IR68305-18-1	18.0	72.3	21.2	42.0
1996 WS	IR71026-3-2-4-3-5-2	38.8	74.1	41.6	44.8
	IR69705-1-1-3-2-1	6.4	6.0	1.8	35.1
	IR71030-2-3-2-1	6.1	13.4	20.9	12.8
Indonesia					
Celuk,	IR62	3.8	9.1	2.9	2.0
Bali	IR64	48.0	64.8	64.2	5.6
1995 DS, 1996 WS	IR68305-18-1	18.2	41.4	15.3	1.4
	IR71026-3-2-4-3-5-2	29.7	52.1	31.3	5.2
	IR69705-1-1-3-2-1	3.7	2.0	1.2	2.7
	IR71030-2-3-2-1	1.8	4.4	0.7	1.5
Maros,	IR62	3.3	6.1	0.6	10.4
South Sulawesi	IR64	8.2	13.4	3.5	15.2
1995 DS, 1996 WS	IR68305-18-1	2.2	5.8	0.2	14.1
	IR71026-3-2-4-3-5-2	3.4	5.6	0.2	13.8
	IR69705-1-1-3-2-1	4.4	4.3	0.0	11.0
	IR71030-2-3-2-1	2.2	2.6	0.0	12.0
India					
Chakdaha,	IR62	1.5	7.8	9.8	26.6
West Bengal	IR64	4.3	18.0	20.0	27.9
1996 WS	IR68305-18-1	1.1	5.1	10.8	35.9
	IR71026-3-2-4-3-5-2	0.8	6.0	23.8	20.5
	IR69705-1-1-3-2-1	0.3	1.1	9.5	24.9
	IR71030-2-3-2-1	6.1	31.1	16.9	26.0
Tirur,	IR62	2.3	14.5	2.5	10.4
Tamil Nadu	IR64	10.0	24.9	16.8	11.3
1996 DS, 1996 WS	IR68305-18-1	1.1	14.0	2.2	14.4
	IR71026-3-2-4-3-5-2	1.4	16.6	2.2	10.0
	IR69705-1-1-3-2-1	0.6	8.6	2.3	15.1
	IR71030-2-3-2-1	5.9	15.8	7.7	12.4

[a]Average across all seasons and computed from the mean of two samplings at 30-35 and 55-60 d after transplanting. [b]BB = total RTBV from BS and B alone, SS = total RTSV from BS and S alone. Infection with tungro viruses was assessed by enzyme-linked immunosorbent assay, visual incidence was assessed based on characteristic tungro symptoms of stunting and yellowing. [c]Count based on 10 sweeps of a 30-cm-diameter insect net in each plot. [d]WS = wet season, DS = dry season.

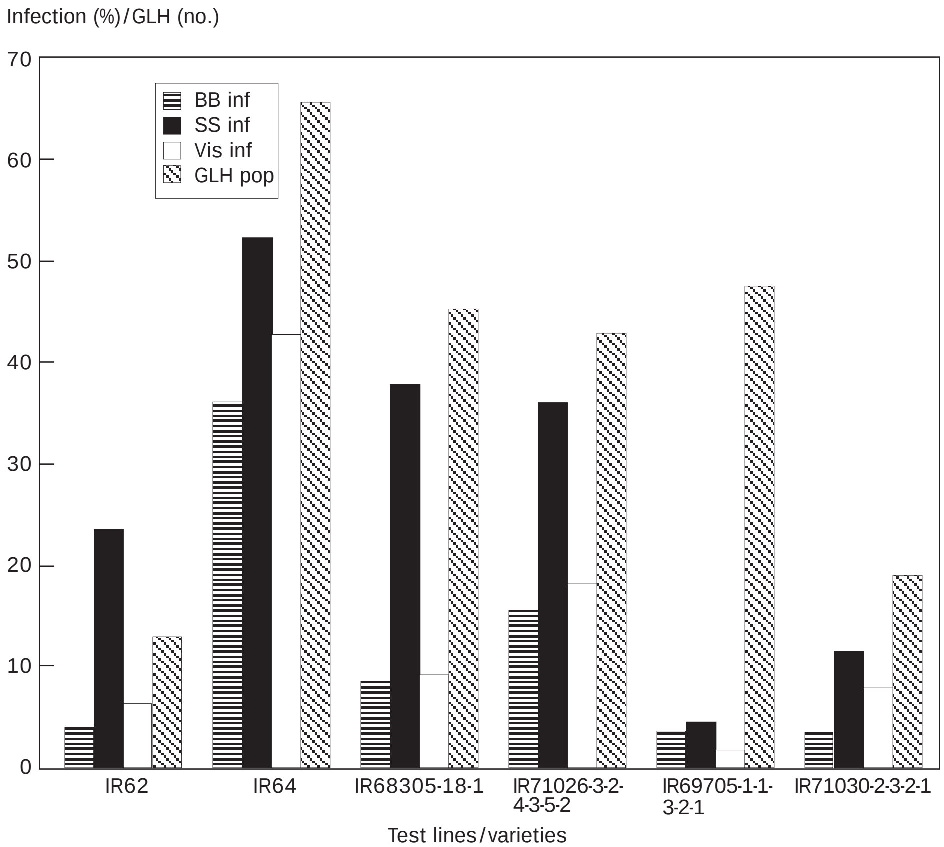
disease and sampled leaves in six quadrats of 4 × 4 hills arranged in a "W" pattern in each plot. We collected vector leafhoppers using 10 sweeps of a 30-cm-diameter insect net in each plot on the same dates as for recording disease.

Tungro disease incidence was low in Maros, Indonesia, as evidenced by the reaction of IR64, but was high enough at all other locations to allow the performance of the test entries to be evaluated effectively (see table). Tungro incidence was the highest in Celuk, Indonesia, and Midsayap, Philippines. Locational differences in the reaction of the test lines and varieties were observed only in IR71030-2-3-2-1, which had a relatively high infection with tungro viruses both in Chakdaha and Tirur, India, compared with other locations (see table).

The figure shows the average reactions of the test lines and varieties, regardless of test location and season. Infection with rice tungro bacilliform virus (RTBV) was the lowest in IR69705-1-1-3-2-1, IR71030-2-3-2-1, and IR62 at 3-4%. In contrast, a mean RTBV infection of 16% was recorded in IR71026-3-2-4-3-5-2. Mean infection with rice tungro spherical virus (RTSV) was the lowest in IR69705-1-1-3-2-1 and IR71030-2-3-2-1 at 5% and 12%, respectively. RTSV infection in IR71026-3-2-4-3-5-2 and IR68305-18-1 was 36% and 38%, respectively. Tungro incidence scored visually was 2% in IR69705-1-1-3-2-1 and was less than 10% in IR62, IR71030-2-3-2-1, and IR68305-18-1 (see figure). Tungro incidence on the susceptible check, IR64, was 44%. Green leafhopper numbers were the lowest on IR62 and IR71030-2-3-2-1 and were similar to those on the susceptible IR64 on the other lines.

The most promising advanced breeding line was IR69705-1-1-3-2-1, which showed tolerance for RTBV and resistance to RTSV at all test locations. This indicates that the virus resistance was successfully transferred from its parent, Utri Merah, and that this resistance is likely to be effective against tungro disease at a wide range of locations. IR71030-2-3-2-1 showed resistance to both RTBV and RTSV at most sites, but infection was relatively high in Chakdaha and Tirur. The virus-resistant parent of this line, ARC11554, originates from India. Further evaluation needs to be done to confirm the results. ■

Multiple submissions. Normally, only one report for a single experiment will be accepted. Two or more items about the same work submitted at the same time will be returned for merging. Submitting at different times multiple notes from the same experiment is highly inappropriate. Detection will result in the rejection of all submissions on that research.



Mean tungro disease incidence (□), infection with rice tungro bacilliform (▤) and spherical (■) viruses, and number of green leafhoppers (▨) per 10 sweeps of a 30-cm-diameter insect net in advanced breeding lines and varieties at six locations in India, Indonesia, and the Philippines in replicated field trials in 1995 and 1996.

Pest resistance

Advanced breeding lines with resistance to rice tungro viruses

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Some 139 advanced breeding lines with improved agronomic characters derived from crosses involving tungro-resistant rice varieties were evaluated for resistance to rice tungro viruses under greenhouse conditions. These lines consistently showed a resistant reaction to tungro under natural field infection in the tungro nursery at IRRI for at least six growing seasons. In the crosses, Utri Rajapan, Utri Merah, ARC11554, Habiganj DW8, and wild rices *Oryza longistaminata* and *O. rufipogon* (accession no. 105908 and 105910 and one with an unknown accession no.) were used as sources of resistance to tungro, whereas IR1561-228-3-3, IR24, and IR64 were used as the recurrent parents. Except for ARC11554, *O. longistaminata*, IR24, and IR64, all the other parents are susceptible to the virus vector green leafhopper (GLH).

The breeding lines were tested for tungro reaction using the forced-inoculation method. Some or 30-40 seven-day-old seedlings of each breeding line were inoculated with the virus for 24 h in test tubes using three viruliferous GLH, *Nepho-tettix virescens* (Distant), fed for 4 d on plants infected with rice tungro bacilli-form virus (RTBV) and rice tungro spherical virus (RTSV). After inoculation, the seedlings were planted in clay pots at 10 seedlings pot^{-1} and maintained for 1 mo inside insect-proof enclosures in the greenhouse. Leaf samples were collected from each plant and tested by enzyme-linked immunosorbent assay (ELISA). In the 1995 dry-season test, inoculated seedlings of the test lines were transplanted in the field after leaf sampling to further subject the materials to natural infection. Each of the lines was planted in 2 rows of inoculated seedlings, with 20 hills row^{-1}. One month after transplanting, leaf samples were again collected from each plant and tested by ELISA.

Only 94 of the breeding lines tested were confirmed to have resistance to tungro. Of these, 4 showed resistance to both RTBV and RTSV, whereas the other 90 breeding lines showed resistance to RTSV only (Table 1). Two breeding lines each from the crosses involving *O. rufipogon* (accession no. 105910) and Habiganj DW8 were resistant to both RTBV and RTSV, whereas breeding lines derived from crosses involving the other parents showed resistance to RTSV only. Progenies of *O. rufipogon*, Utri Merah, and Utri Rajapan were among the lines that exhibited a high level of resistance to RTSV.

An increase in RTBV and RTSV infection was observed in most of the breeding lines when inoculated seedlings of the test materials were transplanted in the field and further exposed to natural infection (Table 2). Breeding lines from Utri Merah and Utri Rajapan crosses, however, showed a decrease in RTBV infection even after further exposure to natural infection. Utri Merah is known to have resistance to the multiplication of RTBV and the decrease in RTBV detected in these breeding lines is presumed to be due to a decrease in virus titre in the infected plants.

Some of the most promising breeding lines from the crosses tested in these trials were selected for further evaluation in areas with high tungro incidence. These breeding lines are now being tested in replicated field trials in India, Indonesia, and the Philippines. ■

Table 1. Average percentage infection of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) in advanced breeding lines with different sources of resistance.

Cross	Resistant lines (no.)	Infection[a] (%)				
		BS	B	S	BB	SS
	1995 dry season[b]					
IR1561-228-3-3*3/*O. longistaminata*	16	8.3	57.2	2.0	65.5	10.3
IR1561-228-3-3*2/Utri Rajapan	15	14.8	72.7	0.2	87.5	15.0
IR1561-228-3-3*2/Utri Merah	10	8.6	56.1	2.1	64.7	10.7
IR1561-2l28-3-3*4/Utri Merah	10	5.7	53.1	1.7	58.8	7.4
IR1561-228-3-3*6/ARC11554	5	5.0	50.0	1.6	55.0	6.6
IR1561-228-3-3*4/Habiganj DW8	2	1.5	15.5	1.5	17.0	3.0
IR1561-228-3-3*6/Habiganj DW8	2	6.0	61.5	0.0	67.5	6.0
	1996 wet season					
IR1561-228-3-3*2/*O. longistaminata*	2	1.5	69.0	1.5	70.5	3.0
IR1561-228-3-3*3/*O. longistaminata*[c]	2	1.5	71.5	1.5	73.0	3.0
IR1561-228-3-3*2/*O. longistaminata*//IR24	2	1.5	82.5	0.0	84.0	1.5
IR1561-228-3-3*4/*O. longistaminata*//3*IR24	4	1.5	59.0	0.0	60.5	1.5
IR1561-228-3-3*2/Utri Merah[c]	3	1.0	30.0	0.0	31.0	1.0
IR1561-228-3-3*4/Utri Merah[c]	2	0.0	40.5	0.0	40.5	0.0
IR1561-228-3-3*2/Utri Merah//IR24	3	9.0	48.3	0.0	57.3	9.0
IR1561-228-3-3*6/ARC 11554[c]	5	2.4	43.6	0.6	46.0	3.0
IR1561-228-3-3*3/Habiganj DW8	1	3.0	47.0	0.0	50.0	3.0
IR1561-228-3-3*4/Habiganj DW8[c]	2	4.0	24.5	4.5	28.5	8.5
IR1561-228-3-3*6/Habiganj DW8	1	9.0	53.0	0.0	62.0	9.0
IR1561-228-3-3*3/Habiganj DW8//4*IR64	5	3.0	39.8	0.0	42.8	3.0
IR1561-228-3-3*2/Utri Rajapan[c]	2	5.0	77.5	0.0	82.5	5.0
IR1561-228-3-3*2/Utri Rajapan//IR24	3	1.0	68.7	0.0	69.7	1.0
IR1561-228-3-3/*O. rufipogon* (Acc. 105910)	1	0.0	76.0	0.0	76.0	0.0
IR1561-228-3-3/*O. rufipogon* (Acc. 105908)//IR24	5	0.0	69.4	0.0	69.4	0.0
IR24/*O. rufopogon* (Acc. 105910)//3*IR64	2	0.0	26.0	0.0	26.0	0.0
IR1561-228-3-3//IR42/*O. rufipogon* (unknown Acc. no.)	5	0.0	60.2	0.8	60.2	0.8

[a]Av of resistant lines. Infection of tungro viruses was assessed by enzyme-linked immunosorbent assay. BS = RTBV + RTSV, B = RTBV alone, S = RTSV alone, BB = total RTBV (BS + B), SS = total RTSV (BS + S). [b]Two inoculation trials conducted. Percentage infection is av of two trials. [c]Advanced progenies of breeding lines identified as resistant in 1995 dry season trial.

Table 2. Average percentage infection of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) in advanced breeding lines inoculated in the greenhouse and subjected to natural infection in the field.

Cross	Lines tested[a] (no.)	Infection (%)[b]				
		BS	B	S	BB	SS
IR1561-228-3-3*3/*O. longistaminata*	4	18.8 (4.6)	55.3 (68.4)	2.8 (0.5)	74.1 (73.0)	21.6 (5.1)
IR1561-228-3-3*2/Utri Rajapan	4	32.6 (20.3)	52.8 (71.4)	4.5 (0.1)	85.4 (91.7)	37.1 (20.4)
IR1561-228-3-3*2/Utri Merah	4	5.7 (4.3)	43.0 (71.8)	3.2 (0.6)	48.7 (76.1)	8.9 (4.9)
IR1561-228-3-3*6/ARC11554	4	8.8 (2.8)	64.0 (59.2)	1.8 (0)	72.8 (62.0)	10.6 (2.8)
IR1561-228-3-3*6/Habiganj DW8	4	9.2 (5.0)	59.8 (47.4)	1.6 (0)	69.0 (52.4)	10.8 (5.0)

[a]Test lines were inoculated with RTBV + RTSV in the greenhouse at 7d after sowing (DAS) and transplanted in the field at 38 DAS. Values represent infection with tungro viruses at 69 DAS. Values in parentheses represent infection with tungro viruses at 38 DAS. [b]Infection of tungro viruses was assessed by enzyme-linked immunosorbent assay. BS = RTBV + RTSV, B = RTBV alone, S = RTSV alone, BB = total RTBV (BS + B), SS = total RTSV (BS + S).

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted. Examples are single-season, single-trial field experiments. Field trials should be repeated across more than one season, in multiple seasons, or in more than one location as appropriate. All experiments should include replications and an internationally known check or control treatment.

Stress tolerance — adverse soils

Seasonal differences in iron toxicity tolerance of lowland rice cultivars

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Iron toxicity is a major stress and yield-reducing factor in irrigated and rainfed lowlands in West Africa. Varietal tolerance is the most practical and cost-effective means of reducing iron toxicity in iron-toxic soils. We have been evaluating lowland rice cultivars for iron toxicity tolerance at Korhogo, Côte d'Ivoire, a site with a consistent and high iron toxicity pressure on plants. Because irrigation water is available, it was possible to evaluate germplasm in both the wet and dry seasons.

We have observed that iron toxicity pressure is higher in the dry season than in the wet season at Korhogo. In the 1994 wet season (Jul-Nov 1994) and 1995 dry season (Dec 1994-Apr 1995), we evaluated the performance of 12 elite selections (based on evaluations made in 1992 and 1993). To determine the yield potential of these cultivars, they were also grown at Mbe, which provides a lower level of stress.

Experiments at both sites used a randomized complete block design with four replications. The plot size was 12 m^2 at Mbe and 24 m^2 at Korhogo. All plots received 20-36-36 kg NPK ha^{-1} as a basal application. A total of 80 kg N ha^{-1} was added to each plot. The soil at Mbe was an Alfisol (pH 6.2; organic carbon, 1.8%; extractable Fe, 93 mg kg^{-1}) with sandy clay-loam texture; the soil at Korhogo was an Ultisol (pH 5.7; organic carbon, 1.02%; extractable Fe, 154 mg kg^{-1}) with sandy loam texture.

The cultivars evaluated at Korhogo had large differences in yield during the wet and dry seasons (see table). Iron toxicity scores at Korhogo, based on bronzing symptoms on the rice plant

Performance of 12 lowland rice cultivars evaluated for grain yield (t ha^{-1}) and iron toxicity score (ITS) at sites with high iron toxicity (Korhogo) and low iron toxicity (Mbe), Côte d'Ivoire, 1994 wet season and 1995 dry season.

Cultivar	Korhogo 1994 wet season Grain yield	Korhogo 1994 wet season ITS[a]	Korhogo 1994 dry season Grain yield	Korhogo 1994 dry season ITS	Mbe 1994 wet season Grain yield
TOX3118-6-E2-3-2 (WITA 1)	6.7	1	5.0	2	7.6
CK4	6.1	1	5.0	2	8.3
CK73	4.9	2	4.9	3	4.2[b]
TOX3052-41-E1-2	6.3	1	4.8	3	8.1
TOX3100-32-2-3-5 (WITA 3)	4.3	3	4.7	3	7.8
TOX3050-46-E3-3	6.0	1	4.6	3	6.2
TOX3081-36-2-3	6.2	1	4.4	3	6.0
TOX3027-43-1-E3-1-1-1	5.5	2	4.1	5	7.5
TOX3093-35-2-3-3 (WITA 2)	4.8	2	3.7	5	7.6
Suakoko 8	3.7	2	3.3	3	5.3
Bouake 189	4.7	3	2.9	7	6.5
TOX 3069-66-2-1-6	4.2	5	2.8	7	7.7
LSD (0.05)	1.1		0.8		0.8

[a]Based on the *Standard evaluation system for rice* with a scale of 1-9, where 1 = growth and tillering nearly normal and 9 = almost all plants dead or dying. [b]Yield was low because of bird damage.

foliage, were higher (indicating higher iron toxicity) in the dry season than in the wet season. Iron toxicity in the growing season was not observed to any significant extent at Mbe and the rice plants grew normally there.

Seasonal differences in yield were larger for susceptible cultivars such as Bouake 189 and TOX 3069-66-2-1-6 than for iron-tolerant cultivars such as CK 4, Suakoko 8, and WITA 3. The yield potentials of cultivars CK 4, WITA 1, WITA 2, and WITA 3 were clearly expressed in the 1994 wet season experiment at Mbe (see table). The iron-toxicity susceptible cultivars Bouake 189 and TOX 3069-66-2-1-6 yielded 6.5 and 7.7 t ha^{-1}, respectively, at Mbe.

These results indicate that iron toxicity, coupled with dry-season environmental conditions at Korhogo, reduces the grain yield of both iron-toxicity-tolerant and -susceptible cultivars. The high temperatures in the dry season affect crop physiology, especially during grain maturity. High temperature may also enhance transpiration rates of rice plants, which could cause a higher uptake of iron. It is also known that in a growing medium where iron in solution is high (which is expected in the dry season because of the high prevailing temperatures), iron uptake increases with higher transpiration rates because of a passive uptake mechanism. In addition, water supplied by rainfall in the rainy season would dilute the iron in a soil solution and could provide some relief from iron toxicity. ■

Correlation of some varietal characteristics with grain yield and stress tolerance index under saline conditions

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Rice production in saline soils could be increased if salt-tolerant genotypes were developed, but progress toward combining superior tolerance with good yield potential is slow, largely because of the nonavailability of reliable and efficient selection criteria. Selecting directly for grain yield under saline conditions may be limited by the low heritability of observed variation and failure to distinguish between yield potential and capacity to cope with adverse stress factors.

We evaluated the correlation of 26 characteristics with grain yield and stress tolerance index (average grain yield under stress in relation to the corresponding controls taken as one) in rice under saline conditions to ascertain the role of these traits in indirect selection for yielding ability under these conditions and in measuring varietal ratings.

We studied 20 rice varieties under laboratory conditions and in the field. In petri dishes with NaCl at electrical conductivity of 12 dS m^{-1} (stress) and distilled water (0.02 dS m^{-1} as a control), 30 seeds of each genotype were placed in petri dishes with filter paper, with four replications. After 48 h, seed water uptake, peroxidase, catalase, alpha, beta, and total amylase isozyme activity in germinating seeds, seed respiration, and seed redox potential were evaluated. After 7 d, seed germination, seedling height, root length, fresh and dry weight of seedlings, leaf respiration, total water content, relative leaf water content, transpiration, sap cell concentration, proline content, and total chlorophyll content were measured. In the field, the genotypes were sown in specially designed 3 m × 3 m × 1 m test plots in saline soil (9 dS m^{-1}) and in nonstress productive soil over three seasons. The experiment was laid out in a randomized block design with four replications. Normal cultural practices were followed. We collected data on agronomic attributes (plant height, panicles plant^{-1}, panicle length and weight, filled grains panicle^{-1}, and grain yield) from 10 plants selected at random in each replication. We computed the correlation coefficient of all traits estimated.

Seed water uptake, peroxidase activity, seed germination, seedling height, root length, seedling dry weight, total water content, and

Correlation of some characteristics of rice varieties grown in saline conditions with grain yield and saline stress index.

Characteristic	Correlation with	
	Grain yield	Saline stress tolerance index
Seed water uptake	0.47*	0.51*
Peroxidase	0.42*	0.69*
Catalase	0.15	0.36
Alpha amylase	0.10	0.11
Beta amylase	0.02	0.15
Total amylase	0.47*	0.15
Seed respiration	–0.18	0.28
Seed redox potential	0.02	0.15
Seed germination	0.68**	0.57*
Seedling height	0.71**	0.72**
Root length	0.62**	0.78**
Seedling fresh weight	0.05	0.26
Seedling dry weight	0.63**	0.66**
Leaf seedling respiration	0.29	0.30
Total water content	0.46*	0.65**
Relative leaf water content	0.57*	0.62**
Transpiration	0.05	0.04
Sap cell concentration	0.02	0.01
Proline content	0.21	0.39
Total chlorophyll content	0.25	0.29
Plant height	0.80***	0.83***
Panicles plant^{-1}	0.30	0.29
Panicle length	0.32	0.40
Panicle weight	0.81***	0.83***
Filled grains panicle^{-1}	0.33	0.30
1000-grain weight	0.73**	0.38

* = significant at P=0.05, ** = significant at P=0.01, and *** = significant at P=0.001.

relative leaf water content were highly correlated with the saline stress tolerance index (see table), indicating that measuring varietal ratings for salt tolerance at the early stage of growth via these traits was likely to be effective.

At the late stage of growth, plant height and panicle weight correlated highly and significantly with grain yield under saline conditions, as well as with the saline stress tolerance index, showing that varietal evaluation and indirect selection for grain yield in saline soil via these traits would be an even better method. ■

Multiple submissions. Normally, only one report for a single experiment will be accepted. Two or more items about the same work submitted at the same time will be returned for merging. Submitting at different times multiple notes from the same experiment is highly inappropriate. Detection will result in the rejection of all submissions on that research.

Integrated germplasm improvement — upland

Altamirano, Mandisovi, and Quebracho: new rice cultivars from Argentina

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Altamirano P.A. is, because of its growth duration, tolerance for low temperatures, and good performance on saline and alkaline soils, recommended for sowing in temperate zones or under these soil limitations, according to the new aims of our rice program.

This variety is 0.98 m tall, resists lodging, and has intermediate threshability. It reaches maturity in 133 d and its yield potential is 8,000 kg ha^{-1}. The caryopsis is 7.47 mm long and 2.79 mm wide and the ratio of length to width is 2.67, matching that of the commercial type.

Its endosperm has a medium amylose content (21%) and an intermediate gelatinization temperature. Its protein content is 8.35%. It is moderately resistant to *Pyricularia oryzae* Cav.

This variety originated from the cross of experimental line H-115-19-1 and variety Yerua P.A. to obtain the highest quality of grain, yield, and *P. grisea* Cav. resistance. Line H-115-19-1 came from the cross of varieties Dawn and Zenith. Crossing was carried out by the rice program at the Ing. Agr. Julio Hirschhorn Experiment Station. A combination of mass and pedigree selection was used.

Because of its earliness, Altamirano was released for cultivation in areas near 30 °S in Buenos Aires Province.

Mandisovi P.A. was bred to satisfy the demand for aromatic rices, which, unlike La Calendaria FA, has a caryopsis that corresponds to the long-wide type. It can be consumed both as polished or integral rice (this alone or mixed with red pericarp rice).

Mandisovi is 0.83 m tall, resists lodging, and reaches maturity in 135 d. Its yield potential is 6,000 kg ha^{-1} and it has intermediate threshability. Mandisovi's caryopsis is 7.64 mm long and 2.7 mm wide and its ratio of length to width is 2.82.

The endosperm contains an intermediate amylose content (23%) and low gelatinization temperature. Its protein content is 8.80% and it has a weak aroma. Mandisovi has moderate resistance to *P. oryzae* Cav.

This variety was obtained by crossing African cultivar Chocoto and H161-18/ /desc./80-17. Line H161-18 was developed by crossing IR1103-15-10 and Calady 40 sel. FA to obtain earliness and high protein content. The crossing was carried out by the rice program. A combination of mass and pedigree selection was used. The target area for diffusion is 32 °S near Villaguay City.

Quebracho P.A. is the first Argentine cultivar of the long-wide type, and it is aromatic and has a red pericarp. This release aimed to satisfy an increasing interest in the consumption of special rices. It is consumed as integral grain, alone or combined with similar rices of normal pericarp.

Quebracho is 0.89 m tall and resists lodging. It reaches maturity in 145 d and yields 7,000 kg ha^{-1}. It has intermediate threshability. The caryopsis is 8.1 mm long and 2.75 mm wide, and its ratio of length to width is 2.94.

For quality, it is important to mention its medium amylose content (22%) and its intermediate gelatinization temperature. Its protein content is 9.68% and it is strongly aromatic. Quebracho is resistant to *P. oryzae* Cav.

This cultivar was developed by crossing Chocoto and H161-18/ /desc./ 80-17, in a crossing carried out by the rice program. A combination of mass and pedigree selection was used. The probable target area is 32 °S near Villaguay City. ■

Four promising medium-duration upland rice breeding lines for the République Démocratique du Congo

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Several upland rice varieties have been cultivated under upland (dryland) conditions, the main rice ecosystem for RDC. Ry1 (IRAT2) is a 140-cm-high, medium-duration (120 d), blast-resistant, and lodging-tolerant variety. It was selected especially for grain yield (averaging 3.2 t ha^{-1}) and for yield stability across locations where tested. It was released in 1982 to replace R66, an old cultivar yielding 2.5 t ha^{-1}. But because RY1 rice is sticky when cooked, the cooking process is more difficult for consumers, who prefer cooked rice that is harder, flakier (not sticky), whiter, and denser in appearance and that remains soft even when stored overnight. This behavior of RY1 rice after cooking could be attributed to its low amylose content (15.6%), which has resulted in poor acceptance of RY1 by farmers.

Most of the research carried out in our breeding program involved the creation of medium-height (100-140 cm), lodging-tolerant, medium-duration (120-140 d), blast-resistant, high-yielding (more than 3 t ha^{-1}) varieties with good grain characteristics (length more than 9 mm; length to width ratio at least 3; width to thickness ratio about 1; 1,000-grain weight more than 30 g; endosperm translucency at least 60%) and good cooking quality (harder and flakier cooked rice grains).

Seven pure breeding lines (Table 1) selected from two crosses—RY1/OS6 (PR42) and OS6 × RY7/OS6 (PR55)—were compared with RY1, used as a check, during two wet crop seasons (1995 and 1996) at the Yangambi research station. At Yangambi, the soil is sandy with 20-30% clay, lighter at the surface than deeper. Annual rainfall and monthly temperature average 1,885 mm and 24 °C, respectively. The 2-yr experiment was laid out in a randomized complete block design with four replications. Plots were 3 m × 6 m, in which 4-5 grains $hill^{-1}$ were sown at 30 × 20-cm spacing. No fertilization was used.

On average, life cycle, lodging tolerance, plant height, reaction to brown leaf spot, leaf blast, and leaf scald were similar for the breeding lines and the check RY2 (Table 2). Grain quality characteristics of the breeding lines, except for endosperm translucency, were good and also comparable with those of RY1. But yield potential and endosperm translucency varied among the materials tested. Four breeding lines (PR42-44-7-8-1, PR42-44-7-56-2, PR42-44-8-44-1, and PR55-5-2-17-16) had yield potential comparable with that of RY1 (Table 1) and endosperm translucency above or equal to the minimum required for market acceptability. These lines were selected for testing in different INERA substations located in rice-growing zones of the country.

The materials selected could eventually be recommended either for cultivation to replace RY1 or for use in breeding programs which aim to develop cultivars with high and stable yield potential and good cooking quality. ■

Table 1. Yields of seven selected breeding lines at Yangambi, 1995-96.

Breeding line/variety		Mean yield (t ha^{-1})[a]		
Number	Name	1995 crop season	1996 crop season	Av
1	PR42-44-7-8-1	2.5 abc	2.6 bcd	2.6 bc
2	PR42-44-7-8-2-1	2.4 bcd	2.4 cd	2.4 cd
3	PR42-44-7-56-1	2.3 cd	2.8 abc	2.6 bc
4	PR42-44-7-56-2	2.6 abc	3.4 a	3.0 ab
5	PR42-44-8-44-1	2.3 cd	3.3 abc	2.7 abc
6	PR55-3-1-18-3	1.9 d	2.1 d	2.0 d
7	PR55-5-2-17-16	2.9 ab	3.2 ab	3.0 a
8	RY1 (IRAT2, check)	3.0 a	3.0 abc	3.0 ab
	Av	2.5	2.8	2.7
	CV (%)	13.7	13.6	10.4

[a]In a column, means followed by the same letters do not differ significantly from each other at the 5% level by DMRT.

Table 2. Plant characteristics of seven selected breeding lines at Yangambi, RDC (av of 2-yr observations).

Characteristic	Breeding lines/varieties number							
	1	2	3	4	5	6	7	8
Duration (d)	120	119	119	125	120	120	120	125
Plant height (cm)	121	118	123	126	126	118	120	116
Lodging (score)[a]	1	1	3	3	3	1	1	1
Grain length (mm)	9.55	9.88	9.74	9.40	9.95	9.70	9.56	10.01
Grain width (mm)	3.32	3.47	3.69	3.69	3.64	3.60	3.66	3.59
Grain thickness (mm)	2.47	2.46	2.44	2.48	2.47	2.53	2.52	2.51
L/W	2.88	2.85	2.64	2.55	2.73	2.69	2.61	2.79
1,000-grain weight (g)	38.4	39.0	44.0	40.0	36.5	40.5	42.3	37.5
Translucency (%)	60.5	49.7	38.7	63.3	60.0	53.4	65.0	58.6
Disease reactions[a]								
Brown spot	MR	MR	MS	MR	MR	MR	MR	MR
Leaf blast	MR	MR	MR	MR	MR	MR	MR	MR
Leaf scald	R	R	R	R	R	R	R	R

[a]Scored using the *Standard evaluation system for rice.* R = resistant, MR = moderately resistant, MS = moderately susceptible.

A seed production system for backstopping a hybrid rice breeding program

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For a hybrid rice breeding program to succeed, it should have a system for mass producing parental lines and developed hybrids. The parental lines should be multiplied efficiently without compromising purity. Sufficient hybrid seeds of acceptable purity should be made available for the various stages of evaluation. At IRRI, we employ a system for mass producing parental lines and hybrids for in-house use and sharing with collaborators.

The scheme for increasing seed of promising parental lines starts with nucleus seed production and is followed by breeder seed production. These stages of seed multiplication are carried out under strict isolation conditions. Experimental hybrids are produced in quantities depending on their current stage of yield evaluation. In producing seeds for trials requiring a few thousand seeds, we use the "isolation-free" system. This allows us to produce seeds of several hybrids in small adjacent plots. To produce a few kilograms of hybrids for multilocational testing and sharing with collaborators, we use 100-500-m^2 partially isolated plots. Within this seed production system, we assess the outcrossing potential of the seed parent and determine the ease of production of particular hybrid combinations. We determined the quality of output of the various seed production steps through grow-outs conducted after each season. ■

Standardizing hybrid rice seed production practices

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Seed yield in hybrid rice seed production plots depends, among other things, on the area under the female parent and the extent of seed set. Factors influencing seed set percentage on the female parent include row ratio, row direction, height of the pollen parent, weather conditions, particularly at the time of flowering such as wind velocity, pollen load, nature of the hybrid combination, and the adoption of practices that promote out-pollination such as proper application of GA_3 and supplementary pollination.

We conducted an experiment to find out the optimum row ratio of the pollen parent to the seed parent and the appropriate season for maximizing seed yields in male sterile lines and hybrid rice. The material for the study consisted of IR58025A, with its maintainer line in cytoplasmic male sterile (CMS) line multiplication, and IR58025A, with restorer line IR40750. Only in the 1993 wet season (WS) was IR46 used as a restorer in hybrid rice seed production. Using these experimental materials, a trial involving both CMS multiplication and hybrid seed production was conducted in a fixed row ratio of 2 male:16 female parents during 1993-95 WS and dry season (DS) with six replications. The spacing adopted was 30 cm between two male rows, 20 cm from male to female row, and 15 cm each for female to female row and plant to plant. Seeding of the female parent was done only once, whereas the male parent was sown twice at an interval of 3-5 d except in the 1995 WS, when only one seeding was done. Seedlings of appropriate age were transplanted at the rate of a single seedling $hill^{-1}$ for the male and female in the 1993 WS and 2-3 seedlings for the male and 2 seedlings for the female during the remaining seasons. Seed production practices such as GA_3 application at 50 g ha^{-1} and supplementary pollination were commonly adopted. Leaf clipping, however, was practiced only during the 1993 WS.

Besides days to flowering and extent of synchronization, observations were recorded on percentage seed set and seed yield of individual female parent rows in each plot and in all replications. By using the yield of individual rows, the seed yield for different row ratios such as 2:2, 2:4, ..., and 2:16 were computed by adding the yield of the 2nd, 3rd, ..., and 8th row from both sides at a time. The results showed a constant decline in seed set in CMS multiplication and hybrid seed production, with a gradual increase in row ratio from 2:2 to 2:16.

The optimum row ratio in hybrid seed production varied from 2:8 (1993 and 1994) to 2:12 (1995) in the WS, whereas in the 1995 DS it was 2:10. Seed yield obtained at optimum row ratios was the highest in the 1995 WS (1,636 kg ha^{-1}) and the lowest in the 1993 WS (720 kg ha^{-1}). The low mean yields in 1993 and 1994 in the WS were mainly due to nonsynchrony in flowering between the male and female parents. The mean seed yield was also maximum in the 1995 WS (1,427 kg ha^{-1}), which was attributed to higher pollen load by virtue of perfect synchrony resulting from one-time sowing and planting of the male parent seedlings. Similarly, in CMS multiplication of IR58025A, seed yield was the highest with the ratio of 2:6 (1994 and 1995 WS) and 2:8 (1993 WS and 1995 DS). The main reason for the very low yield (515 kg ha^{-1}) in the 1995 WS was incessant rain during flowering. The mean seed yield obtained in different seasons indicated DS was more favorable for successful commercial seed production. ■

Evaluating hybrid seed production technology along with the new growth hormone Mangiferin

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Doubts have been raised about the economic viability of hybrid seed production as rice is predominantly a self-pollinated crop. An efficient seed production package is as important as improving cytosterile lines and developing and evaluating hybrids. We attempted to evaluate hybrid seed production technology using the new growth hormone Mangiferin because the cost of gibberellic acid (GA_3) was high. Besides Mangiferin, glycine was also used to economize hybrid seed production in rice. Using GA_3, boric acid, urea, Mangiferin, and glycine in different concentrations, we studied their effect on several characters in hybrids, such as duration of opening of florets, stigma exsertion, angle of opened florets, plant height before and after spraying, panicle exsertion at 5%, at 50% flowering, and at maturity, grain yield ha^{-1}, 1000-grain weight, and spikelet length. Analysis of variance showed highly significant differences for all the characters except panicle exsertion at 50% flowering, which was significant only at 5%. In general, treatment combinations of GA_3 and Mangiferin produced a positive response for most floral and associated traits. GA_3 at 40-60 ppm or GA_3 +1.5% boric acid influenced more than one character: duration of opening of florets, stigma exsertion, grain yield $plant^{-1}$, plant height, and panicle exsertion. The treatment with GA_3 +1.5% boric acid was one of the most effective combinations as it influenced almost all the characters studied. Mangiferin in different combinations and concentrations also responded like GA_3. Mangiferin alone (60 ppm) or in combination with boric acid influenced many traits: duration of opening of florets, stigma exsertion, angle of opened florets, grain yield ha^{-1}, plant height, and panicle exsertion. All these traits recorded higher values than the control. The treatment containing GA_3 or Mangiferin (60 ppm) along with flag leaf clipping and rope pulling had much higher values for duration of opening of florets and stigma exsertion than the control. Another important finding was the use of glycine in enhancing outcrossing in rice. GA_3 and glycine (40 ppm each) applied together resulted in 23% more yield than with the control. ■

Synchronization studies in hybrid rice seed production

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The two parents of a hybrid combination differ in their growth duration and therefore flower at different times even when sown on the same date. To produce hybrid seed successfully on a commercial scale, male and female parents planted side by side in a fixed row ratio should flower simultaneously, which is called synchronization. Synchronized flowering between two parental lines of different growth duration can be achieved by seeding them on different dates which is termed seeding interval (SI). The method of arriving at an SI using growth duration is simple to practice. In this method, the difference between parental lines in the number of days to initial heading or 50% flowering from seeding is used to determine SI. The growth duration of a variety, however, is known to be influenced by seasonal and weather conditions. Therefore, it is essential to determine an SI between the two parents of a hybrid for each season and location. The present study aimed at understanding the effect of different seeding dates in a season on growth duration and its implications in hybrid seed production. The material consisted of 19 restorers belonging to different maturity groups—early (6), medium (5), and late (8)—and 3 cytoplasmic male sterile (CMS) lines with their maintainers. All were sown on five different dates from 11 Jun 1994 at 5-d intervals. The seedlings were uprooted 30 d after sowing and planted in a randomized block design with three replications at a spacing of 20×15 cm. Observations on initial heading and days to 50% flowering were recorded for each entry and in each replication. The first and last sowings increased growth duration irrespective of the material used; the last sowing on 1 Jul increased growth duration by 5-8 d in restorers, 4 d in CMS lines, and 12 d in maintainers compared with the first sowing. Other sowings did not influence growth duration markedly.

The results clearly show that there is a definite time period for sowing within which growth duration is not affected significantly. Therefore, growth duration could safely be used to determine SIs to ensure synchronized flowering in parental lines. Studies should be conducted for a given hybrid combination at each seed production location and for each season. Seeding interval determined by growth duration would then become a much more reliable parameter for long-term use. ■

Effect of seedling age on flowering time in A, B, and R lines

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Flowering time in parental lines plays a vital role in hybrid rice seed production. Transplanting rice seedlings at the right age assumes special significance in obtaining higher yields in cultivation as well as in hybrid seed production. In conditions where timely planting is not possible because of unavoidable circumstances, one is bound to transplant aged seedlings. In hybrid rice seed production, in spite of staggered seeding, simultaneous planting of male and female parents is preferred to avoid inconvenience and wasted labor. An experiment was therefore conducted during the 1994 wet season to find out the effect of seedling age at transplanting on flowering time in A, B, and R lines. The experiment was laid out in a randomized block design using five cytoplasmic male sterile lines along with their corresponding maintainers, six restorer lines, and one check variety in three replications at a spacing of 20 × 15 cm. Sequential transplanting was done at an interval of 5 d using 15-50-d-old seedlings. Observations were recorded on days to 50% flowering.

The results showed that seedling age exerted a significant and positive effect on flowering; older seedlings at transplanting delayed flowering in all the lines studied. Instead of using seedlings of the optimum age (20 d), transplanting 15-d-old seedlings advanced flowering by 1 d in all the lines. When 25-d-old seedlings were used for transplanting, flowering delay was negligible in the R and B lines, but delay was 1 d in the A line. Flowering in the R lines was delayed markedly (3 d), followed by A and B lines (2 d), when 30-d-old seedlings were transplanted.

Restorer lines, which generally have a longer growth duration than their female counterparts, are sown first to produce hybrid rice seed. Therefore, at the time of transplanting, R line seedlings would be older than A line ones. Recent studies have indicated that the optimum standard of synchronization is that the female parent should flower 1 or 2 d earlier than the male parent.

Our study indicated that flowering was advanced by 1 d in A lines when 15-d-old seedlings were transplanted; it remained the same in B and R lines if 20-25-d-old seedlings were transplanted. In a hybrid combination involving a male parent with 10 d longer growth duration than the female parent, simultaneous transplanting using 15-d-old A line seedlings and 20-25-d-old seedlings of B and R lines can be done without affecting the expected time of flowering. Transplanting seedlings aged more than 30 d showed positive and similar effects in delaying flowering in A, B, and R lines. The results in our studies indicate that similar information for the parents of commercial hybrids must be obtained in both seasons in the target area prior to large-scale seed production. ■

Storage potential of parental lines of hybrid rice

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To elucidate the storability of parental lines of hybrid rice, we studied seed quality parameters (such as germinability and vigor index) and some biochemical traits. Seeds of different parental lines of hybrid rice—A lines (IR62829A and IR58025A), B lines (IR62829B and IR58025B), and R lines (IR10198-66-2R, AS89044, Pusa 150R, C20, and C22) having superior germinability—were stored in cloth and 400-gauge polyethylene bags. The seeds were evaluated for seed quality parameters at bimonthly intervals for 12 mo. Finally, they were subjected to accelerated aging for 9 d in an aging chamber (40 °C and 100% relative humidity).

IR10198-66-2R and AS89044 (R lines) maintained prolonged viability, whereas deterioration was faster in C20. A lines usually recorded high germinability initially but deteriorated faster than their respective maintainers during storage. A similar trend was noticed in dry matter production and vigor index. Biochemical analysis showed a steady decrease in dehydrogenase activity and an increase in both free sugars and electrical conductivity of seed leachates as the storage period increased. Among the containers tested, the polyethylene bag proved its superiority over the cloth bag in maintaining vigor and viability, probably because of less influence from external factors such as relative humidity or temperature. It is obvious from the study that, besides container and genotype influence, the male sterility system also has a key role in seed storability. ■

Dormancy of seeds of some rice hybrids and their parents

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The extent of seed dormancy in hybrids and their parents was investigated during the 1994 wet season. Harvested seeds from parents, hybrids, and check varieties were stored in paper bags and tested for germination at 5-d intervals. The study included the hybrids IR58025A / IR9761-19-R and IR58025A / IR29723-143-3-2-1R, male parent IR62829A, and check varieties Mandya Vijaya and IR20.

The results indicated that both cytoplasmic male sterile (CMS) lines, IR58025A and IR62829A, break dormancy 25 d after maturity and record more than 90% germination. The hybrid IR58025A / IR9761-19-1R recorded 72% germination after 25 d and 88% after 30 d. Its restorer took 30 d to break dormancy, with 84% germination. The other hybrid, IR58025A / IR29723-143-3-2-1R, recorded 92% germination after 30 d, whereas IR29723-143-3-2-1R did not germinate at all even after 30 d. It took 45 d after harvest to record more than 85% germination. Check varieties Mandya Vijaya and IR20 broke dormancy after 20 d. The results demonstrated that CMS lines IR58025A and IR62829A can be used for sowing

25 d after maturity. Restorer lines IR9761-19-1R and IR29723-143-3-2-1R can be sown only 30 and 45 d after harvest, respectively. It is safe to market the hybrid seeds 30 d after harvest. ■

Significance of stigma exsertion in enhancing outcrossing in male sterile rice lines

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An investigation undertaken to study the floral characteristics of male sterile lines will lead to better outcrossing and enhanced seed set. Eight cytoplasmic male sterile (CMS) lines were used for the study. Floral characters such as rate of stigma exsertion, stigma length and width, stigmatic area, style length, and natural seed set of these lines were observed during the 1995 wet season.

The natural seed set in these CMS lines ranged between 1.86% in IR68275A and 10.6% in IR58025A, with a mean value of 5.59%. Among the floret characteristics studied, stigma exsertion showed a predominant influence on seed set. The mean stigma exsertion rate ranged between 6% in IR68275A and 48% in IR58025A. IR58025A, IR68281A, and IR67684A showed a significantly higher percentage of stigma exsertion. The significantly higher seed set (10.6%) in IR58025A was attributed to its higher stigma exsertion rather than to any other floral characteristics. The genotype with the least stigma exsertion (IR68275A) recorded the lowest natural seed set (1.86%). Genotypes with a higher rate of stigma exsertion recorded a higher style length, as observed in IR58025A, IR68281A, and IR67684A. Even though stigma exsertion and style length in IR67684A were higher than in other genotypes, seed set was low (4.1%), indicating the linkage factor involved with cytoplasm for male sterility. In IR64707A, multiple stigmas were recorded in 3% of the florets.

Our results indicated that, among floral traits, better stigma exsertion should be given maximum importance when developing desirable CMS lines. IR58025A showed maximum seed set (47.68%) and maximum style length (1.22 mm). Although genotype IR67684A showed many favorable floral characteristics for high seed set, it is undesirable because of the interaction of genome and cytoplasm on seed set. ■

Crop and resource management

Fertilizer management

Effect of N levels and time of application on grain yield of hybrid rice

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During the 1995-96 wet season and dry season, we studied the performance of three hybrids—KHR1, ProAgro 103, and MGR1—using Jaya and Rasi as standard checks. This study included growth and grain yield performance at four levels of N (0, 60, 120, and 180 kg ha^{-1}). Three schedules of N application were followed: three splits (50:25:25% at basal, tillering and panicle initiation), four splits (25% N at basal, tillering, panicle initiation, and 50% flowering), and five splits (25% N at basal, tillering, and panicle initiation and the remainder applied in two equal splits at 50% flowering and 10 d later). Grain yield differences among the test hybrids and varieties were significant during both seasons. The maximum grain yields were recorded for ProAgro 103, Vikas, KHR1, and MGR1. Rasi produced 5-14% less grain yield than ProAgro 103. Varieties responded linearly to applied N levels up to 120 kg ha^{-1}. Grain yield differences were not significant among different schedules of N application, indicating that more than three splits of N application are not required for higher grain production by hybrid rice in Vertisol soils. ■

Crop management

Three-drying cultivation of rice: a new technology for rice production in drought-prone areas

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Shandong, China, has a dry spring and rainy summer. In Linyi district, for example, mean annual rainfall is 872-949 mm, of which 125-150 mm (15%) occur in spring and 560-600 mm (65%) in summer. Because of waterlogging in the wet summer period, grain yields of rainfed crops such as maize, soybean, or sweet potato were often poor in low-lying farming regions. When rice was dry-seeded late in spring after fall wheat, the medium-duration rice varieties could not ripen because of the shortened growing period. It was difficult to grow rice seedlings because of the lack of water in spring. Therefore, only a fall wheat crop could be grown in the region.

This paper reports research examining the ability to raise rice seedlings,

The effect of drought treatments on growth and yield of rice variety A7929 at various stages of crop development in TDCR and conventional management.

Drought treatment stage[a]	Third-leaf stage: Green wt of 100 plants (g) – Plant	Third-leaf stage: Green wt of 100 plants (g) – Root	Seedling age (55 d): Plant height (cm)	Seedling age (55 d): Tillers (%)	Seedling age (55 d): Tillers – Three tillers (%)	Transplanting shock (d)	4 d after transplanting (roots): No.	4 d after transplanting (roots): Mean length (cm)	Grains panicle^{-1} (no.)	1,000-grain wt	Unfilled grain (%)	Grain yield (g m^{-2})	Compared with check (±%)
Early	26.5	8.2	21.7	87.2	21.2	0	7.3	4.0	81.3	31.9	4.3	684.7 ± 8.03**	+28.58
Middle	18.1	6.9	33.1	18.1	0	6	1.2	0.4	36.9	26.7	47.5	301.5 ± 10.28	–43.31
Late	17.9	6.2	32.4	17.6	0	5-7	1.1	0.36	56.9	26.4	23.6	413.5 ± 8.04	–22.36
Complete growth	27.1	8.4	22.1	85.9	18.7	0	6.8	3.8	22.7	26.0	43.6	270 ± 5.34	–49.3
Conventional	18.3	6.3	32.3	17.9	0	5-7	1	0.33	68.2	31.9	4.1	532.5 ± 7.76	100

[a]Early stage = emergence of seedling to jointing; middle stage = jointing to heading; late stage = heading to ripening. **S_d = 9.24, t = 16.47, P = 0.01, T = 9.925, 16.47 >9.925 P<0.01.

prepare the ricefield, and care for the crop in dry conditions and with less water. The resulting system is referred to as three-drying cultivation of rice (TDCR). The TDCR system was studied from 1965 to 1981. This system reduced the detrimental effects of drought stress and made it possible to rotate summer rice and fall wheat, both of which could produce a good crop. TDCR has now become a model for rice growing in semiarid regions of China. Results of this work and the procedures recommended follow.

Dry-raising sound rice seedlings

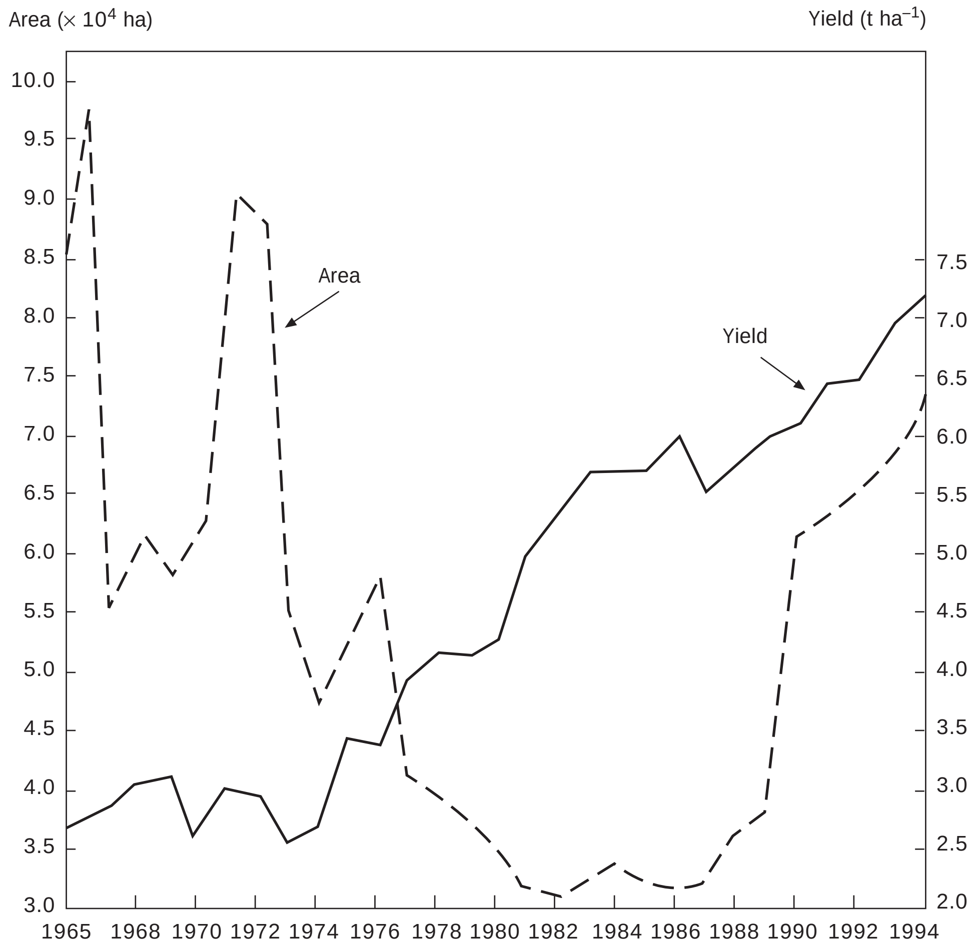
A test was designed to survey drought resistance of rice with spot observations in ricefields in 1973-77. This showed that rice could tolerate some drought at the seedling stage (see table). Mean plant height of dry-raised seedlings was only 21.7 cm after 50-55 d during the seventh leaf stage, but yields exceeded those of conventional management. Seedlings can be raised in the upland nursery during the 50-60 d before the wheat harvest. The seeding rate is 67.5-75.0 g m^{-2} on clay soil and 45-60 g m^{-2} on loam soil. The crop is irrigated 2-3 times in the seedling stage, each time with 37.5-45.0 L water m^{-2}. Dry-raised seedlings use only 80-90% as much water as wet-raised seedlings.

Dry soil preparation of the ricefield

After the wheat harvest, the land is plowed, made level, and irrigated. Seedlings are then transplanted using the water used for land preparation.

Care of the ricefield

Summer rice needs only supplemental water during the rainy season. Ways to save water include (1) waiting to irrigate the field until 3 d after transplanting, and (2) watering the field only when no rain has occurred for 7 consecutive d during the rainy season. In this way, water consumption can be reduced by 40-50%. Fields usually need to be irrigated 7-8 times with 450 m^3 water ha^{-1} each time in the growing period. When drought is severe, up to 10 irrigations may be required to obtain high yields.



Area and yield of rice in Linyi district, Shandong, China, 1965-94. Conventional management was practiced from 1965 to 1981, the three-drying cultivation of rice (TDCR) was used partially from 1982 to 1987, and TDCR was used throughout the district from 1988 to 1994.

Impact on rice production

Since the late 1970s, drought has caused drastic cuts in rice area in Linyi (see figure). After 1982, TDCR became more popular and by 1988 was used by all farmers. Ricefields multiplied and rough rice yield increased year after year. By 1994 there was a 33% and 26% increase in per unit area yield compared with before 1982 and up to 1988, respectively. Yields of wheat following rice also increased from 1.5 to 5.4 t ha^{-1}. Therefore, profit increased by 22%. Yield increased because the dry-raised seedling itself was healthy and mid-late rice cultivars would be planted in time to use their 20-d-longer growth period. Pests and diseases are insignificant and rotation cropping is improved.

TDCR has several advantages: (1) it is economical in water, labor, seeds, and energy; (2) it reduces costs and labor; and 3) it ensures a good harvest despite drought or waterlogging. ■

Agronomic package for hybrid rice cultivation

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Yield stagnation or even a decline has been observed in many rice-growing areas, particularly in potentially highly productive areas. To increase rice production, a few rice hybrids have been developed and released in recent years in India. To exploit the crop's full heterotic potential, it is essential to develop a package of optimum production practices for hybrid rice cultivation. We therefore attempted to study nursery management, seeding densities, seedling ratios, transplanting dates, N management, and hybrid response at several locations under the coordinated rice improve-ment program.

The studies revealed that the optimum seed density of 15-20 kg in a 1,000-m^2 nursery and planting in the second fortnight of July (1 seedling hill^{-1}) are ideal practices for obtaining superior grain yield in hybrids. The results also indicated that different rice hybrids performed well at different locations: Hybrid ProAgro at DRR and Faizabad; ProAgro and CRH1 at the Central Rice Research Institute and Chinsurah. The local standard HKR46 performed well at Kaul. These hybrids recorded superior grain yields and showed higher N use efficiency at these locations. Grain yield differences in the tested hybrids were not significant at Aduthurai, Mandya, and Pantnagar. As the tests were made in the wet season, the hybrids may not have exhibited their full yield potential at Cuttack and Maruteru because of rain. The response to N was limited up to 100 kg N ha^{-1} at Cuttack, Chinsurah, and Pantnagar, and up to 150 kg N ha^{-1} at Aduthurai, Hyderabad, Mandya, and Faizabad. Hybrids failed to respond beyond 150 kg N ha^{-1} at most test locations. Applying the recommended N in three splits (50% basal + 25% tillering + 25% booting) was the best management practice for hybrids in Vertisols at DRR. ■

Integrated germplasm improvement — weeds

Chemical weed control in rice nurseries of the hill zone of Karnataka

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Weeds pose a threat to rice cultivation from the nursery stage in the hill zone of Karnataka (south India), which has 182,000 ha under rainfed rice (the sole food and field crop of the zone). This area is located between 12-14° N and 74-76° E. Average annual rainfall is 2,460 mm, of which 83% occurs between June and September (with the remaining 17% from October to December). Rice nurseries are sown from the first week of June to the second week of July depending upon the toposequence and rainfall pattern for the wet season and during the second week of December to the second week of January for the summer (dry) season.

Rice nurseries are infested by grass sedges and broadleaf weeds that

Table 1. Effect of herbicides on germination of rice and dry weight of rice seedlings in the hill zone of Karnataka, India.

Treatment	Germination (%) recorded at 10 DAS[a]				Mean of 2 yr	Dry weight (av) of 10 seedlings at 25 DAS (g)				Mean of 2 yr
	Kharif (1993-94)	Summer (1993-94)	Kharif (1994-95)	Summer (1994-95)		Kharif (1993-94)	Summer (1993-94)	Kharif (1994-95)	Summer (1994-95)	
1. Control, unweeded check	92	94	94	95	94	1.06	1.13	1.12	1.27	1.19
2. Butachlor preemergence 50 EC (1.25 L ha^{-1})	92	94	88	92	91	2.39	2.43	2.43	2.67	2.55
3. Benthiocarb-30 EC (1.25 kg ai ha^{-1}) preemergence	74	76	68	72	72	1.84	1.94	1.96	2.01	1.98
4. Pendimethaline 30 EC (preemergence) (1.0 kg ai ha^{-1})	72	73	68	64	69	1.92	1.82	2.01	1.98	1.99
5. Butachlor (5%) granules (25 kg ha^{-1})	73	74	77	79	75	2.12	1.93	2.20	2.08	2.14
6. Anilophos 30 EC @300 mL ha^{-1}) (3 DAS) Postemergence	89	93	90	88	90	2.26	2.33	2.32	2.46	2.39
7. Hand weeding at 10 and 20 DAS	92	93	93	94	93	1.94	2.03	2.10	2.19	2.14
LSD (P = 0.05)						0.03	0.08	0.12	0.27	0.16

[a]DAS = days after sowing.

smother rice seedlings and pose a threat when transplanted into the main ricefield, resulting in increases in the cost of cultivation and decreases in grain yield.

We conducted field experiments during the kharif (wet season) and summer (dry) seasons for 2 yr (1993-94 to 1994-95) to find a suitable herbicide to control nursery weeds. The experiments were conducted at the Regional Research Station, Mudigere, in a randomized block design with four replications and seven treatments. The plot size was 1 m^2 with nurseries grown under both dry (raised) and wet (flat) beds. The soil was a red sandy loam with pH 5.2, 78% organic carbon, 7.5 kg P ha^{-1} and 68 kg K ha^{-1}. Seeds of cultivar Intan were sown during the second week of June (wet season) and second week of December (dry season). Herbicides were applied within 24 h of sowing, except for Anilophos, which was applied 3 d after sowing. A common recommended basal dose of 90-45-45 kg NPK ha^{-1} was applied before sowing.

Butachlor 50EC and Anilophos 30EC had no phytotoxic effect on rice. The germination percentage of rice was higher on Butachlor 50EC, Anilophos, hand weeding, and control plots (Table 1). Weed control efficiency, dry weight of seedlings, and seedling height were also higher for these treatments compared with the control (Table 2). Better rice seedling growth was probably because of the weed-free environment and better use of available moisture, light, and applied nutrients. From an economic point of view, nursery weed control with effective herbicides cost $1.83 (Rs 55) per 750 m^2 area of nursery—the area required for a 1-ha ricefield. ■

Table 2. Seasonal dry weed weight (DWW) and weed control efficiency (WCE) in hill zone of Karnataka, India.

Treatment	1993-94				1994-95			
	Kharif		Summer		Kharif		Summer	
	DWW (g)	WCE (%)[a]	DWW (g)	WCE (%)	DWW (g)	WCE (%)	DWW (g)	WCE (%)
1	142.4	–	102.2	–	132.2	–	96.2	–
2	52.6	63	30.6	70	48.4	63	26.3	73
3	79.7	44	59.3	42	86.3	35	56.4	41
4	83.2	41	46.2	55	78.3	41	43.3	55
5	71.4	50	42.3	59	68.3	48	38.1	60
6	56.6	60	32.5	68	52.2	60	31.3	67
7	50.9	64	28.2	72	45.2	66	25.2	74
LSD (P = 0.05)	10.1	–	13.7	–	12.1	–	14.0	–

[a]WCE = [Control WW – treatment WW] / control WW × 100.

Weed control in dry-seeded lowland rice

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Traditional growers of transplanted rice in the Cauvery new delta zone of Tamil Nadu State often switch to semidry rice culture because of the nonavailability of water and labor. Under semidry rice culture, premonsoon dry seeding is practiced and the rice crop is submerged after about a month. A major constraint in this type of rice cultivation is high weed incidence.

We therefore evaluated five weed control treatments involving two preemergence herbicides followed by hand weeding, one preemergence herbicide followed by a postemergence one, a postemergence herbicide followed by hand weeding, and two hand weedings during 1992 and 1994 in September to January (late samba season) in the Cauvery new delta zone.

One unweeded control plot was maintained separately to assess weed control efficiency (WCE). The dry seeds of ADT 38 (135 d duration) were sown on a dry field and submerged after 1 mo. The trial was laid out in a randomized block design with four replications.

The soil was a sandy loam. Thiobencarb was applied 6 d after seeding (DAS), pretilachlor plus at 3 DAS, and 2,4-D Na salt and bentazon at 25 DAS. Plots treated with preemergence herbicides were hand weeded at 25 DAS and the bentazon-treated plot at 45 DAS. Plots with two hand weedings were weeded at 25 and 45 DAS.

The experimental fields were dominated by *Echinochloa colona* among grasses, *Cyperus rotundus* among sedges, and *Trianthema portulacastrum* among broadleaf weeds. In the weed

Effect of weed control on grain yield, weed dry weight, and weed control efficiency in dry-seeded lowland rice in the Cauvery new delta zone, Tamil Nadu, India, 1992 and 1994.

Treatment	Rate (kg ai ha^{-1})	Grain yield ($t\ ha^{-1}$)			Weed dry weight ($t\ ha^{-1}$)			WCE[a] (%)		
		1992	1994	Mean	1992	1994	Mean	1992	1994	Mean
Thiobencarb followed by 2,4-D Na salt	2.0 + 1.0	3.8	3.8	3.8	0.6	0.6	0.6	80.1	45.0	62.5
Thiobencarb followed by hand weeding	1.5	4.3	5.1	4.7	0.5	0.5	0.5	79.6	70.3	74.9
Pretilachlor plus followed by hand weeding	0.3	5.0	6.0	5.5	0.4	0.4	0.4	89.1	80.9	85.0
Bentazon followed by hand weeding	0.8	3.0	2.9	2.9	0.8	0.8	0.8	54.1	59.1	56.6
Two hand weedings	–	4.3	4.8	4.5	0.6	0.7	0.7	60.5	70.7	65.6
LSD (0.05)	–	0.04	0.06	0.05	0.02	0.08	0.05	–	–	–

[a]Mean of four replications.

control treatments, pretilachlor plus (0.3 kg ai ha^{-1}) with one hand weeding significantly reduced total weed dry weight at 60 DAS, with a maximum WCE of 85%. This treatment also produced the best yield—5.49 t ha^{-1} (see table). Thiobencarb (1.5 kg ai ha^{-1}) with one hand weeding was as effective as two hand weedings. No post-emergence herbicide was as effective for dry-seeded lowland rice. ■

Research methodology

The relationship between experimental plot research and Texas rice producers' ratoon field results

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At several recent Texas (USA) rice industry meetings, rice consultants and producers mentioned observing input responses different from those reported by extension and research specialists. This study documents the correlation between scientists' recommendations based on existing theory drawn from rice plot research and actual results from commercial fields obtained from producers' surveys during 1987-89. Scientists' expert ex ante opinions on the effects of several predetermined, decision, and uncertain factors on ratoon crop rice (*Oryza sativa* L.) field yield and quality (milling yield, head yield, and grade) were documented. A modified Delphi procedure, whereby scientists come to a consensus agreement, was used to determine an extensive set of independent variables hypothesized to either positively or negatively affect ratoon crop yield and quality. The scientists' identified variables provided the basis for a mail survey of Texas rice producers' cultural practices and yield-quality responses during 1987-89. Following collection of the survey data, multiple regression procedures and associated statistical tests were used to identify statistically significant ratoon yield and quality-influencing variables.

Summary statistics for the ratoon crop models, 1987-89 Texas ratoon crop survey.

Item	Ratoon crop models[a]			
	RY[b]	RYM[c]	RHY[d]	RG[e]
F value	9.8350	2.6570	2.5010	1.6730
Prob > F	0.0001	0.0001	0.0001	0.0047
R square	0.6397	0.3413	0.4057	0.0203
Adj R square	0.5746	0.2129	0.2898	0.0816
CV	1.6388	2.6347	5.2959	71.1072
Observations (no.)	413	381	381	380

[a]Each model has approximately 40-50 variables that were hypothesized to affect yield and quality according to rice research and extension scientists. The variables include those that are (a) known at the beginning of the production period (predetermined variables such as soil type), (b) controlled by the decision maker within the production period (decision variables (such as fertilizer management), and (c) beyond the decision maker's control (uncertain variables, such as climate). [b]RY = ratoon crop yield. [c]RMY = ratoon crop milling yield. [d]RHY = ratoon crop head yield. [e]RG = ratoon crop grade.

Table presents summary regression results. The predetermined variables included management (3 variables), soils (2), water management (2), land preparation (4), and rotation (7). The decision variables were varieties (2), fertilization (10), emergence/seeding (3), water management (8), diseases (3), pests (4), and harvesting (10). The uncertainty variables consisted of weather (6) and diseases (2).

Low coefficients of determination indicate that the model formulations and the hypotheses identified for the ratoon crop yield and quality models do not fully account for the variability in actual ratoon crop field yields and quality. In many cases, scientists' hypotheses matched producers' ratoon yield and quality responses; however, sometimes the apparent direction of effect in the data set was in an opposite direction than hypothesized. For example, 1988 was hypothesized to have been a more favorable year for ratoon field yields and quality. Statistical results indicate that the scientists' hypothesis of higher field yields was supported, but their hypothesis regarding higher quality (milling yield) was rejected.

Comparison of the number of statistically significant variables between the yield and quality models indicates that 42% of the scientists' hypothesized yield variables were significant, whereas 45% of the scientists' hypothesized quality variables were significant. Hypothesized signs for the statistically significant variables were then compared with calculated signs for alternative farm scenarios based on the regression results. Agreement with scientists' hypotheses occurs if the calculated sign is the same as the hypothesized sign. Such "in agreement" results suggest that scientists well recognize and understand the effect of these factors on Texas rice farmers' ratoon crop yields and quality. Comparison between the yield and quality models indicates that, for the yield model, 36% of the statistically significant hypotheses were in agreement, whereas 24% were in agreement for the quality models. In summary, scientists were less likely to determine the input impacts on quality rather than yield. These results indicate the importance of determining direct and interactive effects of production variables on rice quality.

The use of producer surveys provides opportunities for researchers to extensively evaluate numerous producer circumstances beyond the capability of experimental plot research and verification trials. This type of evaluation can lead to the identification of interaction variables and constraints to production. In instances where new production practices evolve (such as the introduction of high-yielding semidwarf rice varieties), producer surveys may point to the need for a refinement of recommendations.

Producers can use the results to compare their farm responses with those of others. Identification of the principal sources of variation will allow producers to focus on information that can provide a basis for refining their production practices. Producers' knowledge of the relationship between production inputs and rice quality can be improved if research and extension specialists report yield and quality results from research and experimental trials and if more research is devoted to producer-controlled impacts such as postharvest handling. ■

Comparing methods of stability analysis in rice hybrids

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Yield heterosis in rice is reported to interact with environment. Identifying rice hybrids with stable performance is a prerequisite to successfully exploiting this technology over a large area. The popular parameter for selection of stable entries used by many breeders is the varietal mean averaged over locations. Another method is to rank entries for each location and then use mean performance of the rank to assess their potential. It is well known that genotype × environment (G × E) interactions in multilocational yield trials and the comparison of cultivar means are not very useful. In addition, the mean and its ranks do not indicate the location-wise magnitude of differences between the test entry and the standard check against which selection is to be made. In recent years, many new methods have been proposed for stability analysis. We compared the following three methods with selection based on the experimental mean: 1) a superiority measure of a cultivar, 2) nonparametric measures of phenotypic stability, and 3) relative yield as a measure.

We used the grain yield data of a hybrid rice trial conducted over 12 locations in the 1994 wet season for the study, and calculated the rank correlation (*rs*) between methods. The results showed that selection based on means of entries was closer to method 3, *rs* = 0.99, followed by the superiority measure (*rs* = 0.95). The ranking based on nonparametric measure was not related to the mean. Of the three methods used, the superiority measure was found to be useful for identifying stable hybrids. We analyzed the yield data from six trials conducted during 1994-95 to ascertain the usefulness of the superiority measure for identifying stable hybrids. The best-yielding hybrid was found to be the most stable. The superiority measure—as a method—is simple, convenient, and quite useful, because it uses only one parameter, which makes comparison among test genotypes easier. This method also indicates the highest yielding geno-type, one that could be recommended for the whole region. ■

Education and communication

Role of voluntary agencies in popularizing hybrid rice production in India

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The Sri Aurobindo Institute of Rural Development, Gaddipalli, a nonprofit-oriented, nonsectarian, voluntary, and autonomous organization was established in 1973. A Krishi Vigyan Kendra (KVK) was started in 1985 with funds from the Indian Council of Agricultural Research (ICAR). This KVK was judged as the best among 261 KVKs in the country during 1994-95. Nalgonda District is in the southern Telangana zone of Andhra Pradesh. This is a rural district and 88% of the population depends on agriculture. Hybrid rice in China on a large scale proved to have a more than 25% yield advantage over conventional pureline varieties. The wide adaptability of rice hybrids has produced increased rice production and productivity in China since the mid-1980s. This success prompted ICAR to accelerate research on hybrid rice, through an ICAR-UNDP-funded project in India. This research network project involved 12 research centers (two lead, seven associate, and three strategic centers) and state seed production agencies located in the target environment. Through this network, several rice hybrids were developed and released for commercial cultivation. To popularize hybrid rice production on a large scale, the Sri Aurobindo Institute developed an integrated project that involved adaptive research at the institute farm; on-farm testing in farmers' fields; layout demonstrations on hybrid rice seed production; production and distribution of good quality hybrid rice seeds; training farmers, farm women, rural youth, and science graduates; organizing demonstrations in F_1 commercial seed production; popularizing hybrid rice technology through extension services; and producing multimedia training materials on hybrid rice technology. The important lesson we learned was that for each location and season, we needed to determine the seeding interval for the parental lines. During the past three seasons (1995-96), hybrid rice seed production was carried out on 164 ha in farmers' fields. A total yield of 195 t of hybrid seeds was produced and supplied to various companies and individual farmers. This seed was enough for the commercial production of hybrid rice on 9,750 ha. During the 1996 wet season, hybrid rice seed production was carried out on 90 ha.

Training progressive farmers, youth, and farm women in hybrid rice seed production and F_1 commercial cultivation promotes hybrid rice cultivation and increases rice yields. Training was organized in hybrid rice seed production for various categories of clients—farmers, farm women, farm youth, extension officers, and representatives of seed companies. More than 33,400 man-days of training were imparted during 1995-96. With the assistance of the United Nations Development Programme, this KVK organized a large-scale training program for farm women. ■

Socioeconomic impact

Economics of hybrid rice seed production in India

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Input-output data on hybrid seed production were obtained from seed growers' farms under private companies and a nongovernment organization (KVK, Gaddipally, Andhra Pradesh) from 1992-93 to 1994-95. Using these data, we studied the cost-return profile of F_1 seed production. The F_1 seed yield was only 560 kg ha^{-1} when it was produced for the first time in 1992-93, but it increased to 1,385 kg ha^{-1} in 1994-95. The average total cost of F_1 seed production was Rs 23,840 ha^{-1}. Costs involved 45% for labor, 24% for manure and fertilizers, and 8% for gibberellic acid. The cost of 1 kg of seed produced dropped from Rs 33 (US$0.92) in 1992-93 to Rs 17 (US$0.48) during 1994-95, primarily because of increased yield. Because hybrid rice seed production is labor-intensive, 280-300 additional man-days of employment could be generated in the rural area, especially for women. In addition, gross and net returns to F_1 seed production are Rs 42,710 (US$1,186) and Rs 18,870 (US$524) ha^{-1}, respectively, at Rs 25 (US$0.69) as the procurement price kg^{-1}. At the rate of the procurement price paid to seed growers by the seed industry, however, the computed eco-nomically viable threshold seed yield was 1,900 kg ha^{-1}. If F_1 seed production is to be made economically viable to seed growers at 1,385 kg ha^{-1} of seed yield, the procurement price should be Rs 34 (US$0.95) kg^{-1}. The ratio of seed (F_1) area to commercial cultivation area of hybrid rice is estimated at 1:37.6. Thus, close to 53,000 ha are needed for an F_1 seed production program to meet the seed requirement of 2 million ha under hybrid rice by the year 2000. Our results stress the need to further improve F_1 seed yields. We also need to formulate an incentive-oriented and forward-contract base price policy for F_1 seed to induce seed growers to produce the required hybrid rice seed. ■

Impact of hybrid rice on India's food economy: implications and policy issues

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Basic data from the literature on the nature and impact of the adoption of hybrid rice in China and experiences in other research centers were gathered. Additional supporting data were collected from farmers' fields in the major rice-growing states in India where rice hybrids were released recently. All these data formed the basis for this study. Hybrid rice outyields existing conventional high-yielding varieties by 1-2 t ha^{-1} in irrigated environments. The adoption of hybrid rice would shift the production function farther upward and the increased rice output in irrigated areas would result in a higher domestic supply. In the short run, this could lead to a further widening of the income inequalities between irrigated and unirrigated regions. In addition, hybrid rice would benefit large farmers, who are early adopters with an ability to purchase costly hybrid rice seed every crop season. A long-term use of this technology, however, would benefit the entire rice-farming community and urban population as well. Hybrid rice technology would generate a more marketable surplus. As a consequence, higher domestic prices of rice would be prevented in the consumer market, which would benefit urban consumers, especially low and middle class groups. Hybrid rice would also add to central buffer stocks and increase the supply of rice through the public distribution system at cheaper prices. Because hybrid rice technology is labor-intensive, particularly seed production, it generates additional employment opportunities, especially for women (nearly 280-300 man-days ha^{-1}) in rural India. Thus, the purchasing power of landless labor would increase through an increase in earnings from labor.

Evidence from China, a centrally planned economy, shows that direct government intervention through incentive policies, apart from yield advantage, played a significant role in popularizing hybrid rice on a large scale. These policies involved an incentive output price for hybrid rice grains despite poor grain quality, on a par with that of other popular varieties; the assured procurement of surplus output at an incentive price; a supply of hybrid seed free of cost during the initial stage; a supply of other inputs such as fertilizer at concessional rates for farmers who adopt hybrid rice; and a well-organized seed production system. Experiences in the United States and Japan market economies during the 1980s, however, indicate that farmers did not accept hybrid rice because of its poor grain quality. Now India has emerged as the second country after China, in the development and release of high-yielding rice hybrids. The fixing of a support price for hybrid rice grains by the government, on a par with that of popular varieties, would certainly induce rice farmers in irrigated regions to adopt hybrid rice on a large scale. ■

Instructions for contributors

NOTES

General criteria. Scientific notes submitted to the IRRN for possible publication should
- be original work,
- have international or pan-national relevance,
- be conducted during the immediate past three years or be work in progress,
- have rice environment relevance,
- advance rice knowledge,
- use appropriate research design and data collection methodology,
- report pertinent, adequate data,
- apply appropriate statistical analysis, and
- reach supportable conclusions.

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted. Examples are single-season, single-trial field experiments. Field trials should be repeated across more than one season, in multiple seasons, or in more than one location as appropriate. All experiments should include replications and an internationally known check or control treatment.

Multiple submissions. Normally, only one report for a single experiment will be accepted. Two or more items about the same work submitted at the same time will be returned for merging. Submitting at different times multiple notes from the same experiment is highly inappropriate. Detection will result in the rejection of all submissions on that research.

IRRN categories. Specify the category in which the note being submitted should appear. Write the category in the upper right-hand corner of the first page of the note.

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pest resistance
  diseases
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stress tolerance
  drought
  excess water
  adverse temperature
  adverse soils
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integrated germplasm improvement
  irrigated
  rainfed lowland
  upland
  flood-prone (deepwater and tidal wetlands)
seed technology

CROP AND RESOURCE MANAGEMENT
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soil microbiology
physiology and plant nutrition
fertilizer management
  inorganic sources
  organic sources
crop management
integrated pest management
  diseases
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  weeds
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Manuscript preparation. Arrange the note as a brief statement of research objectives, a short description of project design, and a succint discussion of results. Relate results to the objectives. Do not include abstracts. Do not cite references or include a bibliography. Restrain acknowledgments.

Manuscripts must be in English. Limit each note to no more than two pages of double-spaced typewritten text. Submit the original manuscript and a duplicate, each with a clear copy of all tables and figures. Authors should retain a copy of the note and of all tables and figures.

Apply these rules, as appropriate, in the note:

- Specify the rice production ecosystems as irrigated, rainfed lowland, upland, and flood-prone (deepwater and tidal wetlands).
- Indicate the type of rice culture (transplanted, wet seeded, dry seeded).
- If local terms for seasons are used, define them by characteristic weather (wet season, dry 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 genetic background for new varieties or breeding lines.
- For soil nutrient studies, include a standard soil profile description, classification, and relevant soil properties.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use common names or local names alone.
- 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.
- Use generic names, not trade names, for all chemicals.
- Use the International System of Units for measurements. For example, express yield data in metric tons per hectare (t ha^{-1}) for field studies. Do not use local units of measure.
- Express all economic data in terms of the US$. Do not use local monetary units. Economic information should be presented at the exchange rate US$:local currency at the time data were collected.
- When using acronyms or abbreviations, write the name in full on first mention, followed by the acronym or abbreviation in parentheses. Use the abbreviation thereafter.
- Define any nonstandard abbreviations or symbols used in tables or figures in a footnote, caption, or legend.

Each note can have no more than two tables and/or figures (graphs, illustrations, or photos). All tables and figures must be referred to in the text; they should be grouped at the end of the note, each on a separate page. Tables and figures must have clear titles that adequately explain the contents.

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