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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Vol. 23, No. 1, 1998

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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.

As listed in its most recent Corporate Report, IRRI receives support, through the CGIAR, from a number of donors including UNDP, World Bank, European Union, Asian Development Bank, and Rockefeller Foundation, and the international aid agencies of the following governments: Australia, Belgium, Canada, People’s Republic of China, Denmark, France, Germany, India, Indonesia, Islamic Republic of Iran, Japan, Republic of Korea, The Netherlands, Norway, Philippines, Spain, Sweden, Switzerland, United Kingdom, and United States.
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, Pant Nagar), Myanmar (Yangon, Vezin), the Philippines (Los Banos, 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 \times E) interaction analysis and superiority analysis helped identify the stability of the hybrids and forecast their adaptability to untested locations. The G \times 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, 2RI158, 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. IR38025A/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, 3RI160, and PMS10A/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.

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**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 exertion, outcrossing rate, duration and angle of glume opening, growth duration, number of effective tillers, spikelets panicle, 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 (IR580280, 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.

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**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 exertion, 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.

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**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 F1 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) cyto sterile 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 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 cyto sterility sources, they were testcrossed with four maintainers—V20B (maintainer of WA), IR66707B (maintainer of O. perennis), Yar-Ai-ZhaoB (maintainer of Gambiaica), and MS577B (maintainer of O. sativa f. spontanea)—and the elite inbred lines SPR7210-1-3, IR48725-B-B-120-1, NDR30074, TT150-61, and R657-93-869. The sterility of the four CMS lines was maintained by the four main- tainers. 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**

B. C. Viraktamath, M. T. Lopez, and S. S. Virmani, IRRI

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 charac- terized 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 CFP and CFP than the A line. To have a stable CMS line, the nuclear genome should have the fertility gene C 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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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 Ca2+-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 TGL. 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).

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 pOSrbcS-1 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.

Cited references

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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.
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 F₁ 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 F₁ 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 PM53A—showed marked differences in pollen and spikelet fertility. When C29 was crossed with IR62829A and PM53A, it behaved as a partial restorer (21-90% pollen and spikelet fertility) with PM53A, 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

F. U. Zaman, M. J. Abraham, U. S. Natarajan, A. Mahendru, and F. Mohammad, Division of Genetics, Indian Agricultural Research Institute (IARI), New Delhi 110012, India

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 cyosterility source from Pusa 743), Pusa 3A wild abortive (WA), and IR58025A (WA) with the Basmati cultivar or breeding line that had shown high F1 fertility (60-70%) in previous testcrosses. All the F1s were raised. Seeds from the best fertile plants were harvested and subjected to grain and cooking quality tests. Only those were harvested and subjected to grain raised. Seeds from the best fertile plants were harvested and subjected to grain and cooking quality tests. Only those possessing ideal Basmati characteristics were raised to the F2 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 F3. In the F3, 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 F4. In the F4, and later generations, the entire process was again repeated as in the F3. Likewise, the material was advanced to the F5 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 compared 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).
**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 orf156 as a probe. This revealed differences in polymorphism between the mitochondrial DNA of the CMS line and fertile maintainers. In the case of HindIII-digested DNA, the orf156 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 HindIII-digested DNA of all five cybrids showed hybridization of orf156 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**


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


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

C. L. Casal, Jr. and S. S. Virmani, IRRI

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
armromatic 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**

F. U. Zaman, M. J. Abraham, U. S. Natarajan, A. Mahendru, and F. Mohammad, Division of Genetics, Indian Agricultural Research Institute, New Delhi 110012, India

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 F1 hybrid was 100%. The F1 was backcrossed to Pusa Basmati 1 and a BC1 population of about 600 plants was raised. All the plants showed 100% pollen sterility. Segregation was observed for various plant characters. Twenty BC1 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 BC1 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 BC1 plants raised from the above crosses were screened for pollen sterility; all the plants were 100% sterile. Three plants were selected from each BC1 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 polymorphism. 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 combinations based on genetic divergence.

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**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. At the same time, resistance of seven F1 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.

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

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**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—Basmoti 385 (P5), Haryana Basmoti 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 F1 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 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 plant-lets 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 F1 clones of the former cross showed four clones with long, bold grain and a nontranslucent 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.
Table 1. Resistance spectrum (%) of San-Huang-Zhan No. 2 from 1985 to 1995 in Guangdong, China.

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</thead>
<tbody>
<tr>
<td>RS</td>
<td>100</td>
<td>100</td>
<td>98</td>
<td>95</td>
<td>96.5</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>99.5</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Resistance spectrum (%)</th>
<th>LD (lesions cm⁻¹)</th>
<th>LS (mm)</th>
<th>DLA (%)</th>
<th>Field observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Guangdong⁷ China²</td>
<td>OD²</td>
<td>RV²</td>
<td>OD</td>
<td>RV</td>
</tr>
<tr>
<td>SHZ</td>
<td>99.5</td>
<td>95.2</td>
<td>0.3</td>
<td>4</td>
<td>1.3</td>
</tr>
<tr>
<td>IR36 (check)</td>
<td>58.2</td>
<td>-</td>
<td>0.4</td>
<td>6</td>
<td>1.4</td>
</tr>
<tr>
<td>B40 (check)</td>
<td>-</td>
<td>6.6</td>
<td>100</td>
<td>6.9</td>
<td>100</td>
</tr>
</tbody>
</table>

⁷Including 220 isolates in Guangdong. ²Including 124 isolates in China. OD = observed data = mean of three experiments with 6 replications. RV = relative value = tested data of cultivar/tested data of B40 × 100. LB = leaf blast. PB = panicle blast.

Table 3. Reaction to ZB13 blast isolate of F₁ and F₂ plants from crosses of San-Huang-Zhan No. 2 (SHZ).

<table>
<thead>
<tr>
<th>Cross</th>
<th>F₁ reaction</th>
<th>F₂ reaction</th>
<th>Reaction</th>
<th>Expected ratio</th>
<th>χ²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO 39/SHZ</td>
<td>R</td>
<td>331</td>
<td>10</td>
<td>63:1</td>
<td>3.31</td>
<td>0.05-0.1</td>
</tr>
<tr>
<td>B40/SHZ</td>
<td>R</td>
<td>228</td>
<td>8</td>
<td>63:1</td>
<td>0.54</td>
<td>0.25-0.5</td>
</tr>
<tr>
<td>SHZ/CO 39</td>
<td>R</td>
<td>401</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHZ/B40</td>
<td>R</td>
<td>601</td>
<td>0</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

⁸R = resistant, S = susceptible.

**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 hill¹. 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* 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.

<table>
<thead>
<tr>
<th>Test location/season</th>
<th>Varieties/lines</th>
<th>Infection (%)</th>
<th>GLH (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BBp</td>
<td>SS</td>
</tr>
<tr>
<td>Philippines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maligaya, Nueva Ecija</td>
<td>IR64</td>
<td>27.0</td>
<td>67.3</td>
</tr>
<tr>
<td>1995 WS, 1996 WS</td>
<td>IR68305-18-1</td>
<td>2.0</td>
<td>55.2</td>
</tr>
<tr>
<td></td>
<td>IR71026-3-2-4-3-5-2</td>
<td>2.0</td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td>IR69705-1-3-2-1</td>
<td>2.3</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Tirur, India</td>
<td>IR62</td>
<td>8.9</td>
<td>48.8</td>
</tr>
<tr>
<td>1995 WS, 1996 DS</td>
<td>IR68305-18-1</td>
<td>18.0</td>
<td>72.3</td>
</tr>
<tr>
<td></td>
<td>IR71026-3-2-4-3-5-2</td>
<td>38.8</td>
<td>74.1</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>IR71030-2-3-2-1</td>
<td>6.1</td>
<td>13.4</td>
</tr>
<tr>
<td>Midsayap, Indonesia</td>
<td>IR62</td>
<td>8.9</td>
<td>48.8</td>
</tr>
<tr>
<td>1995 WS, 1996 DS,</td>
<td>IR68305-18-1</td>
<td>18.0</td>
<td>72.3</td>
</tr>
<tr>
<td></td>
<td>IR71026-3-2-4-3-5-2</td>
<td>38.8</td>
<td>74.1</td>
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<tr>
<td></td>
<td>IR69705-1-3-2-1</td>
<td>6.4</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>6.1</td>
<td>13.4</td>
</tr>
<tr>
<td>Maros, South Sulawesi</td>
<td>IR62</td>
<td>3.3</td>
<td>6.1</td>
</tr>
<tr>
<td>1995 DS, 1996 WS</td>
<td>IR68305-18-1</td>
<td>18.2</td>
<td>41.4</td>
</tr>
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<td>29.7</td>
<td>52.1</td>
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<td>2.0</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>1.8</td>
<td>4.4</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chakdaha, West Bengal</td>
<td>IR62</td>
<td>1.5</td>
<td>7.8</td>
</tr>
<tr>
<td>1996 WS</td>
<td>IR68305-18-1</td>
<td>4.3</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>IR71026-3-2-4-3-5-2</td>
<td>1.1</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>IR69705-1-3-2-1</td>
<td>0.8</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>6.1</td>
<td>31.1</td>
</tr>
<tr>
<td>Midsayap, Philippines</td>
<td>IR62</td>
<td>2.3</td>
<td>14.5</td>
</tr>
<tr>
<td>1995 WS, 1996 DS</td>
<td>IR68305-18-1</td>
<td>10.0</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>IR71026-3-2-4-3-5-2</td>
<td>1.1</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>IR69705-1-3-2-1</td>
<td>1.4</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>IR71030-2-3-2-1</td>
<td>0.6</td>
<td>8.6</td>
</tr>
</tbody>
</table>

*Average across all seasons and computed from the mean of two samplings at 30-35 and 55-60 d after transplanting. 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. Count based on 10 sweeps of a 30-cm-diameter insect net in each plot. WS = wet season, DS = dry season.

disease and sampled leaves in six quadrats of 4 x 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 Chakdaha, 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).
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

E. R. Angeles, R. C. Cabunagan, E. R. Tiongco (presently with Philippine Rice Research Institute, Maligaya, Nueva Ecija, Philippines), O. Azzam, P. S. Teng, and G. S. Khush, IRRI, and T. C. B. Chancellor, Natural Resources Institute, UK

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.
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).

Table 1. 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.

<table>
<thead>
<tr>
<th>Cross</th>
<th>Resistant lines (no.)</th>
<th>Infection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BS</td>
<td>B</td>
</tr>
<tr>
<td>IR1561-228-3*3/O. longistaminata</td>
<td>16</td>
<td>8.3</td>
</tr>
<tr>
<td>IR1561-228-3*2/Utri Rajapan</td>
<td>15</td>
<td>14.8</td>
</tr>
<tr>
<td>IR1561-228-3*2/Utri Merah</td>
<td>10</td>
<td>8.6</td>
</tr>
<tr>
<td>IR1561-228-3*3/4/Utri Merah</td>
<td>10</td>
<td>5.7</td>
</tr>
<tr>
<td>IR1561-228-3*3/6/ARC11554</td>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>IR1561-228-3*4/Habiganj DW8</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>IR1561-228-3*6/Habiganj DW8</td>
<td>2</td>
<td>6.0</td>
</tr>
</tbody>
</table>

1995 dry season

<table>
<thead>
<tr>
<th>Cross</th>
<th>Lines tested (no.)</th>
<th>Infection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BS</td>
<td>B</td>
</tr>
<tr>
<td>IR1561-228-3*2/0. longistaminata</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>IR1561-228-3*3/0. longistaminata</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>IR1561-228-3*2/0. longistaminata</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>IR1561-228-3*4/0. longistaminata</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>IR1561-228-3*2/Utri Merah</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>IR1561-228-3*4/Utri Merah</td>
<td>2</td>
<td>0.0</td>
</tr>
<tr>
<td>IR1561-228-3*2/Utri Merah //IR24</td>
<td>3</td>
<td>9.0</td>
</tr>
<tr>
<td>IR1561-228-3*6/ARC11554</td>
<td>5</td>
<td>2.4</td>
</tr>
<tr>
<td>IR1561-228-3*3/3/Habiganj DW8</td>
<td>1</td>
<td>3.0</td>
</tr>
<tr>
<td>IR1561-228-3*4/Habiganj DW8</td>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>IR1561-228-3*6/Habiganj DW8</td>
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<td>9.0</td>
</tr>
<tr>
<td>IR1561-228-3<em>3/3/Habiganj DW8 //4</em>IR64</td>
<td>5</td>
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<td>IR1561-228-3*3/2/Utri Rajapan</td>
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<td>5.0</td>
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<tr>
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</tr>
<tr>
<td>IR1561-228-3*3/O. rufipogon (Acc. 105908) //IR24</td>
<td>5</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.0</td>
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<tr>
<td>IR1561-228-3*3 //IR42/0. rufipogon (unknown Acc. no.)</td>
<td>5</td>
<td>0.0</td>
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</tbody>
</table>

1996 wet season

<table>
<thead>
<tr>
<th>Cross</th>
<th>Lines tested (no.)</th>
<th>Infection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BS</td>
<td>B</td>
</tr>
<tr>
<td>IR1561-228-3*3/O. longistaminata</td>
<td>4</td>
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</tr>
<tr>
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<td>32.6</td>
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<tr>
<td>IR1561-228-3*2/Utri Merah</td>
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<td>5.7</td>
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<td>IR1561-228-3<em>2/3</em>IR11554</td>
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<td>8.8</td>
</tr>
<tr>
<td>IR1561-228-3*6/Habiganj DW8</td>
<td>4</td>
<td>9.2</td>
</tr>
</tbody>
</table>

1996 wet season

**Stress tolerance — adverse soils**

**Seasonal differences in iron toxicity tolerance of lowland rice cultivars**

L. Sahrawat and B. N. Singh, West Africa Rice Development Association (WARDA), 01 BP 2551 Bouake 01, Côte d’Ivoire, West Africa

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 m² at Mbe and 24 m² 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, 0.52%; 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.
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.

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

L. M. González and R. Ramírez, Nuclear Laboratory of the Agricultural Research Institute “Jorge Dimitrov,” Gaveta Postal 2360, Bayamo 85100, Granma, Cuba

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

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>1994 wet season Grain yield</th>
<th>1994 dry season Grain yield</th>
<th>1994 Mbe wet season Grain yield</th>
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<tr>
<td>TOX3118-6-E2-3-2 (WITA 1)</td>
<td>6.7</td>
<td>1</td>
<td>5.0</td>
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<tr>
<td>CK4</td>
<td>6.1</td>
<td>1</td>
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</tr>
<tr>
<td>CK73</td>
<td>4.9</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>TOX3052-E1-2</td>
<td>6.3</td>
<td>1</td>
<td>4.8</td>
</tr>
<tr>
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<td>4.3</td>
<td>3</td>
<td>4.7</td>
</tr>
<tr>
<td>TOX3050-46-E3-3</td>
<td>6.0</td>
<td>1</td>
<td>4.6</td>
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</tr>
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<td>2</td>
<td>4.1</td>
</tr>
<tr>
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<td>4.8</td>
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<td>Suakoko 8</td>
<td>3.7</td>
<td>2</td>
<td>3.3</td>
</tr>
<tr>
<td>Bouake 189</td>
<td>4.7</td>
<td>3</td>
<td>2.9</td>
</tr>
<tr>
<td>TOX3069-66-2-1-6</td>
<td>4.2</td>
<td>5</td>
<td>2.8</td>
</tr>
</tbody>
</table>

LSD (0.05) 1.1 0.8 0.8

*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. *Yield was low because of bird damage.

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Correlation with</th>
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</thead>
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<tr>
<td></td>
<td>Grain yield</td>
</tr>
<tr>
<td>Seed water uptake</td>
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</tr>
<tr>
<td>Peroxidase</td>
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<td>Seed germination</td>
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<td>Relative leaf water content</td>
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<td>Total chlorophyll content</td>
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<td>Panicle weight</td>
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<td>Filled grains plant(^{-1})</td>
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<tr>
<td>1000-grain weight</td>
<td>0.73**</td>
</tr>
</tbody>
</table>

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

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

J. J. Marassi, A. A. Vidal, and R. Bezu, Rice Program, Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata, C.C. 31 (1900), Buenos Aires, Argentina

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. oryzae* 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 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.

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

B. Mateso, K. Kasongo, and B. Lienge, Centre de recherches de Yangambi, Institut national pour l'étude et la recherche agronomiques (INERA), B.P. 2015, Kisangani, République Démocratique du Congo (RDC)

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 sub-stations 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.
A seed production system for backstopping a hybrid rice breeding program

R. S. Toledo, C. L. Casal, and S. S. Virmani, IRRI

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-m² 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 GA3 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 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 GA3 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 (1999) 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 (1995 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.
Doubts have been raised about the economic viability of hybrid seed production as rice is predominantly self-pollinated. 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**

S. Singh, B. C. Viraktamath, M. S. Ramesha, C. H. M. Vijayakumar, and M. I. Ahmed, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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 a 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**

B. C. Viraktamath, S. Singh, C. H. M. Vijayakumar, M. S. Ramesha, and M. I. Ahmed, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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
involving a male parent with 10 d planted. In a hybrid combination 20-25-d-old seedlings were transplanted; it remained the same in B and R lines if 15-d-old seedlings were transplanted. Observations were done at an interval of 5 d using 15-25-d-old seedlings. 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.

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**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). 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-R 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.
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

Zhou Jie, Zhou Long, Rice Research Institute, Agriculture Bureau, Linyi, Shandong, China

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,
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.

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<table>
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<tr>
<th>Drought treatment stage (^a)</th>
<th>Third-leaf stage</th>
<th>Seedling age (55 d)</th>
<th>Transplanting shock (d)</th>
<th>4 d after transplanting (roots)</th>
<th>Grains panicle (^{-1})</th>
<th>1,000-grain wt</th>
<th>Unfilled grain (%)</th>
<th>Grain yield (g m(^{-2}))</th>
<th>Compared with check ((\pm%))</th>
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</thead>
<tbody>
<tr>
<td>Early</td>
<td>26.5 (8.2)</td>
<td>21.7 (87.2)</td>
<td>21.2 (0)</td>
<td>7.3 (4.0)</td>
<td>81.3 (31.9)</td>
<td>4.3</td>
<td>684.7 ± 8.03**</td>
<td>+28.58</td>
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<tr>
<td>Middle</td>
<td>18.1 (6.9)</td>
<td>33.1 (18.1)</td>
<td>0 (6)</td>
<td>1.2 (0.4)</td>
<td>36.9 (26.7)</td>
<td>47.5</td>
<td>301.5 ± 10.28</td>
<td>-43.31</td>
<td></td>
</tr>
<tr>
<td>Late</td>
<td>17.9 (6.2)</td>
<td>32.4 (17.6)</td>
<td>5 (7)</td>
<td>1.1 (0.36)</td>
<td>56.9 (26.4)</td>
<td>23.6</td>
<td>413.5 ± 8.04</td>
<td>-22.36</td>
<td></td>
</tr>
<tr>
<td>Complete growth</td>
<td>27.1 (8.4)</td>
<td>22.1 (85.9)</td>
<td>18.7 (0)</td>
<td>6.8 (3.8)</td>
<td>22.7 (26.0)</td>
<td>43.6</td>
<td>270 ± 5.34</td>
<td>-49.3</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>18.3 (6.3)</td>
<td>32.3 (17.9)</td>
<td>0 (5-7)</td>
<td>1.8 (0.33)</td>
<td>68.2 (31.9)</td>
<td>4.1</td>
<td>532.5 ± 7.76</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Early stage = emergence of seedling to jointing; middle stage = jointing to heading; late stage = heading to ripening. **S\(_p\) = 9.24, t = 16.47, P = 0.01, T = 9.925, 16.47 > 9.925, P < 0.01.**
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 the tested hybrids were not significant at Aduthurai, Mandya, and Pantnagar. As a result, profit increased by 22%.

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.

Integrated germplasm improvement — weeds

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

M. Syed Anwarulla, NARP, Regional Research Station, Mudigere 577132, Karnataka, India

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%) recorded at 10 DAS*</th>
<th>Mean of 2yr</th>
<th>Dry weight (av) of 10 seedlings at 25 DAS (g)</th>
<th>Mean of 2yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Control, unweeded check</td>
<td>92</td>
<td>94</td>
<td>94</td>
<td>95</td>
</tr>
<tr>
<td>2. Butachlor preemergence 50 EC (1.25 L ha⁻¹)</td>
<td>92</td>
<td>94</td>
<td>88</td>
<td>82</td>
</tr>
<tr>
<td>3. Benthioctave 30 EC (1.25 kg ai ha⁻¹) preemergence</td>
<td>74</td>
<td>76</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>4. Pendimethaline 30 EC (preemergence) (1.0 kg ai ha⁻¹)</td>
<td>72</td>
<td>72</td>
<td>68</td>
<td>64</td>
</tr>
<tr>
<td>5. Butachlor (5%) granules (25 kg ha⁻¹)</td>
<td>73</td>
<td>74</td>
<td>77</td>
<td>79</td>
</tr>
<tr>
<td>6. Anilophos 30 EC @300 mL ha⁻¹ (3 DAS) Postemergence</td>
<td>89</td>
<td>93</td>
<td>90</td>
<td>88</td>
</tr>
<tr>
<td>7. Hand weeding at 10 and 20 DAS LSD (P = 0.05)</td>
<td>92</td>
<td>93</td>
<td>93</td>
<td>94</td>
</tr>
</tbody>
</table>

*DAS = days after sowing.
Weed control in dry-seeded lowland rice

R. Rajendran and N. Kempuchetty, Tamil Nadu Rice Research Institute, Aduthurai 612101, India

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.

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 m² 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 m² 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1993-94</th>
<th>1994-95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kharif</td>
<td>Summer</td>
</tr>
<tr>
<td></td>
<td>DWW (g)</td>
<td>WCE (%)</td>
</tr>
<tr>
<td>1</td>
<td>142.4</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>52.6</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>79.7</td>
<td>44</td>
</tr>
<tr>
<td>4</td>
<td>83.2</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>71.4</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>56.6</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>50.9</td>
<td>64</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>10.1</td>
<td>–</td>
</tr>
</tbody>
</table>

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

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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate (kg ai ha⁻¹)</th>
<th>Grain yield (t ha⁻¹)</th>
<th>Weed dry weight (t ha⁻¹)</th>
<th>WCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiobencarb followed by 2,4-D Na salt</td>
<td>2.0</td>
<td>1.0</td>
<td>2.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Thiobencarb followed by hand weeding</td>
<td>1.5</td>
<td>4.3</td>
<td>4.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Pretiachlor plus followed by hand weeding</td>
<td>0.3</td>
<td>5.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Bentazon followed by hand weeding</td>
<td>0.8</td>
<td>3.0</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Two hand weedings</td>
<td>–</td>
<td>4.3</td>
<td>4.3</td>
<td>4.8</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>–</td>
<td>0.04</td>
<td>0.06</td>
<td>0.05</td>
</tr>
</tbody>
</table>

*Mean of four replications.
control treatments, preti1achlor 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 weedicings. 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.

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 comprehensively evaluate numerous producer circumstances beyond the capability of experimental plot research and verification trials. This type of evalu-
comparison 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
C. H. M. Vijayakumar, M. I. Ahmed, B. C. Viraktamath, S. Singh, and M. S. Ramesha, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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 genotype, one that could be recommended for the whole region.

Role of voluntary agencies in popularizing hybrid rice production in India
G. G. Reddy and G. Satyanarayana, Krishi Vigyan Kendra, Sri Aurobindo Institute of Rural Development, Gaddipalli, Nalgonda 508201; and M. I. Ahmed and K. Krishnaiah, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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.
Economics of hybrid rice seed production in India

A. Janaiah and M. I. Ahmed, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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 F1 seed production. The F1 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 F1 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 F1 seed production were 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 economically viable threshold seed yield was 1,900 kg ha\(^{-1}\). If F1 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 (F1) area to commercial cultivation area of hybrid rice is estimated at 1:37.6. Thus, close to 53,000 ha are needed for an F1 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 F1 seed yields. We also need to formulate an incentive-oriented and forward-contract base price policy for F1 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

A. Janaiah, M. I. Ahmed, and K. Krishaiah, Directorate of Rice Research, Rajendranagar, Hyderabad 500030, India

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.
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• be original work,
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• report pertinent, adequate data,
• apply appropriate statistical analysis, and
• reach supportable conclusions.

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• 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.

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