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VARIETAL RESISTANCE TO THE BROWN PLANTHOPPER AND YELLOW STEM BORER

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Significant advances have been made in the development of rice varieties with resistance to the brown planthopper (BPH) and the yellow stem borer (YSB), important rice pests throughout tropical Asia, including southern China. Varieties resistant to those pests are widely grown in Asia. Through evaluation of more than 33,000 varieties from the world rice collection, about 300 with high BPH resistance have been identified. Four BPH-resistance genes have been identified and used in IRRI's breeding program. Several BPH biotypes have been characterized through international collaboration to investigate the response of differential varieties. New techniques quantify BPH resistance levels more accurately.

Of about 9,000 world-collection varieties evaluated for YSB resistance, only about 20 showed moderate resistance. The multiple crossing technique is being used to raise the levels of YSB resistance above those of the donor parents.

Insecticides have been used extensively to control BPH and YSF. In the last decade advances in the development of varieties with BPH and YSB resistance have been significant. This paper discusses the advances in development of methodology to identify and characterize varietal resistance to these rice insects.

Records of brown planthopper (BPH) attacks on rice date to 18 AD in Korea and to 697 AD in Japan (Suenaga and Nakatsuka 1958). But the BPH has only recently been considered a major pest in tropical Asia. Since 1973 losses in Indonesia alone have been estimated at US$l50 million. The yellow stem borer (YSB) is a recurring pest. Of the approximately 20 stem borer species reported to attack rice, the YSB is the most destructive and widely distributed. It is found in regions of Asia and in West Africa.

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BROWN PLANTHOPPER

Indian scientists reported the existence of varietal resistance to the BPH in the field in 1954 (Khush 1972). All of the Ch varieties introduced from China were highly susceptible, but several local Indian varieties were resistant. IRRI began to screen for BPH resistance in 1967. Today several Asian countries have active programs to identify and incorporate BPH resistance into agronomically desirable plant types.

Screening for resistance

Greenhouse. Greenhouse screening has been emphasized, but verification tests must also be conducted in areas with high BPH field populations. Greenhouse screening techniques developed at IRRI are being used (with modifications in some cases) in Bangladesh, India, Indonesia, Japan, Korea, Malaysia, the Solomon Islands, Sri Lanka, Taiwan, and Thailand. The screening methods were described by Choi (1979).

At IRRI, virus-free insects are reared on 40- to 50-day-old plants of the susceptible Taichung Native 1 (TN1) or other highly susceptible varieties in a 0.5- x 0.5- x 1-m cage. Each cage supports 2,000-3,000 late-instar nymphs. (In Japan and Korea, insects are mass-reared on seedlings in a transparent plastic cage -- a useful method in areas with cold winters because the cages are small and can easily be accommodated in laboratory rearing rooms.)

The test entries are sown in two types of seedboxes. In the 60- x 45- x 10-cm seedbox, each line is planted in a 15-cm row along with the susceptible check TN1 and the resistant check (Mudgo and ASD7 for biotype 1 screening, ASD7 for biotype 2, and Mudgo for biotype 3). To conserve space, a new seedbox has been developed. It is 106 x 61 x 7 cm and has 252- x 5- x 5-cm compartments. Susceptible and resistant checks are planted in the outer compartments and in two rows of compartments near the center. The seedboxes are then placed on a galvanized iron tray containing water. At about 7 days after seeding, seedlings at the 1- or 2-leaf stage are infested wi-th about 5 second- and third-instar nymphs/plant. When about 90% of the susceptible check plants are killed (about 7-12 days after infestation), the damage is scored (Table 1). In the screening of the germplasm collection or in other nonreplicated tests, entries rated 0-3 are retested. Selected lines or varieties are often further evaluated to determine the mechanisms of resistance.

Field. Before release breeding lines identified as resistant in the greenhouse must be evaluated in the field. Because field resistance may not be expressed in the seedling stage, field screening also identifies varieties with field or general resistance to the various BPH biotypes.

Table 1. Ratings and symptoms used to score brown planthopper resistance in the greenhouse and in the field.

Grade[a]	Rating[b]	Damage symptoms	
		Greenhouse	Field[c]
0	HR	No visible damage (equal to resistant check)	No visible damage
1	R	Partial yellowing of 1st leaf	Partial yellowing with sooty mold at base of plant
3	MR	1st and 2d leaves partially yellow	Stunting and yellowing
5	MS	Pronounced yellowing, some stunting or wilting	Pronounced yellowing or browning, stunting, some dead plants
7	S	More than half of the plants wilting or dead, remaining plants severely stunted	Most plants browning or dead
9	HS	All plants dead (equal to susceptible check)	All plants dead

[a]Standard Evaluation System for Rice (SES). [b]HR = highly resistant, R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, HS = highly susceptible. [c]Mochida et al 1979.

Field screening at some locations is often difficult because of the unpredictability of BPH populations. But the discovery that entomologists could manipulate BPH populations by applying certain insecticides that cause BPH resurgence has made field screening in certain locations possible (Heinrichs et al 1978).

For field screening several border rows are first planted with a BPH-susceptible variety. Depending on seed availability, one to four 5-m long rows of the test entries are planted. One to three rows of the susceptible check are planted between each test entry. The amount of susceptible material depends on the level of expected infestation. BPH populations are induced by spraying the susceptible rows at the end of the test entry with methyl parathion, fenthion, fenitrothion,

diazinon at 100 g a.i./ha, with decamethrin at 10 g a.i./ha, or with any other insecticide that causes resurgence. The BPH on each of 5 hills in each plot are counted between 40 and 50 days after transplanting (DT). Two similar countings are done every 20 days. The varieties are rated for damage on the field scale in Table 1. Damage is rated when about 95% of the TN1 plants have been killed and 3 more times at 5-day intervals.

Sources of resistance

Of the more than 33,000 varieties from the world collection screened by IRRI entomologists for resistance to BPH since 1966, about 300 have been selected. All are indicas; most are from South India and Sri Lanka. More than 500 indica varieties and lines have been found resistant to BPH in screening in the Philippines, Japan, Korea, Taiwan, Thailand, Indonesia, India, Sri Lanka, and Solomon Islands (Choi 1979). Also identified as resistant to the 3 Philippine biotypes at IRRI are 27 accessions of wild rices including *Oryza australiensis, O. brachyantha, O. latifolia,* and *O. punctata* from Australia, India, Africa, Costa Rica, and Guatemala.

Genetic studies have identified four BPH resistance genes (Table 2) Besides the monogenic BPH-resistant varieties listed in the table, four others -- PTB21, PTB33, Sudu Hondarawala, and Sinna Sivappu -- have two unidentified genes for resistance. The recently identified genes *Bph 3* from Rathu Heenati and *bph 4* from Babawee, and the two unidentified genes in PTB33 have been used in the breeding program.

Table 2. Genes of some brown planthopper-resistant varieties (Khush 1977 and IRRI 1978).

Varieties with given gene for resistance			
Bph 1	*bph 2*	*Bph 3*	*bPh 4*
TKM6	ASD7	Rathu Heenati	Babawee
Mudgo	PTB18	PTB19	Gambada Samba
MTU15	H105	Gangala	Hotel Samba
CO22	ASD9	Horana Mawee	Kahata Samba
	Palasithari 601	Muthumanikam	Thirissa
	H5	Kuruhondarawala	Sulai
		Mudu Kiriyal	Vellai Illankali
			Heenhoranamawee
			Kulu Kuruwee
			Lekam Samba
			Senawee

Several resulting new lines have resistance to the three Philippine biotypes and have been sent to other countries through the BPH Collaborative Project to determine their resistance to other biotypes.

Nature of resistance

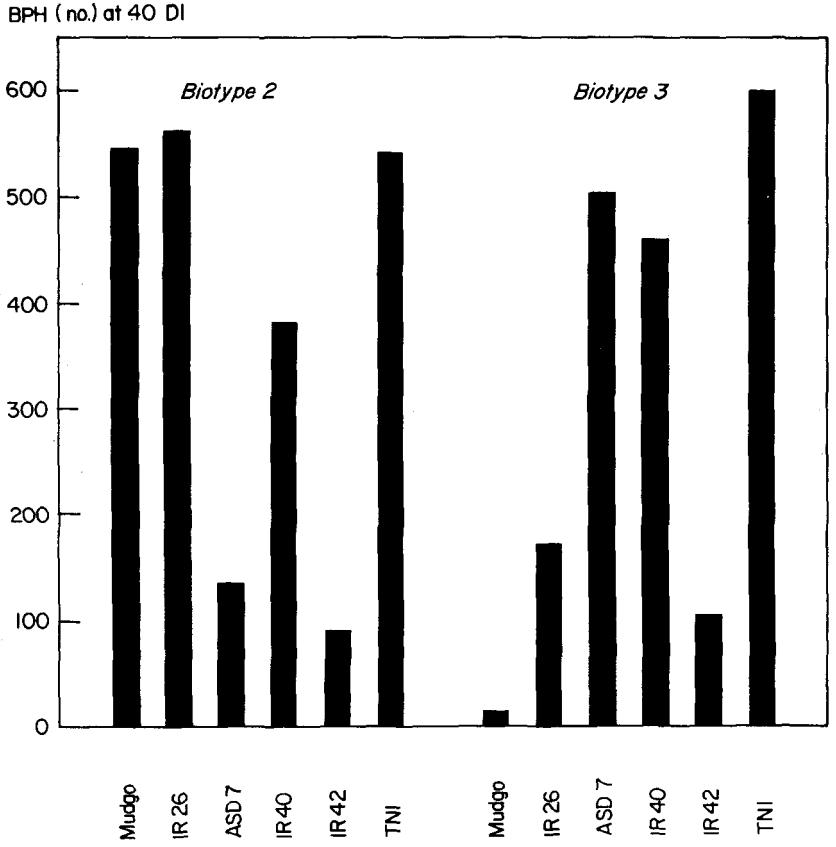
Preference. Pathak and Khush (1979) described a methodology for determining the preferences of BPH nymphs and adults. The seedling screening technique described earlier is used to determine nymphal preferences. The number of nymphs on each entry is recorded 24 hours after infestation and at 2–day intervals thereafter until the susceptible check is killed.

In determining adult preferences, individual plants of test entries are randomly grown 10 cm apart in seedboxes. At 30 days after sowing, the plants are pruned to 2 tillers/plant and 1– to 2–day-old adults are released on them. The insects are counted 3–12 hours after infestation, and then daily for 3 days. The number of eggs laid on each plant is then recorded.

Antibiosis. There are various techniques for measuring the BPH antibiosis levels of rice varieties. Although time–consuming, they are particularly useful in identifying varieties with moderate levels of resistance and with field resistance. The techniques that use survival and development of nymphs, population development, and feeding rates as measures of antibiosis are discussed.

1. *Survival and development of nymphs.* Ten 30–day-old plants of each test entry are transplanted into 10–cm clay pots, covered With 6– x 30–cm mylar film cages, and infested with 10 newly emerged nymphs. The number of surviving nymphs is recorded 24 hours after infestation and at 5–day intervals thereafter Until all nymphs on the susceptible check become adults.

2. *Survival and population development.* Ten–day-old seedlings are planted in 16–cm clay pots, in 5 replications. Each pot contains 3 seedlings (1 pot/replicate). Thirty days after transplanting (DT) the plants are placed inside 13– x 90–cm mylar cages with fine–mesh screen windows and infested with 10 freshly hatched nymphs. The surviving insects are counted at 20 days after infestation (DI) for insect survival and at 40 DI for populatipn buildup. In cases where heavy populations develop and kill the susceptible check before 40 DI, the insects on all test entries are counted just before the susceptible check dies, and the actual date of counting is recorded.

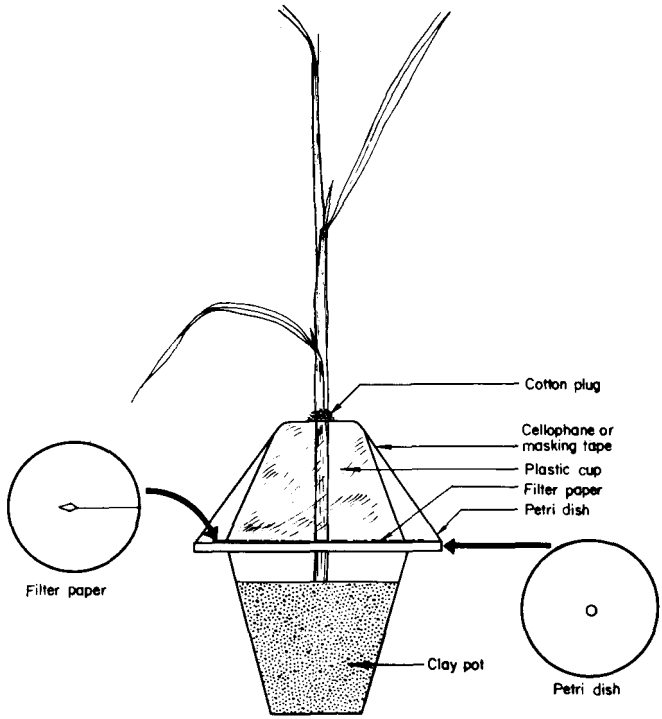


1. *Populations at 40 days after infestation (DI) resulting from 10 newly hatched nymphs of brown planthopper (BPH) females of biotypes 2 and 3 fed on selected varieties. IRRI greenhouse, 1978.*

Another method for determining the rate of population development is placing a pair of newly emerged adults on a 30-day-old plant growing in a 13- x 90-cm mylar film cage. The total number of insects at 20 and 40 DI indicates survival and population increase. Figure 1 illustrates the population development of biotypes 2 and 3 feeding on various varieties.

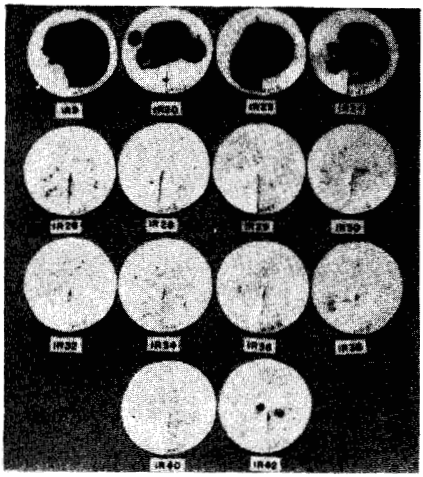
3. *Feeding rate.* Several techniques for determining the quantity of BPH feeding have been developed. The filter paper and volumetric techniques (Paguia et al 1980) are described.

The filter paper method uses a feeding chamber (Fig. 2) developed by Sogawa and Pathak (1970). The chamber consists of an inverted transparent plastic cup placed over filter paper resting on a plastic petri dish. Five 2-day-old adult



2. *An apparatus for collection of honeydew.*

females previously starved for about 5 hours are placed into the chamber through a hole at the top of the cup. The hole is plugged with a cotton wad to prevent insect escape. The insects are allowed to feed overnight. The next morning the filter paper is treated with 0.001% ninhydrin in acetone solution. After oven-drying for 5 minutes at 100°C, the honeydew stains appear as violet or purple because of the amino acid contents. The area covered by the purple stain indicates the amount of feeding (Fig. 3). The area of the spots can be estimated either visually or, more accurately, by using the tracing-paper technique. In the latter, the spots are traced on tracing paper. The tracing paper is placed over graphing paper and squares covered by the spots are counted. The method has been successfully used to determine the amount of feeding of the three biotypes of differential varieties (Table 3) and may be used to identify biotypes.



3. *Honeydew excreted on filter paper by 5 brown planthopper biotype 1 female adults on 30-day-old IR varieties. IRRI, 1978.*

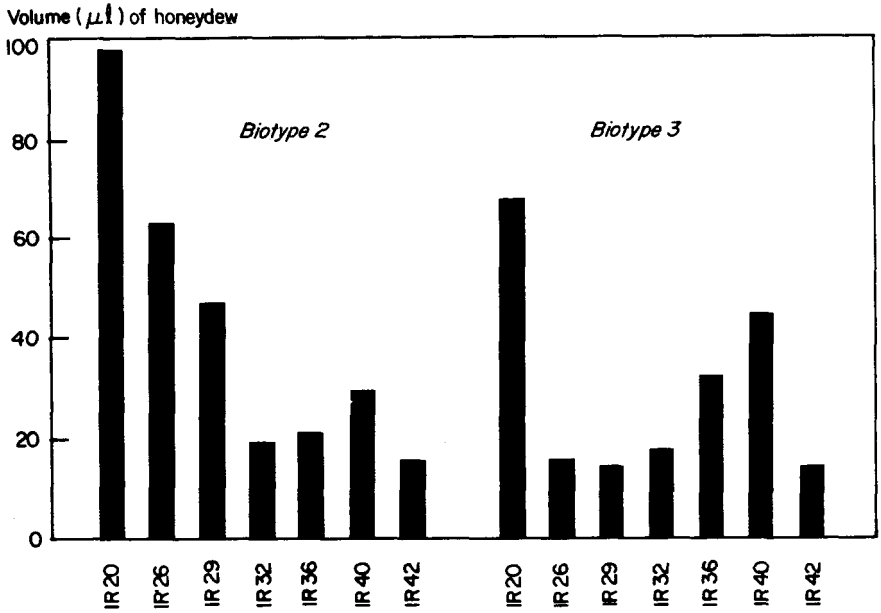
Another technique is cutting out the stained portions of the filter paper and weighing those portions on a milligram balance. Results are expressed in milligrams of filter paper containing honeydew droplets.

In the volumetric method, fresh honeydew is collected in a feeding chamber as described earlier but slightly modified by Alam (1978) and Iman (1978). Parafilm is stretched over the base of the inverted cup to seal the chamber. Five previously

Table 3. Area of ninhydrin-positive honeydew excreted by brown planthopper biotypes 1, 2, and 3 on rice varieties. IRRI, 1978.

Variety	Resistance gene	Area[a] (mm^2) Biotype 1	Biotype 2	Biotype 3
TN1	None	668 a	838 a	929 a
Mudgo	*Bph 1*	83 b	504 a	74 b
ASD7	*bph 2*	68 b	229 b	625 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level.



4. *Volume of honeydew excreted by 5 brown planthopper females feeding on IR varieties. IRRI, 1978.*

starved 2-day-old BPH females are placed in the chamber through a small hole at the top of the cup. The hole is then tightly sealed with parafilm to minimize evaporation of the honeydew droplets and to make quantification possible. Overnight feeding provides sufficient honeydew droplets on the parafilm for measurement. Calibrated micropipettes of various sizes (1-100 μℓ) are used to measure the volume of excreted honeydew. Figure 4 indicates the volume of honeydew excreted by biotypes 2 and 3 feeding on IRRI varieties.

Tolerance. Some workers do not consider tolerance a desirable type of resistance. Few techniques have therefore been developed to determine tolerance levels. Tolerance is a component in recent IRRI studies to determine the mechanisms involved in the field resistance of certain varieties (Dang Thanh Ho, IRRI, personal communication). Varying BPH populations are placed on the test entries at 25 and 40 DT and the level of tolerance is based on the number of tillers produced, the leaf area index, and the yield.

Causes of resistance

Only recently have studies to determine the biochemical bases of BPH resistance received considerable research input at IRRI.

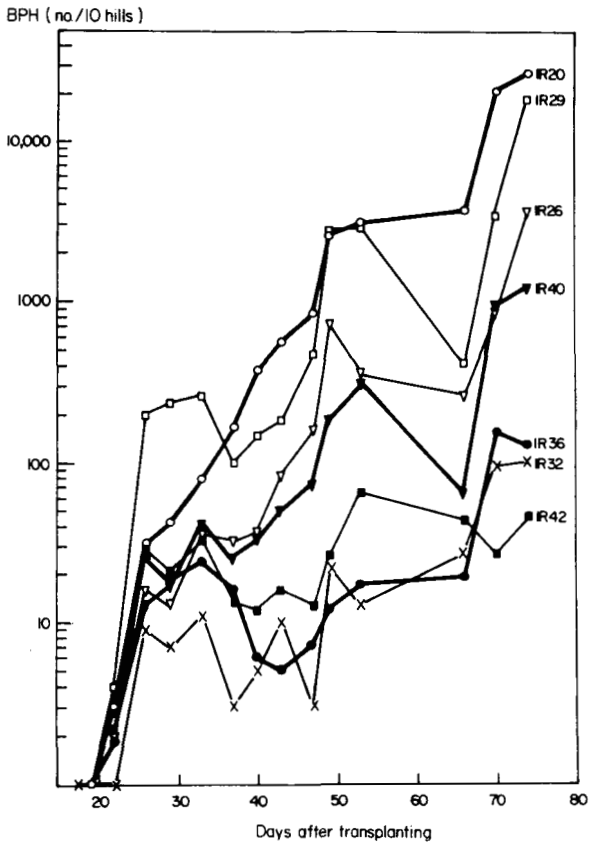
The various amino acid contents of cultivars vary. Studies in 1977 indicated that amino acids differ in activity as feeding stimulants in the three biotypes (IRRI 1978). Asparagine and valine are highly phagostimulatory to biotype 1, alanine to biotype 2, and valine and serine to biotype 3.

Cooperative studies with scientists from the Tropical Agriculture Research Center (TARC) and Hokkaido University in Japan showed that oxalic acid isolated from the resistant variety Mudgo acted as an antifeedant to BPH (IRRI 1978). More recent studies have shown oxalic acid to be present in all rice varieties tested, but levels are highest in BPH-resistant varieties (K. Sogawa, IRRI, personal communication).

Field resistance

Recognition of the occurrence of BPH biotypes has sparked interest in the development of varieties with field or general (horizontal) resistance to all biotypes. Plant pathologists are considering field resistance for disease control but it is a new concept in varietal resistance to rice insects. Certain varieties such as Kencana in Indonesia (Mochida et al 1979) have no major genes for resistance and are susceptible in greenhouse seedling screening as older plants but, are resistant in the field. At IRRI and at other locations, Triveni, which has no major resistance gene, has been observed as susceptible in the seedling stage but resistant in the field. IR26 and Mudgo, which carry the *Bph 1* gene for resistance, are susceptible to biotype 2 in the greenhouse. IR26 is readily killed in IRRI fields, where biotype 2 is abundant, but Mudgo is resistant. Techniques to identify field-resistant varieties and to determine the causes of field resistance are being developed through the Collaborative Project on BPH resistance.

Besides field screening, two other techniques are used to study the level of field resistance. One determines the rate of population development and the other the amount of feeding on varieties of various ages. In IRRI field tests, varieties with the same major resistance genes have responded differently to BPH attack. For example, Mudgo had low BPH populations while IR26, which has the same major resistance gene, had high BPH populations and was hopperburned. In field studies BPH populations were low on IR36, IR32, and IR42 but high in IR40 which has the same major resistance gene *bph 2* (Fig. 5). IR32, IR36, and IR42 may have minor genes that contribute to field resistance. Studies on the rate of papulation development and feeding on older plants have indicated that greenhouse techniques that can identify varieties with minor genes for field resistance can be developed. But additional techniques must be developed to efficiently identify field-resistant varieties, determine the mechanisms involved in field resistance, and breed for field resistance. The advantages of growing field-resistant varieties over growing vertically resistant varieties must also be assessed.



5. Brown plonthopper (BPH) populations on susceptible and resistant varieties sprayed 7 times with cypermethrin, a resurgence-inducing insecticide. IRRI, 1978.

Biotypes. The first indication of the existence of BPH biotypes was seen when IR26, the first BPH-resistant variety released by IRRI, was found susceptible when grown in India. After IR26 had been grown for 2 or 3 years in Indonesia and the Philippines, reports of hopper-burn damage indicated a shift in the BPH population where a virulent biotype was becoming abundant because of selection pressure.

Analysis of data from the International Rice Brown Planthopper Nursery (IRBPHN) provided additional information on the existence of BPH biotypes throughout Asia. The reactions of differential varieties indicate that biotypes in Southeast Asia are different from those in South Asia. ARC10550, which is susceptible throughout Southeast Asia, is resistant at all locations in South Asia (Table 4). Differential reactions occur even within even one country in South Asia (see reactions at Pattambi, Hyderabad, Cuttack, and Pantnagar, India,

Table 4. Differential reactions of rice varieties to brown planthopper (BPH) biotypes in greenhouse screening at various locations.[a]

Variety	Gene for resistance	Differential reaction to BPH								
		Southeast Asia			South Asia					
		Philippine biotype			Bangladesh	Pattambi, India	Hyderabad, India	Sri Lanka	Cuttack, India	Pantnagar, India
		1	2	3						
Sinna Sivappu	2, unidentified	R	R	R	R	R	R	R	R	R
Babawee	*bph 4*	R	R	R	R	R	R	R	S	S
PTB33	2, unidentified	R	R	R	R	R	R	–[b]	R	S
Rathu Heenati	*Bph 3*	R	R	R	R	R	S	R	S	S
ASD7	*bph 2*	R	R	S	S	S	S	S	S	S
Mudgo	*Bph 1*	R	S	R	S	S	S	S	S	S
ARC10550	?	S	S	S	R	R	R	R	R	R
TN1	None	S	S	S	S	S	S	S	S	S

[a] Based on International Rice Brown Planthopper Nursery (IRBPHN). 1976–78. R = resistant, S = susceptible. [b] Variable reactions.

Table 4). The Brown Planthopper Collaborative Project was developed to classify the various biotypes more accurately than can be done in the IRBPHN. Entomologists throughout Asia collaborate with IRRI to evaluate a set of differential varieties in greenhouses and fields.

So far, efforts to develop a practical method to characterize BPH biotypes other than by planting differential varieties and observing their reactions to BPH feeding, or the amount of feeding on each, have had little success (Paguia et al 1979). Sogawa (1978a) compared the electrophoretic variations in esterase among the Philippine biotypes and successfully separated out biotype 2 but could not separate biotypes 1 and 3. Sogawa (1978b) also attempted to identify morphologic characters that could be used to identify BPH biotypes. He found some variation in the average number of spines on the hind basitarsus among biotypes, but no sufficient differences to make the method useful for biotype identification.

YELLOW STEM BORER

Rice varieties are known to differ in their susceptibility to the yellow stem borer (YSB) for more than 60 years (Shiraki 1917). But the development of YSB-resistant varieties has been slower than of BPH-resistant varieties because of the lack of major genes that impart high levels of YSB resistance and the lack of efficient screening techniques.

When IRRI first began to screen for stem borer resistance, the field population was about 90% striped stem borers *Chilo suppressalis* and only 8% YSB. The striped borer initially received priority in the screening program (Pathak 1967). Later, screenhouse methods that facilitated screening for YSB resistance were developed.

Field screening for resistance

When conditions are suitable, field screening under natural infestation is preferred for evaluating varieties for stem borer resistance. Little labor is required, field space is not generally a problem, and entomologists can screen several thousand varieties per year. The major problems are that the stem borer populations are often a mixture of species and are too low for adequate evaluation. For proper screening, YSB populations must be sufficient to cause about 40% dead-hearts or 20% whiteheads. The following techniques should provide a population sufficient for field screening:

1. Location. Select a "hot spot" where stem borer populations are generally high.
2. Time of planting. Stem borer populations are seasonal; select the time of year when populations are highest. If light trap data from previous years are available, they can

be used as a guide in determining the planting date.

3. Lights. Adult stem borers are attracted to lights. Other insects are also attracted and, if abundant, may affect the stem borer study.

Planting of test entries. Each entry is planted in a 5-m row. One row of a susceptible (Rexoro or IR29) and another of a resistant check (IR1820-52-2-4-1) are planted after every 20 entries. In the initial screening of the germplasm collection, each entry is replicated only once, but in retests the selected varieties are replicated three times in a randomized complete block design.

Evaluation. Because the number of plants involved in the initial screening of the germplasm collection is large, damage is assessed visually and only the best entries are selected for retesting. In the evaluation of breeding lines and retesting of selected entries from the germplasm collection, deadhearts on all plants, except the two border plants at both ends of the rows, are counted at 30 and 50 DT. Because maturity varies widely in the germplasm collection, whiteheads are generally not counted.

The following rating system for deadheart incidence has been proposed for inclusion in the Standard Evaluation System (SES).

The test is considered valid if deadhearts in the susceptible check average at least 25%. Deadheart percentage are converted on the basis of the insect pressure, as indicated by the susceptible check.

$$\text{Deadheart index} = \frac{\text{Deadhearts (\%) in test entry}}{\text{Deadhearts (\%) in susceptible checks (av of 2 closest replicates)}}$$

The converted figure has a corresponding rating on the 0-9 SES scale as follows:

Scale	*Deadheart index*	*Level of resistance*
0	0	Highly resistant
1	0.10-0.20	Resistant
3	0.21-0.40	Moderately resistant
5	0.41-0.60	Moderately susceptible
7	0.61-0.80	Susceptible
9	>0.81	Highly susceptible

Screenhouse screening for resistance

Source of initial insect population. Egg masses are collected from rice seedlings grown in the field. The leaf portion on which they are

laid is detached, and placed on moist cotton inside a glass jar with a screen cover. Egg masses are often abundant on seedlings at 2 or 3 weeks after transplanting. Weekly planting can provide seedlings regularly if needed. Female moths can also be collected near lights in the evening. Newly laid eggs can be stored in an incubator at 15 to 20°C for about 2 weeks with no decrease in egg hatch.

Planting of test entries. IRRI uses a 25- x 22- x 2-m screen cage and 6 2.5-m wide concrete beds. Seeds of the susceptible check Rexoro or IR29, the resistant check IR1820-52-2, and the test entries are planted in wooden boxes in soil 5 cm deep. At 14 days after sowing, the seedlings are transplanted on the concrete beds, spaced 20 cm between rows and 10 cm within a row. Each variety is planted in 1 row. After every 10 rows of test entries, 1 row of the susceptible and another of the resistant check are planted.

Infesting plants with larvae. At 14 DT, plants are infested with newly hatched larvae. The larvae are removed from the jar with a fine camel's hair brush dipped in water. Five larvae are placed on one tiller in each hill. The larvae readily distribute themselves by moving to other tillers.

Evaluation. The deadhearts are counted 2 times, at 2 and at 4 weeks after infestation. Deadheart incidence is calculated and converted to the SES scale using the procedures described under field screening for resistance.

Sources of resistance

Extensive field screening at the Central Rice Research Institute (CRRI), India, in the 1950s identified TKM6, MTU15, and SL012 as moderately resistant to both deadheart and whitehead damage (Israel 1967). Since 1972 IRRI entomologists have evaluated more than 9,000 varieties from the world collection for YSB resistance in the field and in the house (Akinsola 1973, Manwan 1975, Heinrichs and Malabuyoc, unpubl.). Table 5 lists selected entries. Of the about 100 wild rices screened, none have shown good resistance. The screening of wild rices and *O. sativa* from the germplasm collection continues.

Through screening in the International Rice Stem Borer Nursery (IRSBN), IRRI has identified some breeding lines with resistance to YSB (Table 6). IR1820-52-2 has consistently shown good field and screenhouse resistance at IRRI and in the IRSBN in various countries.

Breeding for YSB resistance

Evaluation of thousands of rice varieties has revealed the generally low level and the continuous or polygenic nature of YSB resistance. To accumulate resistance from several donors for incorporation into

Table 5. Selected cultivars moderately resistant to the yellow stem borer. IRRI 1972-79.

Acc. no.	Cultivar	Origin
5816	CO15	India
6041	CO7	"
6365	MTU15	"
8763	DM27	Bangladesh
10191	Mainagiri	India
11055	Warangal Culture 1253 (EK 1253)	"
11057	Warangal Culture 1263 (EK 1263)	"
11261	Lepgu	Philippines
14423	IARI5829	India
20925	ARC10451	"
21959	ARC12171	"
22023	ARC12387	"
22948	Kong Sralas	Khmer Republic
23177	Phdao Pen DK-81	"
24739	Kuatik Serai Rendah	Indonesia
25832	Aus Balam	Bangladesh
26401	Moni Mukul	"
26952	Biplab	"
29953	Donangnouan	Laos
30848	Liberian Coll. Y-082	Liberia
	IRAM1642	Madagascar
12890	Ratna (CR44-11)	India
	Kwa-hwa-yuan	
	Kobumasari	

improved varieties, IRRI follows a systematic program involving multiple crosses of several rices with low or moderate resistance levels.

The first cycle of the hybridization program, begun in 1975, used these sources of resistance: IR1514A-E666, IR1539-823, IR1628-632, IR1704-3-2, IR1721-11, IR1820-52-2-4-1, IR1917-3-19, IR2061-628, Ratna, WC1263, and IR36. Single and double crosses involving IR36 survived severe field infestations of ragged stunt virus in 1976. In the 1977 dry season, plants were selected in the F_2 field and 459 F_3 lines from 10 crosses were screened under stem borer infestation. In the 1978 wet season those lines were tested in the observational yield trial for blast, bacterial blight, two BPH biotypes, and the green leafhopper (Table 7). The most promising lines were sent to various national programs for further stem borer resistance evaluation. Selected lines from the following crosses have also been included in the special IRTP stem borer screening nursery set: IR1365

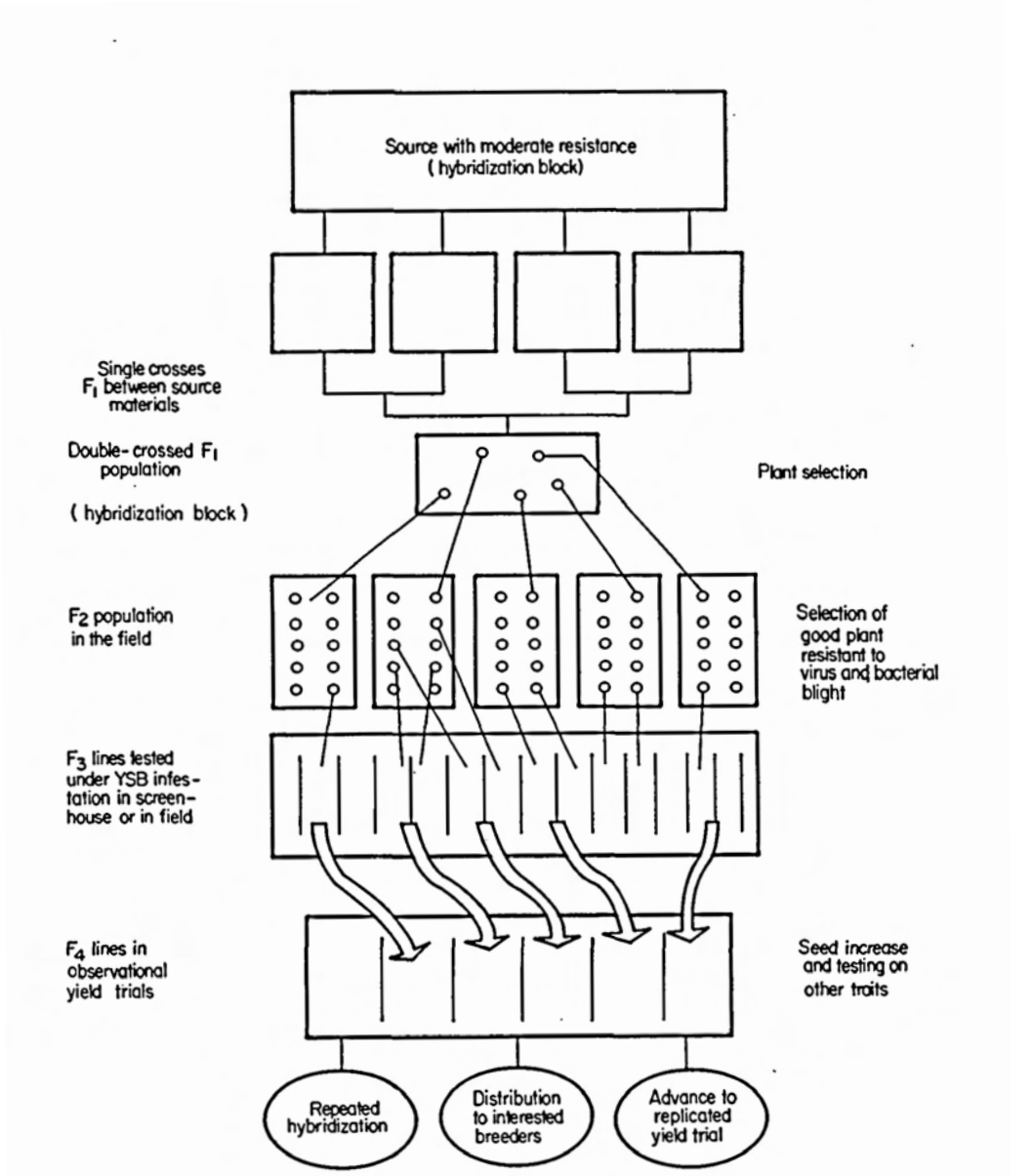
Table 6. Selected entries in the International Rice Stem Borer Nursery with resistance to the yellow stem borer in the Philippines. IRRI, 1976-78.

Designation	Cross	Origin
IET2845	TKM6/IR8	India
IET3093	TKM6/IR8	India
IET5262	IR22/NP130	India
IET5561	Panvel 17-18/IR8	India
IRl544-E666	IR20/TKM6	Philippines
IRl820-52-2	IR539-60/IR1416-128-5	Philippines
IR3941-97-1	CR26-42-5/IR2061-21-3	Philippines
IR5201-122-2	IRl820-52-2/IR2061-464-2	Philippines
IR5201-127-2	IRl820-52-2/IR2061-464-2	Philippines
IR36	IR1561//IR24*4/ *O. nivara* ///CR94-13	Philippines
RD9	LY*Z/TN1//W1256///RD2	Thailand

Table 7. Resistance of selected F_3 yellow stem borer-resistant lines to insects and diseases. IRRI, 1978.

Line	Damage rating[a]					
	Blast	Bacterial blight	Brown planthopper		Green leafhopper	Yellow stem borer
			Biotype 1	Biotype 2		
IR13639-37	1	1	1	1	3	3
IR13639-42	1	1	1	3	3	3
IRl3641-4	1	1	1	3	3	1
Check						
IRl820-52-2 (resistant)	2	7	1	9	3	5
Rexoro (susceptible)	-	-	-	-	-	9

[a]Standard Evaluation System (SES) for Rice: 1 = resistant, 9 = highly susceptible.



6. *Breeding program for resistance to the yellow stem borer (YSB).*

Table 8. Multiple crosses evaluated for yellow stem borer resistance (second cycle) at the Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, Philippines. MRRTC and IRRI, 1978–79.

Designation	Cross	Lines tested (no.)	Lines selected (no.)
IR19334	IR3941–92-2/IR1514A-E666//IR2071-625-1-252	250	43
IR19335	IR3941–9-2/IR1917-3-19-2//IR2071-625-1-252	255	42
IR19361	IR4227–28-3-2/IR1514A-E666//IR2071-625-1-252	250	47
IR19362	IR4227–28-3-2/IR1917-3-19-2//IR2071-625-1-252	200	53
IR19390	IR4427–51-6-3/1R1514A-E666//IR2071-625-1-252	250	86
IR19391	IR4427–51-6-3/IR1820-52-2//IR2071-625-1-252	244	100
IR19392	IR4427–51–6–3/IR1817–3–9–2//IR2071–625-1-252	301	67
	Total	1750	438

Table 9. Resistance to yellow stem borer of selected lines from multiple crosses. MRRTC[a] and IRRI, 1978.

Line	IRRI screenhouse		Field test at MRRTC	
	Deadheart (%)	Grade[b]	Deadhearts (%)	Grade[b]
IR19392-1	19	3	19	3
IR19392-6	19	3	13	1
IR19392-85	20	3	21	3
Rexoro (susceptible check)	65	9	85	9
IRl820-52-2 (resistant check)	23	3	23	3

[a] Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines. [b] 1 = resistant, 9 = susceptible.

(IR1628-632-1/IRl917-3-19-2//IR1539-823-1/IR2071-625-1-252), IR13639 (IR1704-3-2-3/IRl514A-E666//IR1628-632-1/IR2071-625-2-252), and IRl3641 (LRL721-11-68-3/IR2307-64-2//IR1628-632-1/IR1514A-E666). Figure 6 illustrates the flow of materials in the IRRI breeding program for YSB resistance.

In the second breeding cycle, new resistance sources from the International Rice Observational Nursery were used. IR2307-217-2-3, IR3941-97-1, and IR4427-51-6-3 (which are as resistant as IRl820-52-2) were crossed to resistance sources such as IR1514A-E666 and IRl820-52-2. In most crosses IR36 was topcrossed or included as a component of the parentage because of its resistance to the BPH and green leafhopper, and moderate stem borer resistance. During 1978-79, 1,750 F_3 lines were field evaluated in *hot spot* conditions at the Maligaya Rice Research and Training Center (Table 8). Many lines were outstanding (Table 9); those with lower deadheart readings than the resistant check IR1820-52-2 were included in the observational yield trial for selection of other important traits.

In the 1978 wet season, the third breeding cycle was initiated with smrces selected from the first IRSEN such as IET2815, IET2830, and IET2845 (selections of the RP6 cross, TKM6/IR8) and IET5540 (from the R34 cross, IR22/NP130). They were crossed with lines from the first cycle of IRRI's YSB breeding programs; the F_1s will be crossed with lines having the new BPH-resistance genes *Bph 3* and *bph 4.*

CONCLUSION

In the last decade significant advances in the development of rice varieties that are resistant to the BPH and YSB have been made. Those resistant varieties are grown on millions of hectares throughout Asia as components of an integrated control program. But serious obstacles still confront breeders and entomologists who work together developing resistant varieties. In many regions farmers still do not grow insect-resistant varieties because such varieties possess characters that affect their acceptability. The BPH is a constant threat because selection of new biotypes that can negate a resistant variety's value is possible. Although the level of YSB resistance has been increased through multiple crossing, higher resistance levels are still desirable. Such levels of resistance can most expediently be achieved through close cooperation among scientists of all disciplines involved in rice improvement.

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