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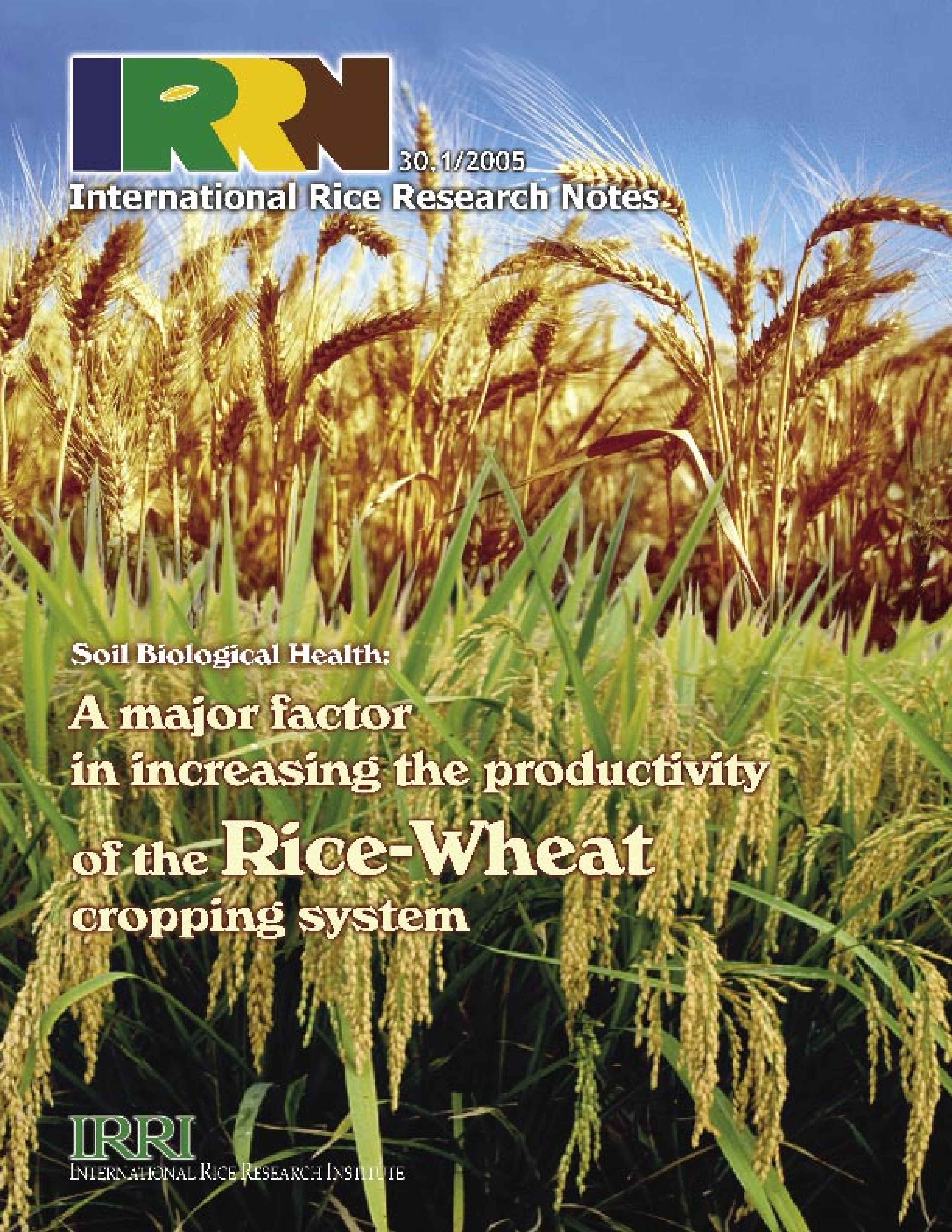

Soil Biological Health:

A major factor in increasing the productivity of the Rice-Wheat cropping system

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MINI REVIEW

Soil biological health: a major factor in increasing the productivity of the rice-wheat cropping system

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The rice-wheat cropping system was rapidly adopted in South Asia after the development of input-responsive, high-yielding varieties of both crops in the 1960s and 1970s. This became one of the world's major food production systems, occupying about 20 million ha and providing staple grains to more than 1 billion people. However, the rice-wheat system is under stress today. Diminishing yields in long-term experiments (Duxbury et al 2000), stagnating farmer yields, and declining factor productivity (Hobbs and Morris 1996) indicate that the sustainability of the rice-wheat system is questionable. Neither farmers nor researchers are sure of the reasons for the alarming trend. Since 1994, the Rice-Wheat Consortium for the Indo-Gangetic Plains—composed of national agricultural scientists from Bangladesh, India, Nepal, and Pakistan, advanced research institutions, and international agricultural research centers—has been working to address sustainability concerns about the rice-wheat cropping system (Gupta et al 2003).

Soil-borne pests of rice and wheat have undoubtedly proliferated under rice-wheat rotations in South Asia (Webster and Gunnell 1992, Bergstrom and Thurston 1988, Wiese 1977). Although considerable effort has been devoted to the management of major foliar pests and diseases, the diagnosis and impact of the soil pest complex, especially root pathogens, have not been adequately investigated (Dubin and Bimb 1994). Poor stand establishment and small, shallow root systems exhibiting symptoms of multiple pathogen damage (caused by *Meloidogyne, Rhizoctonia, Pythium*, and *Helminthosporium*) have been observed in rice-wheat areas of Bangladesh and Nepal. There is a need to quantify the occurrence and impact of these and other pathogens on rice and wheat productivity in South Asia.

Soil solarization can be used as a tool to determine the significance of soil-borne pathogens for the growth and yield of rice and wheat. It involves the heating of moist soil by covering it with clear plastic. Using plastic to trap solar heat to control soil pathogens was originally described by Katan et al (1976). Considerable information is available in the literature from various regions of the world documenting the effects and benefits of solarization for vegetables, fruits, and grain legumes (Katan and DeVay 1991, Stapleton and DeVay 1986, Chauhan et al 1988).

This work describes the use of soil solarization as a diagnostic tool to evaluate the extent and importance of soil-borne pests and diseases as potential constraints to rice and wheat production. We also discuss a more practical method for using soil solarization in rice cropping systems.

Between 1996 and 2000, 48 diagnostic trials with solarization were carried out in Bangladesh and Nepal for rice (nurseries and main fields) and wheat (main fields only). Paired solarized and unsolarized plots ranging in size from 6 to 15 m^2 (nurseries, 2–2.5 m^2) were established in farmers' fields and at experiment stations in Dinajpur, Chuadanga, and Gazipur districts of Bangladesh and in Khumaltar, Bhairahawa, and Sipaghat in Nepal.

Tilled soils were sealed under transparent plastic for 4 wk during early summer or 6 wk in early fall to trap solar heat (Fig. 1a). Before sealing, soils were moistened to field capacity to promote deep soil heating. At 5–10-cm depths, daily maximum soil temperatures during solarization ranged from 35 to 58 °C in early summer and from 40 to 47 °C in early fall. Soil was aerated for 5–7 d after solarization to remove any toxic byproducts prior to seeding (Fig. 1b).

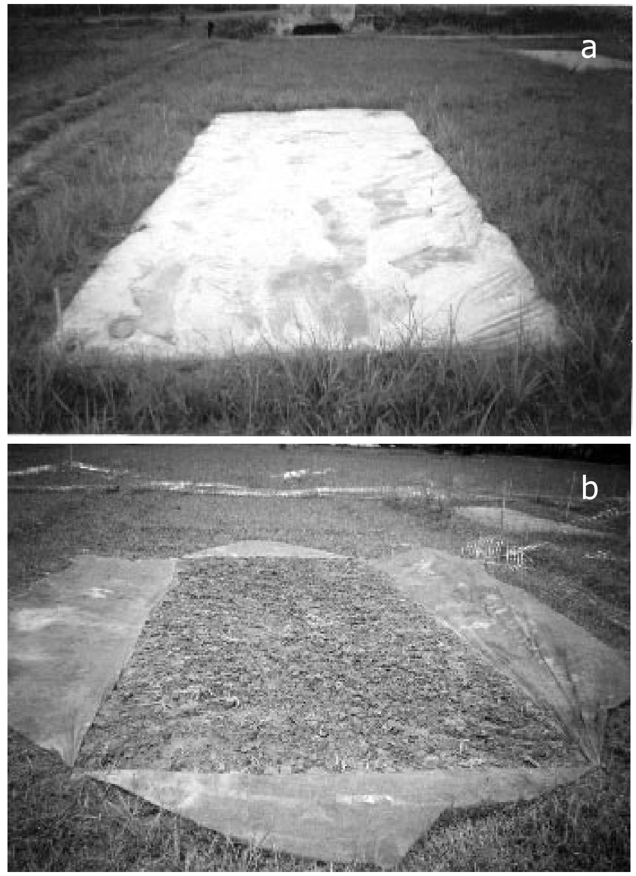

Fig. 1. Soil covered with plastic (a); solarization completed and plot is prepared for seeding (b).

Rice seedlings were raised in solarized and unsolarized nurseries and then transplanted into solarized and unsolarized main fields using a factorial design. Rice varieties Fulbadami, BR11, BR14, and BR32 were used in Bangladesh. Taichung, Khumal 3, and Saryu 52 were used in Nepal. Wheat varieties (Kanchan in Bangladesh and UP 262, Annapurna 1, and Bhrikuti in Nepal) were directly grown in solarized and unsolarized main fields. Treatments were replicated on experiment stations (three to four replications per treatment). Farmer field trials were established as single-plot treatments or, in a few cases, were replicated two-three times.

In several of the trials, agronomic factors including wheat plant populations, rice seedling emergence, plant height, and tillers m^{-2} were measured. Likewise, pathological factors were assessed. Rice and wheat root health at maximum tillering were evaluated visually, using a rating scale of 1 (healthy roots, no visible disease symptoms) to 9 (greater than 75% of root tissue diseased, reduced in size, and with advanced signs of decay) (CIAT 1987). Severity of *Helminthosporium* leaf blight ((*Bipolaris sorokiniana* (Sacc.) Shoem.)) was rated at heading using a double-digit scoring system (00-99) modified from Saari and Prescott's severity scale to assess wheat foliar diseases (Saari and Prescott 1975, Eyal et al 1987). Root-knot nematode (*Meloidogyne graminicola* Golden & Birchfield) galls were counted from randomly selected wheat and rice plants, and incidence of rice sheath blight (*Rhizoctonia solani* Kuhn) at anthesis was also recorded. At six sites, soils were collected from 0–15-cm depths and analyzed for inorganic N (2 M KCl extractable), and, at one site, available micronutrients (DTPA extractable) were also analyzed.

Rice and wheat yields were determined by crop cut from 1-m^2 plots at all sites; grain moisture content was adjusted to 14% for both rice and wheat. Analysis of variance was done for replicated data sets and significant differences were distinguished by Tukey's LSD, using $\alpha = 0.05$.

Demonstrations of solarization for rice nurseries began with farmers at Chandana, Gazipur District, as well as in Kaharol and Birgunj, Dinajpur District, in Bangladesh. Paired solarized and unsolarized nursery plots, ranging in size from 2.5 to 5 m^2, were established on each of 5 farms in 2000 (Gazipur) and on 25 farms in 2001 (Dinajpur).

Nurseries were solarized, as described above, for 4 wk in late spring and early summer. Rice varieties BR26 (Gazipur) and BR11 or Shorna (Dinajpur) were sown into solarized and unsolarized nursery seedbeds and then transplanted into separate unsolarized main fields. Treatments were not replicated, and management followed normal farmer practices after sowing. Rice yields from each treatment were collected by crop cut from a 1-m^2 plot, and these were adjusted to 14% moisture content.

Solarization had beneficial effects on plant establishment and early growth at most sites. With a few exceptions, statistically significant increases in wheat plant population, rice emergence, plant height, and tiller number (Fig.2 a-d) were observed in solarized treatments. For unreplicated trials, consistently higher values of agronomic variables were also found in solarized treatments compared with unsolarized treatments. In addition, at individual sites, rice leaf chlorophyll, productive tillers of rice, and wheat and rice aboveground biomass were higher in solarized plots than in unsolarized ones (data not shown).

Measurements of pathogen effects showed substantial differences between solarized and unsolarized treatments as well. Significantly lower wheat and rice root grades (i.e., healthier root systems) were found with solarization for a majority of the replicated trials (Fig. 3a). The severity of *Helminthosporium* leaf blight in wheat, nematode gall counts on wheat and rice roots, and sheath blight incidence

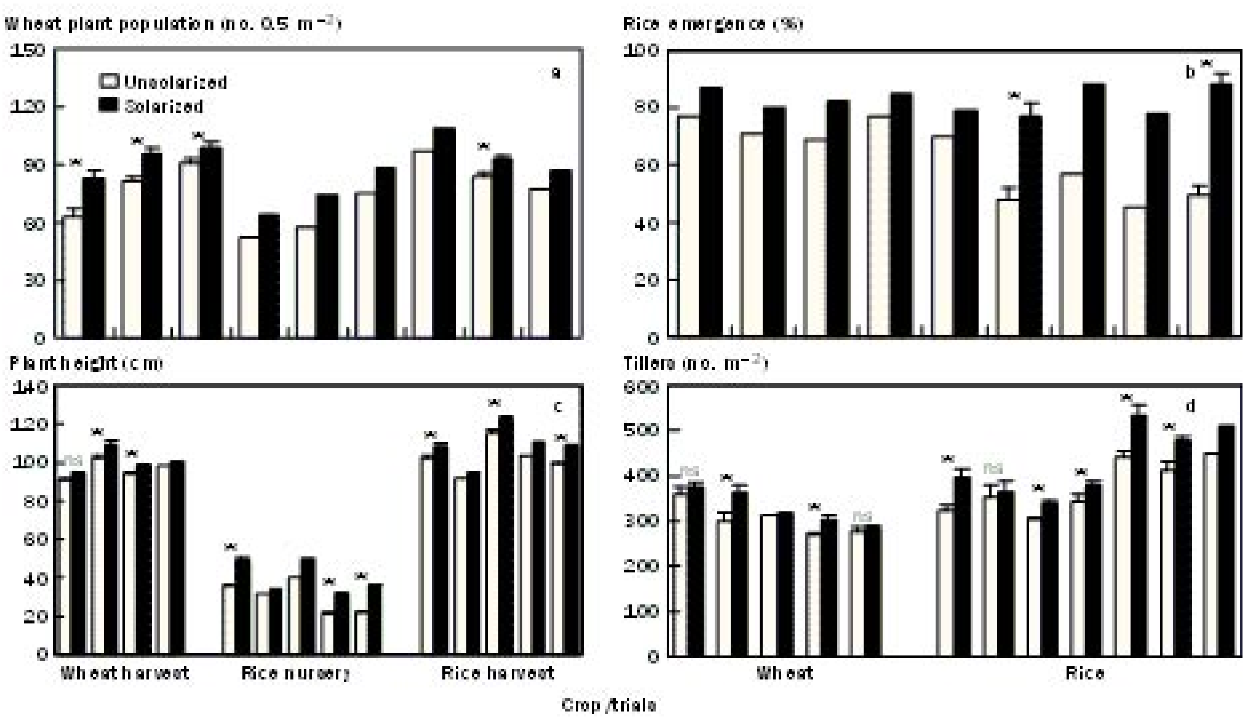

Fig. 2. Wheat plant populations at the three-leaf stage (a), rice seedling emergence (b), wheat and rice plant height at harvest (c), and wheat and rice tiller number (d) from selected trials. Pairs marked with an asterisk (*) differed significantly at α = 0.05; ns = not significantly different; unmarked pairs from unreplicated farmer plots.

in rice were also consistently less in the solarized treatments than in the unsolarized treatments (Fig. 3b-d) for both replicated and unreplicated trials. These results are not surprising since the soil is one of the primary sources of inoculum for *Helminthosporium* leaf blight and rice sheath blight, two important wheat and rice diseases in South Asia (Cook and Veseth 1991, Savary et al 2001, Sharma et al 2004). Likewise, root-knot nematode is a significant soil pest associated with the rice-wheat cropping system (Sharma et al 2000).

Wheat and rice yields from solarized plots reflected improvements in agronomic factors and a reduction in number of soil-borne pathogens at most sites. In 22 wheat studies, mean yield was 3.57 Mg ha^{-1} from solarized plots compared with 2.90 Mg ha^{-1} from unsolarized plots, an average yield increase of 23%. In 13 trials, yields from solarized plots were statistically higher than those from unsolarized plots; five trials showed no significant differences in yield. Yield increases from four unreplicated trials ranged from 25% to 36%. The distribution of wheat yield increases attributed to solarization is shown in Table 1.

The mean yield from 26 trials with rice was 4.34 Mg ha^{-1} from solarized treatments vs 3.51 Mg ha^{-1} from unsolarized treatments, giving an average yield increase of 0.83 Mg ha^{-1} (24%). Rice yields from solarized plots were significantly higher than yields from unsolarized plots in 10 of 19 replicated plot trials. Yields from five unreplicated trials showed increases ranging from 6% to 100% with solarization. The distribution of all rice yield increases due to solarization is shown in Table 1. At three sites, heavy insect pressure and plant damage were observed in the solarized main fields. In these cases, yields decreased or were completely lost. Up until the grain production phase, more vigorous plant growth and higher yield potential were reported with solarized treatments.

Other investigators have observed that the benefits of solarization are not limited to pathogen control. The process also alters nutrient availability and kills weed seeds. Again, weeds are the host of many pathogens. Inorganic soil nitrogen was found to increase by a factor of 1.7–2.4 and available manganese by 3.8 times. Weed growth in wheat after solarization decreased 2.7–5 fold in Bangladesh.

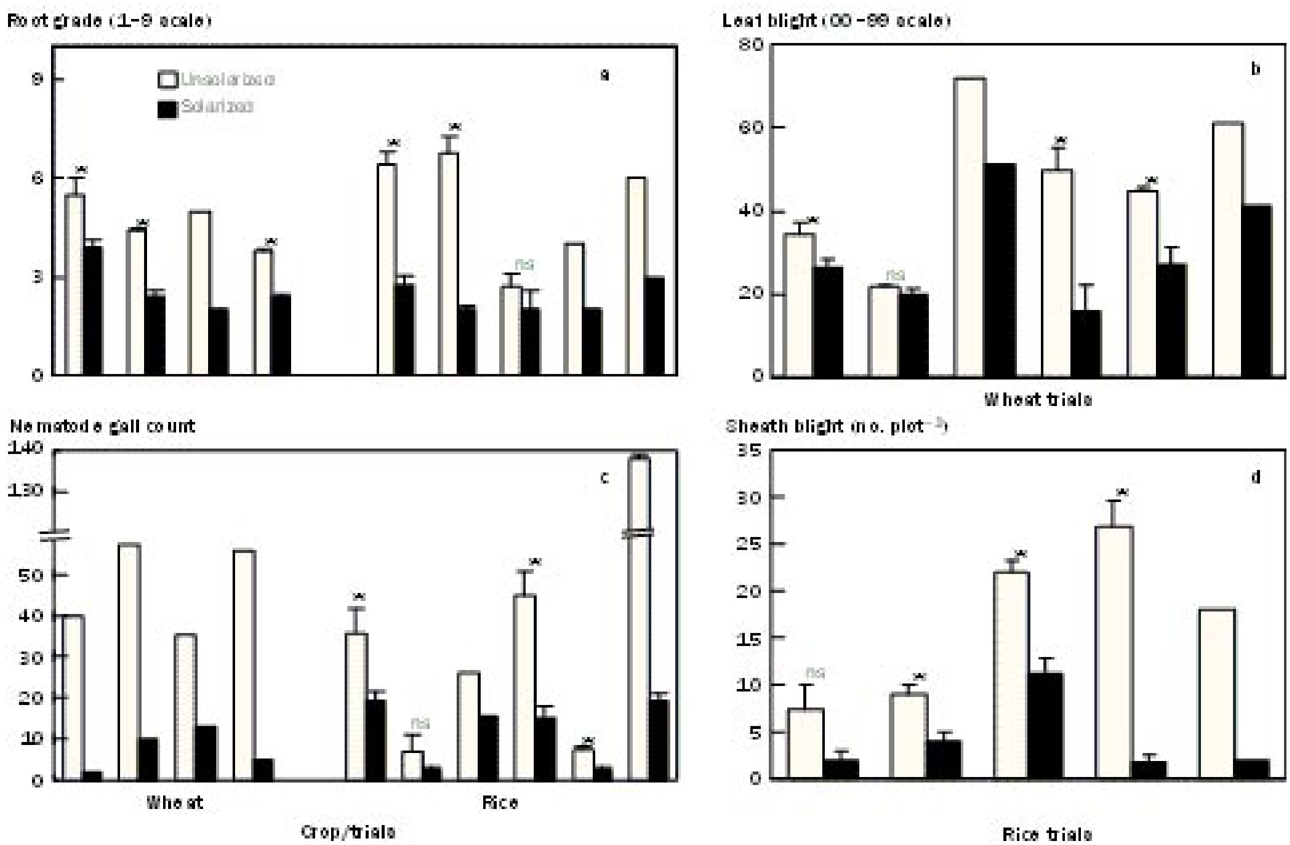

Fig. 3. Effect of soil solarization on rice and wheat root health and soil-borne diseases as measured by root grade (a), *Helminthosporium* leaf blight in wheat (b), nematode gall count on wheat roots (10 plants) and rice roots (5 plants) (c), and incidence of sheath blight in rice (d). Pairs marked with an asterisk (*) differed significantly at α = 0.05; ns = not significantly different; unmarked pairs from unreplicated farmer plots.

Table 1. Impact of solarization on wheat and rice yields from 48 experimental and on-farm trials.

Crop	Yield increase due to solarization (%)	Trials (no.)
Wheat	–6–10	5
	11–25	8
	26–35	5
	36–50	2
	≥51	2
	Total	22
Rice	No yield	2
	–7–10	9
	11–25	4
	26–35	4
	36–50	3
	≥51	4
	Total	26

Rice weeds in solarized plots in Nepal were also substantially fewer than in unsolarized plots. These results confirm the findings of Elmore (1995) and Chen and Katan (1980).

The increased nutrient supply and less weed pressure may have contributed, to some extent, to the improved agronomic performance and higher yields in these diagnostic trials. However, the positive effect of solarization on root health and number of pathogens throughout crop growth at most sites suggests that soil-borne pathogens were a major constraint. Once the root pathogens were reduced by solarization, plant growth and yield responded substantially.

Field-level soil solarization is neither a practical nor an environmentally sound practice for rice-wheat farmers in South Asia. Likewise, chemical treatments for soil-borne pathogens are not readily available, are too expensive for resource-poor farmers, and may have adverse health effects. Solarization of rice nursery soils to produce "healthy seedlings" is a simple, low-cost, nonchemical soil treatment to minimize pathogen pressure in flooded soils.

Demonstrations at several locations in farmers' fields in Bangladesh produced rice seedlings from solarized nurseries that were substantially taller than seedlings from unsolarized nurseries (Fig. 4a). Healthy seedling roots were bigger, lighter in color, and had less pathogen damage. In the field, healthy seedlings exhibited more vigorous growth as reflected by darker green and taller plants (Fig. 4b).

In the diagnostic trials, visible root pathogen infection was observed to be lower in rice plants from solarized nurseries than in those from unsolarized nurseries (data not shown). With the healthy start that rice seedlings get in solarized nurseries, transplants appear to have a greater capacity to withstand soil-borne biological stresses.

Fig. 4. Healthy seedlings (a) on the right raised in solarized nurseries compared with normal rice seedlings on the left; healthy seedlings grown in the main field (b, foreground).

Seedlings from solarized nurseries produced yield increases relative to normal seedlings in most of the demonstrations. Farmers in Gazipur District found that the 2000 spring rice yields increased by 0.3–1.2 Mg ha^{-1} with healthy seedlings. On average, rice yields increased by 18% using seedlings from solarized nurseries (Fig. 5a). Likewise, farmers from Dinajpur obtained 2–42% rice yield increases with healthy seedlings (Fig. 5b).

Even though the demonstrations were not replicated, a clear indication of the benefits of using healthy seedlings from solarized nurseries emerged. Table 2 shows the extent of yield increases obtained with healthy seedlings from farmers' fields. Only 17% of the trials had yield increases less than 10%; in 77% of the trials, yields increased by more than 20%.

Diagnostic trials with solarization were carried out in Bangladesh and Nepal for rice and wheat to assess the extent and importance of soil-borne pests and diseases in the rice-wheat cropping system.

Agronomic, simple pathological assessment, and yield results from a majority of the trials support our premise that root health and soil-borne pathogens are major factors that influence production in this important cropping system.

The diagnostic approach was modified to provide farmers with a simple, low-cost, nonchemical soil treatment to address pathogen pressure in flooded rice. Healthy seedlings, generated using solarized rice nursery soils, increased rice yields at many demonstration sites. Further extension of this technology is ongoing in Nepal and Bangladesh, through NGO partners. To date, more than 3,500 farmers have been introduced to the solarization technology.

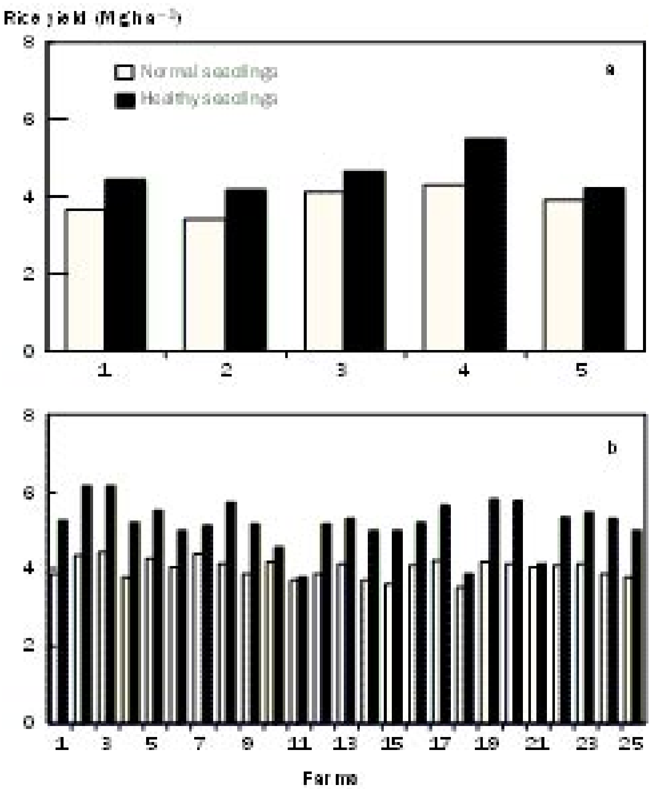

Fig. 5. Rice yields from unreplicated farmer plots in Gazipur (a) and Dinajpur (b) comparing normal seedlings from unsolarized nurseries with healthy seedlings from solarized nurseries.

Table 2. Impact of healthy seedlings on rice yields from 30 on-farm trials.

Yield increase due to healthy seedlings (%)	Trials (no.)
≤10	5
11–20	2
21–30	7
31–40	15
≥41	1
Total	30

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Inheritance of purple pigmentation in two-line rice hybrids

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Many scientists have systematically studied how purple color is inherited in rice leaves. Three pairs of basic genes (C, A, P) control the inheritance of anthocyanin pigments (Nagao 1951). The C-A-P gene system in japonica rice is suitable for indica rice (Kinoshita 1984). Tongmin et al (1996) studied the inheritance of two purple rice lines and the possibility of their use as morphological markers in hybrid rice breeding.

The experiment was conducted in 2000-03 at ACRI. The genotypes involved in the crosses were aromatic rice varieties (ADT41, Pusa Basmati 1, and Basmati 370), nonaromatic varieties (ADT39 and AD98028), and a nonaromatic TGMS line (TS29) with purple basal nodes.

The plants with purple/green pigmentation on the basal node were counted in the P_1, P_2, F_1, F_2, B_1, and B_2 generations in each of the five crosses and chi-square tests were made crosswise to study the inheritance pattern of purple pigmentation. The number of plants with purple and green pigmentation in the basal nodes of the plants in all generations in each of the five crosses and the chi-square values for the genetic ratios are presented in the table. The parents ADT39, ADT41, Pusa Basmati 1, Basmati 370, and AD98028 were green. The hybrids TS29/ADT39, TS29/ADT41, TS29/Pusa Basmati 1, TS29/Basmati 370, and TS29/AD98028 showed green plants in the F_1 generation. The F_2 and B_2 generations segregated for green and purple pigmentation in the ratio of 13:3 and 1:1, respectively. The chi-square values for the fitness of these genetic ratios were nonsignificant. The B_1 generation of all five crosses showed green pigmentation.

The inheritance pattern for purple pigmentation at the basal node revealed that purple pigmentation was recessive to green, owing to its absence in the F_1 generation. The segregation pattern observed in the F_2 generation indicated a ratio of 13:3 for green and purple in all crosses—TS29/ADT39, TS29/ADT41, TS29/Pusa Basmati 1, TS29/Basmati 370, and

Segregation for purple pigmentation in five crosses.

Parent/cross	Generation	Number of plants observed			Ratio	χ^2 value	Probability
		Green	Purple	Total			
TS29		–	50	50	–		
ADT39		50	–	50	–		
ADT41		50	–	50	–		
Pusa Basmati 1		50	–	50	–		
Basmati 370		50	–	50	–		
AD98028		50	–	50			
TS29/ADT39	F_1	25	–	25	–		
	F_2	247	53	300	13:3	0.20	0.50–0.70
	B_1	80	–	80	–		
	B_2	43	37	80	1:1	0.45	0.30–0.50
TS29/ADT41	F_1	25	–	25	–		
	F_2	246	54	300	13:3	0.11	0.70–0.80
	B_1	80	–	80	–		
	B_2	48	32	80	1:1	3.20	0.05–0.10
TS29/Pusa Basmati 1	F_1	25	–	25	–		
	F_2	232	48	300	13:3	1.49	0.20–0.30
	B_1	80	–	80	–		
	B_2	43	37	80	1:1	0.45	0.30–0.50
TS29/Basmati 370	F_1	25	–	25	–		
	F_2	250	50	300	13:3	0.85	0.30–0.50
	B_1	80	–	80	–		
	B_2	46	34	80	1:1	1.80	0.10–0.20
TS29/AD98028	F_1	25	–	25	–		
	F_2	251	49	300	13:3	1.15	0.20–0.30
	B_1	80	–	80	–		
	B_2	36	44	80	1:1	0.80	0.30–0.50

TS29/AD98028. The inheritance pattern for purple pigmentation was confirmed by the testcross ratio of 1:1 in the B_2 generation. The 13:3 genetic ratio for green and purple indicated that the difference between parents in all the crosses was based on two-pair genes, one of which was an inhibitory gene. Thus, the gene action for purple pigmentation was observed to be digenic with inhibitory interaction as shown in these crosses. Tongmin et al (1996) reported two to four genes responsible for pigmentation in leaves, one of which was inhibitory. The results suggest the possibility of using purple pigmentation in the basal node as a gene marker (morphological marker) in hybrid rice breeding programs.

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Inheritance of scentedness in two-line rice hybrids

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Aroma in scented rice has its unique value, from both consumption and commercial points of view. Knowledge of the inheritance pattern of aroma would help in deciding what breeding methods to use to develop high-yielding rice hybrids. Various techniques to detect and evaluate aroma, in order to study the inheritance of aroma in rice and improve the effectiveness of breeding programs for scented hybrid rice, have been proposed (Sood and Siddiq 1978). A digenic segregation ratio of 9 nonaroma:7 aroma was obtained by Tripathi and Rao (1979) and Hsieh and Wang (1988). The segregation ratios of nonaromatic to aromatic plants in two F_2 populations from crosses between aromatic and nonaromatic and between nonaromatic and aromatic were both 3:1. This indicates the inheritance of a single recessive gene with regard to aroma but that, in one F_2 population, from the cross nonaromatic/aromatic, the ratio was 9:7, indicating that two complementary recessive genes control aroma in aromatic rice (Dong et al 2001).

We studied the inheritance of aroma in two-line rice hybrids during 2000-03 in experiments conducted at ACRI. The varieties involved in the crosses were aromatic short-duration rice varieties (Pusa Basmati 1, Basmati 370, and ADT41), short-duration nonaromatic rice varieties (ADT39 and AD98028), and a nonaromatic TGMS line (TS29). Aroma was assessed in the leaves of P_1, P_2, F_1, F_2, B_1, and B_2 generations in each of the five crosses. Determination of the presence of aroma was made according to the method described by Sood and Siddiq (1978). At tillering stage, 2 g of green leaves were excised into fine pieces and kept in test tubes mixed with 10 mL of 1.7% KOH solution. The test tubes were covered immediately and kept under room temperature for about 10 min. Contents were smelled one by one, and the samples classified into aromatic and nonaromatic.

The number of plants with nonaroma and aroma in all generations in each of the five crosses, along with the chi-square values for the expected genetic ratios, is presented in the table. The parents TS29, ADT39, and AD98028 and their F_1, F_2, B_1, and B_2 generations (TS29/ADT39 and TS29/AD98028) were nonaromatic. In ADT41, Pusa Basmati 1, and Basmati 370, all the plants tested were aromatic. The hybrids TS29/ADT41, TS29/Pusa Basmati 1, and TS29/Basmati 370 showed nonscentedness in the F_1 generation. The F_2 and B_2 generations segregated for nonscentedness and scentedness in the ratio of 3:1 and 1:1, respectively. The chi-square values for the fitness of these genetic ratios were nonsignificant. The B_1 generation of these three crosses did not segregate and all the plants showed nonscentedness.

The inheritance pattern for scentedness revealed that aroma was recessive to nonaroma owing to its absence in the F_1 generation in all crosses. The segregation pattern indicated that a single recessive allele influences aroma as seen from the observed F_2 ratio of 3:1 for nonaroma and aroma in TS29/ADT41, TS29/Pusa Basmati 1, and TS29/Basmati 370. The above inheritance pattern for scented hybrids was confirmed by the segregation in the testcross ratio of 1:1 in the B_2 generation. Thus, the gene action for scentedness was observed to be monogenic, as seen in these three crosses. This supports the findings of Sood and Siddiq (1978) and Vivekanandan (1993).

Table 1. Segregation for scentedness in five crosses.

Parent/cross	Generation	Number of plants observed			Ratio	χ^2 value	Probability
		Nonscented	Scented	Total			
TS29		50	–	50	–		
ADT39		50	–	50	–		
ADT41		–	50	50	–		
Pusa Basmati 1		–	50	50	–		
Basmati 370		–	50	50	–		
AD98028		50	–	50			
			–				
TS29/ADT39	F_1	25	–	25	–		
	F_2	300	–	300	–		
	B_1	80	–	80	–		
	B_2	80	–	80	–		
					–		
TS29/ADT41	F_1	25	–	25	–		
	F_2	221	79	300	3:1	0.28	0.50–0.70
	B_1	80	–	80	–		
	B_2	42	38	80	1:1	0.20	0.50–0.70
TS29/Pusa Basmati 1	F_1	25	–	25	–		
	F_2	218	82	300	3:1	0.88	0.30–0.50
	B_1	80	–	80	–		
	B_2	39	41	80	1:1	0.05	0.80–0.90
TS29/Basmati 370	F_1	25	–	25	–		
	F_2	228	72	300	3:1	0.16	0.50–0.70
	B_1	80	–	80	–		
	B_2	41	39	80	1:1	0.05	0.80–0.90
TS29/AD98028	F_1	25	–	25	–		
	F_2	300	–	300	–		
	B_1	80	–	80	–		
	B_2	80	–	80	–		

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Identification of maintainers and restorers using WA source cytoplasmic male sterile lines in rice

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The cytoplasmic male sterile (CMS) lines introduced from China are unsuitable to use as such in developing hybrid rice in India. Therefore, it is imperative to identify maintainers and restorers among the lines developed through conventional breeding procedures. Maintainers with higher adaptability and restorers should have higher combining ability. Four CMS lines (wild abortive, WA, cytoplasmic background)—IR68885A, IR62829A, DRR2A, and PMS10A—and eight testers—BKP232, R827-287, Pusa Basmati, R1060-1674-1-1, R714-2-103, Culture 1001, Super rice 2, and R304-34—were used in the line × tester (4 × 8) analysis with 32 hybrids.

The experiment was laid out in a randomized block design with two replications. Identification of maintainers and restorers was carried out by observing spikelet fertility and pollen fertility. A very low magnitude of pollen and spikelet fertility was observed for hybrids (Table 1). The lines identified as effective maintainers can be further backcrossed with their respective F_1s to look for completely sterile backcross progenies so that these can be developed as new CMS lines. Hybrids showed more than 70% spikelet fertility and 80% pollen fertility (Table 2).

In some cases, the same genotype behaved as a restorer for one CMS line and as a maintainer for the other CMS line. Tester R304-34 behaved as an effective maintainer for CMS line IR68885A and was found to be an effective restorer for CMS line IR62829A. Tester R827-287 was an effective maintainer for CMS line IR62829A and behaved as an effective restorer for CMS lines IR68885A, DRR2A, and PMS10A. The variations in behavior of fertility restoration indicate that either the fertility-restoring genes are different or that their penetrance and expressivity varied with the genotypes of the parents or the modifiers of female background. Similar results have been reported by Hemareddy et al (2000), Gannamani (2001), and Sao (2002).

Table 1. Maintainers for three CMS lines.

CMS line	Effective maintainers	Pollen fertility (%)	Spikelet fertility (%)
IR68885A	Pusa Basmati	3.20	4.45
	R304-34	6.61	2.84
	Culture 1001	1.42	4.54
IR62829A	Culture 1001	7.71	3.24
	R827-287	8.29	5.44
	Pusa Basmati	9.11	2.50
DRR2A	Pusa Basmati	1.65	1.90

Table 2. Restorers for four CMS lines.

CMS line	Effective restorers	Pollen fertility (%)	Spikelet fertility (%)
IR68885A	R827-287	93.42	84.83
IR62829A	R304-34	93.35	72.40
DRR2A	BKP 232	88.38	71.62
	R827-287	86.47	80.82
	R1060-1674-1-1	88.38	80.45
	R304-34	87.62	83.41
PMS10A	R827-287	93.68	75.75

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Detection of quantitative trait loci for leaf chlorophyll content at maximum tillering

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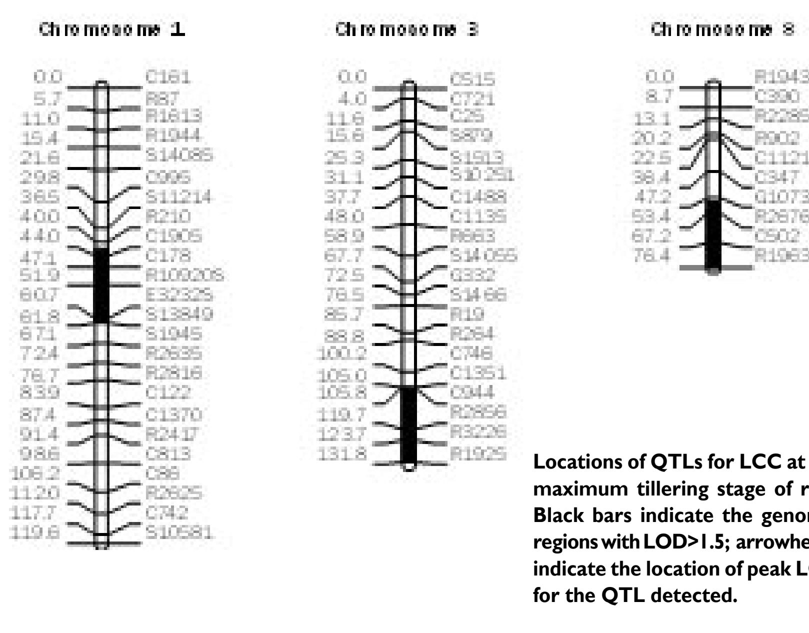
Leaf chlorophyll content (LCC) is an important physiological character, being closely related to photosynthetic ability in rice. In this study, 182 recombinant inbred (RI) lines derived from a backcross of Koshihikari (japonica)/Kasalath (indica)//Koshihikari, kindly provided by the National Institute of Agrobiological Resources, Japan, were used to identify quantitative trait loci (QTLs) for LCC at the maximum tillering stage of rice. The seeds of 182 RI lines, along with those of both parents, Koshihikari and Kasalath, were sown on 10 April 2004. After 30 d, seedlings were transplanted to the experiment farm of Miyazaki University, using a single seedling per hill and 10 × 15-cm spacing. The recommended cultural practices were followed. At maximum tillering stage, 30 newly developed and healthy leaves for each line were selected for LCC measurement with two replicates using a chlorophyll meter (SPAD-502, Minolta Co., Ltd., Japan). Average values for each line and a subset of 162 restriction fragment length polymorphism (RFLP) markers (www.rgrc.dna.affrc.go.jp/jp/data/KK-BIL182-20030506.xls) were used for QTL statistical analysis. The QTL analysis was performed by Windows QTL Cartographer software version 2 (Wang et al 2003) through the composite interval mapping method. A locus with LOD >2.0 was to be declared a putative QTL. In addition, the additive effects and the percentage of variation explained by an individual QTL were also estimated.

Continuous variations and transgressive segregation (data not shown) were observed in the RI population, indicating that LCC was a quantitatively inherited trait. Three QTLs for LCC were identified and mapped to chromosomes 1, 3, and 8 (see table and figure), tentatively named *q*LCC-1, *q*LCC-3, and *q*LCC-8. Individually, qLCC-3 with the largest effect (LOD = 5.5) was detected near R3226 (chromosome 3) and accounted for 14.4% of total phenotypic variation. *q*LCC-1 (chromosome 1) near R10920S and *q*LCC-8 near R1963 (chromosome 8) explained 8.1% and 8.8% of total phenotypic variation, respectively. In addition, Koshihikari alleles in both

QTLs associated with LCC in rice based on composite interval mapping using RI lines derived from backcross Koshihikari/Kasalath//Koshihikari.

QTL	Chr. number	Marker interval[a]	Peak LOD value	Additive effects[b]	Variation[c] (%)
*q*LCC-1	1	R10920S–E3232	2.1	0.86	8.1
*q*LCC-3	3	R2856–R3226	5.5	–1.42	14.4
*q*LCC-8	8	C502–R1963	2.9	0.95	8.8

[a]Markers in boldface indicate the nearest marker to putative QTL. [b]Positive values of additive effects indicate that Koshihikari alleles are in the direction of LCC in rice. [c]Percentage of explained phenotypic variation.



Locations of QTLs for LCC at the maximum tillering stage of rice. Black bars indicate the genomic regions with LOD>1.5; arrowheads indicate the location of peak LOD for the QTL detected.

*q*LCC-1 and *q*LCC-8 and Kasalath allele in *q*LCC-3 contributed to the increase in LCC. The results and the tightly linked molecular markers that flank the QTLs detected in this study may be useful for breeding programs to improve photosynthetic ability in rice.

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Improving rice for broad-spectrum resistance to blast and salinity tolerance by introgressing genes from *O. rufipogon*

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Wild species of *Oryza* are an important source of tolerance for biotic and abiotic stresses. Several genes of agronomic importance such as those that confer resistance to blast, bacterial leaf blight, brown planthopper, tungro, and grassy stunt virus have been transferred from wild species into elite breeding lines of rice, including the quantitative trait loci (QTLs) for biotic and abiotic stress resistance that have been identified earlier (Brar and Khush 1997, Amante-Bordeos et al 1992).

Blast, caused by the fungus *Pyricularia grisea*, is one of the most destructive diseases of rice. Surveys done by Widawsky and O'Toole (1990) and Geddes and Iles (1991) confirm that it remains a serious constraint to rice production in South Asia. Host-plant resistance is the most promising method to control blast (Bonman et al 1992). We report here the transfer of broad-spectrum resistance to blast and salinity tolerance from *O. rufipogon* into high-yielding variety B90-15 (IET15420).

Four *O. rufipogon* accessions were collected from areas in the Andaman and Nicobar group of islands, India, submerged in brackish water. Along with B32-Sel-4 and B29-6 improved breeding lines, these were screened for blast under natural and artificial infection at the seedling stage. These materials were also screened for salinity tolerance at the seedling stage (in hydroponic culture: Toshida medium, at 8 dS m^{-1} and 12 dS m^{-1} at the vegetative and reproductive stages under field conditions with soil EC 6.0–10.0 dS m^{-1}). Accession *O. rufipogon* Coll-4 was found to be highly resistant to both blast and salinity (Table 1). It was crossed

Table 1. Characteristics of the parents and *O. sativa* × *O. rufipogon*-derived line B90-15 (IET15420).

Characteristic	B32-Sel-4 (parent)	B29-6 (parent)	Coll-4 (*O. rufipogon* parent)	B90-15 (introgression line)
Plant height (cm)	95–100	110–115	125–130	105–110
Tillers $plant^{-1}$ (no.)	15–18	10–12	16–20	10–12
Flowering duration (d)	100–105	110–115	115–120	110–117
Awn	Absent	Absent	Present (pigmented)	Absent
Apiculus color	Green	Green	Pigmented	Green
Shattering	Nonshattering	Nonshattering	Highly shattering	Nonshattering
Husk color	Straw	Straw	Black	Straw
Panicle type	Compact	Compact	Open	Compact
Grain type	Long bold	Long slender	Short bold	Short bold
Kernel appearance	Occasionally chalky	Translucent	Red kernel	Very occasionally chalky
Reaction to blast				
At DRR, Hyderabad	S	S	R	R
At Andamans	S	S	R	R
Reaction to BB				
At DRR, Hyderabad	S	S	MR	MR
At Andamans	S	S	MR	MR
Salinity tolerance				
8 dS m^{-1}	S	S	R	R
12 dS m^{-1}	S	S	R	R
Yield (t ha^{-1})				
Normal soil conditions (CD at 5%: 3.34)	4.3	5.1	–	5.5
Saline conditions, EC 9.2–9.8 dS m^{-1}	0.06	1.0	–	3.0

with B32-Sel-4, an improved medium-duration (130 d) breeding line. The F_1 was topcrossed with B29-6, another improved line of late duration (150–155 d). The F_1s of B32-Sel-4/*O. rufipogon* Coll-4//B29-6 were grown under normal field conditions. Half of the F_2 seeds of individual F_1 plants were screened for leaf blast in the nursery under artificial infection and the other half were grown in saline field conditions (6.0–10.0 dS m^{-1}). The blast-resistant plants were grown under normal field conditions. Twenty plants with resistance to leaf blast and with desirable agronomic traits were intermated with another 20 plants grown in saline conditions; again, the F_1s were grown in normal conditions. In the next F_2 generation, the same system of intermating was followed. After that, single-plant pedigree selections in saline conditions were followed, considering duration (130–150 d), semidwarf plant height, tillers per plant, salt tolerance, heavy panicles, grain type, and phenotypic index. Plants with weedy traits—shattering, awned, thin-stemmed, with red kernel, and sterile—were rejected. In the F_5 generations, several homozygous lines were selected on the basis of yield performance in saline conditions with blast resistance. Six lines were selected on the basis of yield higher than that of both their *sativa* parents (B32-Sel-4 and B29-6) under normal and saline conditions. These lines were evaluated in the All-India Coordinated Rice Improvement Program in 1999, 2000, and 2001 at 15 hot-spot locations for blast reaction in the national screening nursery and at 10 locations for yield and salt tolerance in sodic and coastal saline areas of West Bengal, Orissa, Maharashtra, Pondicherry, Andamans, Haryana, and Uttar Pradesh.

In 3 y of testing along with several other improved varieties, and resistant (IR64) and susceptible (HR12) checks, culture B90-15 (IET15420) showed broad-spectrum resistance against all races of blast present in India, except at Rewa, Wangbal, and Lonowala, where it was rated moderately resistant with a score of 6, 4, and 5.3, respectively, on a 0–9 scale (Table 2). The resistant check IR64 showed a susceptible reaction at Ponnampet with a score of 7.3 and a moderate reaction at Pattambi (4.5), Rewa (4.0), Jagadalpur (5.0), Wangbal (5.3), Lonowala (4.7), Gudulur (4.0), and Malan (4.0). HR12 showed a susceptible reaction at most locations.

Both *sativa* parents of B90-15 were susceptible to blast against DRR and Andamans races, indicating that B90-15 has introgressed some major genes conferring broad-spectrum resistance along with some genes for quantitative resistance from *O. rufipogon*. Wang et al (1994) reported that some durable cultivars such as Moroberekan have several dominant genes for complete resistance and some genes for quantitative resistance.

Among the six lines evaluated at 10 locations in the 1999-2001 Saline/Alkaline Tolerance Variety Trial (SATVT), culture B90-15 (IET15420) showed significantly higher yield over that of national check varieties bred for coastal salinity—CST 7-1, CSR 27, and check Jaya (Fig. 1). The

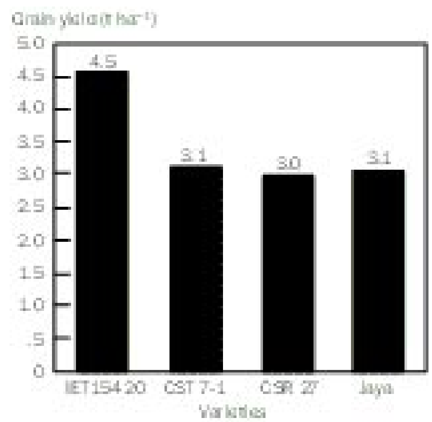

Fig. 1. Mean yield performance of B90-15 and checks evaluated at five locations during 3 y in coastal saline conditions.

Table 2. Reaction of B90-15 (IET15420) to blast at different hot-spot locations in India, 1999, 2000, and 2001.

Location	Screening method[a]	Blast reaction mean score (0–9 scale)		
		B90-15 (IET15420)	IR64 (resistant check)	HR12 (susceptible check)
Southern India				
DRR, Hyderabad	A	0	1.3	6.7
Nellore	N	0.5	1.3	6.0
Ambasamudram	N	0	0	7.0
Mandya	N	1.6	1.6	7.5
Ponnampet	N	0	7.3	8.0
Pattambi	N	2.0	4.5	9.0
Coimbatore	A	2.0	2.0	7.0
Eastern and central India				
Chiplima	A	0	3.0	7.0
Wangbal	N	4.0	5.3	6.3
Rewa	N	6.0	4.0	6.7
Jagadalpur	N	2.3	5.0	8.7
Hazaribagh	N	0.6	3.3	6.7
Northern India				
Lonovala	N	5.3	4.7	6.7
Gudulur	N	3.0	4.0	8.0
Malan	N	2.0	4.0	9.0

[a]A = artificial inoculation, N = natural infection.

yield advantage of B90-15 over these three was 46.1%, 51.9%, and 46.6%, respectively. Since plot size at Gosaba in 2000 and Panvel in 1999 was 1 m^2 only, these data were not considered in calculating the mean. Culture B90-15 yielded significantly higher than did the checks at Canning (West Bengal), Chouldhari (Andamans), Panvel (Maharashtra), and Karaikal (Pondicherry) in high saline conditions (Table 3).

Since both parents (B32-Sel-4 and B29-6) were susceptible to salinity and blast and since wild rice was resistant, the salinity tolerance and blast resistance in culture B90-15 have been introgressed from *O. rufipogon*. These results indicate that, for introgression of multiple traits from closely related wild species of rice, one to two backcrosses or a topcross, followed by selected intermating in the backcrossed F_2 generations, may help achieve several desirable agronomic traits. After 3 y of testing in the SATVT, B90-15 (IET15420) has been identified as promising and is an ideal release in coastal saline conditions in the states of West Bengal, Andamans, Maharashtra, and Pondicherry in India.

Table 3. Mean grain yield of B90-15 (IET15420) at different locations under coastal saline conditions tested in the Saline/Alkaline Tolerance Variety Trials, 1999, 2000, and 2001.

State	Location	No. of years tested	Yield (t ha^{-1})				EC (dS m^{-1})	pH	Remarks
			B90-15	National checks (saline-tolerant)		Yield check			
				CST 7-1	CSR 27	Jaya			
West Bengal	Canning	3	4.3	3.3	2.6	3.0	6.0–7.5	6.0	Brackish water inundation
	Gosaba	1	2.4	2.5	1.4	2.0	6.5–8.0	7.6	
Andamans	Chouldhari	2	2.8	1.2	1.5	1.7	6.1–10.0	5.7–6.2	Brackish water inundation
Maharashtra	Panvel	2	4.5	4.3	4.0	4.2	4.5–5.6	7.5–7.6	Brackish water inundation
Pondicherry	Karaikal	2	3.3	2.0	1.4	1.6	1.8–8.3	–	Irrigation water with RSC-9.0 meq L^{-1}, EC 1.7 dS m^{-1}

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Enhancing outcrossing potential in hybrid rice

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In spite of a successful hybrid rice research program in India, the nonavailability of good-quality seed of CMS-based hybrids, released in the recent past to farmers at a reasonable price, remains a big challenge (Rai 2004). Among other factors, the inherent low variability of suitable floral traits, which influence outcrossing, in parental lines of the respective hybrids is itself a key factor responsible for the low percentage of seed set (Liang et al 1991, Virmani and Athwal 1974, Yadav et al 1998). Keeping these in view along with the mode of action of some homoeopathic medicine on human reproductive systems, a number of these resources were tried to explore their usefulness in enhancing outcrossing of parental lines of hybrid rice. Among them, Pulsatilla, Agnus Cast, and Acid Phos were found worth investigating (Yadav and Srivastava 2003).

This study used a set of IR58025A/NDR3026-3-1 planted at 2 males:10 females in a plot size of 4 × 5 m^2 in a randomized block design with four replications during the 2001, 2002, and 2003 wet seasons at the Crop Research Station in Masodha (26.47°N, 82.12°E, 113 m altitude). Soil at the experimental field was silty loam, with 0.38% organic carbon, 138.50 kg available N ha^{-1}, 18.35 kg available P ha^{-1}, 172 kg available K ha^{-1}, and pH 7.5. The spacing adopted was 30 cm between male rows, 25 cm between male and female rows, 20 cm between female rows, and 15 cm between hills. A 21-d-old single seedling was transplanted in each hill perpendicular to the wind direction. The recommended package of practices was followed to raise the crop (Yadav and Srivastava 2003). Pulsatilla 200 (SBL) at a concentration of 1:100 (chemical and water) was applied before heading, whereas GA_3 (60 g ha^{-1}) was applied at 5–10% panicle emergence on female lines. Agnus Cast 200 (SBL) and Acid Phos 200 (SBL) were also applied at the same concentration (1:100) on alternate days prior to panicle emergence on male lines. Spraying was done using a knapsack sprayer in the evening during clear weather. Flag leaf clipping and supplementary pollination were also done. Fifteen flowers per plant were randomly marked to record relevant observations (Table 1) (Virmani and Athwal 1974), whereas seed yield was obtained on a per-plot basis. ISTA rules (ISTA 1999) were followed in recording some important seed quality parameters (Table 2).

Table 1. Pollination characteristics of hybrid rice as affected by various treatments using the same homoeopathic medicine (pooled data over 3 y).

Treatment	Female parent (IR58025A)			
	Duration of floret opening (min)	Blooming duration of panicle (d)	Angle of floret opening (°)	Stigma exsertion (%)
GA_3 at 60 g ha^{-1}	196.12	5.41	50.83	68.61
Pulsatilla 200	256.00	6.07	63.52	78.53
GA_3 + Pulsatilla 200	215.10	6.33	65.21	80.10
Control	151.12	5.11	40.23	42.81
LSD 5%	50.79	0.83	5.80	6.90
	Male parent (NDR3026-3-1)			
	Blooming duration of panicle (d)	Residual pollen (%)	Duration of pollen viability (min)	
Agnus Cast 200 + Acid Phos 200	7.4*[a]	87.34**[b]	12.22**	
Control	6.0	65.00	7.81	

[a]*P = 0.05, [b]**P = 0.01 (t test).

Table 2. Seed yield, seed quality parameters, and longevity of NDRH2 as affected by some treatments (pooled data over 3 y).

Treatment	Seed set (%)	Seed yield (t ha^{-1})	1,000-seed wt (g)	Seed discoloration (%)	Opened glume (%)	Germination (%)[a]	Vigor index[a]
GA_3 at 60 g ha^{-1}	40.91	1.52	18.03	12.45	28.16	78.29	1,087.13
Pulsatilla 200	35.50	1.25	18.20	8.25	1.20	89.13	1,351.09
GA_3 + Pulsatilla 200	54.27	2.19	18.27	5.19	1.40	87.91	1,296.42
Control	15.18	0.53	18.25	14.10	20.93	79.51	1,125.52
LSD 5%	5.35	0.29	ns	6.27	7.09	2.19	26.90

[a]Six-month storage after harvest under ambient conditions. [b]ns = nonsignificant.

Pulsatilla 200 was found most effective in improving significantly the duration of floret opening, blooming duration of panicle, angle of floret opening, and stigma exsertion in comparison with the control and GA_3 application. The application of Agnus Cast 200 and Acid Phos 200 increased significantly the blooming duration of panicles, the percentage of residual pollen, and the duration of pollen viability (Table 1). These enhanced outcrossing characteristics led to an increase in seed set (54.27), seed yield (2.2 t ha^{-1}), and various quality parameters and longevity, even in comparison with hybrid seed obtained after GA_3 application (60 g ha^{-1}), a common treatment in hybrid rice seed production (Table 2). The results show that such eco-friendly treatments can be successfully used in the production of precious hybrid seed in rice particularly and could also be tried for some other hybrid cultures.

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The Njavara collection: a composite but distinct gene pool

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In India, the ancient books *Charakasamhitha* and *Susruthasamhitha*, which embody the principles of Ayurveda (traditional health care system), describe the medicinal properties of a rice strain called "Sashtika." It is believed that "Njavara," a medicinal rice strain from Kerala State, India, is a Sashtika. Njavara grains are used for a variety of purposes—as base material for njavarakizhi, an acclaimed ayurvedic treatment for rheumatic complaints; as a supplementary diet for the underweight; and as a health drink. The medicinal and nutritive properties of Njavara have recently received wide recognition and have caught the eye of the corporate sector. However, apart from sporadic reports on the agronomic evaluation of Njavara (Menon and Potty 1998), no information on its genetic structure is available. Here, we report the molecular marker-assisted characterization of Njavara germplasm, which we earlier collected and evaluated morphologically (Sreejayan et al 2003).

Genomic DNA isolated from five individuals each from 28 collections was subjected to random amplified polymorphic DNA analysis using a selected set of nine primers to assess intracollection heterogeneity. A total of 40 distinct electromorphs were selected. The genetic relationships between the electromorphs were examined, along with six other rice varieties, using 1,106 amplified fragment length polymorphism (AFLP) markers generated by 12 primer combinations. A representative AFLP profile is given in Figure 1. With a few exceptions, the Njavara collections were clustered according to three morphotypes identified earlier: tall yellow, dwarf yellow, and dwarf black (Sreejayan et al 2003). The other varieties formed a group distant from Njavara (Fig. 2).

The genetic relationship between Njavara and a larger set of other varieties (including 19 traditional and 6 improved varieties) was assessed using data generated from five microsatellite markers. The 40 Njavara genotypes were separated into a distinct cluster in the resulting dendrogram.

The results show three distinct varietal types of Njavara. Though it represents a composite of varietal types, its gene pool, as a group, is distinct from that of other rice varieties, including traditional ones that have been grown with Njavara in Kerala since ancient times. Njavara may represent either an ancient gene pool that remains unadulterated

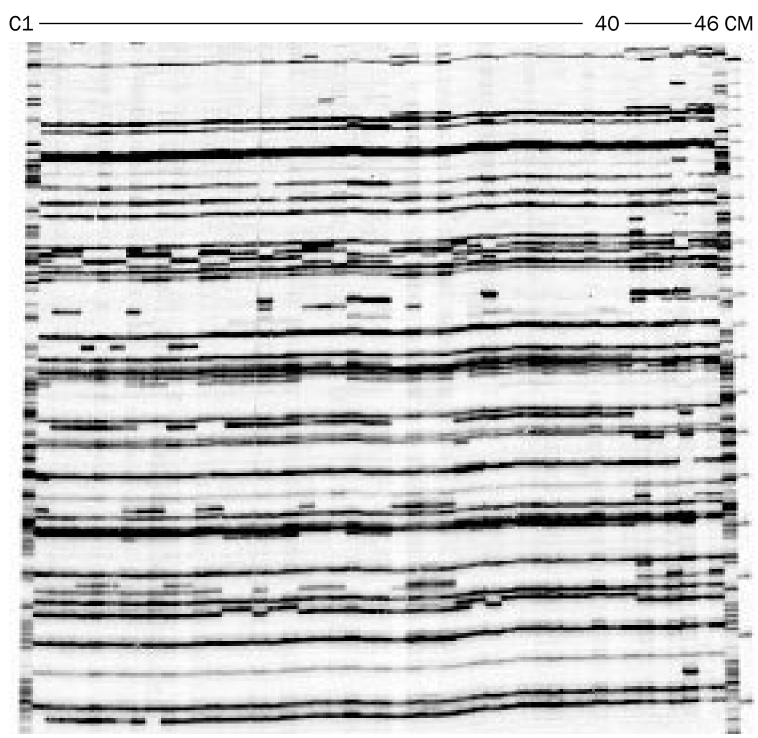


Fig. 1. AFLP profile of 40 electromorphs of Njavara and six other rice varieties generated by the primer combination E-TC × M-CTA. Lanes 1–40: Njavara electromorphs; 41–46: other rice varieties; C: control DNA; M: 30–330-bp DNA ladder.

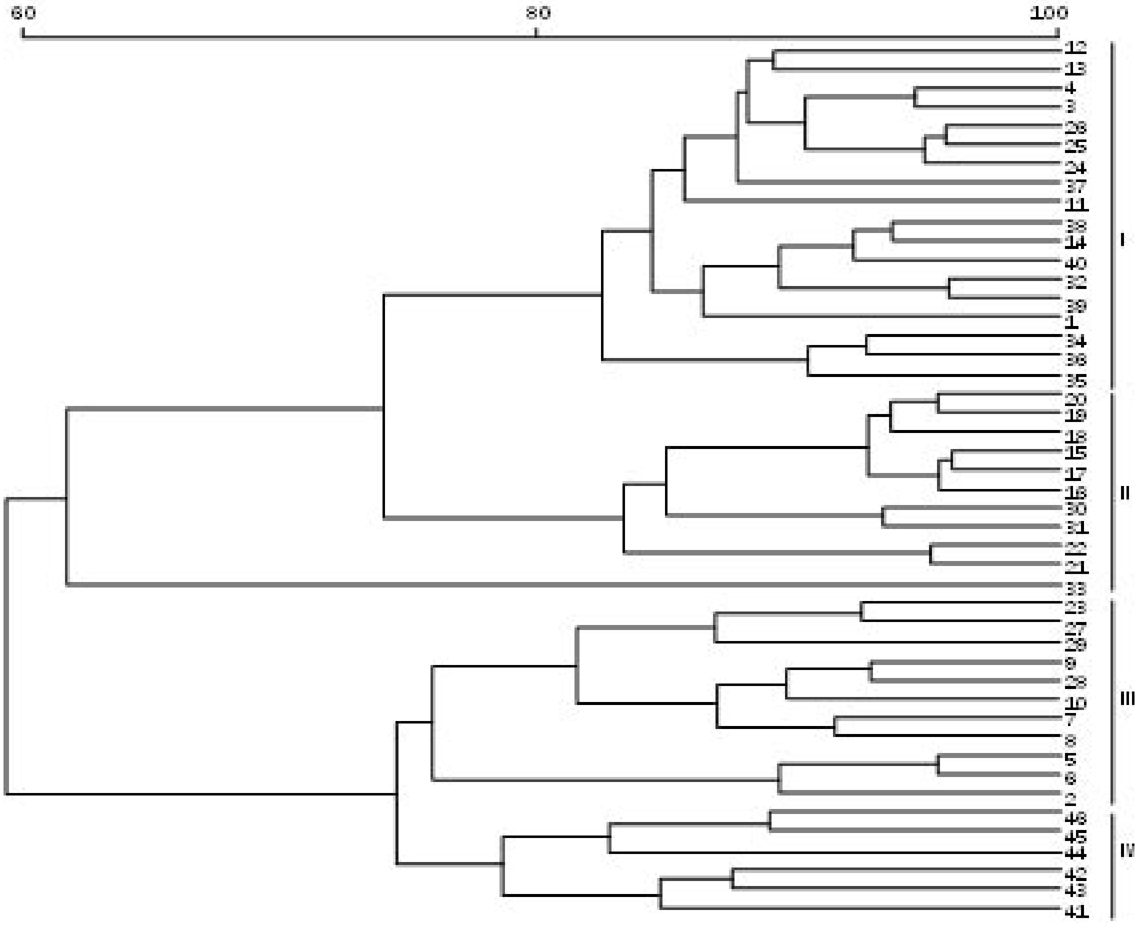
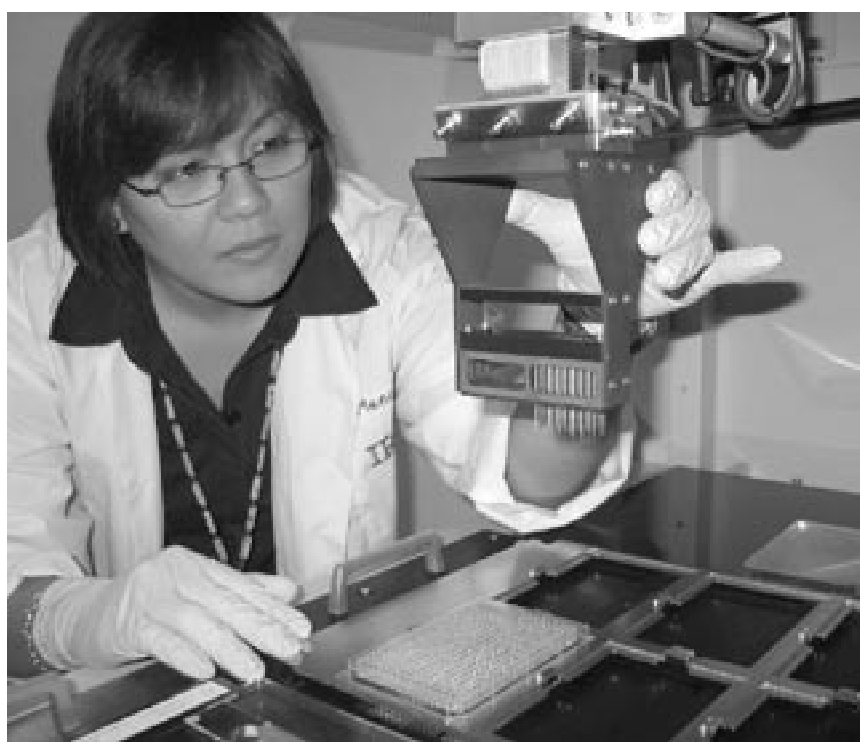


Fig. 2. UPGMA dendrogram of the 40 electromorphs of Njavara and six other rice varieties based on AFLP data. I = tall yellow, II = dwarf yellow, III = tall black, IV = other rice varieties.

or a distinct lineage that has probably undergone independent divergence after its separation from the ancestral gene pool. Perhaps, Njavara could be a suitable organism with which to study "genetic events" associated with crop evolution. It also could be an ideal source of desirable genetic traits to improve the nutritive value of rice.



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Effect of neem seed kernel extracts on stem borer damage and yield of upland rice in southeastern Nigeria

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Stem borers are considered important insect pests of rice in most parts of the world. They have been implicated as the major constraint to rice production in West Africa (Ukwungwu 1990). Reliable data on yield loss caused by stem borers are not available in southeastern Nigeria. However, a screenhouse experiment at Badeggi, in the middle belt of Nigeria, showed that yield loss caused by *Diopsis thoracica* (West) ranged from 5% to 19% (Akinsola 1980). Dakuo et al (1991) reported a yield loss of 33% in irrigated rice caused by lepidopterous stem borers (*Chilo zacconius, C. diffusilineus, Maliarpha separatella,* and *Sesamia calamistis*) in Burkina Faso.

Various control strategies have been adopted against stem borers, one common method being the use of synthetic insecticides, which can be environmentally disruptive and can result in the accumulation of residues in the harvested produce (Chinniah et al 1998). The use of synthetic insecticides is rare in southeastern Nigeria, where farmers produce the bulk of the rice. Although some risks accompany the use of synthetic insecticides, some insecticides of plant origin are safer to handle and use. Neem products are examples of such plant-derived insecticides, which have been used in some Asian countries. Their use on field crops is not yet popular in Nigeria. Our study reports the effect of the frequency of application of 5% neem seed kernel extract (NSKE) on rice stem borer damage and grain yield.

The experiment was laid out in a randomized complete block design with three replications. Plot size was 4 m × 2 m with 0.75-m borders. A medium-duration upland rice variety, FARO 48, was used. Five seeds were planted per hole at a spacing of 20 cm within rows and 25 cm between rows. The experimental treatments were application of 5% NSKE at early tillering; maximum tillering; early booting; early tillering and early booting; maximum tillering and early booting; early tillering, maximum tillering, and early booting; and an untreated control.

The 5% NSKE used was prepared using the method described by Karim et al (1992). It was sprayed to the runoff point at each application. Standard cultural practices as recommended for the crop were followed. The experiment was conducted in 2000 and 2001 at the substation of the National Cereal Research Institute located at Amakama, Abia State, southeastern Nigeria. Data collected were percent whitehead (WH) and grain yield from a 3 m × 2 m area per plot.

The application of NSKE at different plant growth stages reduced WH incidence but the values were not significantly different from that of the untreated control plot in 2000 (see table). However, application from maximum tillering onward reduced WH significantly compared with

Stem borer damage and yield of upland rice FARO 48 as influenced by application of neem seed kernel extracts.

Treatment	% whitehead[a]		Yield (kg ha^{-1})	
	2000	2001	2000	2001
Control	29.38 a	31.27 b	400 a	833 a
Application at early tillering	26.90 a	30.63 b	367 a	867 a
Application at maximum tillering	19.80 a	18.69 a	717 b	917 a
Application at early booting	18.84 a	13.65 a	733 b	1,167 b
Application at early tillering and early booting	22.95 a	14.81 a	750 b	1,200 b
Application at maximum tillering and early booting	16.19 a	12.00 a	1,083 c	1,333 b
Application at early tillering, maximum tillering, and early booting	13.08 a	11.49 a	1,033 c	1,417 b
CV (%)	–	–	33.1	9.4

[a]Means in the same column followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level.

that of the untreated control plot in 2001 (P>0.05). Application of NSKE resulted in significantly higher grain yield than that of the untreated control in 2000, except for application at early tillering. A similar trend was seen in 2001, except that the plots that received treatments at maximum tillering also did not produce significantly higher yield than the control.

Two applications of NSKE, at maximum tillering and at early booting, gave the highest grain yield of 1,083.3 kg ha^{-1} in 2000, whereas three applications, at early tillering, maximum tillering, and early booting, gave the highest grain yield of 1,416.7 kg ha^{-1} in 2001. However, there was no significant difference in grain yield in plots that received two applications (at maximum tillering and early booting) and those that received three applications (at early tillering, maximum tillering, and early booting). Reduction of WH from 2.5–16.31% in 2000 and 0.6–19.8% in 2001 from control plots produced 8.3–158.3% more yield in 2000 and 4–70% more in 2001. The reason for the greater yield than WH reduction by NSKE application is not clear. An understanding of the mechanism behind yield increases is essential before recommendations for adoption are made.

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New record of chrysomelid damage on rice panicles

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The rice crop in the Cauvery delta region of Tamil Nadu State in India was found to be damaged by a chrysomelid, *Cryptocephalus sehestedti* Fabricius (Chrysomelidae: Coleoptera). The identity of this insect pest that invaded the crop at the reproductive stage was confirmed by K.D. Prathapan of Kerala Agricultural University and K. Gunathiliagaraj of Tamil Nadu Agricultural University.

The beetles were found to feed on the spikelets at the flowering and milky stages of the crop. The adult beetle is 2.35 mm long, hemispherical, and yellowish orange with a longitudinal black streak in the mid-elytra (Fig. 1). The beetles were scattered and damage was noticed in patches. The adults escape by making swipe movements when disturbed. Feeding site and host of the larva cannot be established.

The beetle nibbles at the spikelet and feeds on the floral parts inside, resulting in an empty grain with a characteristic short hole (Fig. 2). A single beetle could damage all the spikelets in a panicle, resulting in total chaffiness. The pest was found active in both the dry and wet seasons, coinciding with the flowering stage of the crop. Peak activity was observed from the last week of August to the second week of September, depending on the existence of a suitable crop stage. Coarse-grained varieties such as TKM9, ASD16, and CR1009 were preferred over fine-grained types.

Fig. 1. A *Cryptocephalus sehestedti* F. adult.

There was no report of this rice pest elsewhere in the world. However, two references mentioned *C. sehestedti* as a minor pest: (1) *C. sehestedti* adults were described as feeding on a millet crop in Vasantharaj (2001) and (2) *C. sehestedti* has been listed as one

Fig. 2. Rice panicle showing damaged spikelets.

of the Coleopterans damaging the tree crop *Casuarina equistifolia* J.R. & G. Duke (1983, and www.hort.purdue.edu/neecrops/duke_energy/refa-f.html, Purdue University, USA).

Neither report mentioned what caused the damage [larva (grub) or adult] or exactly what plant part the insect fed on.

Further, quality data cannot be generated as the damaged panicles were very few. In a 0.4-ha rice field, less than 10 panicles showed damage. However, field observations confirmed that all the spikelets in a panicle were damaged (total chaffiness with a short hole on the glumes).

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Rat pest species breeding patterns in the trap barrier system plus a trap crop (TBS + TC) at the PhilRice-CES farm: management implications

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The rice field rat, *Rattus tanezumi*, is the principal non-native rodent pest species reported in the Philippines. A medium-sized murid rodent with a tail that is longer than its head and body (Stuart 2004) is considered to cause serious damage to rice at both pre- and postharvest stages (Singleton 2003, Joshi et al 2000).

In the Philippines, the use of synthetic rodenticides is the most common means of rat control. However, an ecologically based rodent management (EBRM) approach that uses a trap barrier system plus trap crop (TBS + TC) has recently been found to be widely successful on Asian rice farms (Singleton et al 2001). Effective management of *R. argentiventer* in Indonesia and Vietnam using TBS + TC relies on removing female rats from the population before the rice booting stage, before they are able to successfully raise the first litter of the year (Singleton et al 1999). This paper is the first report on the breeding dynamics of *R. tanezumi* caught in a TBS + TC.

During the 2004 wet season, a TBS (22 m × 43 m) with multicapture traps was constructed at PhilRice-CES on 5 June 2004. Then, 22-d-old seedlings of hybrid rice Mestizo 3 were transplanted on 7 June at 20 cm × 20-cm spacing inside the TBS. All the fields surrounding the TBS were planted to rice 6 wk later. After the harvest of the trap crop inside the TBS,

Table 1. **Body measurements of rats trapped in TBS + TC, 2004 wet season, PhilRice-CES.**

Crop stage	Sex[a]	Tail length (mm)[b]	Head + body length (mm)[b]	Ear length (mm)[b]	Pes length (mm)[b]	Total weight (g)[b]
Seedling	Male (1)	110.0 ± 0.0	105.0 + 0.0	–[c]	–	–
	Female (4)	131.3 ± 22.5	123.7 ± 20.6	–	–	–
Vegetative	Male (15)	146.3 ± 15.9	146.7 ± 16.5	–	–	105.3 ± 20.1
	Female (8)	145.6 ± 15.1	144.2 ± 17.3	18.5 ± 0.7	33.0 ± 0.0	104.1 ± 11.7
Booting	Male (3)	160.8 ± 13.4	158.4 ± 2.1	18.6 ± 3.5	35.4 ± 0.7	92.0 ± 7.1
	Female (3)	160.8 ± 17.6	158.4 ± 5.0	18.6 ± 2.1	35.4 ± 0.6	92.0 ± 21.8
Flowering	Male (1)	175.0 ± 0.0	140.0 ± 0.0	20.0 ± 0.0	34.0 ± 0.0	84.0 ± 0.0
	Female (0)	–	–	–	–	–
Maturity	Male (4)	173.8 ± 8.5	173.7 ± 7.5	23.7 ± 7.5	36.0 ± 5.9	–
	Female (0)	–	–	–	–	–
Stubbles/ratoons	Male (19)	155.7 ± 17.3	149.3 ± 17.0	16.7 ± 3.2	33.9 ± 7.6	111.8 ± 40.5
	Female (6)	143.2 ± 23.8	140.0 ± 29.0	17.3 ± 2.1	33.5 ± 2.2	93.4 ± 53.0

[a]Sample size (in parentheses). [b]Mean ± SD for each measurement. [c]– = data not available.

it was rationed to monitor rat breeding.

Every morning, soon after dawn, multicapture traps were inspected for every rat caught. Using techniques specified in the *Field methods for rodent studies in Asia and the Indo-Pacific* (Aplin et al 2003), the following observations and measurements were recorded: sex, head + body length, tail length, ear length, pes (hindfoot) length, weight, and vaginal state. In the rationed crop inside the TBS, additional observations were made on the reproductive status of the trapped rats.

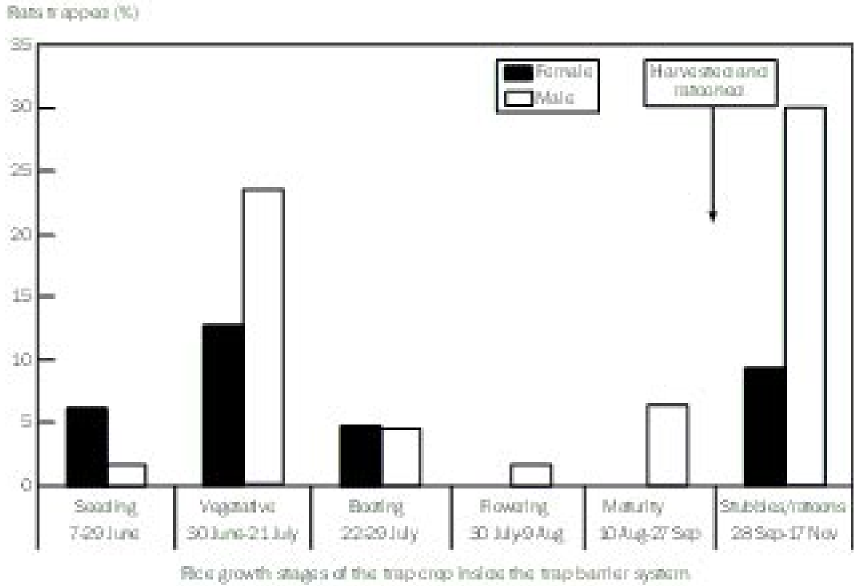
Table 2. Vaginal state of female rats trapped at different rice growth stages in TBS, 2004 wet season, PhilRice-CES.

Crop stage	Vaginal state (%)			
	1[a]	2[b]	3[c]	4[d]
Seedbed				
Seedling	5	0	0	15
After transplanting				
Vegetative	0	0	25	15
Booting	0	0	5	10
Flowering	0	0	0	0
Maturity	0	0	0	0
After harvest				
Stubbles/ratoons	5	0	10	10

[a]Not open (membrane intact or imperforate). [b]Not open but membrane broken (perforate). [c]Open with small hole. [d]Open with large hole.

Based on external features and body measurements, we identified the rat species as *R. tanezumi* (formerly known as *R. rattus mindanensis*). A total of 64 adult *R. tanezumi* were caught in the TBS + TC and 38.2% of these were female (Table 1). About 80% of the trapped females were caught during the early growth stage of the rice crop (see figure). Interestingly, 90% of them had an open vagina, indicating that the females were in a state of excitability and would have accepted the males and conceived (Table 2). However, we failed to cut open and inspect the uterine scars, embryos, and scrota of all rats caught before rationing the trap crop. This indicates that the onset of maturity and breeding of *R. tanezumi* at the PhilRice-CES farm occur early in the rice growth cycle. This coincides with the reproductive stage of the rice plant, thereby providing an abundant food supply. Based on these preliminary results, we expected rat numbers to increase and also to damage rice, starting at maximum tillering and continuing until crop maturity.

Rats were attracted to the rationed rice trap crop inside the TBS as surrounding rice crops were harvested. Six female rats were trapped, four of them adults. They were pregnant, with the number of fetuses ranging from 12 to 14. Meanwhile, 19 males were trapped and 12 were active, as their scrota were descended. This is possible because, after the rice harvest, *R. tanezumi* feeds on other alternative food sources. We observed that the entrance hole of most rat burrows at PhilRice-CES had several predated shells of the golden apple snail (GAS) *Pomacea canaliculata* (Lamarck). GAS is an invasive alien species introduced from Argentina as a protein supplement in the diet of Filipino farmers. Currently, GAS is a serious pest of direct-seeded rice, also serving as an intermediate host of the rat lungworm *Angiostrongylus cantonensis*, which causes eosinophilic



Percent female and male rats trapped in TBS + TC at various rice growth stages and in a rationed trap crop, 2004 wet season, PhilRice-CES.

meningoencephalitis. This poses serious health hazards to rice farmers.

Therefore, at the PhilRice-CES farm, an institutewide management for *R. tanezumi* control should begin at least 2–3 wk before the establishment of the rice crop. The management options recommended are burrow excavation, physical killing, and setting up of a TBS near rat habitats and in areas with a history of high rat damage. All these options executed at the right time and place collectively will reduce the buildup of source rat populations and prevent damage to succeeding crops, thereby reducing sole dependence on sustained poison-baiting techniques. We have recently begun monitoring rats in active burrows to better understand the rat breeding cycle at PhilRice-CES.

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Interaction among resistant rice genotypes, whitebacked planthopper *Sogatella furcifera* (Horvath), and egg parasitoid *Anagrus* nr. *flaveolus*

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Ecological approaches such as the use of resistant varieties are major components of pest management in rice. Rice cultivars resistant to whitebacked planthopper (WBPH) *Sogatella furcifera* (Horvath) (Hemiptera: Delphacidae) are important in integrated pest management. A study was carried out to elucidate the interactions between rice genotypes resistant to WBPH and its egg parasitoid *Anagrus* nr. *flaveolus* (Hymenoptera: Mymaridae). Ten rice genotypes—PSBRc 10, Babawee, IR36, IR72 (resistant), A5174, A5368, A5301, A5372 (moderately resistant), IR26 (susceptible), and TN1 (highly susceptible)—were used in the screenhouse and microplot experiments.

In the screenhouse experiment, 30-, 40-, and 60-d-old potted plants of selected genotypes with WBPH eggs were exposed in the field for natural egg parasitization and the percentage of parasitization was calculated (Otake 1967). Each genotype was replicated five times. In the microplot trial, the selected test genotypes were raised in microplots (100 × 100 × 60 cm) in three replications under unprotected conditions. A sample of 25 tillers was taken at random on 30-, 45-, and 60-d-old plants, observed for parasitized and unparasitized WBPH eggs, and the percentage of parasitization was determined (Otake 1977). The data obtained were analyzed using pooled analysis of variance.

The results of the screenhouse experiment revealed that parasitization of the WBPH eggs by the egg parasitoid *A.* nr. *flaveolus* was more on resistant genotypes than on susceptible TN1 on 30-d-old plants (Table 1). Parasitization was highest on resistant genotype Babawee with 56.8% parasitization, five times more than with susceptible TN1, which had 12.0%. Resistant genotypes PSBRc 10, A5301, A5372, and IR72 had 41.2%, 38.8%, 35.2%, and 34.0% parasitization, respectively. On 45-d-old plants, parasitization on resistant genotypes ranged between 13.2% and 41.8%, whereas on susceptible TN1 it was 7.6%. On resistant genotypes, parasitization by *A.* nr. *flaveolus* was two to six times higher.

The parasitization on 60-d-old plants showed a trend similar to that of the 30- and 45-d-old plants. Resistant genotypes Babawee (21.0%) and PSBRc 10 (19.8%) had six to seven times more parasitization than susceptible TN1 (3.8%). As plant age increased, parasitization by *A.* nr. *flaveolus* decreased. Parasitization was higher on Babawee (39.9%) and was five times more than on susceptible TN1 (7.8%).

In the microplot trials using different ages, the parasitization of WBPH eggs by the egg parasitoid *A.* nr. *flaveolus* on selected rice genotypes ranged from 20.9% to 48.0% (Table 2). On 30-d-old plants, resistant genotypes Babawee (48.0%), IR72 (43.8%), PSBRc 10 (43.4%), A5368 (41.9%), and A5372 (40.2%) had the highest parasitization. Susceptible IR26 had the lowest parasitization (24.3%), significantly different

Table 1. Parasitization of WBPH eggs by *Anagrus* nr. *flaveolus* on different rice genotypes (screenhouse experiments).[a]

Genotype	Parasitization (%) Age of plant			Mean
	30-d-old	45-d-old	60-d-old	
IR36	27.6 ef	25.8 efg	14.4 jk	22.6 D
IR72	34.0 bcd	23.6 fgh	12.0 kl	23.2 D
Babawee	56.8 a	41.8 b	21.0 ghi	39.8 A
PSBRc 10	41.2 b	33.6 d	19.8 hi	31.5 B
A5174	21.4 ghi	13.2 jk	7.4 lm	14.0 E
A5301	38.8 bc	31.0 de	17.8 ij	29.2 BC
A5368	30.4 de	24.0 fgh	11.4 kl	21.9 D
A5372	35.2 cd	26.0 efg	13.0 cdjk	24.7 CD
IR26	17.8 ij	12.0 kl	9.2 kl	13.0 E
TN1	12.0 kl	7.6 lm	3.8 m	7.8 F

[a]Mean of five replications. In a column, means followed by the same small letter are not significantly different at $P = 0.05$ by Duncan's multiple range test. In a column, means followed by the same capital letter are not significantly different at $P = 0.05$ by DMRT.

Table 2. Parasitization of WBPH eggs by *A.* nr. *flaveolus* on different rice genotypes (microplot experiment).[a]

Genotype	Egg parasitization (%) Age of plant 30-d-old	45-d-old	60-d-old	Mean
IR36	39.2 b-f	33.1 efg	24.3 h	32.2 AB
IR72	43.8 ab	35.6 def	25.4 h	34.7 A
Babawee	48.0 a	38.3 b-f	23.4 h	36.6 A
PSBRc 10	43.4 abc	39.6 b-f	26.5 h	36.5 A
A5174	39.4 b-f	36.6 c-f	21.1 h	32.4 AB
A5301	39.9 b-f	39.1 b-f	25.8 gh	35.0 A
A5368	41.9 a-d	38.6 b-f	22.8 h	34.4 A
A5372	40.2 b-e	36.7 b-f	20.9 h	32.6 AB
IR26	24.3 h	26.7 gh	28.0 gh	26.3 B
TN1	34.4 b	32.8 fg	26.7 gh	31.3 AB

[a]Mean of three replications. In a column, means followed by the same small letter are not significantly different at $P = 0.05$ by Duncan's multiple range test. In a column, means followed by the same capital letter are not significantly different at $P = 0.05$ by DMRT.

from susceptible TN1 (34.4%). Parasitization on resistant genotypes ranged from 33.1% to 39.6% and all were on a par among themselves, except for IR36 on 45-d-old plants. Susceptible IR26 and TN1 recorded 26.7% and 32.8% parasitization, respectively, and were significantly different among themselves and from other resistant genotypes. On 60-d-old plants, there was no significant difference in the extent of parasitization between resistant and susceptible genotypes. Parasitization on resistant genotypes ranged between 32.2% and 36.6%, whereas that on susceptible TN1 was 31.3%.

The high level of parasitization on the resistant genotypes could be attributed to the smaller number of eggs per hill and number of eggs per egg mass compared with those on susceptible TN1. The resistant rice plants also slowed down the growth rate of WBPH, thereby making it available to natural enemies for a longer time and increasing its mortality. Price et al (1980) reported that the longer life cycle of the host can be successfully exploited by the natural enemies.

Chantarasa et al (1984) described an inverse density-dependent relation between parasitization and size of host egg mass. Moreover, the adult parasites spent more time on the resistant genotypes locating the feeding and oviposition sites, during which time more eggs were parasitized (Price 1986).

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Effects of *cow-five*, a fermented mixture of cow products, and soapnut on leaffolder

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Called *Panchakavya* in Tamil Nadu, *cow-five* is a fermented mixture of cow dung, urine, milk, ghee, and curd (yogurt). Of late, farmers have started to use it for crop protection as it is considered to possess pest control properties, probably a feeding deterrent action (Natarajan 2003). We conducted two screenhouse experiments and a field experiment in irrigated lowland rice during 2003-04 at ACRI to evaluate its efficacy against the leaffolder *Cnaphalocrocis medinalis* (Guenée). Soapnut (*Sapindus saponaria* L., *sapindaceaea*) solution was also evaluated as a sticking agent.

To prepare *cow-five*, 500 g of ghee (Aavin) was first added to 5 kg of fresh cow dung and mixed well into a paste. This was kept in an airtight container for 3 d. On the fourth day, cow urine (3 L), milk (2 L), curd (2 L), and water (5 L) were added to the mixture and mixed well in a wide-mouthed plastic container. This semisolid stock was stirred well every morning and every evening, letting it undergo fermentation in a shady place. About 15 L of crude yellowish green mixture of *cow-five* was ready for use in a week's time and it was usable for at least 2 mo. The mixing of cow dung and ghee on the first day was necessary to keep the preparation moist. From this *cow-five* stock, a 3% solution was prepared by adding water before the experiments. Soapnut solution (0.5%) was prepared by soaking crushed soapnut berries overnight at the rate of 5 g L^{-1} of water before filtering this solution through a muslin cloth.

In the screenhouse experiments, 25-d-old rice seedlings (Co 43) were transplanted, one each in soil-filled plastic tea cups (6 cm diameter, 5 cm high). The cups, with a few holes punched just above the bottom to allow lateral root growth, were placed in water-filled trays (28 × 23 × 7 cm). Three weeks later, foliar sprays were made on these plants using a hand atomizer to run-off level. There were five treatments, including a water-spray control, replicated 10 times in a completely randomized design. The next day, field-collected *C. medinalis* larvae (3rd instar) were released (two per plant) in a 6.4-cm-diameter mylar cage. The leaf area consumed by the larvae was recorded after 48 h by measuring the length and width of the parts of the leaf affected. The affected parts are seen as parallel streaks of varying lengths. The length of each streak on the leaf was measured using a scale and the leaf area consumed by the larvae was calculated by multiplying the total length of all such streaks on a leaf by 1.0 mm, the average width of one streak. To take a measurement, the leaf was clipped off the plant and placed between two transparent glass plates (0.2 mm thick, 12.0 × 27.0 cm size) to prevent the leaves from rolling. This experiment was repeated twice. The data were transformed into square root values before analysis of variance (ANOVA) and the means were separated by LSD.

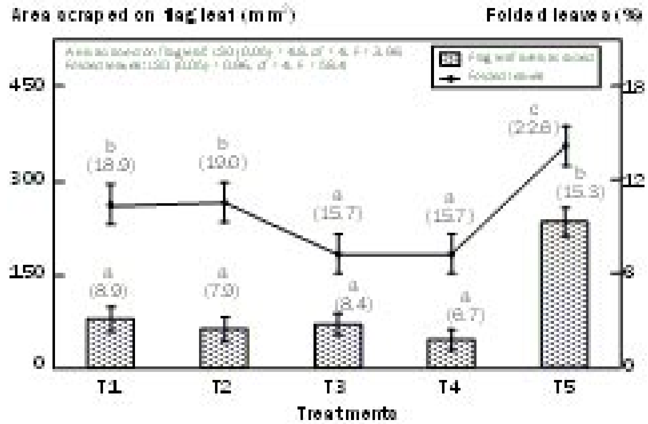
In the field experiment, 21-d-old seedlings were transplanted at 20 × 20-cm spacing in 4 × 4.5-m plots laid out in a randomized block design with four replications. Treatments were the same as those mentioned earlier. The normal package of practices was followed in growing the crop. Three sprayings were given at weekly intervals starting at 65 d after transplanting. Post-treatment counts were made 7 d after each spray. The percentage of folded leaves was assessed plot-wise by counting the total number of leaves and the affected ones on 10 randomly selected plants. As was done in the screenhouse experiments, linear feeding injury to the flag leaves was assessed by collecting 10 leaves in each plot at random. The transformed data were subjected to ANOVA.

The results indicated a low to moderate effect of *cow-five* on *C. medinalis*, especially in combination with soapnut solution. In the screenhouse, when used alone, 3% *cow-five* was not effective against *C. medinalis* (see table). However, when mixed with 0.5% soapnut solution, it was able to reduce feeding significantly ($P < 0.05$) compared with the control, but it was inferior to 0.07% endosulfan. In the field, 0.07% endosulfan was twice as effective as 3% *cow-five* with or without 0.5% soapnut solution, which was on a par with 0.07% endosulfan (see figure). However, injury to the flag leaves indicated no differ-

Effect of *cow-five* on *C. medinalis* in the screenhouse.[a]

Treatment	Mean leaf area consumed (mm^2) Experiment 1	Experiment 2	Pooled mean
Cow-five (3%)	357.7 (18.9) c	230.0 (15.2) c	293.9 (17.2) cd
Cow-five (3%) + soapnut solution (0.5%)	278.9 (16.7) b	159.0 (12.6) b	218.9 (14.8) b
Soapnut solution (0.5%)	303.3 (17.4) bc	220.0 (14.8) bc	261.7 (16.2) bc
Endosulfan (0.07%) (Endocel 35 EC)	96.9 (9.9) a	77.0 (8.8) a	86.9 (9.4) a
Control	376.7 (19.4) c	277.0 (16.7) c	326.8 (18.1) d
SE	1.0	1.1	0.8
LSD (0.05)	2.0	2.3	1.6

[a]Mean of 10 replications. Numbers in parentheses are $\sqrt{x + 0.5}$ transformed values. In a column, means followed by the same letter are not significantly different at the 5% level by LSD.



Effect of *cow-five* on feeding by *C. medinalis* larvae on flag leaves and on the percentage of folded leaves in the field. T1, *cow-five* (3%); T2, *cow-five* (3%) + soapnut solution (0.5%); T3, soapnut solution (0.5%); T4, endosulfan (0.07%); T5, control; vertical lines indicate standard error. Numbers in parentheses are angular (% folded leaves) and $\sqrt{x + 0.5}$ (scraping on flag leaves) transformed values.

ences in treatment effects. There was no significant difference among the treatments in terms of certain plant characters and yield.

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Erratum:

The name of the first author of the article "Farmers' participatory evaluation of saline-tolerant rice varieties" on p 83-84 of the IRRN December 2004 issue should have been **K. Ponnusamy** instead of L. Ponnusamy. We apologize for the error.

Off-season survival of golden apple snails in the Philippines

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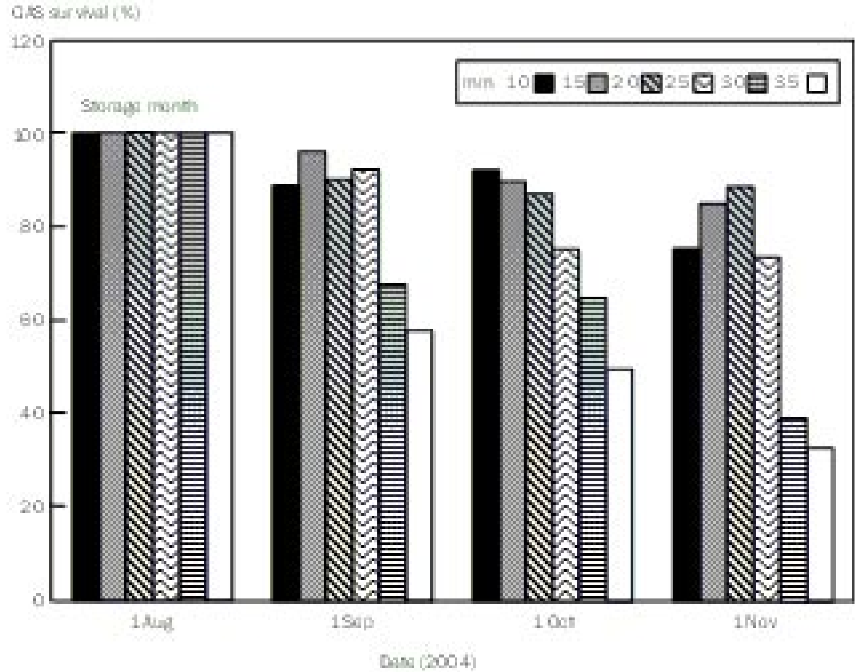
Golden apple snail (GAS) *Pomacea canaliculata* (Lamarck), an invasive species, was first introduced in southern and eastern Asia around 1980. It came from Argentina and Taiwan, meant for local consumption and for export as a gourmet item. In its introduced range, it became the top pest of aquatic crops such as rice and taro.

Reducing GAS densities during the off-season (nonrice-growing months) should significantly reduce crop damage during rice-planting months, but the lack of information on off-season GAS survival hinders the development of an effective management strategy. Hence, we estimated the percent survival of various GAS sizes for 3 mo after storage in nylon net bags (680 cm long × 450 cm wide) at the PhilRice screenhouse.

On 1 Aug 2004, about 5,000 GAS of various sizes were collected from the PhilRice-Central Experiment Station waterlogged rice fields, irrigation canals, and fish ponds. GAS were sorted by size (10, 15, 20, 25, 30, and 35 mm) to a range of ± 1 mm using a digital vernier caliper (Mitutoyo®). For each GAS size, 495 individuals were placed in dry nylon net bags, with 99 individuals per bag replicated five times. The net bags with GAS were hung on a wire lining to prevent predation by rats and fire ants and to provide good exposure to atmospheric conditions.

Exactly 1 mo after storage, the first observation on GAS survival was made. Thirty-three GAS were removed randomly from each net bag and immersed in a plastic tray full of water. After 25 min, the



Percentage survival of golden apple snails of various sizes at different dates after storage in net bags.

dead and live GAS were recorded in each size category. Dead GAS had the following signs: their operculum did not open or retract to external stimuli, they continued to float on the water surface, and they were immobile. Similar observations were made on the remaining stored GAS in October and November using the same sampling procedures and sample size. GAS survival (%) for each size group was computed using the formula: number of GAS alive in the specific GAS size group/total GAS observed for the specific GAS size × 100.

GAS survival, irrespective of GAS size on the day of storage, was 100%. The lowest survival was observed on 30- and 35-mm GAS (see figure). Generally, GAS survival patterns decreased with length of storage. The increased mortality of large-sized GAS could be attributed to their higher metabolic rates during aestivation (dormancy), thereby depleting reserve protein (energy) sources faster. We observed that the large GAS failed to tightly seal their operculum, which may have enhanced the loss of body fluids. Also, we noticed several larvae of adult saprophytic flies coming out of the partially closed operculum. Again, this condition would have provided easy access for saprophytic flies to lay eggs. Though our experimental setup is devoid of soil and the GAS were exposed to the open environment in nylon net bags, we recorded surprisingly high survival on the 10-, 15-, 20-, and 25-mm GAS (75.7%, 85%, 88.3%, and 74.2%). This suggests that, under field conditions and disregarding natural predation by rats and fire ants, a much higher survival is expected as GAS are buried deep into the soil and are less exposed to environmental stresses. We are now investigating whether various land cultivation methods after the rice harvest will enhance natural GAS mortality.

Evaluating integrated nutrient management for the *biasi* system of rainfed rice cultivation

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Biasi is a set of cultural operations traditionally practiced in direct-seeded rice. In this operation, the field is plowed by an indigenous plow in standing water 30–50 d after emergence. Bullock plowing often followed planking and *chalai* (thinning and distribution) operations. This system is very popular in the eastern region of India; about 75% of the area (25.5 million ha) is under the *biasi* system. The effectiveness of the system greatly affects yield. Often, operation is delayed because there is less rain to flood the field. The post-*biasi* operation, which is done to redistribute seedlings, has high labor requirements and is costly. The other major drawbacks are high plant mortality (38–40%) and heavy weed intensity. It is important to evaluate a suitable integrated nutrient management system under *biasi* to increase yield with minimal operational cost. Use of green manure, especially *Sesbania rostrata*, which nodulates in roots as well as in stems, gives better performance and maintains the nutrient supply. A significant savings of 40 kg N ha^{-1} was recorded by incorporating 40-d-old *S. rostrata* in a standing rice crop under *biasi* (IGKV 1994). Green manure incorporation will thus improve yield.

A field experiment was conducted in a farmer's field near IGAU during the 2000-01 kharif under rainfed conditions. It was laid out in a randomized block design with four replications. The treatments consisted of no fertilizer, with inorganic fertilizer, and a combination of inorganic plus biofertilizer—0-0-0 kg NPK ha^{-1} (T_1), 60-30-30 kg NPK ha^{-1} (T_2), and 30-30-30 kg NPK ha^{-1} + *S. rostrata* + phosphorus-soluble bacteria (PSB) (T_3). Rice variety IR36 (at a seeding rate of 100 kg ha^{-1}) and *S. rostrata* (at 10 kg ha^{-1}) were mixed and then broadcast. Initially, powdered PSB at 5 g kg^{-1} of seed was thoroughly mixed with the rice seed. *Biasi* was done at 40 d after sowing (DAS), followed by *chalai*. At the same time, *S. rostrata* was buried in the soil and allowed to decompose. Other pre- and postharvest observations were made and analyzed. The pooled data are presented in Tables 1–3.

No treatment had a significant effect on the plant population before *biasi* (Table 1). Treatment T_3 gave the lowest plant mortality (22.0%) due to *biasi*, followed by treatment T_2 (24.82%). A nonsignificant effect on weeding efficiency was found because of *biasi*. However, the highest weeding efficiency was noted under T_3. This may be because fewer weeds appeared in the rice crop

Table 1. Effect of various nutrient management treatments on growth and population of rice under the *biasi* system.

Treatment	Plant population (before *biasi*) (no. m^{-2})	Plant population (after *biasi*) (no. m^{-2})	Plant loss due to *biasi* (%)	Plant height (cm)	No. of weeds per m^2 (before *biasi*)	No. of weeds per m^2 (after *biasi*)	Weeding efficiency (%)
0-0-0 kg NPK ha^{-1}	251	180	28	62.2	319	145	63
60-30-30 kg NPK ha^{-1}	286	215	25	64.7	405	149	63
30-30-30 kg NPK ha^{-1} + GM + PSB	277	216	22	65.4	377	136	63
CD (0.05)	ns	ns	3.55	1.22	ns	ns	ns

Table 2. Effect of various nutrient management treatments on yield and yield attributes of rice under the *biasi* system.

Treatment	Panicles (no. m^{-2})	Panicle length (cm)	Grains per panicle (no.)	1,000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
0-0-0 kg NPK ha^{-1}	252	17.58	62.3	25.45	1.9	2.7
60-30-30 kg NPK ha^{-1}	381	18.13	74.5	26.60	2.8	4.1
30-30-30 kg NPK ha^{-1} + GM + PSB	398	18.75	81.8	27.18	3.0	4.3
CD (0.05)	3.86	0.39	6.38	1.26	2.53	1.66

before the *biasi* operation as most weeds were suppressed by the *S. rostrata*; in T_2, no green manure was used.

Application of 30-30-30 kg NPK ha^{-1} + *S. rostrata* + PSB resulted in significantly high plant height (65.4 cm), panicle length (18.75 cm), number of grains panicle^{-1} (82), and 1,000-grain weight (27.18 g) (Tables 1 and 2). These observations confirmed the findings of Hiremath and Patel (1998), who reported that N application (25–100 kg ha^{-1}) along with green manure increased the values of growth and development parameters. Maximum grain yield (30.12 kg ha^{-1}) was also noted in the same treatment. Bhandari et al (1992) reported that green manure + 50% NPK produced as much rice grain yield as did 100% NPK.

Table 3 shows the economic analysis of the different integrated nutrient management packages under the *biasi* system. A net income of Rs 7,560 ha^{-1} was obtained with T_3 because of less chemical fertilizer applied. Treatment 3 gave better benefits from the investment point of view; this was supported by Jeyabal et al (1999), who reported the highest (2.80–3.25) benefit-cost ratio with combined application of inorganic fertilizer and biofertilizer compared with fertilizer alone.

Application of 30-30-30 kg NPK ha^{-1} + *S. rostrata* at 10 kg ha^{-1} + PSB gave higher grain yield and net income than did the rest of the nutrient management packages. This treatment may be recommended under the traditional *biasi* system to improve rainfed rice cultivation.

Table 3. Economic analysis of various nutrient management treatments under the *biasi* system.

Treatment	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	Benefit-cost ratio
0-0-0 kg NPK ha^{-1}	7,140	9,897	2,757	0.36
60-30-30 kg NPK ha^{-1}	8,592	15,015	6,423	0.75
30-30-30 kg NPK ha^{-1} + GM + PSB	8,440	16,020	7,560	0.90

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Chemical properties of lateritic soil and yield of rice as influenced by addition of fly ash

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Fly ash is a waste product from thermal power stations. It has no economic use and it is a pollution hazard. Coir pith is an organic waste and rice husk ash is a rare waste product from rice mills. A study was undertaken to assess the use of these waste materials in improving the lateritic soils of Kanyakumari District, Tamil Nadu, India, under irrigated rice cultivation. In this area, rainfall is more than 1,500 mm. Because of slow soil reaction during rice cultivation, most of the macro- and micronutrients are not in the available form, resulting in low productivity. A field experiment was conducted in a farmer's field. The lateritic soil has a pH of 4.79. Rice variety ADT37 was used. Different combinations of fly ash (10 and 15 t ha^{-1}) with different doses of lime, rice husk ash (12.5 t ha^{-1}), raw coir pith (12.5 t ha^{-1}), and coir pith compost (12.5 t ha^{-1}) were tried in a randomized block design with three replications. Initial and postharvest soil samples were collected and their chemical properties analyzed (Jackson 1973). Grain and straw yields were also recorded.

Fly ash is a potentially problematic waste product after the combustion of coal in thermal power stations (Chandra 1997). It is alkaline (pH 9.47), rich in Ca, but low in other plant nutrients (Regupathy 1988). The soil under study was found to be sandy clay loam with a bulk density of 1.66 Mg m^{-3}. Organic carbon content was low; cation exchange capacity (CEC) was 10.10 cmol (p^+) kg^{-1}. Available P (8.1 kg ha^{-1}) and K (82.0 kg ha^{-1}) were low. Exchangeable Ca and Mg were 3.50 and 2.96 cmol (p^+) kg^{-1}, respectively.

Grain yield was maximum (60 t ha^{-1}) in the treatment with fly ash (15 t ha^{-1}) and lime (12 t ha^{-1}) (Table 1). Application of fly ash, lime, and other industrial wastes had a positive effect on grain and straw yield of rice. The increase in yield with the fly ash treatment could be attributed to the improved physical and chemical characteristics of the soil (Matte and Kene 1995).

The pH, EC, and CEC of the red lateritic acid soil increased with fly ash addition (Table 2). The higher content of Ca and Mg oxides would have released more OH ions and caused pH to rise. The results indicated an increase in EC because of the addition of the soluble salts from the fly ash to the soil. But, the addition of lime, rice husk ash, and coir pith increased the CEC of the soil. Organic carbon content increased from 0.22% to 0.36% due to organic compounds released from coir pith compost. Available NPK and exchangeable Ca and Mg likewise increased with fly ash application. The addition of organic matter would have increased microbial activity and subsequently increased N availability. The addition of Ca and Mg may be responsible for the rise in pH and solubilization and release of soil P through the replacement of adsorbed phosphate ions (Regupathy 1998). The availability of K increased markedly with fly ash addition (Sahoo and Kar 1998) because fly ash and rice husk ash contained adequate amounts of K. Exchangeable Ca and Mg content was maximized with the application of fly ash with lime, but available Fe content of the soil decreased. The Zn

Table 1. Effect of treatments on grain and straw yield (t ha^{-1}) of ADT37.

Treatment[a]	Grain yield	Straw yield
Control (120:38:38 kg NPK ha^{-1})	3.9	4.2
Fly ash (10 t ha^{-1})	5.1	5.6
Fly ash (10 t ha^{-1}) + lime (12 t ha^{-1})	5.9	6.4
Fly ash (10 t ha^{-1}) + lime (6 t ha^{-1})	5.6	6.2
Fly ash (10 t ha^{-1}) + lime (3 t ha^{-1})	5.3	5.8
Fly ash (10 t ha^{-1}) + RHA (12.5 t ha^{-1})	5.3	5.8
Fly ash (10 t ha^{-1}) + RCP (12.5 t ha^{-1})	5.2	5.6
Fly ash (10 t ha^{-1}) + CCP (12.5 t ha^{-1})	5.3	5.7
Fly ash (15 t ha^{-1})	5.4	5.8
Fly ash (15 t ha^{-1}) + lime (12 t ha^{-1})	6.0	6.6
Fly ash (15 t ha^{-1}) + lime (6 t ha^{-1})	5.8	6.3
Fly ash (15 t ha^{-1}) + lime (3 t ha^{-1})	5.5	5.9
Fly ash (15 t ha^{-1}) + RHA (12.5 t ha^{-1})	5.5	5.9
Fly ash (15 t ha^{-1}) + RCP (12.5 t ha^{-1})	5.4	5.9
Fly ash (15 t ha^{-1}) + CCP (12.5 t ha^{-1})	5.5	5.9
SEd[b]	49	62
CD[c] (P = 0.05)	100	127

[a]RHA = rice husk ash, RCP = raw coir pith, CCP = composted coir pith. [b]Standard error deviation. [c]Critical difference.

Table 2. Effect of treatments on chemical properties of the soil.

Treatment[a]	pH	EC (dS m^{-1})	CEC (cmol (p^+) (kg^{-1})	Organic carbon (%)	Available nutrients (kg ha^{-1})			Exchangeable nutrients (cmol (p^+) kg^{-1})		Available micronutrients (mg kg^{-1})			
					N	P	K	Ca	Mg	Cu	Mn	Fe	Zn
Control (120:38:38 kg NPK ha^{-1})	4.99	0.07	10.03	0.220	236.9	9.0	87.3	3.57	2.98	0.19	0.17	27.20	0.12
Fly ash (10 t ha^{-1})	5.55	0.11	12.40	0.272	246.1	14.0	110.0	6.00	4.89	0.41	0.20	19.80	0.36
Fly ash (10 t ha^{-1}) + lime (12 t ha^{-1})	5.81	0.14	13.33	0.279	253.0	15.7	118.3	9.67	7.00	0.40	0.18	9.18	0.18
Fly ash (10 t ha^{-1}) + lime (6 t ha^{-1})	5.73	0.13	13.20	0.276	251.2	14.7	117.3	9.17	6.32	0.42	0.18	9.20	0.22
Fly ash (10 t ha^{-1}) + lime (3 t ha^{-1})	5.70	0.12	13.00	0.273	249.6	13.7	116.3	8.17	5.92	0.48	0.18	12.52	0.26
Fly ash (10 t ha^{-1}) + RHA (12.5 t ha^{-1})	5.65	0.11	14.00	0.324	248.7	15.3	123.7	7.33	5.42	0.78	0.19	9.20	0.18
Fly ash (10 t ha^{-1}) + RCP (12.5 t ha^{-1})	5.24	0.11	13.10	0.348	261.0	14.7	111.3	5.17	4.27	0.68	0.19	10.68	0.32
Fly ash (10 t ha^{-1}) + CCP (12.5 t ha^{-1})	5.18	0.10	13.03	0.352	262.2	15.0	112.3	5.00	4.44	0.62	0.22	10.32	0.36
Fly ash (15 t ha^{-1})	5.59	0.12	12.50	0.276	250.2	14.7	112.3	7.50	5.75	0.70	0.20	18.82	0.40
Fly ash (15 t ha^{-1}) + lime (12 t ha^{-1})	5.86	0.18	13.60	0.285	255.4	18.3	120.0	11.50	7.23	0.44	0.19	9.12	0.22
Fly ash (15 t ha^{-1}) + lime (6 t ha^{-1})	5.76	0.15	13.40	0.280	252.4	16.3	118.3	9.83	6.74	0.52	0.19	9.18	0.24
Fly ash (15 t ha^{-1}) + lime (3 t ha^{-1})	5.73	0.13	13.10	0.276	251.2	14.7	117.3	8.67	6.24	0.60	0.19	11.90	0.28
Fly ash (15 t ha^{-1}) + RHA (12.5 t ha^{-1})	5.69	0.12	14.10	0.329	250.4	16.7	126.0	8.17	5.75	0.88	0.19	9.18	0.22
Fly ash (15 t ha^{-1}) + RCP (12.5 t ha^{-1})	5.25	0.12	13.17	0.351	262.2	15.3	112.7	5.00	4.25	0.72	0.18	10.66	0.36
Fly ash (15 t ha^{-1}) + CCP (12.5 t ha^{-1})	5.21	0.11	13.37	0.360	263.3	16.0	113.3	5.33	4.41	0.64	0.20	13.01	0.42
SEd[b]	0.03	0.01	0.09	0.01	0.8	0.79	0.60	0.34	0.24	0.05	0.01	0.05	0.01
CD[c] (P = 0.05)	0.07	0.03	0.20	0.02	1.7	1.63	1.23	0.69	0.49	NS	0.02	0.11	0.03

[a]RHA = rice husk ash, RCP = raw coir pith, CCP = composted coir pith. [b]Standard error deviation. [c]Critical difference.

content of the soil, however, was not affected significantly. Fly ash contained a negligible amount of Fe but the lime addition decreased Fe availability in the soil. This was due to the consequent rise in pH and the replacement of Fe^{3+} with Ca and Mg ions.

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Managing iron toxicity in acid sulfate rice soils by integrating genetic tolerance and nutrition

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Iron toxicity (Fe) is a major problem in acid sulfate rice soils in the tropics. It is a physiologically complex nutrient disorder and deficiency in several other nutrients—especially P, K, Mg, and Zn—has been shown to play a major role in its occurrence (Sahu 2001). Iron toxicity is caused by excess uptake of Fe and is controlled by various factors such as genetic tolerance, active Fe content, soil nutritional status, and soil reaction rather than by total Fe content. Deficiencies in Ca, Mg, and Mn are rarely observed in lowland rice, but those in P, K, and Zn deserve special attention in order to reduce Fe toxicity (Sahwarat 2000). Hence, to manage Fe toxicity, an integrated approach involving the use of Fe-tolerant rice varieties, soil and water management, and plant nutrition is more appropriate. This study aimed to determine the effects of the integration of genetic tolerance (by selecting varieties that vary in tolerance) with nutrition (through different levels of fertilizers and lime) on iron toxicity and its influence on rice yield in low-lying acid sulfate rice soils of Kuttanad, Kerala, India.

We carried out a field experiment in sandy clay loam soil (Typic Sulfaquent) of the Regional Agricultural Research Station in KAU during the *rabi* season (Nov-Feb) for 3 y. Soils of the experimental area have a pH (H_2O) of 4.2 and a pH (KCl) of 3.4, an EC of –0.82 dS m^{-1}, 3.2% organic carbon with very low available P (Bray I), low exchangeable bases, free Fe content of 6.41%, and DTPA-extractable Fe of 420 mg kg^{-1}. The treatments are four levels of lime: I0—no lime (standing water 5 cm high retained in the field for 3 d and thereafter drained out through surface channels); I_1—half of the lime requirement (1/2 LR); I_2—full lime requirement (LR); and I_3—package of practices recommended by KAU (350 kg lime ha^{-1} as basal + 250 kg lime ha^{-1} 1 mo later) and two levels of fertilizer (I—100% N, P_2O_5, and K_2O and II—100% N + 150% of P_2O_5 and K_2O as per the recommended 90:45:45 kg ha^{-1}) and three varieties (Phalguna, tolerant; Prakash, sensitive; and Jyothi, locally preferred variety) in a split-plot design. Root characteristics and Fe toxicity scores were noted at critical growth stages. All the soil chemical parameters were estimated using standard methods described by Page (1982) and Fe content of the plant was estimated in the HNO_3-H_2SO_4-$HClO_4$ extract as described by Jackson (1973) and determined by atomic absorption spectrophotometry.

Results indicate that varieties and levels of lime and fertilizers have significantly influenced grain and straw yield of rice (Table 1). The highest grain and straw yields were recorded by Phalguna, which received lime at ½ LR and 150% of the recommended dose of P and K fertilizers. These yields were significantly superior to those of locally preferred variety Jyothi. However, application of lime at ½ LR and 150% of N and K fertilizers have also significantly increased both grain and straw yields of Jyothi. The influence of liming was more evident at higher doses of N, P, and K fertilizers, indicating the need for a higher level of nutrients for rice in Fe-toxic acid sulfate soils. This also confirmed the urgency to have genetically improved cultivars and identify locally preferred Fe-tolerant varieties. However, the number of productive tillers (Table 2) was significantly influenced by variety only. The Fe-tolerant variety Phalguna and the locally preferred variety Jyothi were on a par with each other and significantly superior to Prakash. Though the effect was not significant, liming at half LR and higher levels of P and K fertilizers have favorably influenced the number of productive tillers. The high reserve acidity of the soil (Table 3) may explain the lack of a significant influence of liming. Thampatti et al (1998) reported no significant difference in exchangeable acidity due to liming in acid sulfate rice soils in Kuttanad.

Variety and fertilizer level had significantly infuenced only the Fe content of straw, which was much higher than that of grain. In both grain and straw, Fe content was lowest for Phalguna and highest for Prakash. Among the levels of lime, lime at ½ LR recorded the lowest Fe content. Higher doses of P and K fertilizers had signifi-

Table 1. Grain and straw yield of rice (t ha^{-1}) and Fe content (in parentheses, mg kg^{-1}) as influenced by levels of lime and fertilizer and variety.

Treatment[a]	Grain yield (t ha^{-1}) and Fe content (mg kg^{-1})							Straw yield (t ha^{-1}) and Fe content (mg kg^{-1})						
	Phalguna		Prakash		Jyothi		Mean (lime)	Phalguna		Prakash		Jyothi		Mean (lime)
	I	II	I	II	I	II		I	II	I	II	I	II	
No lime	3.10	3.22	2.73	2.82	2.97	2.99	2.97	3.51	4.43	4.45	4.57	3.10	3.23	3.88
	(275)	(202)	(296)	(261)	(280)	(260)	(262)	(388)	(370)	(428)	(423)	(422)	(404)	(406)
½ LR	4.45	4.81	2.97	3.02	3.09	3.46	3.63	4.96	5.28	4.66	4.96	3.28	3.81	4.49
	(272)	(161)	(288)	(245)	(234)	(211)	(235)	(376)	(351)	(415)	(385)	(381)	(342)	(375)
Full LR	3.62	3.82	2.77	2.85	3.02	3.15	3.20	4.43	4.85	4.62	4.87	3.07	3.51	4.23
	(296)	(232)	(314)	(294)	(302)	(249)	(281)	(396)	(372)	(406)	(398)	(396)	(378)	(391)
Recommended	3.80	3.95	2.81	2.88	3.01	3.16	3.27	4.49	4.93	4.28	4.52	3.14	3.53	4.15
practice	(279)	(250)	(316)	(298)	(308)	(278)	(383)	(383)	(365)	(414)	(399)	(405)	(383)	(392)
Mean (varieties)	3.85 (246)		2.86 (289)		3.11 (265)			4.61 (365)		4.59 (409)		3.34 (389)		
Fertilizers			I—3.20 (288)							I—4.00 (401)				
			II—3.34 (245)							II—4.38 (381)				
CD (0.05)														
Lime			0.076 (ns)[b]							0.058 (13.8)				
Varieties			0.049 (29.9)							0.050 (11.9)				
Fertilizer			0.040 (18.1)							0.041 (9.8)				

[a]Lime requirement. [b]ns = not significant.

Table 2. Characteristics of rice roots as influenced by variety and levels of lime and fertilizer at panicle initiation stage.

Treatment[a]	Healthy roots hill^{-1} (no.)							Fe toxicity-affected roots hill^{-1} (no.)						
	Phalguna		Prakash		Jyothi		Mean (lime)	Phalguna		Prakash		Jyothi		Mean (lime)
	I	II	I	II	I	II		I	II	I	II	I	II	
No lime	12	15	6	7	8	10	9.6	26	24	31	29	32	28	28.3
½ LR	14	20	7	7	10	20	13.0	25	22	34	30	32	26	28.2
Full LR	13	16	7	8	9	13	11.0	24	23	30	30	32	31	28.5
Recommended practice	13	17	7	7	9	10	10.5	25	24	32	30	32	34	29.0
Mean (varieties)	15.0		7.0		11.1			24.1		30.8		30.6		
Fertilizers			I—9.6							I—29.7				
			II—12.5							II—27.3				
CD (0.05)														
Lime					2.1						ns[b]			
Varieties					2.3						3.5			
Fertilizers					1.8						1.9			

[a]LR = lime requirement. [b]ns = not significant.

Table 3. Effect of liming on soil chemical characteristics at different growth stages of rice.

Treatment[a]	pH		Exchangeable acidity (cmol kg^{-1})		Potential acidity (cmol kg^{-1})		DTPA-extractable Fe (mg kg^{-1})		
	Active tillering	Panicle initiation	Active tillering	Panicle initiation	Active tillering	Panicle initiation	At planting	Active tillering	Panicle initiation
No lime	4.2	4.5	2.0	3.0	24.4	27.0	368	373	406
½ LR	4.7	5.0	1.6	3.5	23.6	27.1	356	386	409
Full LR	4.7	5.0	1.2	3.4	23.4	28.4	324	402	442
Recommended practice	4.4	4.5	2.1	3.3	24.6	28.3	363	386	426
CD (0.05)	ns[b]	ns	ns	ns	ns	ns	13.1	ns	14.2

[a]LR = lime requirement. [b]ns = not significant.

cantly reduced the Fe content of both grain and straw, indicating the favorable influence of liming and a higher fertilizer dose on retarding iron toxicity in acid sulfate soils. However, liming at full LR and "package of practice" recommendations were not able to reduce Fe concentration in the grain; an Fe concentration higher than that of the control treatment that received washings alone was observed. The control recorded the highest concentration in the straw, indicating that Fe was not partitioned to the grain.

An increase in Fe toxicity score from active tillering to booting was observed. The DTPA-extractable Fe also increased from planting to panicle initiation (Table 3). Varieties and levels of fertilizers have significantly influenced the Fe toxicity score, with Phalguna showing the lowest score at higher doses of fertilizers. Prakash had the highest score, while Jyothi was in between the other two. Since the acidity component and DTPA-extractable Fe did not show any significant difference at different levels of lime (Table 3) because of high reserve acidity, the same effect might have been reflected in the iron toxicity symptoms. However, the integration of genetic tolerance and nutrition management could reduce the intensity of iron toxicity in acid sulfate soils.

The number of healthy roots and those affected by Fe toxicity was significantly influenced by variety and fertilizer level. But the levels of lime had significant effects on the number of healthy roots only. Since the free Fe content of the soil is very high, liming may not have influenced the number of healthy roots affected by Fe toxicity. Tolerant variety Phalguna maintained the highest number of healthy roots and the lowest number of roots affected by Fe toxicity. The results showed that genetic tolerance and appropriate nutrients could reduce the intensity of Fe toxicity and bring about sustainable yield increases in Fe-toxic sulfate soils.

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Effect of nitrogen and silicon levels on growth, yield attributes, and yield of rice in Alfisols

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A sufficient supply of silicon in the soil is required for healthy growth and higher productivity of the rice (*Oryza sativa* L.) crop. Applied Si seems to interact favorably with other nutrients (N, P, and K) and offers the potential to improve efficiency in terms of yield response. Silicon helps rice plants to resist biotic stresses (insect pests and fungal diseases) and tolerate abiotic stresses (Al, Fe, and Mn toxicities). It also helps reduce cuticular transpiration and, to some extent, crop lodging caused by excessive N supply (Savant et al 1997). It has been observed that rice plants in the most productive ecosystem of Varanasi region, which is identical to that of the northeastern plain zone of India, have started showing a tendency to lodge, even with the use of nonlodging, high-yielding, and short-duration varieties at the recommended fertilizer doses. It is therefore essential to understand the relationship between Si and N. This study aimed to determine the effects of N and Si levels on rice grown in Alfisols.

A pot experiment was conducted during the 2000 and 2001 rainy seasons at BHU to find out the effect of N and Si application on growth, yield attributes, and yield of rice. The experimental soil was an Alfisol with pH 6.3, 0.51% organic C, EC 0.33 dS m^{-1} at 25 °C, 267.2 kg available N ha^{-1}, 9.1 kg available P ha^{-1}, 233.5 kg available K ha^{-1}, and 269.8 kg available Si ha^{-1}. The experiment was carried out in a complete randomized block design using rice cv Swarna (MTU7029). The experiment used five N levels—60, 90, 120, 150, and 180 kg ha^{-1}—and four Si levels—0, 50, 100, and 150 kg ha^{-1}, with three replications. Fertilizers were applied just before transplanting. Half the amount of N and full P (60 kg ha^{-1}), K (60 kg ha^{-1}), and Si were applied basally in the pot. The remaining N was applied in two equal splits, at tillering and panicle initiation. The nutrients were supplied as urea, single superphosphate, and muriate of potash, whereas Si was supplied as calcium silicate. Medium-sized pots (45 cm × 30 cm) were used for growing the plants. Soil in each pot was puddled and two seedlings $hill^{-1}$ were transplanted, with five hills maintained in each pot. The soil in the pot was kept in a water-saturated state until seedling establishment. Other standard agronomic management practices were followed.

Results showed that N and Si application had a significant influence on dry matter production at all crop growth stages (Table 1). The N level of 180 kg ha^{-1} produced the maximum dry matter at physiological maturity. This was significantly superior to lower N levels but statistically on a par with 150 kg N ha^{-1}. Dry matter production increased significantly and progressively with increasing Si levels up to 150 kg ha^{-1}. Yield attributes such as number of productive tillers, grains $panicle^{-1}$, and test weight increased markedly with increasing N levels up to 180 kg N ha^{-1} (Table 2). Grain yield depends on these yield attributes, which

Table 1. Dry matter accumulation of rice as influenced by N and Si levels (pooled data over 2 y).[a]

Treatment	Dry matter accumulation $hill^{-1}$ (g)			
	Tillering	Late jointing	Panicle initiation	Physiological maturity
N level (kg ha^{-1})				
60	1.3	7.9	22.6	33.3
90	1.5	8.7	25.4	35.7
120	1.5	9.0	26.5	37.2
150	1.6	9.6	28.9	38.7
180	1.7	10.0	30.0	39.4
SE ±	0.03	0.16	0.40	0.38
CD (*P* = 0.05)	0.09	0.44	1.14	1.08
Si level (kg ha^{-1})				
0	1.2	7.0	22.2	34.4
50	1.5	8.5	25.7	36.5
100	1.7	9.7	30.0	37.8
150	1.9	11.0	30.7	38.9
SE ±	0.02	0.09	0.24	0.30
CD (*P* = 0.05)	0.05	0.28	0.68	0.81

[a]Interactions between N and Si are nonsignificant.

were all favorably affected by N application. A significant improvement in almost all the yield attributes was also observed up to 150 kg N ha^{-1}. However, the various N levels did not show any significant effect on test weight. Grain and straw yield also increased with increasing N up to 180 kg ha^{-1}, followed by 150 kg ha^{-1}. Silicon application significantly increased all yield attributes except test weight. As Si increased, productive tillers and grains panicle^{-1} also increased, the highest value being observed at 150 kg Si ha^{-1}. Similarly, yield increased with increasing Si levels, the highest yield being obtained at 150 kg Si ha^{-1}. Rani et al (1997) reported similar findings.

Swarna (MTU7029) can be fertilized with 150 kg N ha^{-1} and Si to obtain higher yield. Therefore, to realize the potential of rice varieties that respond to higher levels of N, application of Si should be integrated into a fertilizer program.

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Table 2. Yield attributes and rice yield as influenced by N and Si levels (pooled data over 2 y).[a]

Treatment	Yield attributes			Yield (g hill^{-1})	
	Productive tillers (no. hill^{-1})	Grains panicle^{-1} (no.)	Test weight (g)	Grain	Straw
N level (kg ha^{-1})				15.4	22.1
60	10.0	104.1	17.1	17.5	23.2
90	11.0	109.0	17.1	19.1	24.1
120	11.8	117.7	17.2	20.4	24.9
150	12.4	119.2	17.4	20.6	25.3
180	12.9	123.9	17.5	0.11	0.14
SE ±	0.16	1.90	0.07	0.31	0.41
CD (P = 0.05)	0.45	5.40	NS		
Si level (kg ha^{-1})					
0	10.1	105.5	17.1	16.8	22.5
50	11.2	113.0	17.2	18.2	23.4
100	12.2	117.3	17.3	19.2	24.4
150	13.0	123.3	17.4	20.2	25.4
SE ±	0.07	0.50	NS	0.07	0.09
CD (P = 0.05)	0.20	1.40	NS	0.18	0.24

[a]Interactions between N and Si are nonsignificant.

A modeling approach to optimize nitrogen dose for drum-seeded wet rice

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Nitrogen is critical in any fertilizer management program for rice as it plays an important role in realizing the yield potential of high-yielding varieties (Budhar and Palaniappan 1996). As a cereal, rice is highly responsive to N application. In India, transplanting has been the traditional system of crop establishment, but cultivation of wet-seeded rice is gaining momentum because of high demand for labor during peak seasons for transplanting and availability of water for shorter periods. The N dose for wet-seeded rice is currently the same as that applied in transplanted rice. Our investigation was conducted to find the optimum N dose for drum-seeded wet rice.

Field experiments were conducted during the 2001-02 monsoon season (rabi) and the 2002 dry season (kharif) at TNAU (11°N, 77°E, 426.7 m elevation). The field was puddled using a country plow and leveled uniformly using a bullock-drawn wooden plank. Soil at the test site was clay loam, with pH 7.3, 0.34% organic C, and available NPK of 192.3, 16.3, and 494.2 kg ha^{-1}, respectively.

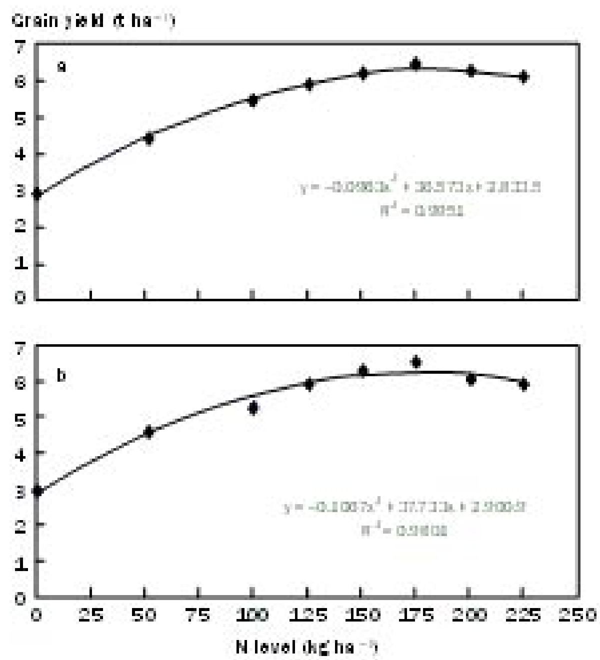
The seeds were soaked in water overnight and incubated for 24 h. Sprouted seeds of rice cultivar ADT44 were line-sown at 80 kg ha^{-1} using an IRRI drum seeder (manually operated with a row spacing of 20 cm) onto puddled soil on 13 Oct 2001 and 4 July 2002. Nitrogen was applied as per treatments (see table) in four equal splits (20 d after sowing [DAS], active tillering, panicle initiation, and flowering). A single dose of 50 kg P ha^{-1} as basal and 50 kg K ha^{-1} was applied along with the N. Eight levels of N—control (0), 50, 100, 125, 150, 175, 200, and 225 kg ha^{-1}—were applied using a randomized block design with three replications. Plant samples from a 0.5-m^2 area were taken to determine the number of tillers m^{-2} and panicles m^{-2}. Yield components were noted from the net plot area.

Effect of N levels on tillers m^{-2}, panicles m^{-2}, and yield (t ha^{-1}) of drum-seeded wet rice.

N level (kg ha^{-1})	2001-02 monsoon season				2002 wet season			
	Tillers m^{-2} (no.)	Panicles m^{-2} (no.)	Unproductive tillers (%)	Grain yield (t ha^{-1})	Tillers m^{-2} (no.)	Panicles m^{-2} (no.)	Unproductive tillers (%)	Grain yield (t ha^{-1})
0	323	226	30.0	2.9	307	215	30.2	2.8
50	401	312	22.2	4.4	409	318	22.5	4.6
100	458	371	18.9	5.4	472	382	19.1	5.3
125	496	413	16.7	5.9	506	421	16.9	5.9
150	528	460	12.9	6.2	544	472	13.2	6.3
175	551	473	14.2	6.4	568	487	14.3	6.5
200	569	456	19.8	6.3	586	478	18.4	6.1
225	583	448	23.2	6.1	595	458	23.0	6.0
CD (P = 0.05)	24.4	20.8	1.8	0.3	28.3	19.4	2.0	0.2

Application of 225 kg N ha^{-1} resulted in a higher number of tillers in both seasons. However, a significant variation was observed only up to 150 kg ha^{-1}. Beyond this level, the increase in number of tillers with successively higher additions of N was progressively smaller. The number of panicles per unit area responded positively up to 175 kg N ha^{-1}. Similar findings were reported by Stutterhim et al (1994). The percentage of unproductive tillers was minimum at 150 kg ha^{-1}; beyond that, an increasing trend was noted. In this study, higher grain yield could be realized with fertilizer N up to 175 kg ha^{-1}. Nair and Gupta (1999) reported a similar yield at 180 kg N ha^{-1}.

The yield response to different N levels was fitted into a quadratic equation to work out the physical (condition for physical optimum, dy/dn = 0, where dy is the increment in yield and dn is the increment in N) and economic optima (condition for economic optimum, dy/dn = pn/py, where pn is the price of N, in Rs kg^{-1}, and py is the price of grain, in Rs kg^{-1}). The physical optimum dose of N at which the highest yield could be obtained was found to be 189.8 kg and 176.8 kg for the monsoon and dry season, respectively (see figure). The economic optimum dose is that at which the highest net return can be obtained. This was found to be 179.6 kg and 174.4 kg for the monsoon and dry season, respectively. The present N dose for wet-seeded and transplanted rice is 150 kg ha^{-1}. The optimization studies point to an additional 20–30 kg of fertilizer N needed to enhance the yield potential of wet-seeded rice.



Optimization of N dose for drum-seeded wet rice during monsoon (a) and dry (b) seasons.

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Ergosterol content of *Basidiomycetes* culture in rice

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Mushrooms are a rich source of natural vitamin D. Plant sterols are recognized as having positive health effects because they have been shown to decrease serum cholesterol levels and to play an important role in preventing colon cancer (Mattila et al 2002). Mushrooms contain a high amount of ergosterol, provitamin D_2, which can be converted to vitamin D_2 by ultraviolet (UV) irradiation. Because ergosterol is abundant in mushrooms, the best source of vitamin D is therefore sunlight. Vitamin D_2 is derived by photo irradiation from its precursor ergosterol.

Ergosterol undergoes photolysis when exposed to UV light of wavelengths 280–320 nm, yielding a variety of photo irradiation products. The principal ones are provitamin D_2, tachysterol, and lumisterol. Provitamin D_2 undergoes spontaneous thermal rearrangement to vitamin D_2. In the kingdoms Plantae and Animalia, ergosterol or vitamin D_2 is almost absent. Therefore, the intake of vitamin D from food is mainly emphasized in both northern and southern latitudes. Eating vitamin D-enriched food makes calcium more available for children, the elderly, and postmenopausal women (Mau et al 1998).

Our study aimed to evaluate the ergosterol content of koji (Kim et al 2000), a product made from rice. Mycelia of five mushroom species—*Basidiomycetes (Ganoderma lucidum, Phellinus linteus, Cordus versicolor, Pleurotus ostreatus,* and *Lentneus edodes*)—were grown in a flask containing one of the three rice cultivars Heughang, Hyangnambyeo, and Dongjinbyeo as a medium. The ergosterol contents in these rice koji were compared. The mycelia of these mushroom species were grown in a flask containing 250 mL of medium inoculated with 10 mL of homogenate of mycelia previously subcultured on potato dextrose agar (PDA). Cultures were incubated in a rotary shaker at 25 °C, pH 6.0, and 100 rpm for 3 wk. Then, mushroom mycelia were put in an incubator at 25 °C for 30 d. Heughang, Hyangnambyeo, and Dongjinbyeo were used as media. The rice koji was harvested and freeze-dried. All dried samples of rice koji were ground in a cyclotech mill and passed through a 0.5-mm sieve. The experiment, replicated four times, was carried out at the Laboratory of Rice Processing, NHAES, in 2002.

Ergosterol fractions were extracted and analyzed using the AOAC method as modified by Mattila et al (2002). Freeze-dried rice koji powder (5 g) was mixed with 4 mL of sodium ascorbate (Wako Pure Chemical Co., Osaka, Japan), 50 mL of ethanol (95% pure), and 10 mL of 50% potassium hydroxide (Wako). The mixture was saponified under reflux at 78 °C for 1 h. After cooling, the mixture was first extracted with 15 mL of de-ionized water and 50 mL of ethyl ether, then with 10 mL of ethanol and 50 mL of n-pentane, again with 50 mL of n-pentane, and finally with 20 mL of n-pentane. The organic layers were pooled, washed three times with 50 mL of 3% potassium hydroxide in ethanol, and washed with de-ionized water to neutrality. The organic layer was dried using a rotary evaporator. It was filtered using a 0.45-µm NY filter prior to injection onto a high-performance liquid chromatograph (HPLC). The HPLC system consisted of a 25-µ sample loop, AD20 absorbance UV-VIS detector, a Dionex LC20, and a prodigy ODS-2 (4.6 × 250 mm), Phenomenes Inc., Torrance, CA).

Contents of ergosterol in rice using *Basidiomycetes*, Korea, 2002.

Variety[a]	Ergosterol (µg g^{-1} DW)b				
	Ganoderma lucidum	*Phellinus linteus*	*Cordus versicolor*	*Pleurotus ostreatus*	*Lentneus edodes*
Heughang	512.0 a	247.5 a	245.8 b	240.5 c	80.1 c
Hyangnambyeo[c]	326.5 c	170.2 b	255.2 a	252.9 b	117.7 a
	(144.2 a)	(50.9 b)	(148.4 a)	(244.3 a)	(75.2 b)
Dongjinbyeo	455.6 b	241.6 a	212.0 c	278.0 a	143.4 b
	(124.9 b)	(111.2 a)	(126.4 b)	(215.0 b)	(110.0 a)

[a]Heughang is a colored rice, Hyangnambyeo is an aromatic rice, and Dongjinbyeo is plain rice.
[b]Values within a parameter followed by different letters are significantly different at $P<0.05$.
[c]Numbers are ergosterol values in brown rice; numbers in parentheses are ergosterol values in milled rice.

The mobile phase was methanol/acetonitrile (LC grade), 35:65 (v/v), at a flow rate of 0.8 mL min^{-1}, and UV detection was at 282 nm. Statistical analysis was done using Duncan's multiple range test.

Ergosterol content was 80.1–512.0 μg g^{-1} (dry weight, DW) in brown rice koji and 50.9–244.3 μg g^{-1} DW in milled rice. Brown rice koji had more ergosterol than milled rice koji. Among the *Basidiomycetes*, the highest ergosterol contents were observed in *G. lucidum* of brown rice koji (326.5–512.0 μg g^{-1} DW) and in *P. ostreatus* of milled rice koji (215.0–244.3 μg g^{-1} DW). Among the cultivars tested as culture media, Heughang had the highest ergosterol contents in *G. lucidum* (512.0 μg g^{-1} DW) and *P. linteus* (247.5 μg g^{-1} DW), Hyangnambyeo in *C. versicolor* (255.2 μg g^{-1} DW), and Dongjinbyeo in *P. ostreatus* (278.0 μg g^{-1} DW) and *L. edodes* (143.4 μg g^{-1} DW) of the brown rice koji. The ergosterol contents in *Basidiomycetes* of milled rice koji differed as seen in Hyangnambyeo (50.9–244.3 μg g^{-1} DW) and Donjinbyeo (110.0–215.0 μg g^{-1} DW). Ergosterol contents between *Basidiomycetes* and cultivars were statistically different at $P<0.05$.

These results indicate that rice koji prepared using *Basidiomycetes* can be marketed as a functional food (vitamin D), that is, a food that has health-promoting effects beyond its nutritive value.

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Nitrogen management for direct wet-seeded rice

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Direct seeding is generally practiced under semidry conditions in Tamil Nadu, India. However, the use of direct-seeded rice for lowland areas is gaining importance because of water scarcity, failure of monsoon, paucity of labor, and escalating labor cost. Proper nutrient and irrigation management strategies need to be developed for direct wet-seeded rice. An experiment was carried out to study the effect of time and rate of N application on yield of direct wet-seeded rice under lowland conditions.

Field experiments were conducted during the 2001-02 dry seasons at the central farm of TNAU in Aduthurai. The soil was silty clay (Typic Haplustert) with neutral pH (7.5) and an EC of 0.39 dS m^{-1}. The initial nutrient status of the experimental field indicated low N (216.4 kg ha^{-1}), medium Olsen P (15.7 kg ha^{-1}), and medium K (324.8 kg ha^{-1}) levels. The experiment used five treatments laid out in a randomized block design with four replications. Nitrogen was applied in three and four splits at various stages—basal and 21 and 35 d after sowing (DAS), at panicle initiation (PI), and at first flowering—and at various doses (17%, 25%, 33%, and 50% of the recommended N, i.e., 125 kg ha^{-1}). Recommended doses of 50 kg P_2O_5 ha^{-1} (full basal) and 50 kg K_2O ha^{-1} (50% basal and 50% at PI) were applied uniformly to all treatments. At harvest, grain and straw yields were recorded and the corresponding N-use efficiency {NUE (AE*)} and benefit-cost ratios (B:C) calculated. The results of the two-season field experiment revealed that N application in four splits at varying levels (17% at 21 DAS, 33% at 35 DAS, 33% at PI, and 17% at first flowering) gave a significantly higher grain yield (4.18 t ha^{-1}, 21.4% yield increase over four equal splits), high N-use efficiency (14.0), and higher B:C (2.07), whereas N application in four equal splits as per existing recommended practice gave only 3.44 t ha^{-1}, low N-use efficiency (8.1), and a B:C of 1.69 (Table 1). From these results, it could then be inferred that, for direct wet-seeded rice, application of 25% N as basal can be skipped for directly sown rice because it may not be immediately used. It is likely to be nitrified and moved

Yield, N up

Treatment		Yield (t ha^{-1})		% increase over T_2	N uptake (kg ha^{-1})		NUE-AE[a]	B:C
		Grain	Straw		Grain	Straw		
T_1	Control (without N)	2.43	4.91	–	21.1	19.4	–	1.35
T_2	N in four equal splits (25% basal, 25% at 35 DAS, 25% at PI, and 25% at first flowering)	3.44	6.05	–	32.4	20.3	8.1	1.69
T_3	N in four equal splits (25% at 21 DAS, 25% at 35 DAS, 25% at PI, and 25% at first flowering)	3.82	6.93	10.7	38.4	36.0	11.1	1.89
T_4	N in three splits (25% at 21 DAS, 50% at 35 DAS, and 25% at PI)	4.11	7.5	19.2	43.5	40.9	13.4	2.03
T_5	N in four splits (17% at 21 DAS, 33% at 35 DAS, 33% at PI, and 17% at first flowering)	4.18	7.69	21.4	47.6	45.8	14.0	2.07
	LSD (0.05)	0.28	0.23	–	3.35	2.16		

[a]AE: agronomic efficiency = $\Delta Y/Nr$ (kg grain increase /kg N applied).

beyond the root zone as nitrate under the prevailing aerobic conditions.

Moreover, it was shown that N use as reflected in the higher N-use efficiencies of 11.1%, 13.4%, and 14.0% in treatments that did not receive basal N application (T_3, T_4, and T_5, respectively) has resulted in corresponding significant yield increases of 10.7%, 19.2%, and 21.4% over T_2 (the existing recommended practice). These results support the findings of Kim (1996). Hence, split application of N (17% N at 21 DAS, 33% at 35 DAS, 33% at PI, and 17% at first flowering) could be recommended for adoption. This will ensure optimum N application in a need-based manner to enhance the productivity of direct wet-seeded rice. It must be noted, however, that similar yield values were observed with N application in three splits (T_4). This has special significance under the farmers' practice as it saves on the labor needed for an additional application.

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Effect of flag leaf clipping and GA_3 application on hybrid rice seed yield

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Hybrid rice technology, now a reality in Bangladesh, aims to break the present yield ceiling of inbred rice to meet the future demand for rice in the country. Today, the major constraint to the expansion of this technology is hybrid rice seed production. With a view to increase per unit area production of hybrid seed, a field experiment was conducted at BRRI during the 2001 T. aman (wet season) and 2002 boro (dry season) to find out the effect of flag leaf clipping and gibberellic acid (GA_3) application on hybrid rice seed yield. IR58025A (female parent) and BR827R (male parent) were taken as experimental materials. Four treatments were applied: T_1 = control, T_2 = GA_3 application without flag leaf clipping, T_3 = flag leaf clipping without GA_3 application, and T_4 = GA_3 application with flag leaf clipping. The experiment was laid out in a randomized complete block design with three replications. Unit plot size was 21.5 m^2.

The R line was seeded thrice in both seasons at 5-d intervals. In T. aman, the first set was seeded on 15 July, the second set on 20 July, and the third on 25 July. The A line was seeded on 26 July, synchronizing with the second set of the R line, because the A line was found to flower 6 d earlier than the R line. The R line was transplanted on 10 Aug with 16-, 21-, and 26-d-old seedlings and the A line was transplanted on 16 Aug with 21-d-old seedlings in the main field. A 2:8 ratio of R and A lines was maintained for the experiment. Similarly, in the boro season, three R-line seedings were done on 10, 15, and 20 Dec. A-line seeding was done on 21 Dec. The R line was transplanted on 11 Jan 2002 and the A line was transplanted on 17 Jan 2002. Fertilizer was applied at 180:100:70 kg ha^{-1} as urea, triple superphosphate, and muriate of potash, respectively, during T. aman. It was 270:130:120:70 kg ha^{-1} as urea:TSP:MP:gypsum, respectively, in the boro season. Urea was applied in three equal splits in both seasons.

Half of the flag leaf of the A line was clipped using a sickle when primary tillers were at booting stage in both seasons. GA_3 was applied at 75 g ha^{-1} in two splits. The first spraying of GA_3 was done when 10–15% of the tillers started to flower; the second spraying was done 2 d after the first spray using a knapsack sprayer. Supplementary pollination was provided during flowering to facilitate pollen dispersal using a bamboo stick.

In the 2001 T. aman season, the A-line plants were moderately infested by bacterial leaf blight (BLB) and stem borer. Some missing hills were retransplanted by splitting tillers from the main experimental plots. In the 2002 boro season, the R line flowered 2 d earlier than expected. At heading time of the A line, some R-line plants were brought from an adjacent border to cope with the pollen load of the R line.

Results indicated that, in the T. aman season, plant height of the A line differed significantly among different treatments (see

Effect of flag leaf clipping and GA_3 application on the plant characters and yield of an A line in T. aman (wet season) 2001 and boro (dry season) 2002 at BRRI, Gazipur, Bangladesh.

Treatment[a]	Plant height (cm)	Tillers $hill^{-1}$ (no.)	Panicles $hill^{-1}$ (no.)	Outcrossing rate (%)	Seed yield (kg ha^{-1})
2001 T. aman (wet season)					
T_1	66	10.5	9.1	17	685
T_2	90	8.6	5.9	17	677
T_3	63	9.7	7.6	19	709
T_4	82	9.6	6.9	20	724
LSD(0.5)	5.126	1.808	3.115	6.113	181.91
CV (%)	3.4	9.4	21.0	16.0	13.0
2002 boro (dry season)					
T_1	88	15	15	19	1,229
T_2	86	12	10	23	1,406
T_3	79	16	15	25	1,520
T_4	82	13	12	30	1,676
LSD(0.5)	9.064	8.494	7.673	6.283	292.39
CV (%)	5.4	29.8	29.7	12.9	10.0

[a] T_1 = control, T_2 = GA_3 application without flag leaf clipping, T_3 = flag leaf clipping without GA_3 application, T_4 = GA_3 application with flag leaf clipping.

table). The highest plant height was observed in T_2, where GA_3 was applied without flag leaf clipping. But the differences during the boro season were nonsignificant. The number of tillers and panicles per hill remained statistically identical among all treatments in both seasons. The outcrossing rate in the boro season was highest in T_4, where GA_3 and flag leaf clipping were done simultaneously. The average outcrossing rate was also highest in T_4 in the T. aman season, but the differences were nonsignificant. The highest hybrid rice seed yield was observed in T_4, which was significantly higher than that of the control plots in the boro season. Differences in the T_2, T_3, and T_4 were nonsignificant. No significant differences were observed in terms of seed yield among different treatments during T. aman.

It is concluded that hybrid rice seed yield was increased by the application of GA_3 and flag leaf clipping. Seed yield was lower in the T. aman season because of unfavorable weather conditions and pest infestations during the growth period in Gazipur, Bangladesh.

Rice yield as affected by use of biofortified straw compost combined with NPK fertilizer

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To fully exploit the yield potential of input-responsive, high-yielding rice cultivars, agronomists generally consider improving the management of essential macro mineral elements only (NPK) while ignoring the rest. Rice straw as farm waste was found useful for sustaining rice productivity and soil health in a pollution-free environment when used either alone or in combination with mineral fertilizers (macro- and micronutrients) or bioactivators or both (Gaur 1999). This study was conducted during the 2002 and 2003 rainy seasons at the BHU Research Farm to find the efficiency of bio-fortified rice straw compost in combination with NPK in transplanted rice.

Soil at the experimental site was sandy clay loam (Ustochrept) with a pH of 7.2 and an ECe of 0.33 dS m^{-1} at 25 °C. It was moderately fertile, being low in organic C (0.46%) and available N (180 kg ha^{-1}) and medium in available P (19 kg ha^{-1}) and K (206 kg ha^{-1}). The experiment was carried out in a randomized block design. Samba Mansuri (BPT5204) was the test crop used. Half the amount of N and full P and K were applied as basal; the remaining N was applied in two equal splits at tillering and panicle initiation. Rice straw compost was applied at 6 t ha^{-1} before transplanting. To prepare this, rice straw was collected from the threshing floor and brought to the composting pit (3 m length × 2 m breadth × 1 m height). Rice straw was spread layer after layer, with each layer having a thickness of 15 cm. On each layer, urea solution (1 kg urea for 1,000 L of water) was spread. These pits (three in number) were irrigated frequently to maintain the moisture level at 80–100%. The rice straw compost was treated with a suitable culture of N_2-fixing bacteria (*Azotobacter chrococcum* to raise their number to 100 × 10^6 100 kg^{-1} of organic material), P-solubilizing fungi (*Trichoderma viridae* at 300 g t^{-1} of raw material), and PSB (*Bacillus polymyxa* at 500 g t^{-1} of raw material) to obtain compost with enriched quality. Low-grade rock phosphate (1%) was added to improve the P content of the compost. Rice straw compost was enriched with spraying of salt solution containing 12 kg $CaSO_4{\cdot}2H_2O$, 6 kg SSP, 4 kg $MgSO_4$, 500 g $FeSO_4$, 200 g $ZnSO_4$, 15 g $MgCl_2$, 7 g $CuSO_4$, 70 g H_3BO_3, 5 g $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$, and 7 g $CoSO_4$. These salts were sufficient for approximately 1 t of composting biomass and were dissolved in 10 L of water and sprayed on the composting mass at the 30th day of the process. The material was thoroughly mixed three times at 15-d intervals during the entire composting period for proper aeration. The total decomposed rice straw compost thus obtained had a concentration of 0.43% N, 0.09% P, 1.16% K, 0.80% CaO, 0.02% Fe, and 3.82% Si.

The pooled grain and straw yield data (Table 1) were significantly influenced by the biofortified rice straw compost superimposed on NPK. Maximum yield was obtained with the application of rice straw compost inoculated

Table 1. Effect of treatments on grain yield, straw yield, and harvest index of transplanted rice (pooled over 2 y).

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1 (NPK + rice straw compost)	4.5	7.4	37.78
T_2 (NPK + cellulocompost)	4.6	7.5	37.75
T_3 (NPK + azocompost)	5.0	7.7	39.55
T_4 (NPK + bacteriocompost)	5.1	7.9	39.24
T_5 (NPK + cellulocompost + azocompost)	5.1	7.9	39.37
T_6 (NPK + cellulocompost + bacteriocompost)	5.3	8.0	39.84
T_7 (NPK + azocompost + bacteriocompost)	5.6	8.6	39.47
T_8 (NPK + cellulocompost + azocompost + bacteriocompost)	5.4	8.1	39.80
T_9 (NPK + enriched rice straw compost)	4.9	7.6	39.37
T_{10} (NPK only)	4.5	7.4	37.79
SEm ±	0.75	1.3	0.5
CD (P = 0.05)	2.14	3.7	1.4

Table 2. Interaction effect between treatment and year on grain yield of transplanted rice.

Treatment	Grain yield (kg ha^{-1})									
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
Y_1	40.67	41.87	49.07	49.97	51.37	53.73	55.73	55.23	48.13	41.67
Y_2	49.17	49.60	50.83	51.27	51.67	52.13	56.67	52.50	50.43	47.93
SEm ±							1.06			
CD (P = 0.05)							3.03			

with azocompost + bacteriocompost along with NPK (T7). The harvest index was also likewise influenced. The efficient supply of nutrients delayed senescence and increased the life cycle of the plant, which resulted in higher economic yield. Production of rice grain and straw was enhanced with the addition of rice straw compost, *Azotobacter*, and bacteriocompost as well as the integrated use of rice straw compost along with *Azotobacter* and PSB (Singh 2001). The interaction effects between years and treatments were statistically significant (Table 2). Treatments T_1, T_2, and T_{10} resulted in a significant improvement in yield in the second year over the first year. However, the other treatments did not differ significantly due to years. The highest yield was recorded with T_7 in both years.

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Response of rice cv Pusa Basmati 1 to different planting methods

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In India, rice cultivation is becoming increasingly expensive as seedlings are raised in nurseries and transplanted manually. Rice transplanters are yet to be popularized. Manual transplanting alone accounts for nearly 20% of the total cultivation cost. In most cases, the required plant population is not maintained because laborers are not properly supervised as transplanting is done on a contractual basis. Manual transplanting takes longer to complete. Therefore, major constraints are the high cost of manual transplanting and uneven plant population. Our experiment was designed to explore other options for rice crop establishment during the 2000-03 rainy seasons (July-October).

Rice seedlings were raised in a wetbed nursery. Direct drilling and broadcasting of pregerminated seeds of rice were also done in puddle-leveled rice plots on the same day seeds were sown in the nursery to maintain the same seedling age for all treatments. Seed bolls were prepared by mixing fresh cow dung, wood ash, and clay soil (1:1:2 ratio), adding four seeds in each boll, and drying them completely. Seed bolls were dibbled in rows under puddled conditions on the same day seeds were sown in the nursery. Twenty-one-day-old seedlings were transplanted at two to three seedlings per hill at the same spacing as that of drilling, while seed-boll dibbling (at 25 cm between rows) was done in the puddled field. Seedlings of the same age were broadcast for the seedling broadcast treatment. Fertilizer rates were 120 kg N ha^{-1}, 35.2 kg P ha^{-1}, 49.8 kg K ha^{-1}, and 5.75 kg Zn ha^{-1}; half the N and the entire quantity of P, K, and Zn were applied as basal at the time of puddling. Zn was mixed with urea and muriate of potash, and applied together, whereas P was applied separately to avoid fixation of Zn when applied together with P. The remaining N was applied at panicle initiation. The crop was irrigated at all critical growth stages. Machete (butachlor) at 0.75 kg ai ha^{-1} was applied on the third day after sowing or transplanting to control weeds. The field had clayey soil with a pH of 7.6, 0.821% organic carbon, 197 kg N, 22 kg P, 219 kg K, and 10 ppm Zn ha^{-1}.

Plant height and yield parameters showed similar trends in both years (Table 1). Plant height, total tiller count, and straw yield were significantly higher for drilled rice than for other treatments, whereas effective (ear-bearing) tillers, panicle length, number of grains per panicle, and grain yield were significantly higher for the seed-boll method. Broadcasting produced the lowest values of all parameters. The better crop performance and higher yield of the seed-boll-sown crop could be attributed to the absence of transplanting shock experienced by the crop in transplanted and seedling-broadcast methods. Earlier reports on direct wet seeding in rows confirm the results of our study (Saman and Pajuab 1980, DamKheong et al 1980, Uemura and Miyasaka 1980, Singh and Mahauta 1980, Sammy and Phang 1980). Thus, seed-boll sowing and spreading of seedlings could be adopted.

The treatments had common field preparation and fertilizer, water, and weed management activities. To assess the economic feasibility of the different methods, additional cost and income under various treatments are given in Table 2. The seed-boll dibbling method gave the highest profit.

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Table 1. Effect of different crop establishment methods on rice yield, 2002 and 2003 rainy seasons. The F test was significant for all values.

Treatment	Plant height (cm)		Tillers $hill^{-1}$ (no.)		Effective tillers (no.)		Panicle length (cm)		Grains $panicle^{-1}$ (no.)		Grain yield (t ha^{-1})		Stover weight (g)		Weight of 1,000 grains (g)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Direct sowing	95	97	17	17	12	12	23	23	170	171	0.4	0.4	10	10	25	25
Transplanting	95	96	15	16	13	13	25	24	184	185	0.6	0.6	8	8	24	24
Seed broadcasting	85	85	7	8	5	5	15	15	67	68	0.4	0.4	10	10	23	23
Spreading of seedlings	91	94	16	18	14	14	23	24	188	188	0.6	0.6	9	9	25	25
Seed-boll placement	83	88	12	14	10	12	22	23	169	177	0.5	0.6	8	8	24	23
SEm ±	0.98	1.33	2.11	1.14	0.76	0.96	0.32	0.61	1.18	1.41	0.187	0.144	2.99	2.06	0.48	0.40
CD (0.05)	2.39	3.25	5.17	2.78	1.86	2.34	0.78	1.48	2.88	3.45	0.458	0.352	7.31	5.04	1.17	0.98

Table 2. Economics of rice crop establishment methods (mean values for 2 y).

Treatment	Cost of crop establishment methods (US$ ha^{-1})[a]			Additional cost over broadcasting ($)	Additional grain yield over broadcasting (kg ha^{-1})	Additional profit over broadcasting ($ ha^{-1}) when sold at $130 t^{-1}
	Laborers (no.)	Rate d^{-1} ($)	Total amount ($)			
Drilling of sprouted seeds	5	1.50	7.50	4.60	390	39.00
Transplanting	55	1.50	82.50	79.50	2,213	287.70
Broadcasting	2	1.50	3.00	–	–	–
Seed-boll dibbling	15	1.50	22.50	19.50	2,759	358.70
Spreading of seedlings	10	1.50	15.00	12.00	1,770	230.10

[a]Exchange rate: $1= Rs 46.15.

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Development of preharvest sprouting tolerance screening technique in rice

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Germination of seeds while on the parent plant before harvest is referred to as preharvest sprouting. Preharvest sprouting of seeds in the panicle is a common problem where rain and flash flood frequently occur and plants lodge because of gusty winds and when temperature remains favorable for germination. The occurrence of preharvest sprouting is erratic and unpredictable. It is a phenomenon, which depends on genetic, physiological, and environmental factors, and is therefore complex and changeable from year to year. Preharvest sprouting in the panicle is undesirable as it reduces both seed quality and quantity. Yield loss occurs because of shattering and threshing when depleted kernels are winnowed out. Specific gravity and packing ratio are reduced in the affected grain and, consequently, it has a significantly reduced test weight (Derera 1989).

So far, an efficient screening technique for identifying materials tolerant of preharvest sprouting has not been developed. Abeysiriwardena et al (1996) suggest that germination of seeds on an intact plant could be a promising method as it shows the germination ability of seeds at maturity. Continuous wetting of rice panicles at maturity results in preharvest sprouting. Considered a major constraint to the production of good-quality grain, preharvest sprouting has been the subject of a considerable amount of research. In a few areas, improved agronomic management has considerably reduced the severity of the problem, but, in most regions where this occurs, a practical solution has not been found. Thus, varieties tolerant of preharvest sprouting should be developed and this requires a reliable screening technique for measuring the degree of tolerance for preharvest sprouting in rice.

Our study was conducted at the BRRI experimental farm during the 2002 aus season (March to June). Five BRRI-released rice varieties—BR14, BR16, BR19, BR26, and BRRI dhan29—were tested, following the two methods regarded as treatments. Here, BR26 and BR14 were used as sprouting and moderately nonsprouting checks, respectively.

In method I, three randomly selected plants were gently bent to submerge panicles into standing water at 23, 30, 37, and 44 d after flowering (DAF). The panicles were submerged for 24 h and kept within a water-soaked cloth bag enclosed in a polyethylene bag for 6 d. The panicles were sprinkled with water twice a day. The panicles were kept a total of 7 d for water-soaked conditions (24 h under anaerobic and 6 d under aerobic conditions). Both ends of the bag were tied to prevent the cloth bag from drying. The plants were kept upright with a bamboo stick.

In method II, three randomly selected plants were gently bent to submerge panicles into standing water at 23, 30, 37, and 44 DAF. The panicles were submerged in standing water for 7 d.

A split-split-plot design with three replications using varieties as the main plot, panicle age as the subplot, and inundation as the sub-subplot was followed. Thirty-day-old seedlings of all varieties were planted in 2-m × 2-m plots. Two to three seedlings were planted in each hill at 25- cm × 15-cm spacing. The recommended cultural practices were followed. Three plants were randomly selected for inundation. The flowering dates of the selected plants were noted carefully. After inundation, the panicles of selected plants were collected and the number of germinated and nongerminated grains counted. Sprouting percentage was then computed.

Irrespective of variety and panicle age, higher percentages of sprouted seeds were found in method I than in method II, except for BR26, which, under method II, had a higher percentage of sprouted seeds at 30 and 37 DAF (see table). The lower percentages of sprouted seeds in method II might be the result of improper germination conditions—panicles were kept in standing water for 7 d so germination was hampered by the anaerobic conditions. It was also found that percent sprouting increased with an increase in panicle age. In the case of BR14, the percent sprouted seeds was 10.35, 12.56, 13.74, and 20.04 for 23, 30, 37, and 44 DAF, respectively. Similar results were found for the rest of the varieties in method I and for BRRI dhan29 in method II (see table). The increase in sprouting with panicle age might be due to the degree of dormancy breakdown. No significant trend was detected in sprouting percentage with increasing panicle age in method II, except for BRRI dhan 29, but the highest percentage of sprouting was found at 44 DAF, irrespective of variety and method (see table). Thus, the best time to identify varieties for sprouting tolerance is 44 DAF. Moderately nonsprouting variety BR14 showed 20.04% and 11.45% sprouting at 44 DAF with methods I and II. A maximum of 20% and 10% sprouting at 44 DAF may be considered highest for moderately nonsprouting and nonsprouting-tolerant variety, respectively. Therefore, method I may be regarded as the more appropriate method to use for identifying varieties tolerant of preharvest sprouting.

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Percent sprouting of rice seeds of five varieties at different dates after flowering determined using methods I and II, 2002.[a]

Method	Variety	Sprouted seeds (%)			
		23 DAF[b]	30 DAF	37 DAF	44 DAF
I	BR14	10.35 y b	12.56 y b	13.74 yz b	20.04 z a
	BR16	6.59 yz b	7.35 z b	10.11 z b	21.31z a
	BR19	4.99 z d	9.24 yz c	16.02 y b	27.88 y a
	BR26	14.61x c	18.68 x bc	22.57 x b	37.91x a
	BRRI dhan29	9.77 y c	13.35 y bc	17.49 y b	22.96 z a
II	BR14	4.66 y b	3.96 y b	3.71 y b	11.45 z a
	BR16	4.72 y b	2.93 y b	6.91y b	16.85 yz a
	BR19	4.23 y b	3.52 y b	6.43 y b	24.74 y a
	BR26	13.67 x c	34.73 x a	27.26 x b	35.69 x a
	BRRI dhan29	1.26 y b	3.10 y b	3.37y b	8.86 z a

[a]Means followed by a common letter(s) within a column or row do not differ at the 5% level by DMRT. Here x, y, and z indicate differences within columns, whereas a, b, c, and d indicate differences within rows. [b]DAF = days after flowering.

IRRN welcomes three types of submitted manuscripts: research notes, mini reviews, and "notes from the field." All manuscripts must have international or pan-national relevance to rice science or production, be written in English, and be an original work of the author(s), and must not have been previously published elsewhere. By submitting the manuscript, the author automatically assigns the copyright of the article to IRRI.

Research notes

Research notes submitted to IRRN should

- report on work conducted during the immediate past 3 yr or work in progress
- advance rice knowledge
- use appropriate research design and data collection methodology
- report pertinent, adequate data
- apply appropriate statistical analysis, and
- reach supportable conclusions.

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted.

Preliminary research findings. To reach well-supported conclusions, field trials should be repeated across more than one season, in multiple seasons, or in more than one location as appropriate. Preliminary research findings from a single season or location may be accepted for publication in IRRN if the findings are of exceptional interest.

Preliminary data published in IRRN may later be published as part of a more extensive study in another peer-reviewed publication, if the original IRRN article is cited. However, a note submitted to IRRN should not consist solely of data that have been extracted from a larger publication that has already been or will soon be published elsewhere.

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.

Manuscript preparation. Arrange the note as a brief statement of research objectives, a short description of project design, and a succinct discussion of results. Relate results to the objectives. Do not include abstracts. Up to five references may be cited. A list of 3–5 key words should be supplied. Restrain acknowledgments. Limit each note to no more than two pages of double-spaced type-written text (approximately 500 words).

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

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

Methodology

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

Terminology

- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
- Use the International System of Units for all measurements. For example, express yield data in metric tons per hectare (t ha^{-1}) for field studies. Do not use local units of measure.
- When using acronyms or abbreviations, write the name in full on first mention, followed by the acronym or abbreviation in parentheses. Use the abbreviation thereafter.
- Define any nonstandard abbreviation or symbol used in tables or figures in a footnote, caption, or legend.

Mini reviews

Mini reviews should address topics of current interest to a broad selection of rice researchers, and highlight new developments that are shaping current work in the field. Authors should contact the appropriate editorial board member before submitting a mini review to verify that the subject is appropriate and that no similar reviews are already in preparation. (A list of the editors and their areas of responsibility appears on the inside front cover of each IRRN issue.) Because only 1–2 mini reviews can be published per issue, IRRN will require high quality standards for manuscripts accepted for publication. The reviews should be 2,000–3,000 words long, including references. Refer to the guidelines for research notes for other aspects of writing and content.

Notes from the field

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

Review of manuscripts

The IRRN managing editor will send an acknowledgment card or an email message when a note is received. An IRRI scientist, selected by the editorial board, reviews each note. Depending on the reviewer's report, a note will be accepted for publication, rejected, or returned to the author(s) for revision.

Submission of manuscripts

Submit the original manuscript and a duplicate, each with a clear copy of all tables and figures, to IRRN. Retain a copy of the note and of all tables and figures.

Send manuscripts, correspondence, and comments or suggestions about IRRN by mail or e-mail to

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Rice

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Just after World War II, rapid population growth with limited rice production led experts to predict starvation in Asia. On its own, the Food and Agriculture Organization (FAO) of the United Nations had declared 1966 the Year of Rice and numerous countries took measures to improve production, marketing, milling, and nutrition. Conferences were organized and scientific research and technology were stimulated. Rice is now the staple food for over half of the world's population but its production faces many constraints under conditions of increasing world population and diminishing resources of water and land.

The United Nations launched the International Year of Rice 2004 on 31 October 2003. This is the second time that the United Nations has paid such a special tribute to rice, the only food crop honored twice. Rice is the single most important employment and income source for the rural poor. Rice will play a significant role in meeting the important UN Millennium Development Goal of poverty reduction in the world. Besides being an essential food, rice is also an important factor in enriching culture, lifestyles, and ecosystem functions. It is thus fitting that the United Nations pronounced 2004 the International Year of Rice to emphasize the important roles rice plays in the livelihoods and culture of humankind. Rice is a symbol of cultural identity, global unity, and life.

To mark the Year of Rice 2004, the Ministry of Agriculture, Forestry, and Fisheries (MAFF) of Japan, research organizations affiliated with MAFF, and the International Rice Research Institute (IRRI) jointly financed and organized the World Rice Research Conference (WRRC) that was held in Tokyo and Tsukuba, Japan, 4-7 November 2004. The WRRC had two parts: the Tokyo Opening Ceremony and Symposium in the Akasaka Prince Hotel graced by His Imperial Highness Crown Prince Naruhito of Japan on 4 November and the International Rice Research Conference at the Tsukuba Congress Center on 5-7 November.

The WRRC attracted 1,274 participants from 43 nations, who presented 190 scientific papers and 302 posters in 20 sessions and 6 workshops. Scientific themes covered genomics to climate change and involved scientists with expertise in genes to ecosystems. Such a broad range of subjects discussed during the conference makes the WRRC one of the most significant scientific events of the last few decades. Scientists presented their latest concepts, research findings, and products, which are captured in the topics presented in this proceedings. The proceedings contains the state of the art in rice science and production that we hope will be useful to rice scientists, extension specialists, development agents, and policymakers who will use this to better the lives of all humans, but especially those of poor farmers and consumers.

Akinori Noguchi
Vice president of the Japan International Research Center
for Agricultural Sciences and chairman
of the WRRC 2004 Organizing Committee

Rice is life: scientific perspectives for the 21st century

Proceedings of the World Rice Research Conference, Tsukuba, Japan

Edited by
K. Toriyama,
K.L. Heong,
and B. Hardy

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