# Studies of varietal resistance in rice to the brown planthopper at the International Rice Research Institute

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Studies of varietal resistance to the brown planthopper (BPH) started at the International Rice Research Institute in 1966. Since then, nearly 26,000 entries from the world germplasm collection have been screened. Biotype studies started in 1971 and three biotypes were identified by 1974. About 42,000 breeding lines were tested for biotype resistance through 1975. Studies on the inheritance of resistance to BPH started in 1968.

The mechanisms of BPH resistance are examined in preference and antibiosis studies and in tolerance tests.

Intensive cultivation of rice resistant to BPH increases the possibility of development of new biotypes. Natural BPH populations are believed to include small proportions of insects that survive on resistant varieties. IRRI studies in the Philippines include planting different varieties in many areas to determine if a variety resistant at one site becomes susceptible at another, and the several-generation rearing on resistant varieties of BPH collected from various areas where resistant varieties are intensively cultivated. No additional biotypes have been isolated. Biotype 2 has become preponderant.

Multiline plantings at IRRI in 1976 showed a decrease in number of BPH as the number of resistant plants increased.

Four resistant varieties were genetically analyzed in 1968 studies and two loci of BPH resistance were identified—*Bph 1* and *bph 2*. In 1976 two new genes for resistance were identified—*Bph 3* and *bph 4*. Mudgo and IR7476,–6 were used since 1967 as donor parents for *Bph 1,* and IR1154-243 and CR94-13 as donors of *bph 2*. Important varieties from IR747$B_2$–6 crosses were IR28, IR29, and IR34. CR94-13 was used extensively as a source of *bph 2,* and two crosses, IR2070 and IR2071, had outstanding BPH resistance. IR32, IR38, and IR40 were selected from IR2070; IR36 and IR42 from IR2071. About half of IRRI's breeding materials have *Bph* 7 and the other half have *bph 2.* Efforts are under way to incorporate *Bph 3* and *bph 4.*

STUDIES AT THE INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI) of varietal resistance in rice to the brown planthopper (BPH) were initiated in 1966. They included field evaluations of 1,350 cultivars planted in 4-row plots; the insects on the plants were sampled at 50 and 70 days after transplanting. Selected varieties were tested in greenhouse experiments for consistency of

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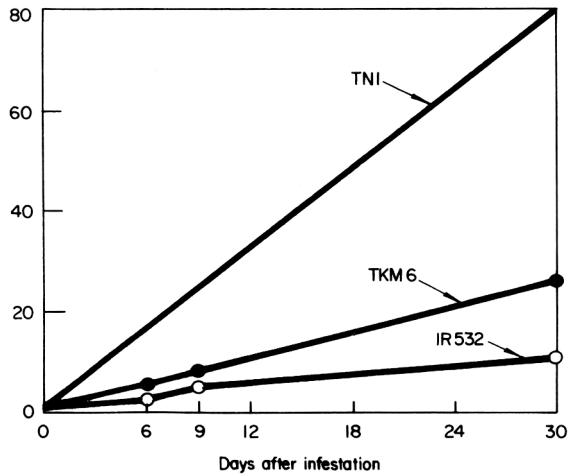
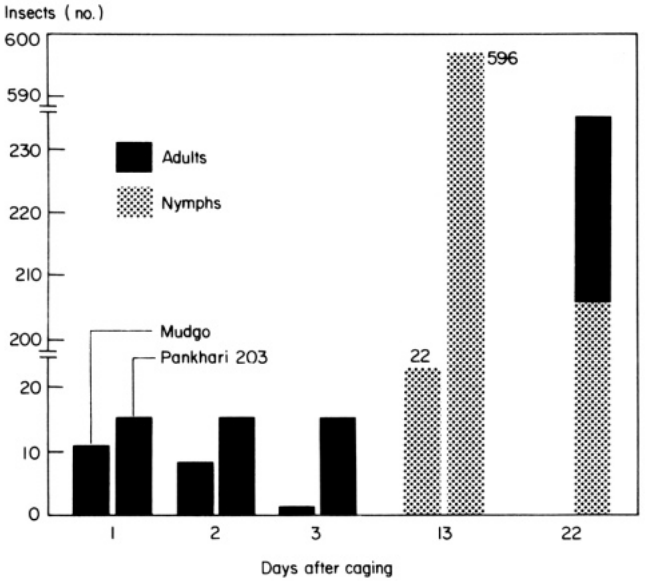
basic insect-host plant interrelationships by determining the preferences of the insects for the cultivars, or the antibiosis effect of the cultivars on the insects, or both. The basic techniques used were adopted from the methodology used in studies of the corn leaf aphid (Pathak and Painter 1958). As far as we know, no such work on the BPH has been previously undertaken.

The studies revealed some differences in varietal susceptibility, but it was about a year later that the variety Mudgo (Pathak et al 1969) and few plants of IR532 (Peta[3] TN1//TKM6) exhibited high levels of resistance (Fig. 1, 2; IRRI 1967b). Nearly 26,000 varieties from the germplasm collections have since been screened for reaction to the insect (IRRI 1967a,b; 1968, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977; Bae and Pathak 1970; Pura 1971; Rezaui Karim 1975).

Studies of the possible occurrence of BPH biotypes began in 1971, when several field populations were collected from different places in Luzon and their survival rates were tested on susceptible TN1 and resistant Mudgo (IRRI 1972). Repeated collecting and rearing of field populations on resistant plants culminated in the identification of BPH biotypes 1, 2, and 3 (IRRI 1975). Projects for identifying other biotypes have since been standardized by rearing field-collected insects on varieties with known genes for resistance. Biotypes 2 and 3 were used in screening the germplasm collections and about 6,000 varieties were tested against each biotype. In the overall screening program, about 50 varieties were found resistant to all three biotypes (Fig. 3). About 42,000 breeding lines have been tested (IRRI 1976) and the number screened for resistance to the three biotypes is increasing yearly.




**1.** Effect of infestation with a heavy population of brown planthoppers on $F_4$ progeny of IR532 and varieties Taichung Native 1 and TKM6. IRRI, 1967.




**2.** Number of *Nilaparvata luens* adults and their progeny at different days after caging rice varieties Mudgo and Pankhan-203. A total of 15 mated females were caged individually on a plant of each variety. IRRI, 1967.

A wide variety of sources of genetic resistance to the BPH is available in the rice germplasm and that resistance appears to be compatible with other desirable plant characters. BPH-resistant varieties, therefore, offer a potential for BPH control. However, the development of biotypes capable of surviving on resistant plants is a major threat to the stability of varietal resistance. The details of BPH studies at IRRI are reviewed in this paper.

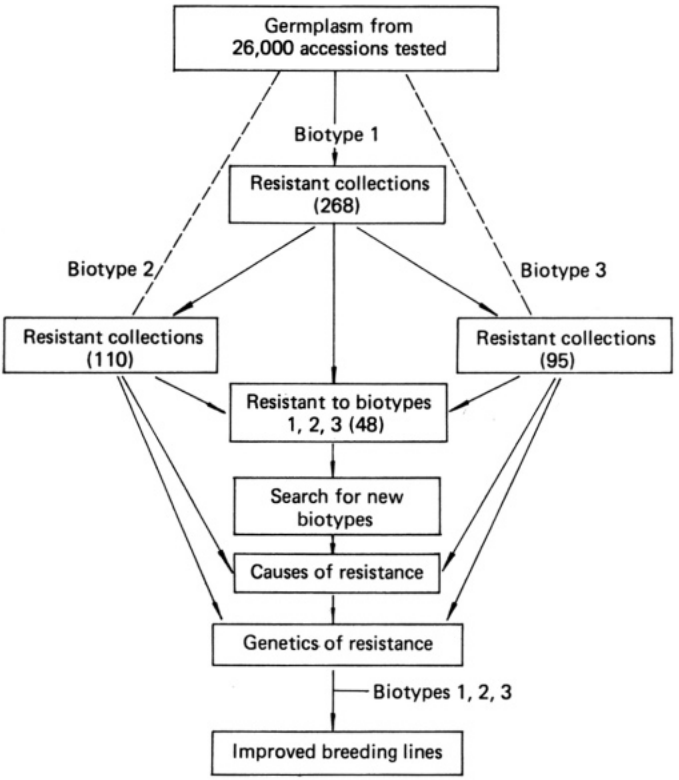
## MASS REARING AND SCREENING

The methodology used in mass rearing and screening of the test varieties is similar to that described by Chen (this volume).

In retesting selected cultivars for resistance, insects are caged on individual potted plants and records are taken of their body size and survival and of the rate of growth of nymphs or longevity of adults. In determining the insects' ovipositional and feeding preferences, the insects are released into a cage containing potted plants of different varieties.

### Differences in damage to resistant and susceptible plants

Individual seedlings of test varieties and of a susceptible check variety are transplanted separately into 15-cm clay pots. At a desired interval after transplanting, each plant is confined with 100 second-instar nymphs in a




**3.** Steps in developing varieties resistant to brown planthopper biotypes. IRRI, 1976.

6- × 30-cm cylindrical mylar cage.

Records of plant damage and insect mortality are taken at appropriate intervals until all susceptible check plants are dead. Plant damage is rated on the standard scoring system of 0–9.

## MECHANISMS OF RESISTANCE

### Preference

*Nymphs.* Pregerminated seeds of selected rice varieties, including resistant and susceptible checks, are sown in rows 20 cm long and 10 cm apart in wooden flats (60 × 45 × 10 cm). One week after sowing, about 5,000 first- and second-instar nymphs are released on the plants. The number of insects on and the grade of damage to each variety are recorded 24 hours after infestation and then at 2-day intervals until the susceptible check is killed.

*Adults.* Individual plants of the test varieties and of the resistant and susceptible check varieties are sown randomly 10 cm apart in wooden flats.

Thirty days after, the flats are placed in a water-filled iron tray in a screen-house. The plants are pruned to two tillers per plant and several hundred 1- or 2-day-old adult insects are released on them. (Individual potted plants can also be used for studying the nonpreference of alate insects). The insects on each variety are counted 3 and 12 hours later, and then everyday for 3 days. The plants are then cut as close to the base as possible and the number of eggs in each is recorded. Removing the chlorophyll with ethyl alcohol, then staining the eggs with acid fucshin in phenol-lactic solution (Gifford and Trahan 1969) is helpful in locating and counting the egg masses.

*Preference of adult brown planthopper for liquid plant extracts of resistant and susceptible varieties.* One-month-old plants are dried at room temperature and ground to a fine powder. The lipoidal materials are extracted from the ground materials with chloroform; and a final extract is made with 80% ethanol. The liquid extract of each variety is placed in a 6- × 1.25-cm glass vial, the mouth of which is exposed through a hole made in black cartolina paper board (50 × 50 cm). One end of a filter paper roll (21 × 1 cm) is dipped to the bottom of the vial, leaving about 15 cm of the roll exposed. The filter paper thus absorbs the liquid extract of the test varieties. A control vial contains distilled water only. The vials are placed in an iron-framed cage of fine-mesh screen walls. Between 300 and 400 1- to 2-day-old adult hoppers are then released into the cage and the number of insects on different vials is recorded at 3, 6, 9, and 24 hours later.

**Antibiosis**

*Survival and development of nymphs.* Ten plants of each selected test variety and of a susceptible check are transplanted individually in 10-cm clay pots. Thirty days after, each plant is caged with 10 freshly hatched nymphs in 6- × 30-cm mylar cages with fine-mesh-screen windows. The surviving nymphs are counted 24 hours after infestation, then every 5 days until all nymphs on the susceptible check become adults.

Individual potted plants are also used for investigating the population buildup of the insect, the effect of plant age on its susceptibility, and a variety of other insect-host plant interrelationships.

*Longevity and fecundity of the brown planthopper on resistant and susceptible varieties.* Ten 30-day-old plants of each selected resistant variety and of a susceptible check are placed singly in 4- × 30-cm test tubes into which a pair of newly emerged male and female brown planthoppers is released. The test tubes contain a standard culture solution (Yoshida et al 1972) for growing rice. The mouth of the test tube is covered with nylon screen. The plants are replaced every 3 days and the number of eggs laid on each variety is counted on dissected plants under a binocular microscope. Insect mortality is recorded daily.

*Amount of feeding by adult brown planthopper.*

- By gain or loss in body weight

Newly emerged females are starved for 3 hours. Five insects are anaesthesized as a group with the application of ether or carbon dioxide for 15 seconds at the rate of 2.5 ml/s; then they are weighed on a Metler H10 analytical balance. The insects are kept in vials for a few minutes to recover, then are placed in 4- × 30-cm test tubes, each containing 15-day-old seedlings of a test variety. Six hours after caging, the insects are removed, anaesthesized, and weighed again. The change in body weight indicates growth. Insects kept without food serve as controls.

- By differences in amount of honeydew excreted
  Selected resistant varieties and a susceptible check are grown singly in clay pots. Twenty days after sowing, each plant is caged with five adult females that had been starved for 3 hours. The conical mylar cages have filter papers attached to their bottoms. Honeydew droplets excreted by the insects are collected on the filter papers. Forty-eight hours after caging, the filter papers are removed and treated with a 0.2% ninhydrin solution, which stains the area wetted with honeydew.

*Feeding behavior.* Seeds of resistant varieties and of a susceptible check variety are grown separately in petri dishes. Seven days after germination, the seedlings of each variety are transferred individually to 2- × 170-cm test tubes containing culture solutions. A newly emerged female adult is placed in each tube. Six hours later, the seedlings are removed and immersed in 70% alcohol. They are stained with 1.0% erythrosine dye in aqueous solution according to the method described by Naito (1964), and the insects' probing or salivary marks are counted under a binocular microscope.

*Survival of adult brown planthoppers feeding on liquid plant extracts.* The plant extracts of selected varieties and checks are obtained through the procedure described under the section Preference of adult brown planthoppers for liquid plant extracts of resistant and susceptible varieties. A control treatment contains 5% sucrose solution. A plant extract or sucrose solution is placed under a "sachet" prepared by stretching a 9-cm parafilm membrane over the open end of a 4-cm-diameter glass tube. The plant extract (0.5 ml) is placed on the stretched membrane, and covered with another stretched membrane. Another glass tube is placed over the liquid-filled sachet so that the sachet remains between the two glass tubes. Ten 1- to 2-day-old females starved for 3 hours are introduced into the upper tube. The insects feed on the extracts through the parafilm membrane. Insect mortality is recorded at 3, 5, and 15 hours after insect release.

**Tolerance test**

Seven-day-old seedlings are transplanted individually in clay pots. At 40 days after transplanting, each pot is infested with a uniform number of first-instar nymphs. A set of plants identical to the treated set is kept free of insects.

Tillering of infested and uninfested plants is recorded. Insect deaths are recorded every other day, and each dead insect is replaced with a live one of the

same age. The durations of infestation appropriately varies in different experiments, but in all experiments, the plants are grown until harvest, when yields of infested plants of each variety are compared with those of the uninfested plants.

## STUDY OF THE LIFE HISTORY OF THE BROWS PLANTHOPPER

### Egg hatching

Seedlings of test varieties are grown individually in small clay pots. Thirty days after planting, each plant is placed in a cylindrical mylar cape with five pairs of 2- to 3-day-old adults. After 12 hours, or approximately an overnight period, the insects are removed. The number of nymphs that hatch each day thereafter is recorded until the 15th day.

### Nymphal development

Seedlings of test varieties are placed individually in test tubes (4 × 30 cm) containing culture solutions. The mouth of each test tube is covered with nylon cloth to permit proper aeration. One newly hatched nymph is placed in each tube. Its molting is observed until it becomes an adult. The nymphs undergo five moltings to become adults. The seedlings in the test tubes are replaced with new ones every 2 days.

## SOURCES OF RESISTANCE

From a mass screening of nearly 26,000 rice varieties, about 500 varieties that received damage grades of 1 to 5 were selected to be retested for resistance to the three BPH biotypes (Fig. 3). Subsequently, 268 selections were classified as resistant to biotype 1,110 to biotype 2, and 95 to biotype 3. Several of the varieties were highly resistant. Varieties resistant to one biotype were not necessarily resistant to the other two. About 50 varieties or selections were identified as resistant to all three biotypes. No variety susceptible to biotype 1 was resistant to biotype 2 or 3 (Table 1). Several breeding lines from IRRI and India are resistant or moderately resistant to the three biotypes (Table 2).

**Table 1. Total number of accessions showing reactions to the three brown planthopper biotypes. IRRI, 1976.**

| Accessions (no.) | Reaction[a] to | | |
|---|---|---|---|
| | Biotype 1 | Biotype 2 | Biotype 3 |
| 48[b] | R | R | R |
| 110 | R | R | S |
| 95 | R | S | R |
| 12 | R | S | S |
| 6000 | S | S | S |

[a]R = resistant, S = susceptible. [b]Including 10 wild rice collections.

**Table 2. Selected lines that are resistant or moderately resistant to the three biotypes of the brown planthopper. IRRI, 1976.**

| Rice selection | Source of test materials | Damage ratings [a] | | |
|---|---|---|---|---|
| | | Biotype 1 | Biotype 2 | Biotype 3 |
| IET 5118 | IRBPHN '76 | 3.0 | 4.3 | 3.7 |
| IET 5119 | " | 3.0 | 2.3 | 5.0 |
| IET 5120 | " | 1.7 | 4.3 | 3.7 |
| IET 5122 | " | 1.0 | 1.0 | 1.0 |
| IET 5236 | " | 1.0 | 2.3 | 4.3 |
| IET 5085 | " | 1.7 | 4.3 | 5.0 |
| IR32 | GEU Elite (WS '76) | 1.7 | 1.7 | 3.7 |
| IR2071-137-5-5-1 | " | 1.7 | 4.3 | 1.7 |
| IR2863-39-2-1 | " | 3.0 | 2.3 | 5.0 |
| IR4432-28-5 | " | 1.0 | 1.0 | 3.7 |
| IR4432-38-6 | " | 1.3 | 1.7 | 5.0 |
| IR4432-52-6-4 | " | 1.3 | 2.3 | 5.0 |
| IR4432-103-6-4 | " | 1.0 | 1.5 | 4.3 |

[a] Av. of three replications using the seedling test method. The moderately resistant varieties will get killed under heavy insect infestations.

**Table 3. Survival of adult brown planthopper (BPH) biotypes on leaf sheath and stem of selected rice varieties. IRRI, 1976.**

| Variety | BPH survival (%) [a] | | |
|---|---|---|---|
| | Biotype 1 | Biotype 2 | Biotype 3 |
| ASD 7 leaf sheath | 8* | 33* | 48* |
| stem | 51 | 79 | 79 |
| Mudgo leaf sheath | 5* | 53* | 7* |
| stem | 28 | 81 | 31 |
| TN1 leaf sheath | 64* | 72 | 75 |
| stem | 88 | 80 | 69 |

[a] Av. of 15 replications. Five newly emerged female adults were caged for 5 days on 80-day-old plants. Asterisk (*) means that there is a significant difference in survival between leaf sheath and stem of a particular variety

Some were resistant at all the test sites of the International Rice Brown Planthopper Nursery.

Fewer insects survived on the resistant varieties than on others, but removal of leaf sheaths from resistant varieties permitted more insects to survive (Table 3). At 3 hours after caging, fewer BPH biotype-1 insects survived on a liquid extract of Mudgo variety than on an extract of the susceptible TN1 variety (Table 4). Differences in plant age did not affect survival on most varieties. But on Rathu Heenati the survival rate of biotype-2 insects was greatly reduced as the plants became older (Table 5). Because of those differences, the resistant varieties suffered much less plant damage than did the susceptible varieties that had identical levels of BPH infestation. When the insects had a choice between resistant and susceptible varieties, a greater number of them gradually accumulated on the susceptible varieties (Table 6). Consequently, the BPH laid fewer eggs in resistant varieties than in susceptible varieties. Generally, the number

**Table 4. Survival of adult brown planthopper on liquid extracts of resistant and susceptible varieties 3, 5, and 15 hours after caging. IRRI, 1975.**

| Variety | Survival (%) | | |
|---|---|---|---|
| | 3 h | 5 h | 15 h |
| XB 5 | 77.5 ab | 67.5 a | 2.5 a |
| Ptb 20 | 77.5 ab | 70.0 a | 12.5 a |
| Mudgo (resistant check) | 750 a | 72.5 ab | 0.0 a |
| TN1 (susceptible check) | 90.0 bc | 85.0 b | 0.0 a |
| Sucrose solution | 95.0 c | 95.0 c | 92.5 b |

**Table 5. Effect of plant age on survival and adult development of planthopper biotype 2 on resistant and susceptible varieties. IRRI, 1977.**

| Variety | Insects (%) that survived at 20 days after infestation | | |
|---|---|---|---|
| | 15 DT | 30 DT | 60 DT |
| M 302 | 68.0 bc | 60.0 b | 84.0 ab |
| H 105 | 81.0 ab | 59.0 b | 78.5 b |
| ASD 1 | 74.5 bc | 63.5 b | 77.0 b |
| SLO 13 | 77.5 b | 65.0 b | 79.0 b |
| CO 9 | 69.0 bc | 63.5 b | 75.5 b |
| TN1 (S) | 92.5 a | 87.5 a | 95.5 a |
| Mudgo (S) | 95.5 a | 73.5 ab | 94.5 a |
| ASD 7 (R) | 59.0 c | 59.5 b | 76.0 b |
| IR32 (R) | 75.5 b | 20.0 c | 42.5 c |
| Rathu Heenati | 80.5 ab | 10.0 c | 31.0 c |

of eggs laid per egg mass in resistant varieties was also lower than that in the susceptible variety (Table 6). Smaller progenies developed from adults caged on resistant varieties for about 1 month than from adults caged on the susceptible variety TN1 (Table 7). Resistant varieties do not offer conditions favorable for normal insect development and multiplication.

**Table 6. Host and ovipositional preference of brown planthopper adults to selected rice varieties. IRRI, 1974.**

| Variety | Female insects per plant[b] | Eggs (no./plant) | Egg masses (no /plant) | Eggs (no /mass) |
|---|---|---|---|---|
| XB 5 | 12.7 a | 92.7 a | 27.2 ab | 3.1 ab |
| HR 12 | 14.0 a | 65.0 a | 18.2 ab | 3.6 ab |
| MCM2 | 15.5 a | 77.8 a | 26.2 ab | 2.6 a |
| Ptb21 | 13.3 a | 41.2 a | 10.5 a | 3.7 ab |
| Ptb 20 | 15.5 a | 72.5 a | 23.0 ab | 3.3 ab |
| Ptb 18 | 20.7 a | 73.2 a | 20.7 ab | 4.2 bc |
| ARC5785 | 20.2 a | 147.0 a | 44.2 ab | 3.4 ab |
| BKN6809-74-40 | 17.2 a | 92.5 a | 28.0 ab | 3.3 ab |
| MCM1 | 38.0 a | 301.7 a | 97.5 bc | 3.2 ab |
| Mudgo (R) | 17.7 a | 144.0 a | 38.0 ab | 4.0 abc |
| TN1 (S) | 130.7 b | 1036.0 b | 165.5 c | 5.4 c |

**Table 7. Population development of brown planthopper biotype 3 on some selected rice varieties.[a] IRRI, 1977.**

| Variety | Insects[b] (no.) |
|---|---|
| Rex/2 x BBT50 | 98 |
| Sudurvi 306 | 50 |
| Murunga 137 | 59 |
| HR 98 | 77 |
| PI 220408 | 161 |
| Murunga 307 | 187 |
| MTU 20 | 247 |
| ASD 7 (susceptible check) | 2,160 |
| TN1 (susceptible check) | 2,226 |
| Mudgo (resistant check) | 0 |

[a] Two pairs of newly emerged adults caged on 60-day-old plants for 30 days. [b] Figures are totals of 5 replications, 4 plants/replication.

## BROWN PLANTHOPPER BIOTYPES

As the area in which resistant rice varieties are intensively cultivated expands, the possibility that the BPH will develop biotypes capable of surviving on resistant plants increases. The development of such biotypes is more likely to be greater when resistance is governed by a single gene. The possibility of the development of biotypes is less on moderately resistant varieties (with polygenic resistance).

Mudgo was tested for its resistance to BPH populations collected from 14 locations on Luzon, Philippines. The insects were reared in the laboratory for at least one generation, then 10 first-instar nymphs were caged on individual 30-day-old Mudgo and TN1 plants. The insects were counted every 2 days.

The insect populations differed significantly in the ability to survive even on susceptible TN1 (Table 8). Several populations such as those collected from Maligaya, Nueva Ecija; Tiwi, Bicol; and College, Laguna, Philippines, had almost twice as many survivors on TN1 as that from Calamba, Laguna. Similar differences in the survival of different populations on the resistant variety Mudgo were recorded. The insects from all localities, however, suffered high mortality on Mudgo, and their survival on TN1 and Mudgo were not correlated, indicating differences in their ability to survive on Mudgo.

IR26 and later IRRI varieties, as well as most breeding lines, are highly resistant to the BPH in many areas. Along with resistant varieties developed by national programs, they provide significant crop protection. Our greatest present concern about these varieties is the possibility of development of new BPH biotypes because varieties with high levels of monogenic resistance are now grown over large areas. Moreover, we now have evidence that different biotypes exist in southern India and Sri Lanka.

The natural insect populations are generally believed to include small proportions of individuals that can survive on resistant varieties. When resistant varieties are intensively planted, a population of insects that can survive on

**Table 8. Survival on Taichung Native 1 and Mudgo of first-instar brown planthopper nymphs reared from insects collected from different locations in the Philippines. IRRI, 1971.**

| Locality | Survival[a] (%) of nymphs on | |
|---|---|---|
| | Taichung Native 1 | Mudgo |
| Maligaya | 61 a | 20 abc |
| Tiwi Tiwi | 58 abc | 15 bc |
| College | 57 abc | 12 cd |
| Candelaria | 52 abcd | 25 a |
| Imus | 56 abcd | 18 abc |
| Iloilo | 54 abcd | 17 abc |
| IRRI | 51 bcd | 17 abc |
| Poypoy | 51 bcd | 7 d |
| Bay | 50 cd | 19 abc |
| Calauan | 50 d | 23 ab |
| Santa Rita | 49 de | 25 a |
| Macabling | 49 de | 8 d |
| Los Baños | 42 ef | 25 a |
| Calamba | 38 f | 18 abc |

[a] 22 days after infestation. Av of 10 replications, each consisting of caging 10 first-instar nymphs on an individual plant of a variety. Any two means followed by the same number were not statistically different at 5% level.

them builds up, and the general population may shift to a new insect biotype. Also, mutation may produce new biotypes capable of surviving on resistant plants. Biotypes that can survive on resistant plants are also believed to be more likely to develop on varieties with monogenic resistance than on those with polygenic resistance. Therefore. IRRI studies of insect biotypes fall into two broad categories :

1. The planting of different varieties in many areas to determine if a variety that is resistant at one location is susceptible at another. If that proves true, the insects in the two areas are suspected to be of different biotypes.
2. The rearing on resistant varieties for several generations of insects collected from various areas, particularly those where resistant varieties are intensively planted. If a population that can survive on resistant plants develops, it is termed a new biotype.

The studies indicate that several BPH biotypes now exist. Three have been identified in IRRI experiments: biotype 1, the type that generally exists at IRRI; biotype 2, capable of surviving on plants of such varieties as Mudgo and IR26, which carry the *Bph 1* gene for resistance: and biotype 3, which survives on plants of varieties carrying the *bph 2* gene such as ASD 7, Ptb 18, and IR32.

In 1974 experiments, a population that survived on varieties carrying the *Bph 1* gene as well as on those that contain the *bph 2* gene was isolated. but attempts to maintain the population and build up another failed. Most BPH tested in the Philippines appear to be of biotype 1, except those in two localized areas: Santa Rosa, Laguna province, about 40 km north of IRRI; and Davao, on the island of Mindanao, 800 km south of IRRI. which belong to biotype 2.

Significantly, the BPH population at IRRI, which has grown alongside varying proportions of resistant varieties since 1967, has remained biotype 1.

Repeated collections of BPH from areas extensively planted to resistant varieties, and efforts to rear those insects on varieties with different genes for resistance, have not resulted in the isolation of additional biotypes. But in several areas of the Philippines, biotype 2 has become preponderant. It is visualized that horizontal resistance will be less conducive to the development of new biotypes.

As a first step toward identifying new sources of resistance to the biotypes at IRRI, the lines that show resistance to biotype 1 are being systematically evaluated. All entries in the germplasm collection also are being evaluated. Rice varieties that react differentially to different biotypes have been identified; many are resistant to all three biotypes.

Nearly 50 collections, including 10 accessions of wild rices, are resistant to all three of the biotypes at IRRI (Table 9). The BPH in India and Sri Lanka apparently differs from all the biotypes at IRRI and is more prolific. The International Rice Brown Planthopper Nursery provides valuable information on biotypes. Some of the breeding lines from India that have been recorded as resistant at Hyderabad are also resistant to all the biotypes at IRRI (Table 2).

## MULTILINES FOR BROWN PLANTHOPPER CONTROL

Plants with polygenic resistance should minimize the development of BPH biotypes. The resistance in most varieties studied is monogenic. Four genes responsible for resistance have been identified. Lines that carry more than one resistance gene are being developed.

As an alternative, a multiline approach was investigated in greenhouse and field experiments. In these experiments, three varieties—IR20 (susceptible), IR30 (with the *Bph 1* resistance gene), and IR32 (with the *bph 2* gene)—were grown in clay pots. Groups of pots were caged, with different proportions of each variety represented in the cages. When the plants were 20 days old, 50 newly hatched nymphs of different biotypes were placed in each cage and the insect population buildup was observed for 34 days.

The cage with the smallest proportion of susceptible plants had the smallest insect population. The populations of biotypes 2 and 3 increased considerably as the proportion of the susceptible plants increased.

The population of biotype 2, however, was much larger than that of the biotype 3, even when the proportion of plants susceptible to the respective biotypes was the same. The indication that biotype 3 is less fecund than biotype 2 was confirmed in another experiment.

A field experiment used IR1917 (resistant to tungro but susceptible to the BPH), IR34 (with the *Bph 1* resistance gene). and IR36 (with resistance gene *bph 2*). The number of insects declined with the increase in resistant plants (Table 10). IR1917 had the highest insect population. The much lower popu-

**Table 9. Reactions of selected varieties to brown planthopper biotypes. IRRI, 1976.**

| Variety | Acc. no | Origin | Brown planthopper biotype | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| AC-1613 | 10638 | India | R | R | R |
| Anethoda | 19684 | Nigeria | R | MR | MR |
| ARC 6650 | 12308 | India | MR | MR | MR |
| Babawee | 8978 | Sri Lanka | R | R | R |
| Balamawee | 7752 | Sri Lanka | R | R | R |
| Balamawee | 8919 | Sri Lanka | R | R | R |
| Bangkok | 15618 | Sri Lanka | MR | MR | MR |
| CR 57–29 | 15775 | India | MR | R | MR |
| Gambada Samba | 15406 | Sri Lanka | MR | MR | R |
| Gangala | 7733 | Sri Lanka | R | R | R |
| Heen Rath | 15735 | Sri Lanka | R | R | R |
| Hondarawala 3786 | 12076 | Sri Lanka | R | R | R |
| Hondarawala 5026 | 12075 | Sri Lanka | R | R | R |
| Hondarawala | 15190 | Sri Lanka | MR | R | R |
| Hondarawala | 15634 | Sri Lanka | R | R | R |
| Hondarawala | 15774 | Sri Lanka | R | R | R |
| Horanamawee | 15332 | Sri Lanka | R | R | R |
| Heenhoranamawee | 15286 | Sri Lanka | MR | R | MR |
| Kahata Samba | 15297 | Sri Lanka | R | R | R |
| Kalu Kuruwee | 15279 | Sri Lanka | MR | R | R |
| Kalu Samba | 15298 | Sri Lanka | R | R | R |
| Karekagga 78 | 19930 | India | MR | R | R |
| Kuruhondarawala | 7731 | Sri Lanka | R | R | R |
| Lekam Samba | 15389 | Sri Lanka | R | R | R |
| Lekam Samba | 15412 | Sri Lanka | R | R | R |
| Mudu Kiriyal | 15489 | Sri Lanka | R | R | R |
| Muhudu Kiriyal | 15182 | Sri Lanka | MR | MR | R |
| Muthumanikam | 15397 | Sri Lanka | R | MR | R |
| Ptb 19 | 6107 | India | R | R | R |
| Ptb 20 | 5920 | India | R | R | R |
| Ptb 21 (Tekkan) | 6113 | India | R | R | R |
| Ptb 33 | 19325 | India | R | R | R |
| Rathu Heenati | 11730 | Sri Lanka | R | R | R |
| Senawee | 15281 | Sri Lanka | R | MR | R |
| Sinna Swappu | 15444 | Sri Lanka | R | R | R |
| Sudu Hondarawala | 15541 | Sri Lanka | R | R | R |
| Sulai | 15421 | Sri Lanka | R | R | R |
| Thirissa | 7734 | Sri Lanka | R | R | R |
| *O. australiensis* | 100882 | India | R | R | R |
| *O. australiensis* | 101144 | Australia | R | R | R |
| *O. australiensis* | 101397 | U.S.D.A. | R | R | R |
| *O. australiensis* | 101410 | Australia | R | R | R |
| *O. brachyntha* | 100115 | Africa | R | R | R |
| *O. brachyntha* | 100893 | India | R | R | R |
| *O. latifolia* | 100167 | Costa Rica | R | MR | R |
| *O. latifolia* | 100169 | Guatemala | R | R | R |
| *O. latifolia* | 100170 | Costa Rica | R | R | R |
| *O. punctata* | 100886 | India | R | R | MR |

lations in plots with IR34 or IR36 may imply that the population at IRRI has high proportions of biotype 1. At 85 days after transplanting, the BPH population in IR1917 was about 20,000 insects $m^2$ and the plots were hopperburned. The populations in the other varieties were comparatively small.

**Table 10. Brown planthopper populations in field plots planted with different mixtures of resistant and susceptible rice plants. IRRI, 1976.**

| Plants (%) in each plot | | | BPH[a] (av. no./plot) at 85 DT | |
|---|---|---|---|---|
| IR1917 (susceptible) | IR34 (*Bph 1* gene) | IR36 (*bph 2* gene) | Actual | Expected |
| 0 | 0 | 700 | 294 | – |
| 0 | 100 | 0 | 738 | – |
| 100 | 0 | 0 | 19,938 | – |
| 17 | 17 | 66 | 604 | 3,709 |
| 17 | 66 | 17 | 736 | 3,864 |
| 33 | 33 | 33 | 824 | 6,990 |
| 60 | 20 | 20 | 3,032 | 12,169 |
| 66 | 17 | 17 | 8,629 | 13,464 |

[a] Av. of 4 replications. Each replication included all Insects on 20 hills in each plot at 85 DT (days after transplanting)

## GENETICS OF RESISTANCE

Studies on the inheritance of resistance to BPH were initiated at IRRI in 1968. Four resistant varieties were initially analyzed and two loci for resistance were identified. Dominant alleles at the *Bph 1* locus govern resistance in varieties Mudgo, Co22, and MTU15 and a recessive gene, *bph 2,* conveys resistance in ASD 7. Recombination between *Bph 1* and *bph 2* has not been observed (Athwal et al 1971). Athwal and Pathak (1972) investigated two more varieties. MGL 2 had *Bph 1* and Ptb 18 had *bph 2* for resistance.

Two breeding lines of improved—plant type—IR747$B_2$6 and IR1154-243—were resistant to BPH in the field in 1969 (IRRI 1970). These lines were selected from the crosses whose parents are susceptible to BPH. Martinez and Khush (1974) studied the inheritance of resistance in these lines and found that IR747$B_2$-6 has a dominant gene for resistance that is allelic to *Bph 1* and IR1154-243 has a recessive gene that is allelic to *bph 2.* TKM 6, one of the susceptible parents of IR747$B_2$-6, when crossed with other susceptible varieties such as TN1, IR20, or TR24, yields a small proportion of progeny that is resistant to BPH. Martinez and Khush (1974) concluded that TKM 6 is homozygous for *Bph 1* and a dominant inhibitory gene *I-Bph 1,* the latter inhibiting the action of the former. In the crosses of TKM 6 and other susceptible varieties, individuals that inherit *Bph 1* but not *I-Bph 1* show resistant reaction.

Twenty-eight varieties were analyzed by Lakshminarayana and Khush (1977) and two new genes were identified. A single dominant gene designated *Bph 3* governs resistance in Rathu Heenati. It segregates independently of *Bph 1.* A single recessive gene designated *bph 4* conveys resistance in Babawee. It segregates independently of *bph 2.* Nine of the varieties analyzed had *Bph 1* and 16 had *bph 2.* One variety had two genes.

In Taiwan, Chen and Chang (1971) investigated the inheritance in Mudgo and concluded that resistance was controlled by a single dominant gene. Three

varieties, IR9-60, Kaosen Yu 12, and H5, were found to have *bph 2* (Chang 1975).

**Breeding for resistance**

We have emphasized the incorporation of resistance to BPH into our breeding materials since 1967. Basically, we used four donor parents, two as sources of *Bph 1* and the other two as sources of *bph 2.* Mudgo and IR747$B_2$-6 were the donors of *Bph 1* and IR1154-243 and CR94-13 the sources of *bph 2.* Crosses between Mudgo and IR8 yielded progenies with good plant type but poor grain quality. Some of these progenies were crossed with IR22 and IR24 and several very promising breeding lines were selected. IR1614-138-3 and IR1614-389-1 were selected from the IR22 crosses. and IR1539-260 and IR1539-823-4 were the promising progenies from the IR24 crosses. These lines had good grain quality but were susceptible to tungro and blast. They were crossed with tungro- and blast-resistant lines in 1970, and multiple resistant lines from the crosses such as IR2034, IR2035, IR2038, and IR2058 were obtained. The promising lines from these crosses were widely used in the hybridization program at IRRI and in other countries.

**Table 11. Improved-plant type brown planthopper-resistant varieties and breeding lines developed at IRRI.**

| Cultivar | Parents | Reststance gene |
|---|---|---|
| IR26 | IR24/TKM6 | *Bph 1* |
| IR28 | Peta[3]/TN1//Gam Pai 15/4/IR8/Tadukan/ITKM6[2]/TN1/// IR24[4]/*O. nivara* | *Bph 1* |
| IR29 | Peta[3]/TN1//Gam Pai 15/4/IR8/Tadukan//TKM6[2]/TN1/// IR24[4]/*O. nivara* | *Bph 1* |
| IR30 | IR24/TKM6//IR20[4]/*O. nivara* | *Bph 1* |
| IR32 | IR20[2]/ *O.nivara*//CR94-13 | *bph 2* |
| IR34 | Peta[3]/TN1//Gam Pai 15/4/IR8/Tadukan//TKM6[2]/TN1/// IR24[4]/*O. nivara* | *Bph 1* |
| IR4-93 | H105/Dgwg | *bph 2* |
| IR747$B_2$-6 | TKM6[2]/TN1 | *bph 1* |
| IR1154-243 | IR8[2]/Zenith | *bph 2* |
| IR1330-3-2 | Leuang Tawng/IR8//W1263 | *Bph 1* |
| IR1539-823-4 | IR24//Mudgo/IR8 | *Bph 1* |
| IR1514A-E579 | IR20/TKM6 | *Bph 1* |
| IR1561-228-3 | IR8/Tadukan//TKM6[2]/TN1 | *Bph 1* |
| IR1614-138.4 | IR22//Mudgo/IR8 | *Bph 1* |
| IR1628-632-1 | IR24//IR8[2]/Zenith | *bph 2* |
| IR1702-74-3 | IR24/Ptb 18 | *bph 2* |
| IR2031-724-2 | IR24[3]/ *O. nivara* ///Peta[4]/TN1//Tetep/4/Leuang Tawng/ IR8//W1263 | *Bph 1* |
| IR2034-289-1 | IR24//Mudgo/IR8///Peta[3]/TN1//HR21/4/IR24[4]/ *Onivara* | *Bph 1* |
| IR2035-290-2 | Peta[4]/TN1//Tetep///Peta[3]/TN1//HR21/4/IR24//Mudgo IR8///IR24[3]/ *O. nivara* | *Bph 1* |
| IR2038-158-2 | IR24//Mudgo/IR8///IR24[4]/ *Onivara* | *Bph 1* |
| IR2070-423-2-5 (IR38) | IR20[2]/ *O. nivara* //CR94-13 | *bph 2* |
| IR2070-414-3-9 (IR40) | IR20[2]/ *O. nivara* //CR94-13 | *bph 2* |
| IR2071-625-1 (IR36) | IR8/Tadukan//TKM6[2]/TN1///IR24[4]/ *O. nivara* /4/CR94-13 | *bph 2* |
| IR2071-586-5-6 (IR42) | IR8/Tadukan//TKM6[2]/TNI///IR24[4]/ *O. nivara* /4/CR94-13 | *bph 2* |

As soon as IR747$B_2$-6 was identified as resistant to BPH, it was included in the hybridization program. It has proved to be good combiner and several promising breeding lines and varieties have been obtained from its crosses (Table 11), the most important being IR28, IR29, and IR34. From a cross of IR24 and TKM 6 made in 1969, a BPN-resistant line was selected. It proved to be resistant to blast, tungro, bacterial blight, and green leafhopper. It was named IR26 in 1973.

A gall-midge-resistant line, CR94-13, was obtained from the Central Rice Research Institute, Cuttack, India. It was selected from the cross Ptb 21/IR8// Ptb 18. It is resistant to BPH and the resistance is conditioned by *bph 2*. CR94-13 was used extensively in the hybridization program at IRRI as a source of *bph 2*. Many promising lines were selected from crosses involving this line. Two crosses, IR2070 and IR2071, were particularly outstanding. The IRRI-named variety IR32 was selected from IR2070. Similarly, Philippine-named varieties IR38 and IR40 were selected from IR2070, and IR36 and IR42 from IR2071.

About half of the IRRI breeding materials have *Bph 1* and the other half have *bph 2*. Efforts are now under way to incorporate *Bph 3* and *bph 4* into the improved-plant-type, multiple disease and insect resistant background. Because the donor parents are poor-plant-type varieties, we are following a backcrossing program using improved lines as recurrent parents.

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