Brown planthopper:

THREAT TO RICE PRODUCTION IN ASIA

International Rice Research Institute

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The responsibility for this publication rests with the International Rice Research Institute.

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VARIETAL RESISTANCE

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Foreword

The brown planthopper has become a serious threat to rice production throughout Asia. The increase in severity of the insect appears to be associated with the technology used in modern rice culture. On 18–22 May 1977, leading rice scientists met in a symposium at the International Rice Research Institute to discuss research results and to develop plans for brown planthopper control. The objectives of the symposium were to bring together all the known information on the brown planthopper, to identify research areas that should be given priority, and to strengthen communication and collaboration among scientists involved in research on this pest.

Until recently we believed that planting of resistant rice varieties and use of insecticides were satisfactory means of controlling the brown planthopper. Just as IR8 was a simplistic solution to the problems of tungro virus control, the brown planthopper resistant variety IR26 was thought to be a simplistic solution to the brown planthopper problem. We were alarmed, however, when we heard that IR26 was susceptible in India, indicating the presence of a different brown planthopper biotype from that of the Philippines. A few years after IR26 was introduced in Indonesia and the Philippines, a brown planthopper biotype capable of destroying IR26 became abundant. To compound the problem, resurgences of the brown planthopper population occurred where insecticides were used.

Our experience has indicated that the simplistic approach to the control of this particular insect is not adequate. In rice entomology, the brown planthopper presents the most outstanding example of a need to develop an approach in which varietal resistance, biological and cultural control, and insecticides should be integrated to develop an economically and ecologically suitable means of control. That will require a thorough understanding of the interaction between the rice plant and the pest. It is apparent that the battle against the brown planthopper will not be won without an interdisciplinary approach that includes international collaboration.

The IRRI symposium covered the taxonomy, biology, and ecology of the brown planthopper and its control through the use of cultural methods, varietal resistance, insecticides, and natural enemies. A selected group of rice entomologists and breeders from most Asian countries participated. This proceedings includes papers prepared for the symposium by entomologists and plant breeders who are the world's leading authorities on brown planthopper. It is the only book dealing exclusively with all the aspects of brown planthopper research for both the tropical and temperate regions. It is hoped that this book will serve as a guide in the setting of research priorities, and as an aid in the writing of proposals for brown planthopper research, and thus serve as a stimulus to accelerate the development of suitable control methods.

N. C. Brady
Director General

PROBLEM

The brown planthopper problem

V.A. Dyck and B. Thomas

The brown planthopper *Nilaparvata lugens* (Stål) recently increased in abundance and caused severe yield losses in several tropical countries of Asia. It is rather widely distributed but is found mainly in South, Southeast, and East Asia. It damages the rice plant by directly feeding on it and by transmitting the grassy stunt disease.

Some damage by the brown planthopper has been reported in Bangladesh, Brunei, China, Fiji, Korea, Malaysia, Papua New Guinea, Solomon Islands, Sri Lanka, Thailand, and Vietnam. But according to available data, the most extensive losses from the insect and the disease have occurred in India (estimated at US$20 million), Indonesia (US$100 million), and the Philippines (US$26 million). Losses from the insect alone are US$100 million in Japan and US$50 million in Taiwan.

The estimated losses due to the brown planthopper and the grassy stunt disease total more than US$300 million. That is a conservative estimate; it includes only losses from reporting countries and excludes expenditures for control operations. A pest management strategy that is compatible with modern rice technology is urgently needed to solve this serious pest problem.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* (Stål) has in recent years caused extensive damage to the rice crop in Asia. Although an important pest in Japan for many years, it was formerly only a minor pest in most tropical countries of Asia. In the past 5 years, however, the BPH populations have greatly increased and caused severe yield losses in several countries. Large-scale damage by the insect has been reported in India, Indonesia, the Philippines, and Sri Lanka, and infestations of varying degrees are now commonly observed in many countries. Many regard the BPH as the number-one insect pest of rice in Asia today, primarily because of the unpredictability of the infestation and the dramatically severe damage it causes.

The pest feeds directly on the growing plant, reducing its yield potential. If the pest density is high, the plant dies and a condition known as hopperburn

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results. The insect may also transmit the grassy stunt disease, which can further reduce yield. Epidemics of grassy stunt have followed major pest outbreaks in India, Indonesia, and the Philippines.

This paper summarizes the few scattered reports of crop damage and loss caused by the BPH, primarily in tropical countries. Also, to give perspective to the importance of the insect, an attempt is made to estimate the monetary value of the pest problem.

DISTRIBUTION

Nilaparvata lugens is widely distributed; it is found in South, Southeast, and East Asia; the South Pacific islands; and Australia (Fig. 1). Earlier reviews have listed specific countries where the pest has been found, but it is now thought that the BPH area extends from Pakistan to Japan, and many islands in Southeast Asia, Micronesia, and Melanesia. The insect is found throughout the year, mainly on rice, except in Japan and Korea where adult pests migrate into the country each summer.

HISTORICAL RECORD OF INFESTATIONS, DAMAGE, AND YIELD LOSSES

Bangladesh

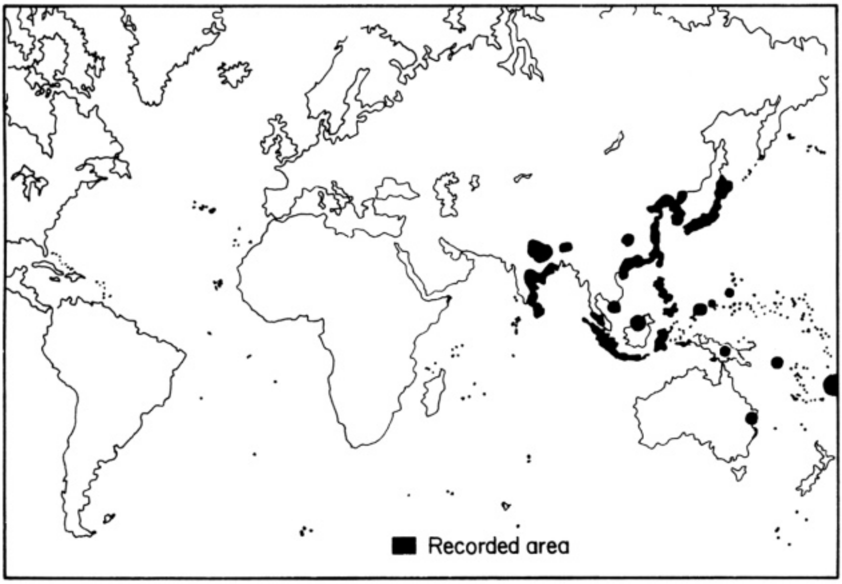
The BPH was first officially recorded in Bangladesh in 1969, but there are earlier records using synonyms of *N. lugens* in 1957 and in 1917. Catches in light traps near Dacca show that the insect population has gradually increased since 1970. The catch in 1976, especially in November, was very large (pers. comm. with S. Alam, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh). The BPH was only a minor pest until high densities developed on crops in two areas near Dacca in 1976. The total area damaged was about 4 ha, with some patches hopperburned. That is the first confirmed case of hopperburn due to the BPH in Bangladesh (Alam and Karim 1977).

Brunei

Nilaparvata lugens occurs in Brunei, but it has not been identified as a pest. There is, however, a report of some hopperburn occurring a few months ago (pers. comm. with D. J. McCrae, Jabatan Pertanian, Department of Agriculture, Brunei).

China

Recent visitors to China have reported that the BPH is a pest there. Research in Japan and Korea. showing that planthoppers migrate to those countries from the southwest with weather systems, suggests some infestation each year in China. But data on crop damage and yield losses attributable to BPH are not available.



1. Distribution of the brown planthopper *Nilaparvata lugens* (Stål). shown by blackened areas (source: R. C. Saxena, IRRI).

Fiji

Hinckley (1963b) regarded planthoppers, including both *N. lugens* and *Sogatella furcifera* (Horvath), as the most important insect pests of rice in Fiji. The insects can kill rice in large patches and in entire fields. Infestations in 1959 occurred throughout the areas with standing rice (Hinckley 1963a). According to a report by Watson (1960) and Hinckley (1963a), about US$500,000 was lost when planthoppers destroyed 22% of the rice crop, or about 2,800 ha. Today the BPH still appears to be a major constraint on rice production in Fiji.

India

The most severe outbreak of the BPH in India occurred in Kerala state at the end of 1973 and early in 1974 (Koya 1974; Nalinakumari and Mammen 1975). Even though the pest had occurred sporadically in 1958 and 1962, the outbreak of 1973–74 was the first major one in Kerala. It occurred in the 'Kole' lands of Trichur district and Kuttanad area in Kottayam and Alleppy districts. The insect outbreak caused economic damage on about 50,000 ha of rice fields (Freeman 1976). About 8,000 ha was almost completely wiped out (Gopalan 1974). Hopperburn frequently developed in patches and sometimes covered whole fields. Most crops showing damage had already headed (Kulshreshtha 1974), although crops suffered some damage at all growth stages (Mammen and Das 1973). In many fields the damage was so great that growers abandoned the crop (Das et al 1972). The loss in grain yield ranged from 10% in moderately affected fields to 70% in those severely affected (Kulshreshtha et al 1974). The damage to the standing crop sometimes reached 100%. Table 1 shows the area equivalent to that which experienced total loss of the rice crop in recent years; the estimate was arrived at by adding losses of various degrees in different areas. The estimated losses in Kerala from 1973–74 to 1975–76 total almost US$12 million.

Other states of India have also reported BPH infestations and damage. Ghose et al (1960) noted that *N. lugens* was a minor pest in Andhra Pradesh. The insect has since become a serious pest. In the 1976 dry season in East Godavari, A. P., about 200 ha was hopperburned and 3,250 ha was severely infested (Prakasa Rao et al 1976). During 1973 several thousand hectares were affected in Orissa (pers. comm. with B. C. Misra, Central Rice Research Institute, Cuttack—753006, India). Chatterjee (1969) reported that the formerly minor insect *N. lugens* had assumed serious proportions on rice in two northern districts of West Bengal. It caused serious damage to both autumn and winter crops. There was an outbreak in one district of West Bengal in 1975, and in several cases the crop was destroyed (Anonymous 1975e). Hopperburn occurred in two districts of Himachal Pradesh in 1973 and 1974 (Bhalla and Pawar 1975). Chelliah and Subramanian (1972–73) mentioned that the BPH occurs in epidemic form once every few years in Tamil Nadu and causes extensive damage. The incidence of the pest was especially high in 1969 and 1971, and Das et al (1972) reported a devastating outbreak in 1972. In Coimbatore district in the 1975 wet season, about 200 ha of rice fields was severely infested, and some hopperburn occurred (Velusamy et al 1975).

Numerous comments in recent literature indicate that the BPH is becoming

Table 1. Damage to the rice crop caused by the brown planthopper in Kerala, India, in recent years.

Crop year	Season	Affected area		Degree of damage (%)	Estimated equivalent area of total crop loss (ha)	Approximate value of crop loss[a] (US$)
		Ha	% of total rice area			
1973–74	Mundakan (Aug.–Jan.)	19,002	5.8	50–100	14,250	4,275,000
	Puncha (Dec.–Apr.)	48,910	63.4	10–100	19,800	5,940,000
1974–75	Mundakan	17,150	5.2	0–100	820	246,000
	Puncha	5.148	6.7	0–100	560	168,000
1975––76	Mundakan	6,087	1.9	0–30	480	144,000
	Puncha	27,356	35.4	0–100	3,230	969,000
Total						11,742,000

[a] Assuming an expected yield of 2.0 t/ha and a rough rice price of US$150/t.

an increasingly damaging pest in as many as 10 states in India, including Uttar Pradesh, Bihar, Haryana, and Punjab (Kalode 1974, 1976; Diwakar 1975; Pawar 1975; Freeman 1976; B. C. Misra, pers. comm.). The amount of grain lost because of BPH infestation in the whole of India has never been estimated, but it must be worth at least US$20 million. That figure is miniscule when compared with one arrived at using Cramer's (1967) calculations. He estimated that 1.8 million tons of rice was lost annually in only three states—Andhra Pradesh, Tamil Nadu, and Orissa. At US$150/t that would be worth more than US$277 million.

Indonesia

Observations in Java as early as 1931, 1939, and 1940 suggested that sucking insect pests were causing direct plant damage in the field (Kalshoven 1950; Mochida et al 1977). Until 1951, 50 to 150 ha of rice in Java was only occasionally infested by leafhoppers and planthoppers (Soehardjan 1973). Crop damage was negligible. The real pest problem first became evident in the 1968–69 crop. Thereafter, larger areas were infested and damage became more severe until the 1974–75 season, when tremendous losses occurred. The severe problem, which continued until at least the 1975–76 season, was compounded by grassy stunt disease. At the height of the epidemic more than 200,000 ha of rice was damaged by the insect and the disease (Table 2; pers. comm. with I. N. Oka, Central Research Institute for Agriculture, Merdeka 99, Bogor, Indonesia; Soehardjan 1973; Anonymous 1975c; Mochida and Suryana 1975; Sama and Halteren 1975; Sastrowidjoyo 1976; Mochida and Dyck 1976; Mochida et al 1977; Oka 1976; Partoatmodjo 1976; Sukarna and Mochida 1976).

BPH damage and grassy stunt infection resulted in great yield losses in

Table 2. Area damaged by the brown planthopper and grassy stunt disease in Indonesia by crop year and region.[a]

Crop year	Area (ha) damaged					
	Sumatra	West Java	Central Java	East Java	Other islands	Total
1968	–	50,000?	2,000	–	–	52,000[b]?
1969	–	?	1,633	–	–	10,000 ?
1969–70, 1970	–	13,443	755	391	–	14,589
1970–71, 1971	672	12,183	4,046	534	–	17,435
1971-72, 1972	3,724	19,881	1,885	9,969	–	35,459
1972–73, 1973	5,411	15,165	2,749	9.568	100	32,993
1973–74	3,199	14,980	4,922	7,039	158	30,298
1974	22,838	–	15,998	–	–	38,836
1974–75	114,193	59,946	23,927	62,589	23,233	283,888
1975	23,915	3,233	37,473	8,966	20,000	120,000 ?
1975–76	17,115	17,671	104,000	70,000	33,641	242,427
1976	400	–	–	–	–	8,000 ?

[a] Data from L N Oka (pers. comm.), Soehardjan (1973). Anonymous (1975c). Mochida and Suryana (1975). Sama and Halteren (1975). Sastrowidjoyo (1976). Mochida and Dyck (1976). Mochida et al (1977). Oka (1976). Partoatmodjo (1976). and Sukarna and Mochida (1976). [b] Caused by planthoppers and leafhoppers

Table 3. Damage to the rice crop by the brown planthopper and grassy stunt disease in Indonesia.[a]

Crop year	Damaged area (ha)	Degree of damage (%)	Estimated equivalent area of total crop loss (ha)	Approximate value of crop loss[b] (US$)
		All islands		
1974–75	248,819	20–100	99,830	46,907,620
1975	95,272	20–100	49,054	23,049,250
Total				69,956,870
		N. Sumatra		
1974	5,076	100	5,076	2,385,080
1975–76	1,402	100	1,402	658.760
Grand total				73,000,710

[a] Basic data from I. N Oka (pers. comm.), Anonymous (1975d), Oka (1976). and Sukarna and Mochida (1976). [b] Based on expected yield of 3.75 t/ha and rough rice price of $125.30/t.

Indonesia in recent years. Yield loss estimates were made for the whole country for the 1974–75 and 1975 crop years (I. N. Oka, pers. comm.; Anonymous 1975d; Oka 1976; Mochida and Suryana 1975, 1976a,b). Within that 12-month period the estimated value of crops lost ranged from about US$30 million to US$70 million (Table 3). With additional data from Sumatra, the maximum total crop loss could amount to US$73 million (Table 3; Sukarna and Mochida 1976). Considering the losses in other years (Anonymous 1975c) not estimated in Table 3, the total amount of grain lost to the BPH and the associated grassy stunt disease would undoubtedly be more than US$100 million. The figure excludes the cost of crop protection, which might reach US$1 million/year. Indonesia has probably suffered more from the BPH than has any other tropical country.

Japan

The BPH has evidently been a pest of rice in Japan since ancient times. Outbreaks date back to AD 697 or 701 (Miyashita 1963; Grist and Lever 1969; Mochida et a1 1977). Since then there have been numerous records of outbreaks, many covering large areas, and some causing severe famine (Miyashita 1963 ; Kuno 1964; Kisimoto 1968, 1971). In 1897, 960,000 tons of rice was lost. That was equivalent to a loss of 18.49% for all of Japan (pers. comm. with R. Kisimoto, Central Agricultural Experiment Station, Konosu, Saitama, 365 Japan; Kuno 1964). Crop damage from *N. Iugens* usually occurs in the same year as that from *Sogatella furcifera,* but *S. furcifera* reaches its peak before *N. lugens*– early in the crop season (Kisimoto 1976a). The latter species may do more damage, since it is most dense during the reproductive period (Kuno 1964).

In this century. outbreaks occurred rather frequently in 1912, 1926, 1929, 1935, 1940, 1944, 1948, 1960,1966, and 1969 (Kono et a1 1961; Miyashita 1963; Kuno 1964; Mochida 1964; Kisimoto 1968, 1976a,b; Kiritani 1976). In 1940 the planthoppers destroyed 240,000 t of rice (Kawada et a1 1954). Kuno (1964) wrote that such damage never recurred because of extensive crop protection measures, particularly the use of insecticides. However, the infestations in 1966 and 1969 were very serious despite chemical applications; more than one-third of the total paddy-field area was seriously damaged. Yield losses were 349,000 t in 1966 and 176,500 t in 1969 (Kisimoto 1976a).

Mochida (1974) observed that over a 10-year period in Kyushu, the yield losses due to insects and diseases in untreated experimental plots averaged 53% (28-100%). The greater part of the loss was attributed to insects, especially to *N. lugens.* Severe hopperburn occurred in 1967 and in 1969 when light-trap catches were high. The correlation coefficient between the occurrence of *N. lugens* in light traps and yield was -0.637 ($0.10 > P > 0.05$). Thus the BPH appeared to be the major cause of the yield losses due to pests.

In 1973, when infestation by the BPH was moderate, losses totaled 83,700 t (Japan 1973).

Rice losses due to the BPH in Japan could be a1 least 1 million t. or probably higher. That much rice may be worth US$100 million.

Korea

In ancient Korean records, 36 out of 167 references to insect infestations can possibly be attributed to planthoppers. Hopper damage was reported as early as 18 AD. Since 1912 the BPH has been authentically recorded four times, and about 10 outbreaks probably have occurred. The pest infested fields in many provinces in 1912; infestations also occurred in 1921, 1922, and 1923. The BPH problem has increased during the last 10 years, although the severity of outbreak varies with season. Some damage occurred in 1965, 1966, 1967, 1969, and 1970 (Lee and Park 1977: Paik 1977).

BPH outbreak was most severe in 1975 in the southwestern part of Korea; it mainly affected the late-maturing local varieties. The insect fed extensively. on plants past the heading stage (Lippold 1976; Paik 1977; Park and Lee 1976). Planthoppers and leafhoppers infested 1.745 million ha of rice in 1975, but only 200,996 ha in 1973 and only 497.507 ha in 1974. The yield loss in 1975 ranged from 24 to 38% in hopperburned areas, and from 2 to 20% in fields that were infested but not hopperburned (Lee and Park 1977). It may be valued at US$10 million.

Malaysia

The BPH used to be a minor pest in Malaysia. In Sarawak, no outbreak has ever been recorded: nor has the pest alone caused appreciable crop damage (pers. comm. with B. H. Voon, Agricultural Research Centre, Semongkok, Department of Agriculture. P.O. Box 977. Kuching, Sarawak, Malaysia). But in 1967 the BPH and *Sogatella furcifera* together attacked and destroyed more than 5,000 ha of paddy fields in West Malaysia (Lim 1971). Losses were about US$1 million. A little hopperburn, affecting about 8 ha, was seen in 1968. More recently, in 1975, a few areas reported outbreaks of the BPH and a few hectares were hopperburned (Anon. 1975b; Heong 1975; pers. comm. with P. A. C. Ooi, Crop Protection Division, Department of Agriculture, Jalan Gallagher, Kuala Lumpur, Malaysia).

Nepal

N. lugens, reported in Nepal in 1965, apparently caused no serious infestations (pers. comm. with K. C. Sharma, Ministry of Food, Agriculture and Irrigation, Agriculture Department, Khumaltar, Lalitpur, Nepal).

Papua New Guinea

Recently small outbreaks of the BPH on New Ireland, New Britain, and the New Guinea mainland, with a few hectares hopperburned, were reported (pers. comm. with P. R. Hale, Department of Agriculture, Stock and Fisheries, Department of Primary Industry, P.O. Box 101, Kavieng, N.I.P., Papua New Guinea). Hale and Hale (1975) noted that in New Ireland the pest caused complete loss of the crop in several fields, and damaged other fields.

Philippines

The earliest recorded damage by the BPH in the Philippines occurred in Calamba, Laguna, in 1954 (Varca and Feuer 1976). Cendaña and Calora (1967) mentioned that an attack by the pest in 1959 in the same town destroyed all fields planted to the variety Milfor. In Ilocos Norte province in the wet season of 1957-58, the BPH caused extensive damage to irrigated lowland rice; even seedbeds were destroyed (pers. comm. with H. A. Custodio, Pest and Disease Division, Bureau of Plant Industry, San Andres, Manila). Some plots on the IRRI farm were hopperburned in 1964. Since 1966 catches of BPH in IRRI light traps gradually increased and reached a peak in 1973 (IRRI 1975). Probably BPH incidence similarly increased in many parts of the country, since serious outbreaks occurred in numerous provinces in 1973 (Bureau of Plant Industry (BPI) et al 1974).

The 1973 infestation affected most rice-producing provinces (Varca and Feuer 1976). BPI et al (1974) list 21 provinces with serious infestations and 14 provinces with moderate infestations. Pest populations reached “explosive” levels, and hopperburn was a common sight. The actual yield losses in the infested provinces were not reported. But Cramer’s method (1967) for calculating losses (5% loss for severe infestation and 2% for moderate infestation) estimates the 1973 yield loss for the country as a whole to be about 150,000 t, worth about US$20 million.

Probably the worst infestation in 1973 occurred in Laguna province, where thousands of hectares were infested. BPH and the grassy stunt disease damaged 85% of the province’s rice fields. In some towns the pest destroyed the crop (Anon. 1975a). About 700 ha was hopperburned, and the yield worth more than US$200,000 was lost.

In general, the pest problem was much reduced in 1974, although infestations and some damage were reported (Dyck 1974; Anon. 1975c; IRRI 1975). In 1975 the BPH infested a thousand or so hectares in Nueva Ecija province, and a few hectares were hopperburned (Anon. 1975a,b). In 1976, damage, especially by BPH biotype 2, was reported in Mindanao. IRRI light-trap catches of BPH in 1976 showed insect resurgence. In the Philippines the BPH infested a total of 50,000 ha in late 1976 and caused a yield loss of about 20%. About 1,000 ha was hopperburned. The national loss incurred, about 0.75%, was worth US$6 million (pers. comm. with R. Feuer, IRRI). The BPH continues to be a threat—possibly the major insect threat—to rice production in the Philippines.

Solomon Islands

When rice was first grown in the Solomon Islands in the early 1960's, the BPH was a serious pest (MacQuillan 1974). Difficulties in controlling the insect stopped rice production for some time. After production was resumed, the pest was controlled effectively for a few years. But an outbreak in 1974 caused some hopperburn and a total crop loss amounting to about US$120,000 (pers. comm. with J. H. Stapley, ILO Research Station, Dodo Creek, Honiara, Solomon Islands). Although an outbreak has not recurred, some damage was again reported in 1975 (Anon. 1975b).

Sri Lanka

Some authors regard planthoppers as very important insect pests of rice in Sri Lanka (Otake et al 1975). Over the past 10 years BPH have appeared in large numbers in several parts of the country, and occasionally have caused hopperburn. In Ampari district the pest became serious in recent years. In 1974 about 16,200 ha was attacked to some degree, and 2,800 ha of rice was destroyed (Fernando 1975). Yield loss amounted to about US$1 million.

Taiwan

Before 1960, the BPH occurred only sporadically (Yen and Chen 1977). In Taiwan since 1960 it has been a major insect pest. It is generally considered as the principal insect pest of rice (Hsieh 1977). Now it is widely distributed and destructive. Outbreaks occurred in central and southern Taiwan during the second crop seasons of 1966, 1967, 1970, 1974, and 1975. The insects infested more than 100,00 ha of rice fields, about 25% of the total area under rice. It also caused severe damage in some parts of southern Taiwan during the first crop seasons of 1966 and 1969 (Table 4; Hsieh 1977). In spite of the extensive use of insecticides, the rice yield annually lost to BPH in 1972–75 ranged from 16,140 to 55,584 t (0.6 to 2.24% of total rice production). In 1975 the estimated value of the lost crop was US$9,715,000. The amount excludes US$28,701,298 that farmers spent to control the insect (Hsieh 1977).

Table 4. Area infested by the brown planthopper in Taiwan, 1966–75.[a]

Year	Infested area			
	In first crop		In second crop	
	Ha	% of total rice area	Ha	% of total rice area
1966	59,543	17.5	104,767	23.3
1967	17,379	5.1	137,419	30.5
1968	6,339	2.0	88,550	19.7
1969	61,172	17.8	79,399	17.3
1970	23,149	6.8	102,680	23.6
1971	16,969	5.1	53,207	12.7
1972	9,479	2.9	56,510	13.7
1973	14,908	4.6	47,827	11.9
1974	12,972	3.7	101,708	23.5
1975	20,886	5.8	110,570	25.6

[a] Data from Hsieh (1977) and the Provincial Department of Agriculture and Forestry, Taiwan.

Yen and Chen (1977) mentioned that US$45/ha was spent in each crop season in 1975 to control the BPH; that is 23% of the total spent in rice crop protection.

The grain lost to the BPH in the last decade or so may be valued at about US$50 million. Adding to this the amount spent on pest-control measures would make the monetary value of the pest problem enormous.

Thailand

No damage from the BPH was noticed in Thailand before 1974. But in that year's dry season the pest population in the Central Plain area became very high. The insects spread throughout the Central Plain and caused hopperburn (Tirawat 1975). A small outbreak developed west of Bangkok (Otake and Hokyo 1976). Some pest problem occurred in 1975 and insecticides were applied to control it (Anon. 1975c).

Vietnam

In 1971 Ngoan reported that planthoppers and leafhoppers were causing more damage in Vietnam than they did before 1967. Damage by planthoppers seemed to be the major insect-limiting factor in rice production. *N. lugens,* which has become increasingly abundant every year, has formed outbreaks. Hopperburn is caused mostly by *N. lugens,* not by *Sogatella furcifera,* Thousands of hectares have been destroyed every year (Ngoan 1971), and yields possibly worth US$3 million have been lost.

According to Huynh (1975), the BPH has been the most serious insect pest of rice in Vietnam since 1970. Hopperburn occurred in 1975 at several locations in the Mekong Delta area.

Table 5. Summary of approximate total monetary loss caused in recent years by brown planthopper and grassy stunt damage to rice.[a]

Country	Loss (million US$)
Fiji	0.50
India	20.00
Indonesia	100.00
Japan	100.00
Korea	10.00
Malaysia	1.00
Philippines	26.00
Solomon Islands	0.12
Sri Lanka	1.00
Taiwan	50.00
Vietnam	3.00
Total	311.62

[a] Calculated from available records.

CONCLUSIONS

Adding up the estimated losses due to the BPH and the grassy stunt disease in most of the countries where the insect is found gives a total of more than US$300 million (Table 5). No doubt that is a conservative estimate. It does not generally include losses during years of moderate or low infestations, or losses in several countries for which information is lacking, or expenditures for control. The estimate would be much higher if all losses everywhere could be totaled.

The BPH will probably remain as a major pest for two reasons. One is that modern agronomic practices and high yielding varieties may themselves be related to the causes of the problem. Another is that present control measures are not entirely satisfactory.

We must improve our pest-control technology, and devise a pest-management strategy that is compatible with modern rice technology. If we are to make further advances in rice science in the rice bowl of the world, the BPH pest problem must be solved.

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TAXONOMY AND ECOLOGY

Taxonomy and biology of Nilaparvata lugens (Hom., Delphacidae)

O. Mochida and T. Okada

Although *Nilaparvata seminula* should be reexamined, 14 determined and 2 undetermined species are known as the members of the genus *Nilaparvata.* Seven determined species, including *N. seminula* and one undetermined species, are distributed in the Oriental and Australian regions. A tentative key to six species in the two regions is given. The life cycle, overwintering, development, effect of temperatures, appearance of wing forms, reproduction, host plants, occurrence, and dispersal are discussed.

THE OUTBREAKS of *Sogatella furcifera* (Horváth) and *Nilaparvata lugens* (Stål) (Hom., Delphacidae) on rice have been recorded in Korea since AD 18 (Okamoto 1924) and in Japan since 697 (Suenaga and Nakatsuka 1958). *N. lugens* has been serious on rice in many tropical countries in the Orient and some Pacific islands in recent years (Mochida et a1 1977). Throughout the world 14 determined and 2 undetermined species are reported as the members of the genus *Nilaparvata.* This paper reviews the taxonomy and biology of *N. lugens* and several allied species.

CLASSIFICATION, DISTRIBUTION, AND HOST PLANTS

Identification of *Nilaparvata*

Homoptera includes such insects as leafhoppers, cicadas, treehoppers, planthoppers, froghoppers, jumping plantlice, white-flies, mealybugs, scale insects, and aphids. Those in the Oriental and Australian regions are divided into two suborders or series : Auchenorrhyncha and Sternorrhyncha. Auchenorrhyncha has two infra-orders : Cicadomorpha and Fulgoromorpha. Fulgoromorpha includes about 15 families including Delphacidae, the largest, which encompasses more than 1,100 species. Venation of the macropterous fore wings or tegumens is characteristic of the family. The spur or calcar at the apex of the hind tibia is also characteristic. Adult members of the genus *Nilaparvata* in

CRIA-IRRI, Sukamandi, West Java, Indonesia; and Tyugoku National Agricultural Experiment Station, Hukuyama, Japan.

the Oriental and Australian regions may be determined from the following key:

1. Tarsi with one or two segments; antennae lacking a terminal arista; often immobile forms. . . . . Sternorrhyncha

– Tarsi with three segments; antennae short, with a terminal arista; active forms . . . . Auchenorrhyncha (2)

2. Intermediate coxae short, differing in appearance from anterior coxae, inserted near the median line; hind coxae mobile; tegulae absent . . . . Cicadomorpha

– Intermediate coxae long, similar to anterior coxae; hind coxae immobile; tegulae over base of fore wing . . . . Fulgoromorpha (3)

3. Antennal flagellum segmented; ocelli not outside lateral carinae of head . . . . Tettigometridae

– Antennal flagellum not segmented; ocelli outside lateral carinae of head . . . . (4)

4. Second segment of hind tarsus small or very small, its apex without or with only two spines . . . . .Tropiduchidae, Issidae, etc.

– Second segment of hind tarsus not very small, its apex with row of small spines . . . . (5)

5. One or both claval veins granulate; apical segment of labium much longer than wide . . . . Meenoplidae

– Claval veins usually not granulate; if so, the apical segment of labium about as long as wide . . . . (6)

6. Anal area of hind wing reticulate . . . . Fulgoridae

– Anal area of hind wing not reticulate . . . . (7)

7. Apical segment of labium about as long as wide . . . . Derbidae

– Apical segment of labium distinctly longer than wide . . . . (8)

8. Claval vein extending to apex of clavus . . . . Achilixiidae, Achilidae

– Claval vein running into claval commissure before apex . . . . (9)

9. Hind tibiae with variable spines but without a large mobile and apical spur or calcar . . . . Dictyopharidae, Cixiidae

– Hind tibiae each with a large, mobile and apical spur. . . . . Delphacidae (10)

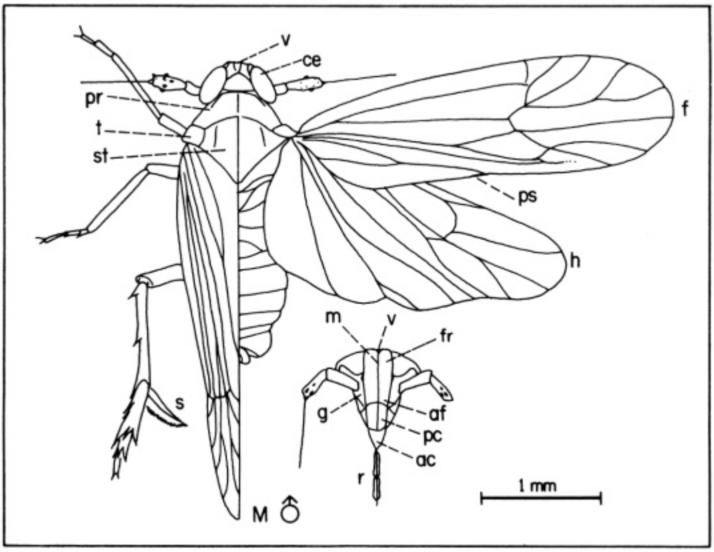
10. Several lateral spines absent on basal segment of hind tarsus . . . . Other genera

– Such spines present.. . . . . *Nilaparvata*

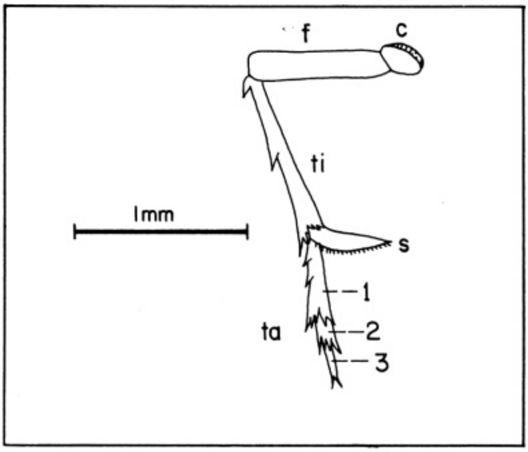
Nilaparvata and tentative key to species in the Oriental and Australian regions

Genus *Nilaparvata* Distant, 1906, Fauna Brit. Ind. Rhynch. 3:473. Figure 1 shows the adult morphological characters of *N. lugens.*

According to Fennah (1969, 1973/75), the two genera *Afrokalpha* and *Nethokalpa* resemble *Nilaparvata* in size and general appearance, but are distinguishable from it by spines present on the basal segment of hind tarsus (Fig. 2). Throughout the world, 14 determined and 2 undetermined species



1. Morphological characters of *N. lugens* (adult macropterous male). ac = anteclypeus; af = apex of frons: ce = compound eye: f = fore wing or tegmen; fr = frons: g = gena; h = hind wing; m = median longitudinal carina; pc = postclypeus: pr = pronotum: ps = pterostigma: r = rostrum: s = spur; st = scutellum: t = tegula: v = vertex.



2. Spines on the basal segment of the hind tarsus of *N. lugens* (macropterous male). c = coxa; f = femur; s = spur; ta = tarsus; ti = tibia.

are known in the genus (Table 1). The genitalia are the most important character that distinguishes the species, especially styles (parameres) and aedeagi for male and lateral lobes (1st valvifers) for female adults. Okada

Table 1. Species belonging to the genus *Nilaparvata,* their distribution, and host plants.

Species	Distribution	Main host
N. albotristriata (Kirkaldy)	Australia, Micronesia (Guam), New Caledonia	?
N. angolensis Synave	Angola	?
N. bakeri (Muir)	Japan, S. Korea, Formosa, Philippines, Sri Lanka	*Leersia japonica*
N. caldwelli Metcalf	Puerto Rico	?
N. camilla Fennah	Sudan	?
N. chaeremon Fennah	Sri Lanka	?
N. diophantus Fennah	Port. Guinea, Senegal	?
N. lugens (Stål.)	From India to Korea and Japan; Pacific Is. Australia	*Oryza sativa*
N. maeander Fennah	Sudan, Fr. Guinea	?
N. muiri China	China, Japan, S. Korea	*Leersia sayanuka*
N. myersi Muir	New Zealand	?
N. nigritarsis Muir	Natal, Sudan (Abyssinia)	?
N. seminula Melichar	C. Java (Semarang)	?
N. wolcotti Muir et Giffard	Puerto Rico	*Saccharum officinarum* (?)
N. sp.[a]	Port. Guinea	?
N. sp.[b]	Japan, S. Korea	*Leersia sayanuka*

[a] Fennah (1958, p. 447). [b] Nasu (1960) and Suenaga and Mochida (1966).

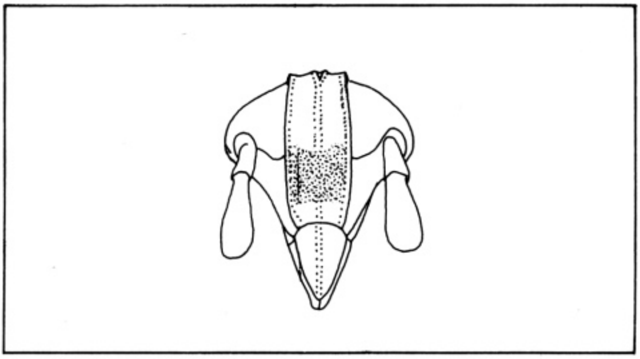
(1977) gave a tentative key to six species in the Oriental and Australian regions as follows :

1. Frons nearly central with an excavation intercepting median longitudinal carina (Fig.3) . . . . *bakeri*

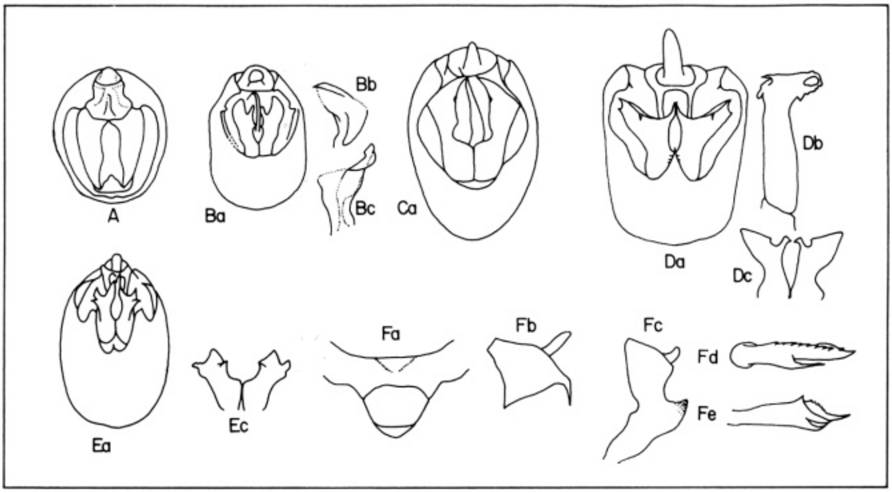
— Frons nearly central without excavation, median carina not intercepted . . . .(2)

2. Pronotum palish or opaque whitish; usually brachypterous . . . . *albotristriata*

— Pronotum fuscous, brownish or stramineous. . . . . (3)



3. Excavation intercepting the median longitudinal carina on the frons of *N. bakeri.*



4. Male genitalia of *N. albotristriata* (A; Kirkaldy 1907), *N. chaeremon* (B; Bb = aedeagus ventral view; Bc = the same dorsal view. Fennah 1973 75), *N. lugens* (C: Cb = aedeagus; Cc, style), *N. bakeri* (D; Db = aedeagus: Dc = style), *N. muiri* (E; Eb = aedeagus: Ec, style), and *N. myersi* (Fa = median portion of diaphragm; Fb = anal segment of male, left side; Fc = style; Fd = aedeagus ventral view; Fe = the same left side. Fennah 1965).

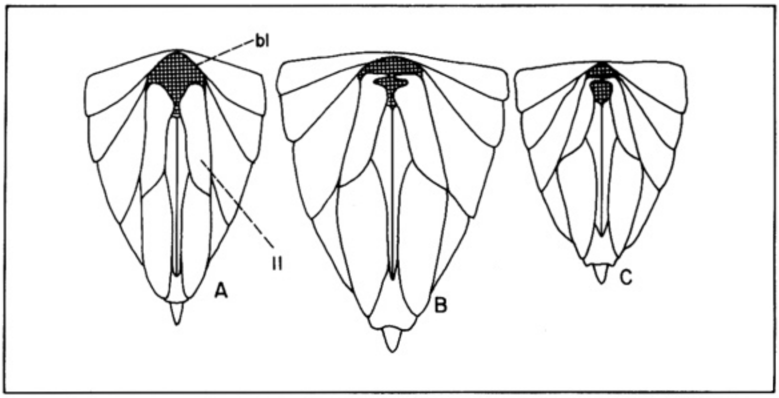
3. Medioventral process of male pygofer present; genital style bifurcated apically . . . . (4)
— Medioventral process of male pygofer absent . . . . (5)
4. Inner margin of female lateral lobe with a spatulated process at base (Figs. 5c and 6c) . . . . *muiri*
— Inner margin of female lateral lobe slightly concave near base (Fig. 6D) . . . . sp.
5. Genital style bifurcated apically; hind tibial spur with about 20 teeth . . . . *myersi*
— Genital style not bifurcated apically, hind tibial spur with about 30–36 teeth . . . . *lugens*

According to Fennah (1973/75), *N. chaeremon* is very evidently related to *N. albotristriata* but differs in its more uniform body color and in structural details of the male genitalia with bifurcated genital style. The hind tibial spur in *N. chaeremon* has about 18 teeth. The genitalia are shown in Figure 4 for males and in Figures 5 and 6 for females in these species.

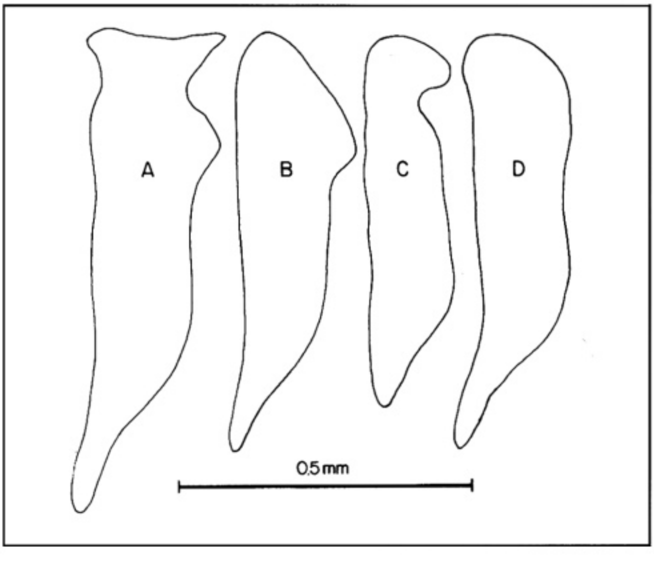
Species distributed in the Oriental and Australian regions

- *N. lugens* (Stål, 1854) Öfv. Svensk Vet. Ak. Forh. 11:246.

Synonyms include:



5. Female genitalia of *N. lugens* (A), *N. bakeri* (B), and N. *muiri* (C). bl = basal lamina; ll = lateral lobe.



6. Lateral lobes of *N. bakeri* (A), *N. lugens* (B), *N. muiri* (C), and *N.* sp. (D) (macropterous female) (Suenaga and Mochida 1966).

1854 *Delphax lugens* Stål
1863 *Delphax sordescens* Motschulsky
1903 *Liburnia sordescens* Melichar
1906 *Delphax oryzae* Matsumura
1906 *Kalpa aculeata* Distant

1906 *Nilaparvata greeni* Distant
1907 *Delphax ordovix* Kirkaldy
1907 *Delphax parysatis* Kirkaldy
1907 *Dicranotropis anderida* Kirkaldy
1907 *Delphacodes anderida* Muir
1917 *Delphacodes parysatis* Muir
1917 *Liburnia oryzae* Matsumura
1932 *Nilaparvata oryzae* Esaki et Hashimoto
1935 *Hikona formosana* Matsumura
1945 *Nilaparvata sordescens* Kuwayama

The male has 15 chromosomes in the primary spermatocyte: n, 15 = 14_{II} + X. The sex determination is of the XO type (Saitoh et al 1970). *N. lugens* is the only pest on rice of economic importance among the members of the genus *Nilaparvata.* The species belonging to *Nilaparvata* collected on lowland rice plants in Indonesia was only *N. lugens.* On the other hand, the light trap occasionally catches a small number of other species such as *N. bakeri* and *N. muiri* in Japan, especially in May, June, and July (Hasegawa 1955a; Nasu 1965).

N. lugens is found in India, Sri Lanka, Bangladesh, Cambodia, Thailand, Vietnam, China, Malaysia including Sarawak, Korea, Japan, Indonesia, Philippines, Australia (Queensland), Caroline and Mariana Islands. Fiji, New Guinea (Papua), and Solomon Islands.

Many plants are reported as host plants, food plants, and plants that serve for oviposition. Like Mochida and Okada (1971, p. 739), we doubt that all serve those purposes in the field. Many authors used the word host plant vaguely in relation to *S. furcifera* and *N. lugens.* We consider that when *N. lugens* repeats its generations on a plant or plants under natural conditions, such plants are regarded as its host plants. Mochida and Okada consider *Oryza sativa* as the main host, but some plants such as *O. alta, O. australiensis, O. brachyantha, O. glaberrima, O. granulata, O. latifolia, O. minuta, O. nivara, O. punctata, O. perennis, Leersia* spp., and *Echinochloa* spp. may become potential host plants in the open field. Lei and Wang (1958) noted that the eggs of *N. lugens* are deposited in the tissues of *Leersia hexandra* (Linn.) Swartz and other weeds along the sides of streams, pools, and ponds in China during the winter. As *Leersia* spp. are the host plants of allied species, however, further examination is needed regarding the identification of the species on such plants.

- *N. albotristriata* (Kirkaldy 1907) Bull. Exp. Stn. Haw. Sug. Plant. Assoc. 3:154, pls. 10 (fig. 15). 14 (figs. 1–3).

1907 *Delphax albotristriatus* Kirkaldy

Hind tibial spur with about 16 well-developed spines. Male pygofer apically rotundate oval, the rim thickened about the anal third and produced there in a short spine. Genital styles broad. bifid apically. Length $2\frac{1}{4}$ to $2\frac{3}{4}$ mm. Brachypterous is known. For identification see Figure 4A.

N. albotristriata occurs in Australia (Queensland, Brisbane, and Bundaberg), Guam, and New Caledonia.

The host plant of this species is unknown.

- *N. bakeri* (Muir, 1917) Proc. Haw. Entomol. Soc. 3: 314–315 (Fig. 47), 336–337.

1917 *Delphacodes bakeri* Muir

Body is slightly larger and darker than *N. lugens.* Macropterous male 2.5–3.0 mm (3.7–4.2 mm, including fore wing) and female 3.3–3.5 mm long (4.4–4.6 mm, including fore wing). Brachypterous male 2.5–2.8 mm and female 2.8–3.4 mm. Frons near center with an excavation intercepting median carina (Fig. 3). Aedeagus for male and lateral lobe for female are specific (Figs. 4–6).

N. bakeri is found in Japan, South Korea, Formosa, Philippines, and Sri Lanka. Mochida and Okada (1971) reviewed references regarding hosts. Main host is *Leersia japonica* Makino.

- *N. chaeremon* Fennah, 1973/75 Entomol. Scand. Suppl. 4: 102–103, Figs. 81–89.

For identification see Figure 4B. *N. chaeremon* occurs in Sri Lanka. The host plant is unknown.

- *N. muiri* China, 1925 Ann. Mag. Natl. Hist. (9), 16:480 (Fig. 4F).

Slightly smaller than *N. lugens.* Body length of macropterous male 2.1–2.3 mm (3.3–3.6 mm including fore wing), female 2.4–2.6 mm (3.4–4.0 mm including fore wing). Brachypterous male 2.0–2.3 mm, female 2.5–2.8 mm. For identification see Figures 4 to 6.

N. muiri is present in China, Japan, and S. Korea.

Mochida and Okada (1971) reviewed references regarding hosts, food, and oviposition plants. Many plants are reported as the host, food, and oviposition plants. However, *Leersia sayanuka* Ohwi is the main host in Japan.

- *N. myersi* Muir, 1923 Trans. N.Z. Inst. 54: 258.

For identification see Figure 4F. *N. myersi* occurs in New Zealand. Its host plant is not known.

- *N. seminula* Melichar, 1914 Notes Leyden Mus. 36: 110–111.

Since Melichar described one male of this species very simply, no rerecord or redescription has been known. A very small, slim delphacid, dark brown in color. Both fore and hind wings hyaline, transparent without marks. Veins extremely slim and outermost one finely granulated; outer and inner apical veins forked. Hind tibiae with two spines. Length of male, including fore wing, 2.25 mm.

N. seminula occurs in Java (Semarang). Its host plants are unknown.

- *N.* sp. Nasu, 1960 Delphax, 2: 3–4.

An undetermined species was recorded in Kyushu and Honshu, Japan. The same species is recorded in S. Korea (Okada 1977). This species resembles *N. muiri* but is distinguishable by the following characters: genital style dark brown, relatively thicker, with large and hemispherical outer process in caudal view. Aedeagus in lateral aspect apically curved rectangularly and produced relatively longer. Inner margin of lateral lobe of female basally slightly concave (Fig. 6D).

Leersia sayanuka Ohwi is the host.

Separation of *Nilaparvata* spp. in the egg and nymphal stage

Nasu and Suenaga (1956a) and Suenaga and Nakatsuka (1958) showed that *N. lugens, N. bakeri,* and *N. muiri* are occasionally distinguishable from each other in the egg and older nymphal stages by the shape of the eggcap or operculum, egg size, and both color and general appearance of nymphs. Hasegawa (1955b) indicated that in the fourth instar *N. lugens* is distinguishable from *S. furcifera* and *Laodelphax striatellus* (Fallén) by the external structure of the anal segments. However, there is no report to distinguish all these allied species in the egg and nymphal stages.

BIOLOGY OF *N. LUGENS*

Life cycle

The eggs are usually laid as egg-groups in the tissue of the lower part of the rice plant, mainly in sheaths but also in leaf blades. But the sizes and sites of egg-groups depend upon the stages of the rice plants (Table 2). When the adult population is high, eggs are found in the upper parts of rice plants. The egg stage is about 7 to 11 days in the tropics. The nymphal stage is 10 to 15 days. The preoviposition period averages 3 or 4 days for brachypterous females and 3 to 4 days for macropterous females. Duration of each stage depends on temperature and cultivars. In the greenhouse each female lays about 100 to 200 eggs. The adults and nymphs usually stay on the lower parts of rice plants. However, when the population is very high—in Java more than 500 per hill—they are observed to swarm even on flag leaves, the uppermost internodes of panicles, and panicle axes.

The average temperatures in tropical lowlands range from about 20 to 30°C–20 to 31° at Calcutta, 25 to 31° at Bangkok, 26 to 28° at Jakarta, and 25 to 30° at Manila. The time from appearance of the adult in one generation

Table 2. Egg-group sizes and oviposition sites in the paddy field at maturity on 20 plants of rice cultivar Kinmaze (Mochida 1964b).

Oviposition site	Egg-groups (no.)	Eggs in an egg-group (no.)		Eggs	
		Mean	(Min to max.)	Total no	% of total
Blades					
Upper surface	176	14.5	(2 to 62)	2558	86.6
Under surface	44	7.7	(1 to 28)	341	11.6
Subtotal	220	13.1		2899	
Sheaths	6	7.8	(5 to 13)	47	1.6
Grand total	226	13.0	(1 to 62)	2946	100.0

Table 3. The average time (days) between *N. lugens* generations on rice seedlings at constant temperatures (Suenaga 1963; Mochida 1964a, 1970).

Stage	25°C			27-28°C		
	Male	Female		Male	Female	
		Brachypterous	Macropterous		Brachypterous	Macropterous
Egg	10.5	10.4			7.9	
Nymph	14.1	14.3			12.0	
Preoviposition period		3.8	7.2		3.0	3.9
Total	24.6	28.4	31.9		22.9	24.8

to that in the following generation is 28 to 32 days at 25°C constant, and 23 to 25 days at 28°C constant (Table 3). The growing duration of existing rice cultivars in the tropics ranges from 78 to 230 days (Grist 1968). Thus, *N. lugens* may be calculated to have 2 to 8 generations during one rice cropping season in tropical lowlands. In fact, *N. lugens* has five generations on a single rice crop in southern Japan (Mochida 1964a), five or six generations in the central part of China (Lei and Wang 1958), and four or five generations in Java (Mochida et al 1977).

The seasonal occurrence of *N. lugens* depends on the presence of rice plants in the tropics. In many rainfed paddy fields in Java, rice is absent during the dry season. *N. lugens* is not found so abundantly in such fields, but is found in some rice fields irrigated in the dry season (Mochida et al 1977).

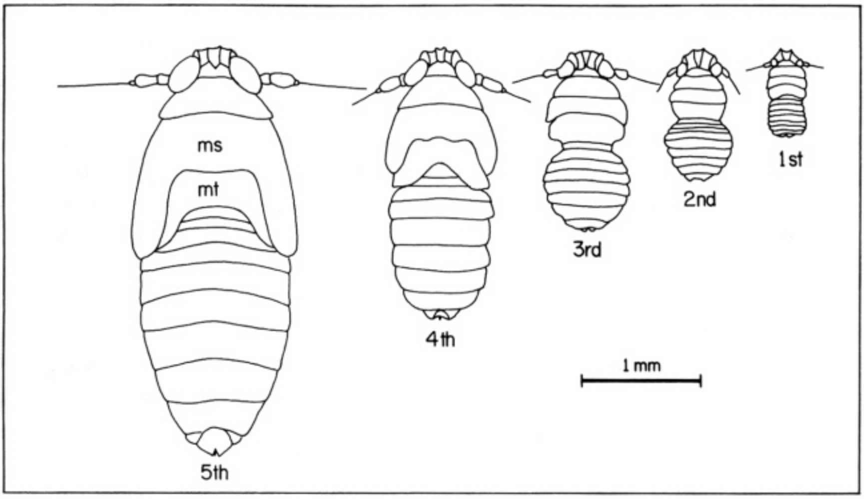
Overwintering

For more than 70 years many entomologists have been trying to find *S. furcifera* and *N. lugens* in Japan during the winter but have found only a few cases at special places. Nasu (1965) studied the eggs in diapause in seven delphacids. The embryonic development in all such eggs in diapause stopped just before the blastokinesis stage in all seven species. When eggs were kept at 25°C, embryonic development started again within several days and the eggs hatched. Nasu could not find these phenomena in the eggs of *N. lugens*. On the other hand, Miyake and Fujiwara (1956, 1957, 1961, 1962) and Miyake (1966) reported the overwintering and diapause of *N. lugens* under experimental conditions in Japan. They observed that eggs destined to diapause were laid by adults or the migratory females that had been reared on the leaf sheaths of rice plants and developed after the heading stage under conditions of high nymphal densities, temperatures lower than 17°C, and a short 10-hour day. The eggs in diapause were defined as those still alive after 24 hours at -4 C. Okumura (1963) said that adults reared in rearing tubes with a short 8-hour day and 15°C produced some unhatched eggs, and that the embryonic development in such eggs was retarded in the yellow-spot stage. He did not explain why unhatched eggs were regarded as eggs in diapause. Because the descriptions of eggs in diapause in *N. lugens* by Miyake and his coworkers and by Okumura are vague, future studies should be made to determine whether those eggs contain embryos in diapause or not. Takezawa (1961) indicated that a few of the eggs laid in ratoons in mid-November survived until March or April. But rice plants and their ratoons in the main islands of Japan disappear in winter or early spring. Accordingly, there are few possibilities that *N. lugens* can overwinter in the egg stage in the main islands of Japan, except in special cases in which a very few *N. lugens* overwinter as eggs and nymphs in several small, warm areas of Southern Japan in some years (Itoga et a1 1956; Sameshima 1956). Most *N. lugens* appearing in the rice fields of Japan in early summer every year have migrated across the East China sea.

Development

Nasu and Suenaga (1956b) and Mochida (1970) described the embryonic development of *N. lugens* The egg consists of the chorion, viitelline membrane, protoplasm, nucleus, yolk, and mycetocyte. The mycetocyte seems to be covered with a thin membrane and can be distinguished easily from other egg contents as a spherical body. It is situated at the posterior end of the egg, and is about 85 or 90 μ in diameter within 4 hours after oviposition; it holds a mass of microorganisms or symbiotes. After maturation, fertilization, and cleavage have advanced within the egg, the events that lead to the formation of the embryo begin to occur at the posterior pole of the egg from the first to the second day after oviposition at 25°C—germband formation. The mycetocyte remains at the posterior pole. Near the posterior pole a slight depression occurs and develops into the mouth of the invagination about 28 to 32 hours after oviposition. This pit deepens rapidly into a slender tube or invagination, and appears in the yolk. As invagination advances, the mycetocyte is situated on the top of the vagination. The invagination proceeds in such a manner that its ventral surface faces the dorsal side of the egg, and its posterior end faces the anterior pole of the egg. The mycetocyte moves subsequently toward the anterior pole with the development of invagination on the second day. The original head, thoracic, and abdominal parts are distinguishable on the third day. At the end of the fourth day and early in the fifth day (90–108 hours), the top and the tail of the invagination are bent and developed backward and forward along the dorsal and the ventral side of the egg, respectively. Simultaneously, the mycetocyte moves along the ventral side of the egg toward the posterior pole. Now the original position of the embryo has been entirely reversed, while the mycetocyte returns to the vicinity of its original position; the blastokinesis has been completed. The rudiments of the eyes appear as red spots shortly after the blastokinesis has been completed (96 to 102 hours). The egg cap is detached from the chorion at the anterior pole of the egg on the seventh day. Hatchlings appear about 9 or 10 days after oviposition.

N. lugens has five nymphal stadia, which are distinguished by shapes of the mesonotum and metanotum, and body size (Fig. 7). Like the embryonic



7. First to fifth instars of *N. lugens.* ms = mesonotum; mt = metanotum.

development, postembryonic development is influenced considerably by temperature.

Effect of temperature

Table 4 shows some bionomical characters related to temperature.

Egg and nymphal stage Nymphal body fluid freezes or becomes supercooled at −6.2°C. Embryonic development ceases below 10°C according to Hirano (1942), 10.5°C according to Kuwahara et a1 (1956), or 10.8°C according to Suenaga (1963). Cessation of postembryonic development is set at 10.5, 9.1 or 9.8°C by the same authors. The hatchability is highest (91.5%) at about 25°C (Fig. 8). The nymphal survival rate is highest (about 96 to 98%) at about 25°C constant (Fig. 9). The time required for completion of embryonic and postembryonic development depends to a considerable extent upon temperature. The duration of the egg stage is 26.7, 15.2, 8.2, 7.9, or 8.5 days at 15, 20, 25, 28, or 29°C constant (Fig. 10), respectively. It is shortest at about 28°C. The duration of the nymphal stage is about 18.2, 13.2, 12.6, 13.1, 17.0, or 18.2 days at 20, 25, 29, 31, 33, or 35°C constant (Fig. 11), respectively. It is shortest, 12.0 days at 27°C. Thus, the shortest total span from egg to adult is about 20 days at 27 to 28°C constant when susceptible cultivars are given as foods. The temperature to which the nymph is exposed is known to affect the adult female's longevity and oviposition (Mochida 1964a). Fourth- and fifth-instar nymphs are normally active between 12 and 31°C (Suenaga 1963).

Adults. The temperature range for normal behavior is 9 to 30°C in the macropterous male and 10 to 32°C in the macropterous female (Suenaga 1963).

Table 4. Bionomical characters of brachypterous (B) and macropterous (M) *N. lugens* kept on rice seedlings.

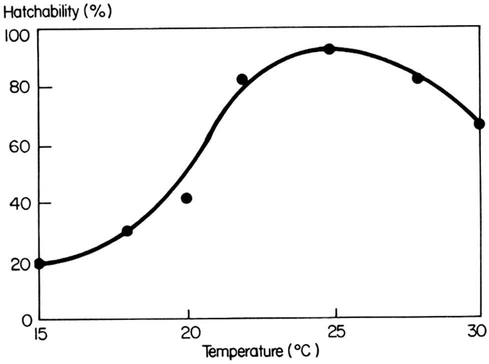
	25°C constant				Natural temp.			
	B♂	M♂	B♀	M♀	B♂	M♂	B♀	M♀
Egg								
Hatchability (%)	91.5[a]							
Egg stage length (days)								
Av.	10.5		10.4[b]					
Min. to max.					6–36[c]			
					6–13[d]			
					9[e]			
Nymph								
Survival rate (%)	96–98[a]							
Nymphal life (days)								
Av.		14.1	14.3[b]					
Min. to max.		(11–16)	(13–15)		11–48[c]			
					12–24[d]			
					12.2[b]			
Adult								
Av. longevity (days)			22.3	27.6[b]	33.5	36.6	26.1	30.7[f]
		11.6		18.6[g]				
Preoviposition period (days)								
Av.			3.8	7.2[b]				
Min. to max							3–6	3–7[c]
Av. (min.–max.) oviposition period (days)			20.7	21.4[b]			11–39	6–42[c]
Eggs/female (no.)							201.6	196.2[c]
Av.			300.7	249.0[b]				
Min. to max.			(86–576)	(0–812)[b]			405.7	236.4[h]
							598.5	543.1[h]
							163.7	148.5[i]
							108.2	139.9[i]
Max.								1474[a]
Eggs/egg-group (no.)			1.74	1.77[j]				1–20[a]
								1–27[g]
								1–62[b]
Sex ratio	1		1					

[a] Suenaga (1963). [b] Mochida (1970). [c] Fukuda (1934). [d] Esaki and Sameshima (1937). [e] Soejitno et al (1974). [f] Kisimoto (1957). [g] Bae and Pathak (1970). [h] Kuwahara et al (1956). [i] Mochida (1964a). [j] Mochida (1964b).

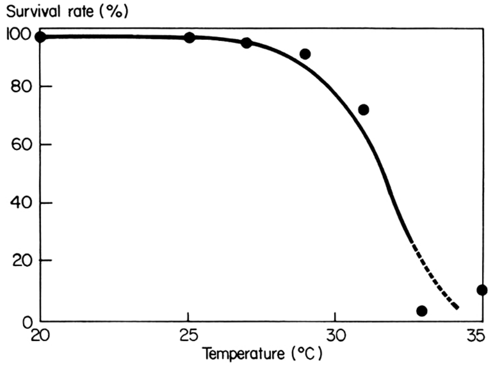
Adult longevity is curtailed as temperature rises in a range between 20 and 33°C (Mochida 1964a). The number of eggs laid by a female is highly correlated to her life span (Kisimoto 1957) and her oviposition period (Mochida 1964a, 1970b). The oviposition rate (eggs per day per female) rises with temperature. The preoviposition period in macropterous females becomes shorter as the temperature rises in the range between 20 and 33°C; that in brachypterous females remains unchanged (Fig. 12).

To study the effect on oviposition, short exposures to different temperatures during the early adult stage of four groups of macropterous females were compared :

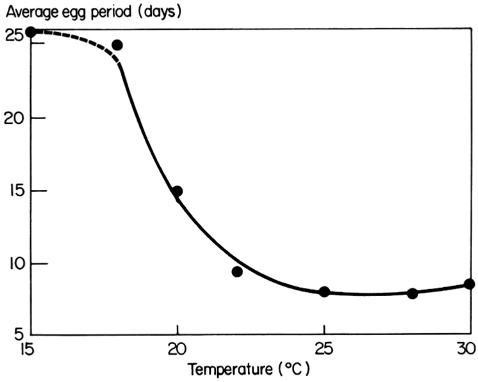
1. Females were kept at 28°C continuously after emergence.
2. Females were kept at 28°C for 48 hours after emergence, then permitted to oviposit at 20°C constant.



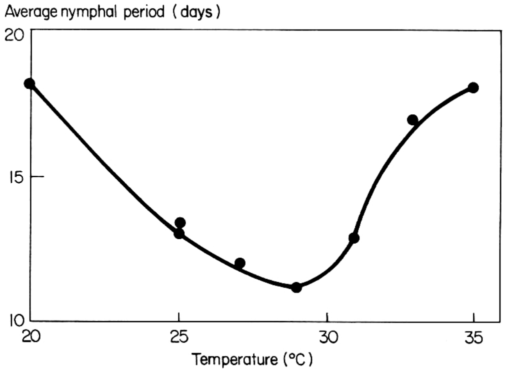
8. Hatchability of *N. lugens* at constant temperatures (data from Suenaga 1963).



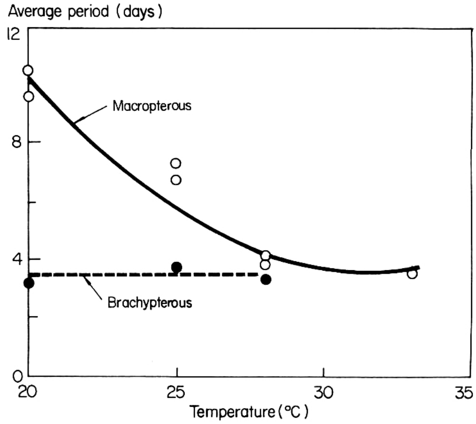
9. Survival rate in the nymphal stage of *N. lugens* at constant temperatures (data from Suenaga 1963).



10. Days required for completion of embryonic development of *N. lugens* at constant temperatures (data from Suenaga 1963).



11. Days required for completion of postembryonic development of *N. lugens* at constant temperatures (data from Suenaga 1963).



12. Preoviposition period of *N. lugens* on rice seedlings (Norin 18) at constant temperatures (data from Mochida 1964a).

3. Females were kept at 28°C for 24 hours after emergence, then at 20°C constant.
4. Females were kept at 20°C continuously after emergence.

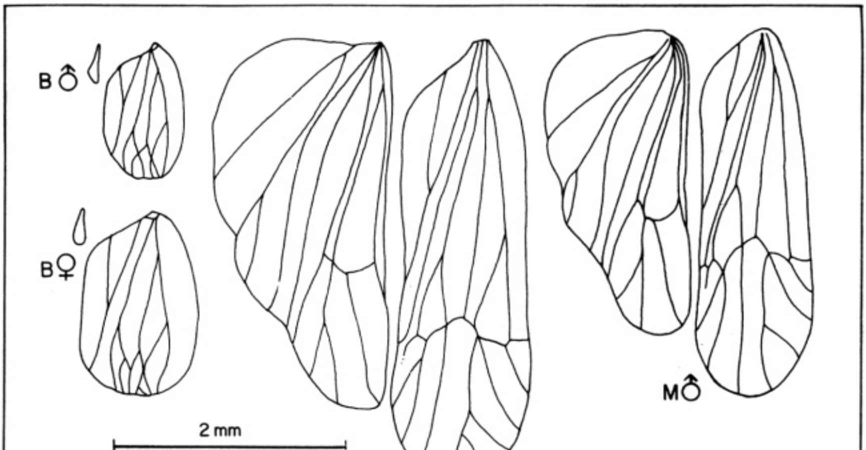
The oviposition rates were the highest in the first group and lowest in the fourth. Those in the second and the third groups were intermediate and about constant throughout the oviposition period (40 to 50 days). This means that temperatures shortly after emergence affect macropterous females in oviposition for long periods (Mochida 1964a).

The temperature conditions not only during the adult stage but during the nymphal stage affect adult longevity, oviposition rate, and preoviposition period in macropterous females. It is difficult to determine which temperature conditions are best suited to population growth of *N. lugens,* but day temperatures of about 28 to 30°C and somewhat lower night temperatures may be suitable for producing large number of adults in the field.

When females with both wing-forms are kept at constant temperatures, their ovarioles do not develop below 17 or 18°C. When such females are kept daily at 25°C for several hours in several days, they start to produce eggs below 17 or 18°C (Mochida, unpubl.). This suggests that egg-formation proceeds in response to hormonal activities at above 17 or 18°C.

Appearance of wing-forms

N. lugens has two wing-forms (Fig. 13). The fact that in delphacids higher population densities during the nymphal stage increase the relative number of macropterous adults was found first by Murata (1930) in *L. striatellus.* According to Kisimoto (1956a,b), relative numbers of the macropterous form of the female of *N. lugens* increased with increases in population density. However, brachypterous males did not appear at the lowest density, but were more numerous at middle densities, decreasing again with density increase. Kisimoto (1957), renewing the food plant at different intervals and using several chemicals, found that deterioration in quality and quantity of food accelerated the increase in relative numbers of the macropterous insects of both sexes. The effect of crowding with feeding unchanged is considered to be a group effect or mutual stimulus. Crowding of nymphs is known to affect the adult wing-forms in



13. Wings of macropterous (M) and brachypterous (B) adults of *N. lugens.*

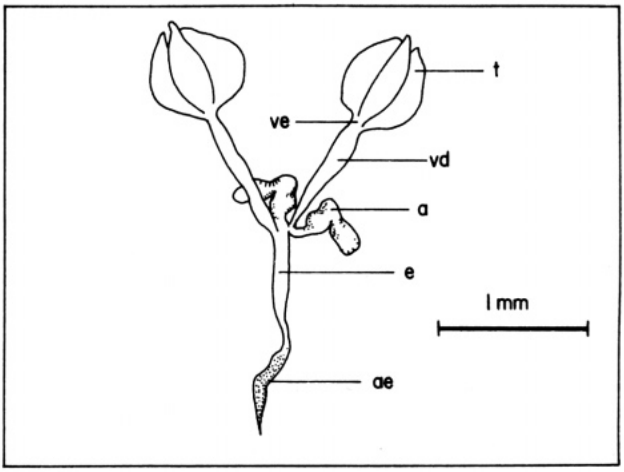
N. lugens (Miyake et al 1951; Johno 1963), as it does in *Javesella pellucida* (F.) (Mochida 1973a). Kisimoto (1957) noted that in *N. lugens* the nymphal period is shorter for the brachypterous form than for the macropterous in both sexes, and that even at high densities, the nymphal period of the brachypterous insect is fairly constant, whereas that of the macropterous insect is lengthened by greater density. A strain producing abundant brachypterous adults was unintentionally selected from the offspring of brachypterous females for many generations (Mochida 1975).

Reproduction

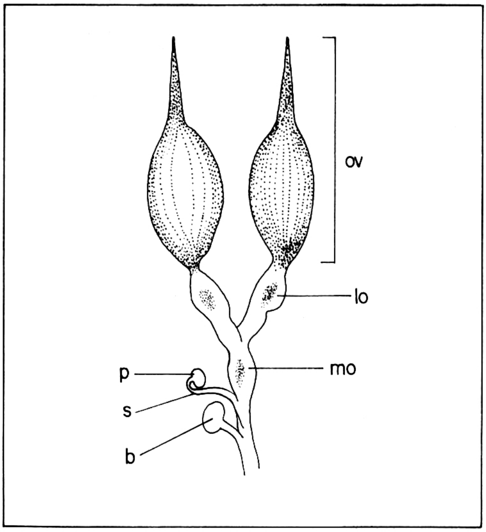
Reproductive organs. Spermatogenesis and oögenesis have been studied by Suenaga (1963). Rudimentary reproductive organs are found in first-instar nymphs. The spermatogonia and the spermatocytes in early stages are present in the middle of the first-instar span. The maturation division of spermatogenesis starts between the end of the third-instar and the early fifth-instar period. The spermatozoa are seen at the bottom of the testicular tubules in the fifth-instar. Because the *N. lugens* female has acrotrophic ovarioles, oögenesis advances rapidly after emergence, as in other delphacids (Mochida 1970, 1973a).

The male reproductive organs consist of two testes, six vasa efferentia, two vasa deferentia, two accesory glands, and a median ejaculatory duct (Fig. 14). Each testis is composed of three lemon-shaped testicular tubules.

The essential parts of the female reproductive organs are a pair of ovaries, a pair of lateral oviducts, a median oviduct, spermatheca, and vagina (Fig. 15). An ovary is made up of a number of ovarioles. An ovariole is made up of a



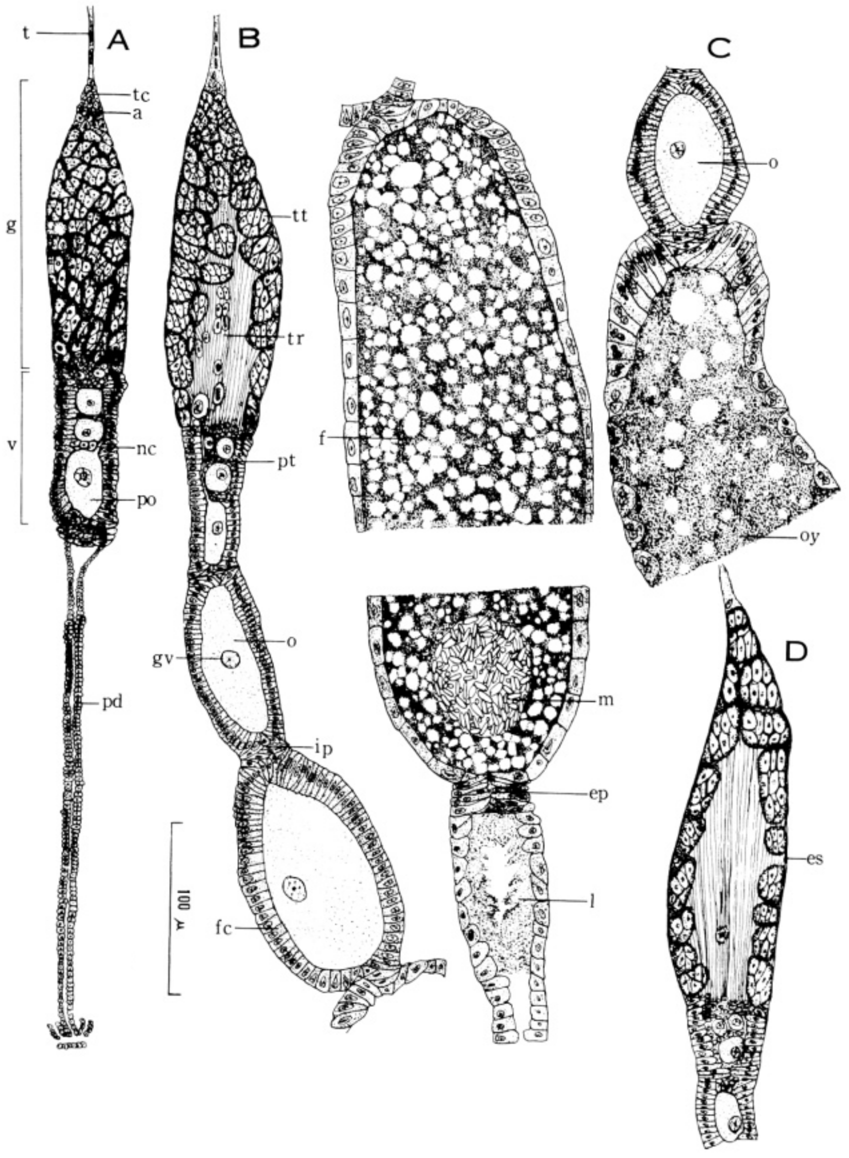
14. The internal reproductive organs of *N. lugens* (male adult). a = accessory gland; ae = aedeagus; e = ejaculatory duct; t = testicular tubule; vd = vas deferens; ve = vas efferens.



15. The internal reproductive organs of *N. lugens* (female adult). b = bursa copulatrix; lo = lateral oviduct; mo = median oviduct; ov = ovary; p = pouched gland; s = spermatheca.

terminal filament, germarium, vitellarium, and ovariole pedicel (Fig. 16). Suenaga (1963) calculated theoretically that the maximum total number of oöcytes produced within a female body was 1,728 to 1,984. He observed that one female produced 1,474 eggs (see Table 4).

Copulation, egg-formation, and egg-deposition. Adult males on rice plants. before copulation, are attracted by the abdominal vibration of females even from a distance of about 80 cm (Ichikawa and Ishii 1974; Ichikawa et al 1975; lchikawa 1976). For 24 hours after emergence males cannot copulate. Their ability to copulate increases up to 5 days after emergence, then decreases (Takeda 1974). A male can copulate at most with nine females for 24 hours; a female can copulate two or more times during her life time (Mochida, unpubl.). Egg-formation is not related to copulation, but discharge of fully grown eggs from the vitellarium of the ovariole is related to copulation, as in the delphacid *J. pellucida* (Mochida, 1970, 1973a). The number of eggs laid by females during their life spans ranges between 0 and 1,474 (Table 4). The number of eggs laid is correlated to life span and ovipositional period, as mentioned in the section on effect of temperature. Although there are many data from several authors, because of large individual variations it seems difficult to decide whether females of one wing-form produce more eggs than females of the other. However, brachypterous females start to oviposit earlier than macropterous females in cool environments. The preoviposition period averages 3 or 4 days for brachypterous females but 3 to 10 days for macropterous ones



16. Longitudinal section of the ovarioles of *N. lugens* (macropterous female). A; female within 4 h after emergence; B; 7-day-old female; C; 7-day-old female (part of the vitellarium); D; 20-day-old female. a = arrested cell; ep = epithelial plug; es = epithelial sheath; f = fully developed egg; fc = follicular cell; g = germarium; gv = germinal vesicle; ip = interfollicular plug; 1 = last remains of corpus luteum; m = mycetocyte; nc = nutritive cord; o = growing oöcyte without yolk; oy = oöcyte with yolk; pd = pedicel; po = primary oöcyte; pt = prefollicular tissue; 1 = basal part of the terminal filament; fc = trophocyte; tr = trophic core; tt = trophic tissue; v = vitellarium (Mochida 1970).

at constant temperatures of 20 to 33°C. Egg-formation is interrupted when fifth-instar female nymphs are irradiated at 15 to 20 krad by Cobalt 60 (Mochida 1973b).

Dispersal

Nymphs and brachypterous adults move by walking and hopping; macropterous adults move by flying, walking, and hopping. First- to fifth-instar nymphs can move 4.8, 10.0, 18.5, 20.7, and 21.1 cm, respectively, at 16°C by hopping (Mochida 1970). The migration and flight of macropterous adults are influenced greatly by their age, sex, and climatic conditions. Macropterous adults take off for flight around sunrise and sunset. Light intensity adequate for takeoff flight is about I to 200 lux. The frequencies of flight activity of *N. lugens* form a bimodal crepuscular curve at times in the temperate zone when low temperatures may suppress sunset flight to produce a unimodal pattern. The low temperature threshold for takeoff is about 17°C. Flight behavior or takeoff is suppressed by winds more than 11 km/hour (Ohkubo and Kisimoto 1971). Flight activity seems to continue under conditions of low temperature, high humidity, and weak wind (Ohkubo 1973). MacQuillan (1975) observed in the tropics that the diurnal flight activity of *N. lugens* has a unimodal crepuscular pattern.

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Ecology of the brown planthopper in temperate regions

E. Kuno

The population of the brown planthopper *Nilaparvata lugens* (Stål) in temperate regions is characterized by discrete periods of seasonal appearance, low initial density, steep and steady growth, clumped spatial distribution, and violent fluctuations from year to year. *N. lugens,* a temporary inhabitant, arrives from long distances barely in the rice-growing season. Its high potential fecundity, high adaptability to its host in various stages, and high tolerance to crowding cause its uneven, clumped spatial distribution within a field. These characteristics also cause the steep and steady growth in population that enables the insect to increase to destructive levels despite its low initial density. The fluctuations in density of initial migrant populations, which are governed by unstable factors, largely cause the violent year-to-year fluctuations in population. The relevance of these characteristics to the strategy for efficient control of the brown planthopper is discussed.

NILAPARVATA LUGENS (Stål), commonly known as the brown planthopper (BPH), is widely distributed in tropical, subtropical, and temperate regions of Asia, where occasional outbreaks seriously injure cultivated rice. There seems to be a distinct difference between the ecology of the BPH in tropical areas where the population may remain in the paddy field throughout the year and that in temperate regions where BPH cannot survive the winter season and is replaced every year by immigrants from southern regions. Such a difference results in different patterns of pest damage and correspondingly different strategies for efficient control.

This paper outlines the ecology of the BPH population in such temperate regions as Japan and Korea on the basis of field population studies conducted mainly in Japan. For comparison, it also describes results of work on the whitebacked planthopper, *Sogatella furcifera* Horvath, whose biology is similar to that of *N. lugens,* particularly in Japan and Korea. The major characteristics of the BPH population are:

- discrete period of seasonal appearance,

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- low initial density,
- steep and steady population growth,
- clumped spatial distribution, and
- violent density fluctuations from year to year.

Those characteristics obviously result from combinations of the physiological properties intrinsic to the insect and the environmental (climatic, biotic, or cultural) conditions of temperate regions.

DISCRETE SEASONAL APPEARANCE

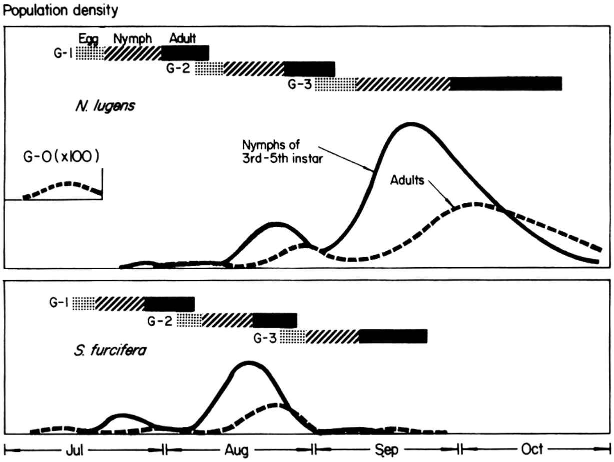
The term *discrete* is used here in two senses. First, the history of the BPH in temperate areas may be called discrete in that its population is seen during only part of each year. In most districts of Japan and Korea, rice is usually grown only from June to October. The initial *N. lugens* population (and that of *S. furcifera*) appears as immigrants soon after the crop is planted.

The population grows for some generations, then disappears after the end of the rice growing season. Extensive land and sea surveys together with experimental analyses of flight activity, now confirm that the initial immigrants in Japan (and probably in Korea) are long-distance migrants, moving from the continent over the East China Sea (Kisimoto 1971, 1976a,b ; Ohkubo 1973). Although some authors have suggested a diapause-like phenomenon in the egg stage (Miyake and Fujiwara 1962; Okumura 1963), a large number of field observations so far indicate that because of the low temperature and lack of alternative host plants, at no developmental stage can the insect normally survive the winter in Japan. The BPH in temperate regions is thus regarded as a temporary inhabitant.

Second, discrete generations can be seen in the population pattern. Each of the usual three generations during the season has a distinct population (Fig. 1), although the generations overlap to a certain extent (Kisimoto 1965; Kuno 1968). Some recent studies indicate the same can also be said of Korea (Lee and Park 1976: Hokyo et al 1975). Undoubtedly, the reason is that the initial invasion usually occurs within a limited period because of the specificity of weather conditions that bring about the migration (Kisimoto 1976a). Also, the rather short lives of the adult insects contribute to the discreteness of generations.

LOW INITIAL DENSITY

A notable feature of BPH populations in temperate regions is the low density of the initial immigrant population, which later sharply increases. The average density of the initial generation in an unsprayed paddy field at the Kyushu Agricultural Experiment Station (Fukuoka, Kyushu Island, Japan) between 1961 and 1968 was about 0.0l/hill (Table 1). That is about one-tenth of the *Sogatella, furcifera* population and is also much smaller than the initial densities



1. Idealized representation of population patterns of *Nilaparvata lugens* and *Sogatella furcifera* during a rice-growing season (G = generation) (from Kuno 1968). Based on data from Kyushu Agric. Exp. Stn., Chikugo, Fukuoka, Japan.

of two other coexisting leafhoppers, *Laodelphax striatellus* and *Nephotettix cincticeps.* In Korea, Hokyo et al (1975) recorded a peak of 0.016 *N. lugens*/hill (at Suweon), which is also much smaller than the 0.25 hill for *S. furcifera.*

The initial density, however, varies widely among different districts of the same country. As anticipated from the specificity of the migration pattern

Table 1. Population growth of *Nilaparvata lugens* **and** *Sogatella furcifera* **in an unsprayed paddy field, 1961–1968. Kyushu Agric. Exp. Stn., Japan.**

Insect species and population factor		Generation			
		Initial (G-0)	First (G-I)	Second (G-II)	Third (G-III)
N. lugens					
Population density (no./hill) [a]	N + A	0.0105	0.586	4.98	19.51
	A	0.0105	0.162	1.38	5.40
Range during 1961 to 1968 [b]	N + A	0.0022 ~ 0.0497	0.122 ~ 3.52	0.532 ~ 48.19	3.35 ~ 214.8
Reproduction rate [c]			15.40	8.50	3.92
Population growth rate			513		
S. furcifera					
Population density (no./hill)	N + A	0.121	0.625	1.65	0.115
	A	0.121	0.187	0.494	0.034
Range during 1961 to 1968	N + A	0.0089 ~ 0.603	0.0330 ~ 5.78	0.0600 ~ 40.18	0.0093 ~ 1.17
Reproduction rate			1.55	2.64	0.07
Population growth rate			4.09		

[a] The density is the average for the period corresponding to each generation (For details of calculation, see Kuno and Hokyo 1970b). N + A: Sum of adults and 3rd–5th instar nymphs; A. Adults only. [b] The range from the minimum to the maximum density observed during 1961–1968. [c] The rate was calculated based on the density of adults

described by Kisimoto (1976a), the initial population in Japan tends to become lower as one moves from southwestern to northeastern districts in the direction of the air-mass movement at the time of invasion (e.g. Suenaga and Nakatsuka 1958). A similar gradient for the initial population was also observed in Korea (Hokyo et a1 1975).

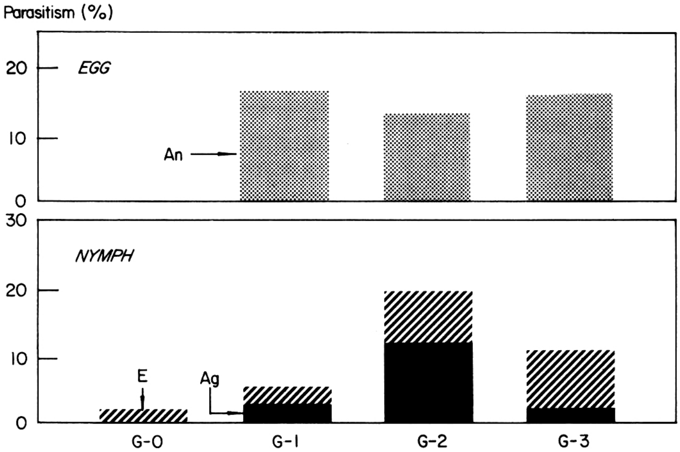
STEEP AND STEADY POPULATION GROWTH

Obviously, the capability for steep and steady population growth makes BPH one of the most important pests of rice despite its low initial numbers. The population growth results from steady multiplication during three generations, which contrasts with the growth of the whitebacked planthopper population, which stops at the second generation and crashes thereafter (Table 1). The initial BPH population multiplies more than 500 times, bringing about an eightfold increase per generation. As a result, a destructively high density of more than 200 nymphs and adults per hill was attained in an outbreak year. In contrast, the whitebacked planthopper has a much lower rate of population growth; it multiplies only 4.1 times, or about two times per generation. That may explain why unlike BPH, it cannot be a serious pest in temperate regions, despite its much higher initial population.

Fecundity

The high rate of the BPH population growth is primarily due to its high fecundity. Suenaga (1963) reported that the number of oocytes per female is about 2,000 on potted rice plants. Kuno (1968) observed 805 to 908 eggs/female in the three generations. On field-grown rice covered with a nylon net, Kusakabe (unpubl.) found nearly 1,000 eggs/female. Those values seem to represent the potential fecundity of the insect in the field. A number of authors (e.g. Suenaga 1963; Mochida 1964) on the basis of laboratory experiments in which either cut plants or seedlings were used have often reported much smaller fecundity values of some hundreds or less. By no means may such conditions be optimum for sap-sucking insects.

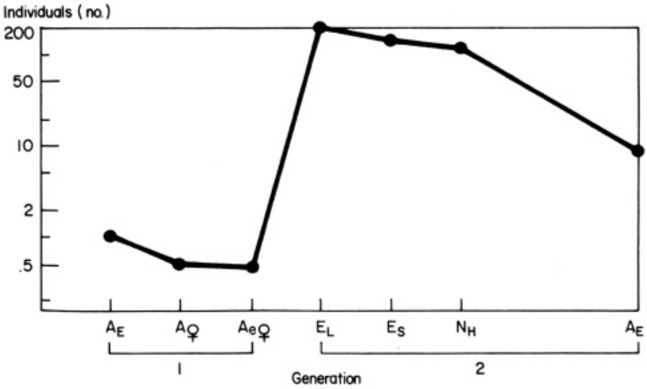
Like other planthopper species, a few days after emergence, BPH adults copulate and begin to lay eggs, then continue to oviposit at a roughly constant rate. The high potential fecundity described above usually cannot be realized in the field because the adult insect's life is shortened by various factors. Kisimoto (1965), for instance, observed a life span of about 9 days for brachypterous females of the first generation. Kuno and Hokyo (1970a,b) estimated that first-generation brachypterous females live 8.1 days as adults and each unparasitized female lays 429 eggs, the egg-laying being less than half the potential. Ichikawa and his collaborators (e.g. Ichikawa 1976a,b) recently found that these planthoppers have an elaborate system of mating communication. It is likely, however, that in the initial low-population generation, fecundity occasionally is reduced because of insufficient chances to mate.



2. Average parasitism of *N. lugens* generations (from Kuno and Hokyo 1970b). Data obtained 1965–68 at Kyushu Agric. Exp. Stn. An = *Anagrus* sp.; E = *Elenchinus japonicus;* Ag = *Agamermis unka.*

Survival of immature stages

A variety of mortality factors operate during the egg and nymphal stages. The egg, which is laid into the tissue of the leafsheath or leaf of rice, is attacked by a mymarid parasite, *Anagrus* sp., whose biology has been studied in detail by Ôtake (1967, 1968, 1969, 1970, 1976). According to a study at Kyushu Agricultural Experiment Station, parasitism by *Anagrus* sp. of the BPH was lower than its parasitism of the other planthoppers and fairly stable throughout the season, varying somewhere between 10 and 20% on the average (Fig. 2). The egg mortality due to other factors. such as predation by the widely distributed mirid *Cyrtorhinus lividipennis* Reuter, or parasitism by some fungi, was observed. Among the mortality factors for nymphs, predation by spiders seems to be of great importance, although few quantitative data have so far been obtained on the actual rate. Among various species of spiders found in paddy fields (Kobayashi 1961; Lee and Park 1976), several species belonging to Lycosidae (*Lycosa pseudoannulata* Boes. et Str., *Pirata subpiraticus* B. et S., etc.), and micryphantidae (*Oedothorax insecticeps* B. et S., *Gnarhonarium dentatum* Trider, etc.) are usually most plentiful both in Japan (Kuno 1968; Kiritani et al 1972) and Korea (Lee and Park 1976; Hokyo et al 1975). Their peak populations sometimes exceed 10/hill. The planthopper nymph is attacked also by some parasites belonging to three taxa: a nematode, *Agamermis unka* Kaburaki et Imamura; a Strepsiptera, *Elenchinus japonicus* Esaki and Hashimoto; and some species of Dryinid wasps (Esaki and Hashimoto 1937). Their parasitism at the Kyushu Agricultural Experiment Station tended to become high in the second BPH generation. The parasites leave the host's body at its



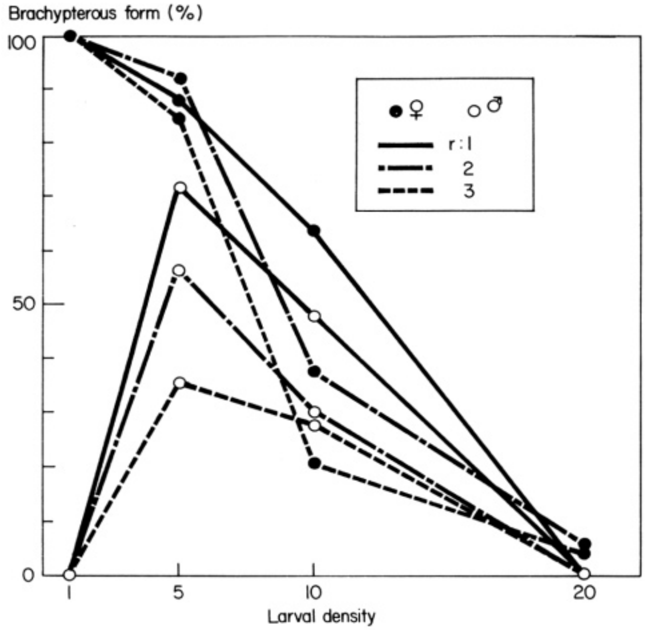
3. Reproduction-survival in the field starting from one first-generation adult of *N. lugens* (from Kuno and Hokyo 1970b). The data were obtained in 1968 at Kyushu Agric. Exp. Stn. A_E = adults emerged; A ♀ = female adults emerged; Ae ♀ = unparasitized female adults; E_L = eggs actually laid; E_S = eggs survived; N_H = nymphs hatched (= E_S − eggs parasitized).

adult stage; thus, although they attack nymphs, their effect is classified as adult mortality or a decrease of reproductive females (their parasitism entirely spoils the host's reproductive ability). Some 50% of the BPH population at the Kyushu Station is lost to egg and nymphal parasites before third-generation adults emerge although individual parasitism rates in each generation are generally rather low (Fig. 2). A number of physical and biological mortality factors may also affect the nymphal stage, as yet there is little information about them.

A presumably typical example of the reproduction-survival curve for the BPH is shown in Figure 3. The high fecundity of the species gives rise to a high rate of increase (about eightfold per generation in this case), notwithstanding a rather low survival rate, especially in the nymphal stage.

Adult wing forms in relation to population growth

The BPH, like many other Delphacids, has two adult wing forms. Kisimoto (1956, 1965) concluded that the macropterous form is migratory and adapted to finding a new habitat for the species, and the brachypterous form is sedentary and adapted to breeding in a suitable habitat. Under experimental conditions the proportion of the macropterous females can vary from 0 to 100%. Poorer living conditions (e.g. dense populations) during the nymphal stage mean more macropterous females. For the male, however, there is apparently an optimum density range that stimulates the appearance of the brachypterous form; the male becomes a macropterous adult at both low and high densities (Fig. 4). Generation-to-generation changes of the proportions of adult forms in the field are shown in Fig. 5. The initial population is naturally composed

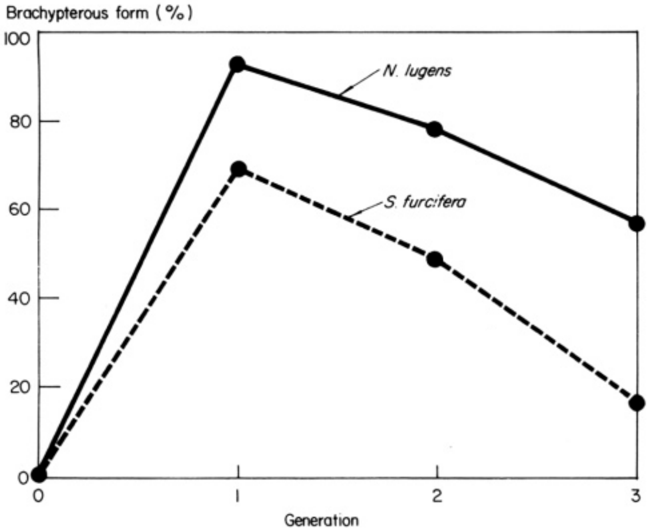


4. Percentage of brachypterous forms in both sexes of *N. lugens* from a rearing experiment in which the initial density and the interval of renewal of the food and the container size (r) were varied (from Kisimoto 1965).

exclusively of macropterous adults. In contrast, most females of the ensuing first generations are brachypterous. The proportion of brachypterous females then tends to decrease toward the last generation as population density increases and the host plants mature. The decrease is much slower than in whitebacked planthopper, however, and most second-generation females are brachypterous although the proportion varies from year to year depending on the population density (Kuno and Hokyo 1970b). Figure 5 thus clearly shows that BPH, in contrast to whitebacked planthopper, has a high tolerance for crowding and a high adaptability to different stages of the host, so that active dispersal from the field does not usually take place until the third or last generation. That may be an important reason for the steady BPH population growth during the rice growing season.

CLUMPED SPATIAL DISTRIBUTION

Clumped or patchy distribution of individuals within a field is another important characteristic of the BPH in temperate regions. Other rice leafhoppers usually show much more uniform population distributions (Kuno 1963,

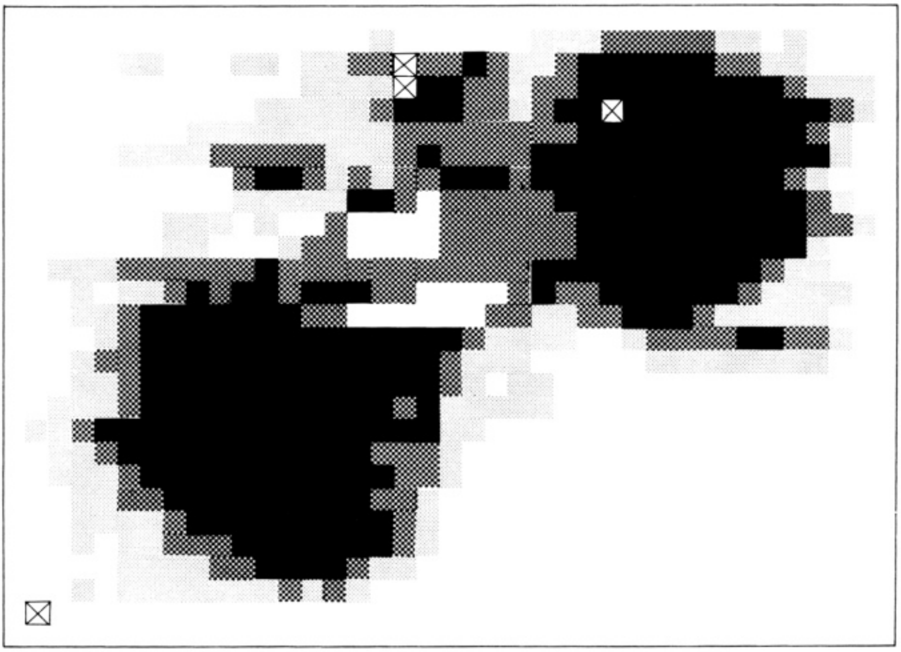


5. Percentage of brachypterous form in females in the field population of *N. lugens* at each seasonal generation (from Kuno 1968). The data were obtained from 1961 to 1966 at Kyushu Agric. Exp. Stn.

1968)—a topic to be described only briefly, because it has been discussed elsewhere (Kuno 1976).

The initial immigration population is distributed nearly at random within a field, as might be expected from the process of its establishment. Its clumped distribution later is the result of growth of a population that has limited ability to travel (Kisimoto 1965; Kuno 1968). It may be regarded as the random distribution of colonies formed from the original immigrants. Mathematically, the number of individuals per hill of rice in the initial population can usually be described by the Poisson distribution, and that in the later breeding population by the negative binomial distribution. That fact can be used to develop efficient sampling plans for making population estimates (Kuno 1976).

In temperate regions, the injury of BPH is usually in the form of patches of hopperburn in a field, each patch drawing a distinct margin (Fig. 6). Such a pattern obviously results from a clumped distribution. That will be confirmed from Figure 7, which shows the relation of the range from minimum to maximum number of individuals on 50 sampled hills to the mean population on successive sampling dates. The range is wide in relation to the mean density, reflecting the clumped spatial distribution. At the time of highest population (278/hill), for example, the range was 10 to 1,274 adults and old nymphs. The maximum value was much more than enough to result in destruction of the hill concerned, while the minimum was far below the injury threshold. The insect's high tolerance for crowding is also evident in the clumped pattern of spatial distribution.

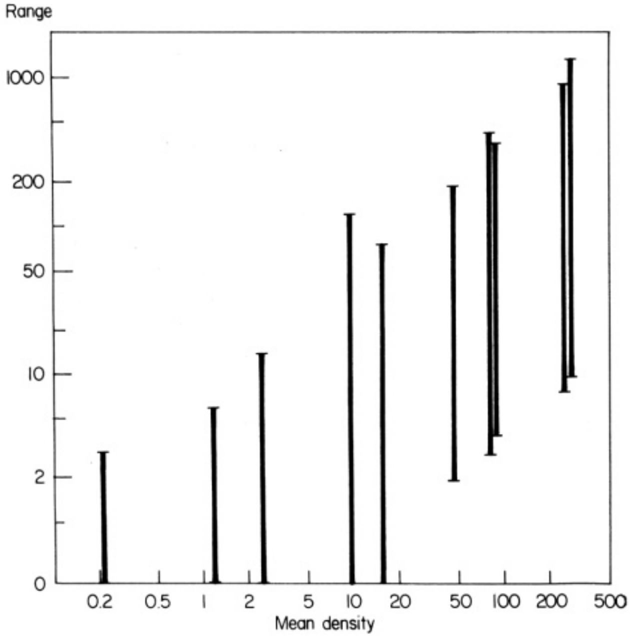


6. An example of the distribution map of hills injured in various degrees by *N. lugens* (from Kisimoto 1965). Small square represents each hill; plain areas are hills not injured; squares shadowed by small dots are hills in which the damage was detectable but none of tillers were killed; squares with large dots are hills some tillers of which were killed; black squares are hills entirely killed; squares crossed are missing hills.

I have shown (1968, 1976) that the degree of aggregation or clumpedness of distribution is closely negatively correlated with the density of the initial population in each year. It may follow that in tropical regions the distribution is usually much less clumped because the population of immigrants established in each field will be much higher. That inference is supported by Otake and Hokyo's field data (1976) taken in Malaysia and Indonesia.

VIOLENT DENSITY FLUCTUATION FROM YEAR TO YEAR

In temperate regions like Japan or Korea, the BPH (and the whitebacked planthopper) is known as a typical outbreak-type pest whose population fluctuates violently from year to year (e.g. Suenaga and Nakatsuka 1958; Paik 1976). For instance, from 1961 to 1968 the maximum population density of the third generation was about 64 times the minimum density (Table 1).



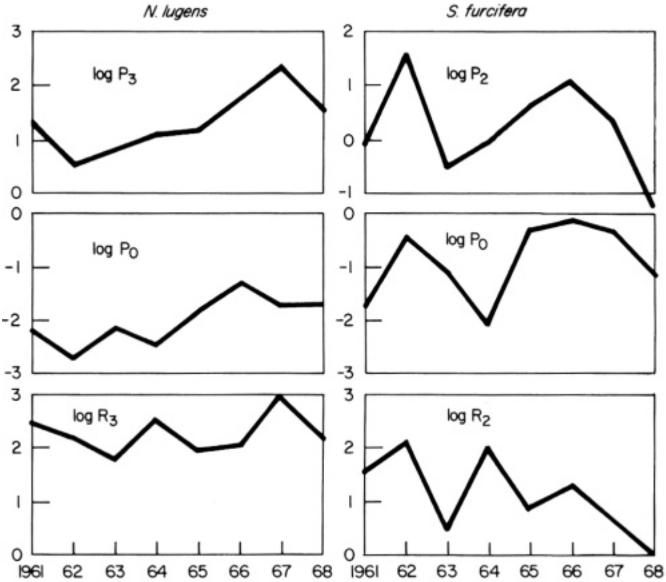
7. Relation of the range of the number of *N. lugens* on a hill to the mean density of *N. lugens* on 50 hills on each sampling date. Based on successive samples from July to October 1967. Data from Kyushu Agric. Exp. Stn.

Thus, while serious rice yield losses occur throughout a region in outbreak years, no great loss may be observed in other years in many parts of the same region.

To analyze such a violent fluctuation, one can first express the density of the third generation, P_3, using its two components, the initial density P_0 and the overall population growth rate R_3 as

$$P_3 = P_0 R_3 \text{ or } \log P_3 = \log P_0 + \log R_3 .$$

Figure 8 compares year-to-year fluctuations of both these components with that of log P_3. The density of the initial population itself fluctuates widely, greatly influencing the density of the later third-generation populations, although the rate of population growth also shows considerable variation from year to year. Such large fluctuations of P_0 can be anticipated because of the possible uncertainty in the two factors determining it — the population density at its unknown premigration origin, and the synoptic weather conditions while it is migrating. The coefficient of determination of log P_0 (in terms of the squared value of the coefficient of correlation with log P_3) was 0.58; that of log R_3 was 0.36. Thus, it may be said approximately that in this case 60%

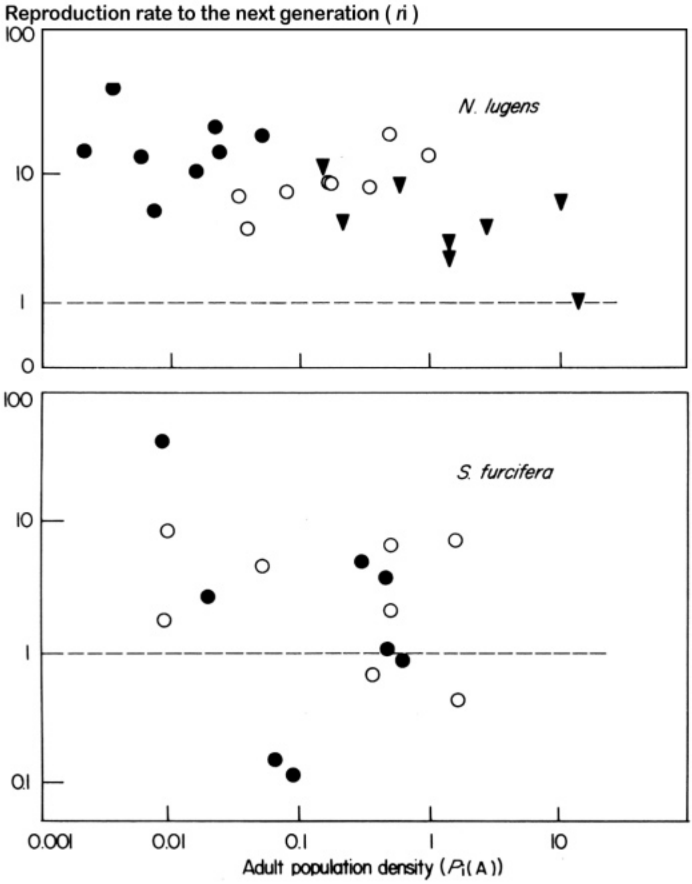


8. Graphical comparison of the)ear-to-year fluctuation of the population density at the peak generation (third for *N. lugens* and second for *S. furcifera*) and those of its two components, the initial density (P_0), and the overall population growth rate (R_3 or R_2). The data were obtained at Kyushu Agric. Exp. Stn.

of the fluctuation of the third-generation population density could be accounted for by the density of the initial immigrant population, and 40% by the fluctuation of the population growth rate in the field.

Further separation of the population growth rate into three subcomponents, r_1, r_2, and r_3, representing the reproduction rate at each generation ($\log R_3 = \log r_1 + \log r_2 + \log r_3$). reveals the fairly high contribution of r_1, indicating the relatively important effect of early-season reproduction on the overall population growth rate. Kuno and Hokyo (1970b) and Kuno (1968) concluded from various analyses of the numerical relationship between rice leafhoppers and their natural enemies that neither predators nor parasites can be key factors governing such fluctuations of the overall population growth rate. There are few data from which to assess the factors responsible for the fluctuation, but some weather factors seem to be important, especially in their effect on host-plant conditions. Kisimoto (1976b) has made clear the importance of host-plant conditions for *N. lugens.* There may also be cases in which the variation of mating rate of the initial generation — inverselydependent on population density — has some effect on the fluctuation of the population growth rate, because the female adult does not copulate until its ovaries mature, i.e. until established in the field after migration in the case of initial population (Katayama 1975).

The whitebacked planthopper's situation is somewhat different; the relative



9. Relation between the population density (P_i) and the reproduction rate to the next generation (r_i) for each of the successive seasonal generations. The data were obtained from 1961 to 1968 at Kyushu Agric. Exp. Stn. ● = G-O ($i = 0$); o = G-I ($i = 1$); p = G-II ($i = 2$).

influence of initial density on peak density (i.e. the density of the second generation) is rather lower (the coefficient of determination was 0.34), because the reproduction rate of the species in the paddy field is far less stable than that of BPH. Figure 9 shows that reproduction rate is not only far lower on the average, but also much more variable than that of BPH. Figure 9 may thus confirm the robustness of the BPH as well as its high tolerance for crowding.

SUGGESTION FOR OUTBREAK FORECASTING

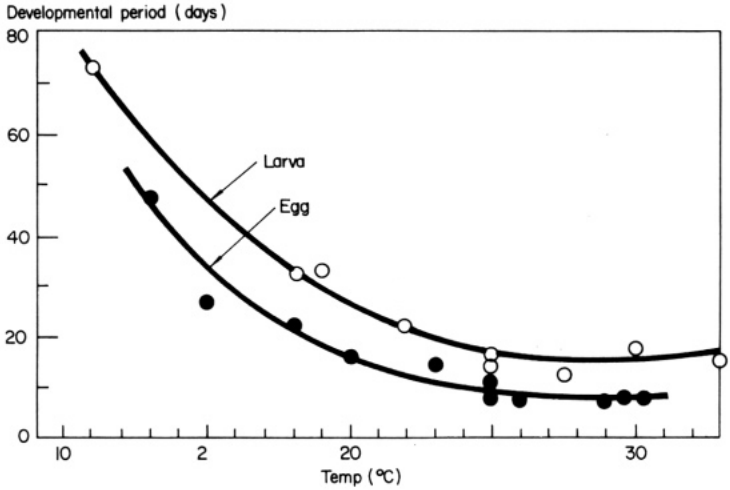
From the knowledge reviewed above, it is now possible to derive a basic strategy for the prediction of BPH outbreaks in temperate regions. Such characteristics of the insect as its sharply defined life cycle originating with low-density immigrants, and its steady population growth over several generation make prediction feasible.

Because there is no way of determining the premigration population, the practical first step in forecasting is to know the time of appearance and the density of the invading initial population as exactly as possible. The time the insects appear may be used in predicting the time later generations occur on the basis of the speed of development in relation to temperature (Fig. 10). As seen in Figure 8, the initial density itself fairly highly correlates with the density of the later third-generation population in question. Thus if initial density can be estimated precisely, the third-generation density may be predicted with considerable certainty as early as 2 or 3 months before the rice is damaged.

Table 2 shows the coefficients of correlation between the densities of the peak of generation (third for *N. lugens;* second for *S. furcifera*) and each preceding generation from 8 years of studies at Kyushu Agricultural Experiment Station.

Precise estimation of the initial population over a wide area, however, usually requires a large amount of labor because of the low density involved. For alternative or additional use, net traps or yellow-pan water traps set in the field are recommended (Kisimoto 1976b).

Although subject to possible disturbance by weather conditions, light trap data are also valuable for assessing the initial population level. For example, I found a high correlation of $r = 0.90$ between the initial density of BPH in the field and the sum of light trap catches (Kuno 1968).



10. Average egg period and nymphal period of *N. lugens* at various temperatures (from Kisimoto 1965).

Table 2. Coefficients of correlation between densities of the peak generation (third for *Nilaparvata lugens,* second for *Sogatella furcifera*) and each preceding generation.[a]

	Generation		
	Immigrant	First	Second
N. lugens	0.761	0.854	0.889
S. furcifera	0.478	0.851	–

[a] Based on an 8-year study at Kyushu Agric. Exp. Stn., Fukuoka, Japan.

In the first generation, which appears about early August, the correlation with the third-generation population, of course, rises further and prediction becomes more precise (Table 2), although injury usually occurs after two generations. Sampling also becomes somewhat less laborious as the population increases. For most efficient control of the BPH, it is therefore advisable to make intensive population censuses of the first generation (Kisimoto 1965; 1976b; Kuno 1968). In the second generation, it is still practicable to predict third-generation density and reliability increases, but in outbreak years injury sometimes begins to occur in this generation.

For the whitebacked planthopper, predictions of the second generation population does not become reliable until the first generation in early August (Table 2) because of the unstable reproduction in the paddy field. But special effort to forecast outbreaks of this species seems pointless in most of the temperate regions because the ability to multiply on rice is so low that serious injury may rarely, if ever, result (Fig. 9).

Attempts to develop a practical system of forecasting BPH outbreaks are now being made in Japan. Kisimoto (1976b), for example, proposed 0.3 to 0.5 females/hill as the critical first-generation population level that will be followed by hopperburn in the autumn. He also designated a tentative threshold in the initial population to discriminate between mass and minor immigration catches of 10 individuals in a net trap and 50 to 60% in water trap. Early control of the population is recommended when a mass immigration is detected. Ideally, threshold values for each generation should be determined for each district because the population growth rate may differ from district to district according to environmental and cultural conditions.

In a system of outbreak forecasting like the one I have discussed, it is indispensable to obtain an objective population estimate with a precision appropriate to the generation being studied. For that purpose I have discussed elsewhere (Kuno 1976) field-sampling techniques adapted to the characteristic spatial distribution of the BPH.

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Ecology of the brown planthopper in the tropics

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C. Y. Hsieh, and R. S. Rejesus

Evidence to date suggests that the change to modern rice cultural practices was the major factor causing the upsurge in the density of, and damage by, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) in recent years. The aspects of these practices that have been shown to increase pest abundance are a high tiller number per square meter, flooding of fields, and application of high doses of nitrogenous fertilizer. More evidence is needed to indicate if the cropping pattern, high yielding varieties per se, weeds, natural enemies of *N. lugens,* climate, or insecticides play a critical role in increasing the pest's abundance.

The density and composition of the BPH in the field fluctuate dramatically within one crop period, within a year, and over a period of years. The changes during a crop period are influenced by crop age and the generation pattern, which is rather distinct in a given field. Dispersing macropterous adults invade a field soon after planting, and usually two major generations develop before crop maturity. The highest insect densities occur when nymphs dominate the population, usually about 60 and 85 days after transplanting. Nymphal mortality may be high. Adult wing form may change during a crop period. Adults disperse out of the field mainly near crop maturity. Dispersal flight is close to the ground, and occurs in the early evening hours.

Within a year's time in a double-cropped area, usually there are two population peaks, one near the end of each crop season. Apparently surrounding crops strongly influence pest density, possibly through the size of the dispersing population. The largest peak in a year may occur in either the dry or the wet season.

Sampling the BPH is difficult because of the aggregated distribution that develops in the field. The tiller number per hill appears to be important in improving sampling methodology. The current methods and objectives of sampling are critically reviewed.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* (Stål) has in recent years become an important insect pest of rice in the tropics. The damage it causes in several countries has increased dramatically within the past 5 years. Numerous authors say the recent increase in damage and in population density may

International Rice Research Institute. Los Baños. Philippines: Central Rice Research Institute. India; Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh; Plant Protection Center, Taiwan; Joint Commission on Rural Reconstruction, Taiwan; and University of the Philippines at Los Baños, Laguna, Philippines.

be related to climate and the growing of the new, high yielding rices with modern technology. This paper reviews critically the known ecology of the BPH in the tropics, and evaluates the various environmental factors that might influence population fluctuations, especially those in the recent outbreaks. It includes information only from tropical countries.

The ecology of the BPH involves the relationship between the insect and its biotic and abiotic environments. The most important factors of the biotic environment are host plants and natural-enemy fauna, those of the abiotic environment are climate and agricultural chemicals. Mochida and Dyck (1976, 1977) reviewed briefly the effect of environmental factors on the BPH. Relevant literature and experimental data are discussed much more fully in this paper.

Because sampling technology is such a basic component of studies of population dynamics, current sampling techniques for *N. lugens* are briefly reviewed. Some aspects of dispersal behavior are also discussed.

EFFECTS OF BIOTIC ENVIRONMENT ON BROWN PLANTHOPPER

Host plants

Rice (*Oryza sativa* L.) is by far the most important host plant of the BPH. Very few BPH have been found on other plants. The observation suggests that other plants provide only a marginal habitat for the insect (Hinckley 1963a; Leeuwangh 1968; Otake and Hokyo 1976; pers. comm. with J. H. Stapley, Ministry of Agriculture and Rural Economy, Guadalcanal, Solomon Islands). However, a few alternate hosts have been noted in the literature: *Eleusine coracana, Leersia hexandra, L. japonica* Makino, *Saccharum officinarum* L., *Zea mays, Zizania latifolia* Turcz., and *Zizania longifolia* (Nasu 1967, 1969; Grist and Lever 1969; Misra and Israel 1970; Anon. 1976b). Pathak (1968) mentions that the availability of food plants affects the population density of BPH.

The dominance of rice as a host plant logically suggests that a fallow period without ratoon rice should reduce the pest population (Dyck 1974b; MacQuillan 1974; Stapley 1975, 1976a; Anon. 1975b; Varca and Feuer 1976). Because rice from stubble can provide a reservoir or even a suitable breeding site for the BPH, stubble management has been suggested as a control measure (Grist and Lever 1969; Ho and Liu 1969 ; IRRI 1972; Soehardjan et a1 1973; Calora 1974; Mochida and Suryana 1975; Sastrowidjoyo 1976). Alternatively, extensive rice areas would increase the pest population (Kulshreshtha et a1 1974; Abraham and Nair 1975; Anon. 1975c). However, speculations in the literature are that increased availability or abundance of nonrice host plants in or near rice fields positively affects pest abundance (Cendaña and Calora 1967; Kulshreshtha et al 1974; Fernando 1975; Varca and Feuer 1976). Experimental data at IRRI suggest that weeds may contribute to an increase in pests as a rice crop nears maturity, possibly by providing an environment with a dense plant stand. However, besides logic, little evidence supports the recommended cultural control measure of “clean cultivation” (Grist and Lever 1969; Chakrabarti et al 1971). MacQuillan (1974) provides some evidence, and Stapley (1975, 1976a) suggests that weeds (for example, *Eleusine indica*) on levees or nearby fields provide an alternative habitat for predators (*Cyrtorhinus* spp.) of BPH. To the degree that they do so, weeds would assist in insect control. More experimental data are needed to clarify the role of nonrice host plants in BPH population dynamics.

Rice

Cropping pattern. The cropping pattern literature has frequently suggested that increasing the number of crops per year on a given plot of land can magnify insect problems (Nickel 1973). Double or continuous cropping, with staggered planting times, contributes to BPH outbreaks. Irrigation and short-duration, photoperiod-insensitive varieties have made possible more than one crop a year. That suggestion is reasonable. The longer a suitable host plant is in the field in a given year, the greater is the chance for pest populations to reach high densities. The insects can easily disperse from one field to another, and spread infestation from old crops to young. The argument appears to have been accepted by many authors (Dyck 1974b; Kalode 1974, 1976; Kulshreshtha et al 1974; MacQuillan 1974; Anon. 1975a; Abraham and Nair 1975; Fernando 1975; Mochida and Suryana 1975, 1976; Stapley 1975; Sastrowidjoyo 1976; Otake and Hokyo 1976; Varca and Feuer 1976; Anon 1977). As a result some have suggested synchronized planting and harvesting as a control measure (Hoppe 1973; Calora 1974).

There are, however. a few cases of hopperburn where only one crop a year is grown in India, Indonesia, and Thailand (Anon. 1975a; Freeman 1976; Mochida and Suryana 1976). Voon Boon Hoe (pers. comm., Agricultural Research Center, Department of Agriculture, Kuching, Sarawak) believes that density of the BPH in Sarawak may be low because only one crop of tall, leafy rice is grown each year. Otake and Hokyo (1976) noted that local varieties in Indonesia, planted synchronously, have low BPH infestations. Despite intensive cropping of high yielding varieties in West Malaysia, the BPH problem is small, possibly because of a break between cropping seasons. Mochida and Suryana (1 976) found that some areas in Indonesia carry two crops per year but have few BPH problems. They concluded that a BPH infestation is highly possible, but not certain, if more than one crop is grown each year. Thus, no really convincing evidence is available to demonstrate that growing more than one rice crop in a single year encourages outbreaks of *N. lugens.* Because of the difficulty of proving that such is the case, the hypothesis, although reasonable, is likely to remain a hypothesis for some time to come.

New high yielding varieties. It is generally accepted that cultivation of high yielding rice varieties increases insect pest problems (Smith 1972; Nickel 1973). Most commonly suggested as a factor associated with recent BPH outbreaks is the introduction of dwarf, high yielding varieties (Banerjee et al 1973 ; Soehardjan 1973; Abraham and Nair 1975; Anon. 1975a, 1977; Pathak 1975; Oka 1976; pers. comm. with J. H. Stapley; pers. comm. with B. Thomas, Kerala Agric. Univ., Kerala, India). Mochida et al (1977) show a rough correlation between the increase in area planted to new varieties in Indonesia, and the increase in pest infestation.

The new varieties are short, have erect leaves, and produce many tillers. The dense plant canopy they form, especially under conditions of high fertility and good water management, no doubt produces a microclimate different from that in fields of traditional varieties. The high-tillering character of the new varieties, possibly combined with dense planting, and the nature of the associated plant canopy have frequently been pointed out to be a critical feature that may affect the insect (Bae 1966; Israel and Prakasa Rao 1968; Chakrabarti et al 1971; Ngoan 1971; Pathak 1971; Das et al 1972; Smith 1972; Pathak and Dyck 1973; Anon. 1975a, c; Diwakar 1975; Fernando 1975; Nishida 1975b; Kalode 1976; Otake and Hokyo 1976; Varca and Feuer 1976).

Some authors have suggested that the new varieties are intrinsically more susceptible to the BPH than are the traditional varieties (Pradhan 1971, 1975; Mochida and Suryana 1975; Way 1976). Diwakar (1975) commented that minor pests are becoming major pests because uniform germplasm is being grown over large areas, and that although the new varieties carry resistance to former major pests, they evidently give new pests an opportunity to develop. However, even though everyone agrees that most new varieties are susceptible to the BPH, some authors have specifically defended them, saying that, in general, they are no more susceptible than the tall indica varieties. Those authors say it is the agronomic practices used with the new varieties that are the crux of the matter (Shastry 1971; Freeman 1976). As a matter of fact, both Pradhan (1971, 1975) and Way (1976) commented that agronomic practices also contribute to pest problems.

Actually we have almost no published evidence that the new varieties themselves contribute to the BPH problem. Some high yielding varieties grown with modern technology have not developed a problem with the pest (Lim and Heong 1976). Also the early maturing of some varieties could reduce the pest problem because fewer generations of the pest can develop on them (Fernando 1975; Varca and Feuer 1976).

Last year at IRRI we tested the effect of old and new varieties on insect populations. Equal numbers of seedlings of each variety were planted at equal spacings in the greenhouse and in the field. The field infestation was high, especially at the peak of the second generation. We found few differences between old and new varieties in the size of the insect population, and even high-tillering varieties did not appear to stimulate the populations to grow larger than on low-tillering varieties. But the differences in tiller number among varieties were not as great as expected. Artificially adjusting the tiller number produced a trend suggesting that more tillers per hill would increase the pest

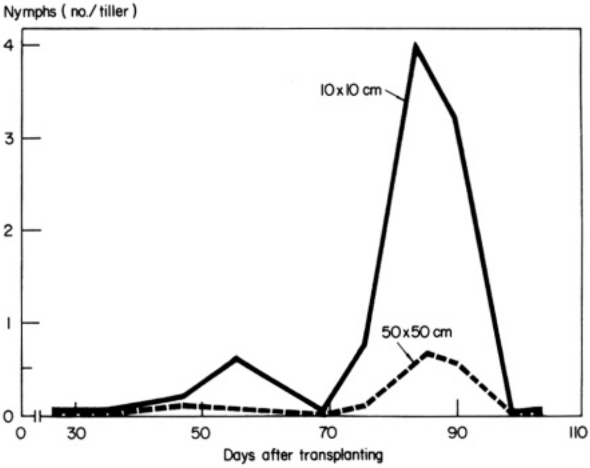
Table 1. Nymphal and adult populations[a] of *Nilaparvata lugens* at peaks of the first two generations per crop on rice cultivars. IRRI greenhouse and field study, 1976 wet season.

Cultivar	Tillers in field (no./hill)	Field population (no./hill)		Caged greenhouse population[b] (no./cage)	
	50 DT	35 DT	63 DT	42 DI	70 DI
Old varieties					
BPI-76 (Nonsensitive)	16	18 bcde	79 bc	593 ab	1290 b
Sigadis	14	24 de	111 bc	–	–
GEB 24	20	27 def	54 b	–	–
New varieties					
IR20	28	16 bcde	85 bc	697 ab	1723 b
IR26 [c]	22	14 abcd	28 b	649 ab	212 a
IR36 [c]	28	11 abc	4 a	–	–
C4-63G	23	23 de	76 bc	–	–
Peltta I-2	21	33 ef	76 bc	–	–
Mahsuri	26	19 cde	63 bc	–	–
Low-tillering					
H4	22	31 ef	108 bc	484 a	1286 b
IR480	19	17 bcde	46 b	673 ab	1052 b
IR127-80-1 [d]	16	39 ef	138 c	–	–
High-tillering					
Peta	23	23 cde	66 bc	547 ab	1747 b
IR8	22	22 cde	73 bc	516 ab	936 b
IR22 [d]	20	32 ef	122 c	–	–
Tiller number artificially adjusted					
IR1917-3-17 low no. [e]	5	7 a	32 b	410 a	929 b
IR1917-3-17 mod. no. [e]	15	19 cde	43 b	559 ab	1409 b
IR1917-3-17 high no. [e]	22	28 ef	89 bc	880 b	1734 b
IR1917-3-17 low no. [d]	5	11 ab	116 bc	–	–
IR1917-3-17 mod no. [d]	15	28 def	139 c	–	–
IR1917-3-17 high no. [d]	33	48 f	123[f] c	–	–

[a] In a column any two means followed by the same letter are not significantly different at the 5% level DT = days after transplanting. DI = days after infestation. [b] Populations initiated with 3 pairs of adults/cage at 60 days after seeding (DS). Plants were replaced every 3 weeks with 60-day-old plants. [c] Varieties showing resistance to insect. [d] To increase planthopper density, diazinon granules at 1 kg a.i./ha were applied at 1 and 20 DT, and methyl parathion was sprayed (0.75 kg a.i./ha) biweekly beginning at 35 DT. [e] Greenhouse plants maintained at 4. 8 and 12 tillers/hill for low, moderate, and high tiller densities, respectively. [f] Hopperburned plots

population (Table 1). We could not demonstrate that the new varieties necessarily increase pest populations, but we showed that a high tiller number per hill may be conducive to an increase in pest density. Our earlier studies indicated that short stature did not affect pest populations (IRRI 1973).

Planting method. The number of tillers in an area is influenced not only by the tillering ability of cultivars, but also by the method of planting. Several authors have suggested that close spacing and the consequent dense crop stand increase the BPH problem (Bae 1966: Cendaña and Calora 1967; Ngoan 1971; Das et al 1972; Mammen and Das 1973; MacQuillan 1974; Abraham and Nair 1975; Anon. 1975c; Freeman 1976). High seeding rates for broadcast rice crops may achieve the same effect (Anon. 1975a; Kulshreshtha et a1 1974; MacQuillan 1974). The effect on the insect is attributed to a suitable micro-



1. Numbers of nymphs of *Nilaparvata lugens* on short Peta transplanted at spacings of 10 × 10 cm and 50 × 50 cm. IRRI, 1972 dry season.

climate, perhaps a higher relative humidity when plant density is high (Kulshreshtha et a1 1974; Feuer 1975).

Israel (1969) and Kalode (1974) suggested that broadcasting, as opposed to transplanting, may contribute to outbreaks and pest damage. Direct seeding or drilling may reduce the pest problem (Hinckley 1963a; Israel 1969).

Field experiments at IRRI tried to verify such suggestions. One experiment with IR20 showed no significant differences among spacings. At times of peak insect density, however, both short Peta (an IR262 line) and tall Peta had significantly more nymphs per tiller and per square meter at the 10- × 10-cm spacing than at 50- × 50-cm (Fig. 1). In 1976 the BPH populations on plant spacings ranging from 5- × 5-cm to 40- × 40-cm were compared. The number of nymphs per hill and the number of tillers per hill were often positively correlated. The number of nymphs per tiller remained relatively constant over various spacings. There was also positive correlation between nymph number and hill density per square meter and between nymph density and tiller number per square meter. However, the nymph population per square meter was generally low when the number of tillers per hill was high (Table 2). The tiller number increased at the cost of hill density per square meter.

Thus, the BPH population appears to respond positively to a greater number of tillers per square meter, which may be achieved through close spacing or—if the spacing is not affected—a high number of tillers per hill.

In a study comparing broadcast-seeded, row-seeded, and transplanted plots planting method had no apparent effect on the pest number (IRRI 1974).

Plant age. It has often been thought that the age of the rice plant in the field influences pest density. The literature has numerous references to a peak in

Table 2. Populations Of *Nilaparvata lugens* nymphs on rice selection IR1917-3-17 transplanted at several spacings and treated with insecticides.[a] IRRI, 1976 wet season.

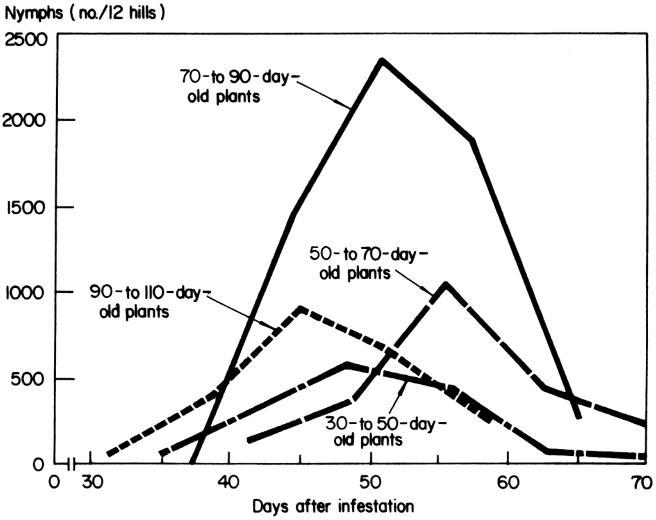
Spacing (cm)	Hills (no./m^2)	7 WT	9 WT				
		Nymphs (no. /m^2)	Nymphs			TIllers	
			(no./m^2)	(no./hill)	(no./tiller)	(no./m^2)	(no./hill)
40 × 40	6	35 a	450 a	72 a	2.8	160 a	26 a
40 × 20	12	32 a	747 ab	60 a	2.7	267 b	22 b
20 × 20	25	77 ab	1,398 ab	56 a	3.7	367 c	15 c
40 × 5	50	205 bc	1,114 ab	23 a	2.5	431 c	9 d
20 × 5	100	467 cd	2,460 b	25 a	3.6	705 d	7 de
5 × 5	400	1,885 d	HB	HB	HB	880[b] e	2[b] e

[a] To increase planthopper density diazinon granules at 1 kg a.i./ha were applied 1 and 4 WT and methyl parathion was sprayed (075 kg ai./ha) biweekly at 6 WT. In a column any two means followed by the same letter are not significantly different at the 5% level. WT = weeks after transplanting. HB = plants hopperburned. [b]One replication only.

the BPH population beyond about 60 days after transplanting, or between the heading stage and harvest, and hopperburn most commonly occurs during this period (Hinckley 1963b; Bae and Pathak 1966; Leeuwangh 1968; Ho and Liu 1969; Chelliah and Subramanian 1973; Pathak and Dyck 1973; Soehardjan 1973; Koya 1974; MacQuillan 1974; Anon. 1976a; Heong 1976; Kalode 1976; Otake and Hokyo 1976; pers. comm. with P. R. Hale). *N. lugens* tended to be more numerous after 60 days, especially in the dry season (Bae and Pathak 1969). Crop age appeared to have a highly significant effect on the insect population (Alam 1971). The two major population peaks within 1 year coincided with the maturation of the main crops at IRRI. Wan (1972) found that the number of planthoppers and leafhoppers (as a group) caught in light traps or in field samples corresponded closely to the percentage of water-soluble protein-nitrogen in the rice plant ($r = +0.9$). The percentage peaked at first flowering. Wan suggests that the protein nitrogen favorably affects the fecundity of the hoppers. Another reason for a peak insect-density near crop maturity is simply that some time is required for the population to increase over a span of two or three generations.

In a critical experiment at IRRI, *N. lugens* was reared in an insectary for three generations on plants of a specific age range. In the second and third generations it was observed that many more insects developed on the 70- to 90-day-old plants than on those of other ages (Fig. 2). When BPH were reared on plants progressing from 10 to 110 days old, the third generation was only one-half the size of that of insects reared on plants kept within the 70- to 90-day period (IRRI 1974). The BPH appears to multiply best on plants in the 20-day period before flowering. Insect density would naturally be greatest following this period.

Young crops can have large infestations and suffer damage, and seedbeds can attract rather large numbers of adults (BPI et al 1974; Mochida et al 1977). Such situations are, however, unusual and occur during outbreaks.



2. Density of the second generation of *Nilaparvata lugens* on IR22 plants of different age ranges in an insectary experiment. IRRI, 1973.

when many adults are dispersing. Most infestations on young plants (Chelliah and Subramanian 1973; Soehardjan 1973; Otake and Hokyo 1976) are small, and occur when normal numbers of macropterous adults multiply in a seedbed or on a young crop.

Natural enemies

The literature contains rather frequent references to organisms that attack BPH. But in most cases the references give no evidence of control of the pest by its natural enemies. Some authors have suggested or believed that the enemies indeed reduced the pest population. Pathak (1968) stated that populations of planthoppers fluctuate according to natural enemies as well as other factors of the environment. On the other hand, Otake and Hokyo (1976) in Indonesia did not notice predators and parasites exerting much control of the BPH, especially in a pest outbreak.

Predators. Studies in greenhouse cages described the activity of several predatory species against BPH (Bae and Pathak 1966, 1968; Dyck and Orlido 1977). B. Thomas (pers. comm.) indicated that in Kerala, India, the BPH population was low recently, partly because of predators. *Cyrtorhinus* spp. reportedly have a depressing or controlling effect on the pest population (Bae 1966; J. H. Stapley 1975, 1976a, b, pers. comm.; Kalode 1976; Murthy et al 1976). *C. lividipennis* apparently prevents the increase of the BPH population in drilled rice fields, but not in transplanted ones (Hinckley 1963a). It appears to be a better predator in cages than in the field. Its peak density occurred at about the same time as that of BPH (Alam 1971).

Spiders apparently play a role in suppressing pest numbers (Chiu et al 1974; Samal and Misra 1975; Kalode 1976). Data by Gavarra and Raros (1975) suggest that low pest densities are caused by high predator densities.

Other predators mentioned in the literature are beetles (Israel and Prakasa Rao 1968; Abraham and Mathew 1975) and ducks (Anon. 1977). Both reportedly controlled BPH effectively in the field.

Two attempts were made at IRRI to demonstrate the real role of predators in the field. Reduced predator populations did not greatly change planthopper density (Dyck and Orlido 1977). However, removing *Nephotettix virescens* Distant significantly increased planthopper density over the control (IRRI 1973). It appears that predators can curtail BPH numbers, but evidence that they do so under normal field conditions is lacking.

Parasites. Little work has been done on parasites of the BPH. Hinckley (1963a) found egg parasitism to be rare in Fiji, but according to Nishida et al (1976) the nonpest status of planthoppers in many areas of Thailand appeared to be due mainly to egg parasitism. In Sri Lanka, parasites were not the only factor limiting planthopper populations; neither did the parasites play a regulative role (Otake et al 1975).

However, recent work in Sarawak, Malaysia, emphasizes the importance of parasites of adult hoppers, especially Strepsiptera and Pipunculidae. Munroe (1974, 1975) states that 20 to 30% of adults are commonly parasitized. He believes that parasites exercise a high degree of natural control over planthoppers in Sarawak. Voon Boon Hoe (pers. comm.) suggests that parasites are harbored by abundant natural vegetation around rice fields of farmers who use low-technology production methods. More evidence is needed to define the role of parasites in BPH control.

Pathogens. There are several records of the killing of BPH by fungi, but the actual contribution of fungi to pest control is unknown. Bae (1966) speculated that an infection of *Entomophthora* spp. helped reduce pest density, but Hinckley (1963a) concluded that fungi were a much less important cause of pest mortality than predators. Dyck and Orlido (1977) attempted to create an epizootic with a fungus in the field, but the pest control achieved was only marginal.

Plant diseases

Preliminary observations in IRRI fields suggested that BPH nymphs preferred hills infected with the grassy stunt disease, of which they are vectors. However, a rearing test in the insectary indicated that population growth was slightly better on healthy plants than on diseased plants (IRRI 1973). The relationship between the disease and the insect needs further study.

Phytophagous insects

No work has been done on competition among BPH, or to see whether the population dynamics of BPH contains a self-regulating component. Hinckley

(1963a) considered the possibility of interspecific competition between *N. lugens* and *Sogatella, furcifera* (Horvath) in Fiji. He concluded that differences in the dominance of the two species during the crop period were due to the effects of crop age and not of competition. Work at IRRI indicated some competition between *N. lugens* and *Nephotettic virescens,* with *N. lugens* as the more successful competitor (IRRI 1973).

EFFECTS OF ABIOTIC ENVIRONMENT ON BROWN PLANTHOPPERS

Climate

Various climatic factors affect BPH development and population dynamics, including outbreaks. The factors suggested include mean temperature, rainfall, and relative humidity. Data collected during the periods of insect population growth or decline implied a relationship between climate and the particular biological parameters measured (Tao 1965; Chou 1969; Misra 1971). However, the data are connected only in a general sense and correlations have to be established. Studies on population dynamics require many years' data. After reviewing the effect of climate on rice insects, Kisimoto and Dyck (1976) cited the need for more proof of relationships between climate and insect biology.

Temperature. Several studies have tried to define the influence of temperature on BPH development. Temperatures between 25 and 30°C are considered optimal for egg and nymphal development (Pathak 1968; Ho and Liu 1969; Bae and Pathak 1970; Chiu 1970; Kulshreshtha et al 1974; Anon. 1975c; Kalode 1976). Temperatures above 30°C, e.g. 33 or 35°C, are unfavorable for insect survival (Ho and Liu 1969; Bae and Pathak 1970; Chiu 1970; Anon. 1975c; Kalode 1976). Eggs have greater tolerance for high temperatures than do nymphs or adults (Bae and Pathak 1970). High temperatures probably influence distribution or even seasonal abundance (Bae and Pathak 1970; pers. comm. with P. C. Lippold, Plant Protection Project, UNDP/FAO, Seoul, Korea). Temperatures below 15-8°C are unsuitable for development (Ho and Liu 1969; Kalode 1974). Overwintering in Taiwan occurs only rarely (Kisimoto and Dyck 1976). Several authors give the time duration of each instar at different temperatures (Ho and Liu 1969; Bae and Pathak 1970; Chiu 1970). Bae and Pathak (1970) reported that fluctuating temperatures had a moderating effect on development.

As expected, the rate of development increases as temperature increases. Misra and Israel (1970) found that the BPH life cycle was shorter in warmer periods than in cooler.

Suggestions that temperature affects the BPH population dynamics are common. High temperatures appear to be associated with high pest numbers (Fukuda 1934; Alam 1971; Hoppe 1973; Anon. 1975a; Tirawat 1975). Narayanasamy (1975), however, found in the field a positive correlation between BPH populations and lower temperatures. Abraham and Nair (1975) suggested that outbreaks may be related to a 20-30°C range of temperature.

Ho and Liu (1969) in Taiwan developed a method of forecasting BPH outbreaks from accumulated data on average temperatures during the winter. If the accumulated temperature was higher than 2,100°C, an outbreak was forecast. The method is probably not suitable for tropical areas, where the insect does not appear to have a resting stage from which the whole population develops according to temperature.

Solar radiation is naturally related to temperature. Alam (1971) suggested that the pest population growth was positively related to hours of sunshine, but Narayanasamy (1975) reported that the population density was higher at a "lower sunshine period." Excessive solar radiation is said to prevent population increase (Pathak 1968: Anon. 1975c).

Except from laboratory studies, we obviously know little about the influence of temperature on population dynamics. Long-term field studies combined with critical experiments in controlled environment facilities are needed to clarify what is really happening in nature.

Relative humidity. It is commonly stated in the literature that a humid environment is preferred by *N. lugens,* and is conducive to its development and population increase (Bae 1966; Cendaña and Calora 1967; Ngoan 1971; Hoppe 1973; Abraham and Nair 1975; Anon. 1975a; Tirawat 1975; Narayanasamy 1975). A range of 70 to 85% relative humidity is optimal for BPH development (Kulshreshtha et al 1974); however, no critical experiments have been conducted to verify the role of atmospheric moisture in population dynamics. Earlier studies at IRRI suggested that constant humidities of 50 to 60% were optimal for population growth (IRRI 1976), but more recent studies using fluctuating humidities indicated that variations within normal field limits were not critical to population increases.

Rainfall. A few authors have found that BPH outbreaks occur during the wet season, or suggest that they are related to rainfall (Grist and Lever 1969; Soehardjan 1973; Anon. 1975a: Huynh 1975; Kurien 1975: pers. comm. with P. R. Hale and B. Thomas). In a portion of central Java, Indonesia, Sastrosoedarjo (1976) found a significant positive correlation (r = 0.907*) between the total yearly rainfall from 1970 to 1975 and the number of infested hectares of rice [log damaged area (ha) = –3.3262 + 2.5545 (mm rainfall)]. As expected, there was a negative correlation between the number of dry months in a year and the area damaged. There was an insignificant tendency toward correlation between the number of rainy days in a year and area damaged (r = 0.838).

More authors, however, suggest the opposite: that outbreaks occur during dry weather, and that relatively low rainfall is conducive to population increase (Fukuda 1934; Bae and Pathak 1966; Pathak 1968; Custodio et al 1973; Narayanasamy 1975; Velusamy et al 1975). In Fiji, Hinckley (1963a, b) found that serious damage occurred in the lower and wetter parts of a field where the insects congregated after a spell of dry weather. In his experience dense populations of BPH were most apt to occur after such a spell. But dry weather, he believed, could not by itself cause a major outbreak, for renewed rainfall may disperse the pest and reduce its density. Heavy rainfall, possibly combined with strong winds, may cause decreased pest numbers (Kulshreshtha et al 1974; Abraham and Nair 1975; Fernando 1975; Varca and Feuer 1976).

Sometimes workers see no specific relationships between rainfall and pest abundance (Leeuwangh 1968 ; MacQuillan 1975 ; Mochida et al 1977). Considering the conflicting and mostly speculative information available, no conclusion can be drawn about the influence of rainfall on the BPH.

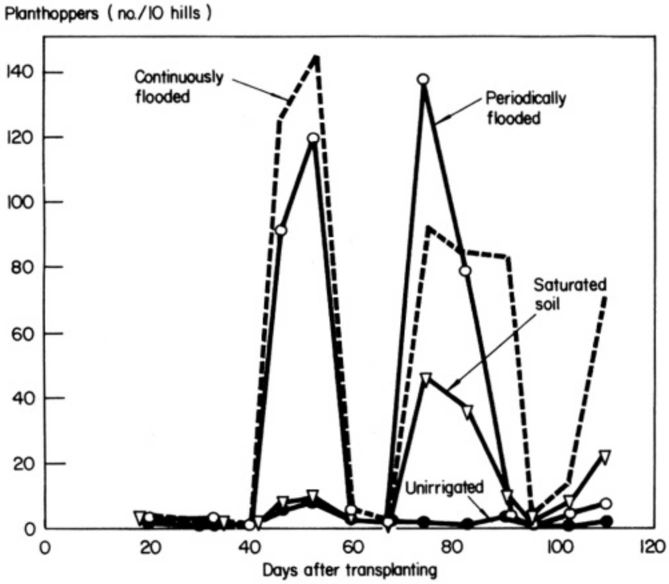
Wind. Feuer (1976) suggested that typhoons could reduce BPH numbers; and the limited air movement within the microhabitat could increase populations (Ngoan 1971; Hoppe 1973; Anon. 1975c).

Microclimate. The dense canopy produced by high-tillering varieties, close spacing and high fertility, combined with continuously flooded fields, produces a microclimate that favors multiplication of BPH (Das et al 1972; Anon. 1975c; Abraham and Nair 1975; Kalode 1976; Alam and Karim 1977). Conditions within the canopy, near the base of the plant, are humid and shaded (Nishida 1975b; Kalode 1976; Varca and Feuer 1976). Such microenvironment is favorable to the pest but is unfavorable to its natural enemies (Nishida 1975b). The halting of irrigation and spreading apart of rows (Dyck 1974b) may represent an attempt to reduce the relative humidity of the microenvironment.

Preliminary observations at IRRI in 1972 indicated that closely spaced plants produced a slightly cooler and more humid microenvironment during the daytime than did widely spaced plants. Lin (1970) made the most extensive observations of the rice microclimate in relation to *N. lugens.* He measured the temperature and relative humidity at 10, 30, 60, and 90 cm above the water surface. The air temperature in the daytime was significantly higher between hills than in the open. The temperature near the water was slightly lower than at higher levels, and became significantly lower when the foliage was greater and provided more shade. Relative humidity was highest near the water surface, and decreased progressively toward the tops of the rice plants. Lin suggests that the theoretically optimum niche for multiplication of the BPH is 10 cm above the water where the relative humidity is high, the temperature is “high,” and the shade formed by foliage is most effective.

Water management

Authors are unanimous in believing that improved irrigation and water standing in the field are conducive to the growth of the BPH population, and probably increase the crop damage (Hinckley 1963a ; Israel 1969; Banerjee et al 1973 ; Pathak and Dyck 1973; Anon. 1975c, 1977; Fernando 1975; Mochida and Suryana 1975, 1976). That is expected in the light of findings with other insects (Smith 1972). To prove the point, pest density at IRRI was monitored during the dry season in plots having varying degrees of standing water or soil moisture. When a plot was flooded continuously or periodically, two large population peaks developed. Only one moderate peak developed when the soil was kept



3. Nymphal populations of *Nilaparvata lugens* on rice variety IR20 with various levels of irrigation. IRRI, 1972 dry season.

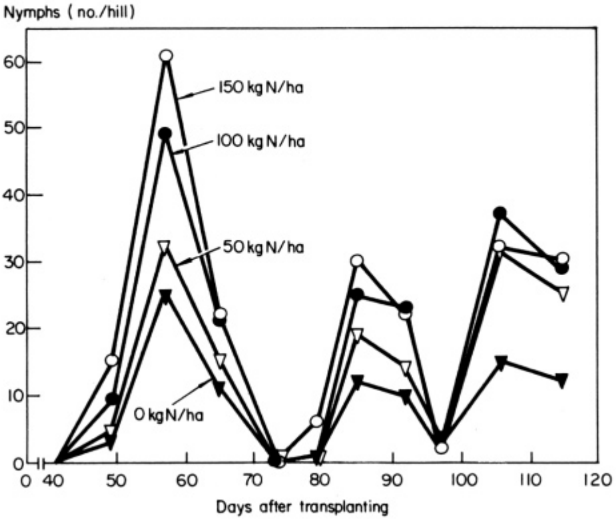
saturated but not flooded; and few insects were found in unirrigated plots (Fig. 3). We can conclude that flooding positively affects pest population increase.

Upland rice fields versus lowland

The conclusion in the section on water management implies that lowland rice fields should have greater pest problems than upland fields. That has generally been true in tropical areas. Stapley (1975, 1976b, pers. comm.) reported that in the Solomon Islands the BPH seldom attacked rice grown "dry," and the insect was never a problem in upland rice. But the change from upland to lowland culture caused the development of BPH as the main rice pest. Wet cultivation of rice leads to more BPH (Wan 1972; Abraham and Nair 1975). However, hopperburn has been observed in upland rice in New Guinea (P. R. Hale, pers. comm.), Indonesia (Sastrowidjoyo 1976), and at IRRI in 1976.

Agricultural chemicals

Fertilizers. It is generally accepted that the addition of fertilizers to crops tends to aggravate pest problems (Smith 1972; Nickel 1973). It is frequently assumed that nitrogenous fertilizers have contributed to the recent increases in the prevalence of BPH (Israel and Prakasa Rao 1968; Pathak 1968, 1971, 1975; Ngoan 1971; Das et al 1972; Smith 1972; Banerjee et a1 1973; Hoppe



4. Populations of nymphs of *Nilaparvata lugens* on rice variety IR22 treated with different levels of ammonium sulfate fertilizer in two doses, 60% at 7 days after transplanting and 40% at 42 days. IRRI, 1971 wet season.

1973; Mammen and Das 1973; Pathak and Dyck 1973; Soehardjan 1973; Kulshreshtha et a1 1974; Abraham and Nair 1975; Anon. 1975a,c, 1977; Nishida 1975b; Velusamy et a1 1975; Freeman 1976; Kalode 1976; Mochida et al 1977; Otake and Hokyo 1976; Varca and Feuer 1976).

Various authors have explained the effect of nitrogen fertilizer on BPH. Several stated that the fertilizer produces a thick canopy (Anon. 1975a; Nishida 1975b) that provides a favorable microenvironment for the insect (Kulshreshtha et a1 1974; Freeman 1976). Others say that nitrogen produces better nourished or more succulent plants (Varca and Feuer 1976).

Some experimental evidence verifies the assumption that nitrogen fertilizer added to rice plants causes an increase in pest population. Abraham (1957) was the first to show in the field that planthoppers were dense on plants treated with a large amount of nitrogen or nitrogen plus P_2O_5. At IRRI greater amounts of ammonium sulfate fertilizer resulted in more planthoppers in the field, on either a per-hill or a per-tiller basis (Fig. 4). Cheng (1971) found that BPH on nitrogen-treated plants produced more honeydew, survived better, and developed a larger population than those on nitrogen-deficient plants. Female BPH reared on plants receiving large amounts of nitrogen fertilizer showed high fecundity (Kalode 1974). Pathak (1975) demonstrated in the greenhouse that increased applications of nitrogen fertilizer improved insect survival and increased the number of progeny.

Considerable evidence shows that the addition of nitrogen fertilizer increases planthopper populations. The reason appears to be more than just a change in the microenvironment, and has something to do with the nutritional status of the plant and the insect's physiology.

Insecticides. Soehardjan (1973) suggests that the frequent application of insecticides is a reason for the increased density of planthoppers. Resistance to insecticides (Fernando 1975) or the rapid breakdown of insecticides (Sethunathan 1971) could be a part of the problem.

Another result of insecticide use could be the unintentional killing of natural enemies of the BPH (Alam 1971 ; Fernando 1975 ; Nishida 1975a.b; Cheng 1976). That has been suggested of predators (Chakrabarti et al 1971 ; Kulshreshtha et al 1974; MacQuillan 1974; Abraham and Nair 1975; Stapley 1975, 1976a,b; Dyck and Orlido 1977; Varca and Feuer 1976; IRRI 1977) and of parasites (Nishida et al 1976).

Stapley (1976a,b) presented field data suggesting that parathion sprayed in the field to kill other pests kills predators of BPH. As a result the BPH soon becomes abundant. Dyck and Orlido (1977) reported that at IRRI high BPH densities frequently followed spray applications of methyl parathion. No doubt, one factor involved was a reduction in the number of predators. Recent experimental data showed that methyl parathion sprays could increase BPH density in upland fields. Other insecticides that have been identified also can aggravate the BPH pest problem (IRRI 1977).

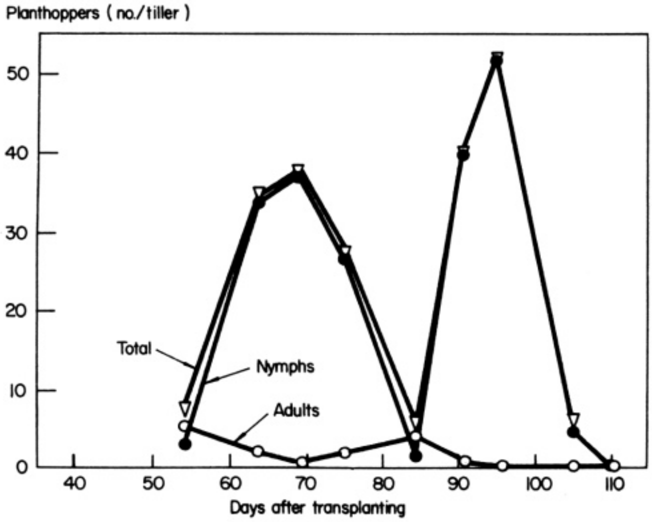
Despite the evidence, there is almost no information on the harmful effects that insecticides may have on beneficial organisms in farmers' rice fields. Given the limited amounts of insecticides used and infrequent applications as a whole, it seems improbable that insecticides could be a major cause of the recent BPH outbreaks. The question warrants further investigation.

POPULATION DYNAMICS OF THE BROWN PLANTHOPPER

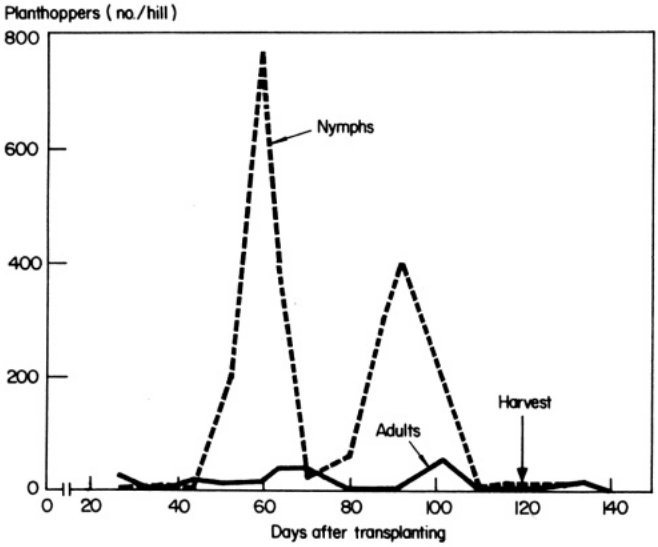
Fluctuations within a crop period

Generation pattern. A few years ago light-trap collection data suggested overlapping BPH generations in the field. But frequent observations revealed that rather distinct generations existed (Pathak and Dyck 1973). Studies at IRRI as early as 1970 show that a regular sequence of nymphs and adults (Fig. 5, 6) markedly changes the planthopper density from week to week, and even from day to day (IRRI 1971, 1972).

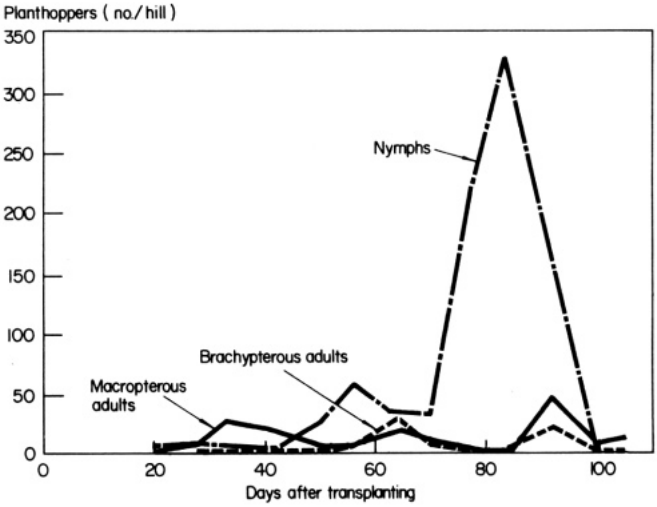
A common pattern is for macropterous adults to invade a crop between 20 and 40 days after transplanting (Fig. 7). The adults scatter randomly in the field (Kalode 1976). The females lay eggs, and nymphs soon appear as the dominant stage. Observations at IRRI some years ago indicated that the nymphs at any one time were in two or three instars. With time the average instar number in the population increased (Fig. 8). When the nymphs developed into adults, some were brachypterous (IRRI 1972). Another generation—sometimes the largest—followed within the crop period. As the crop neared



5. Population of *Nilaparvata lugens* on rice variety IR8. IRRI, 1970 wet season.



6. Population of *Nilaparvata lugens* on rice variety IR20 treated six times with the insecticide diazinon (2 kg a.i./ha). IRRI, November 1970 to March 1971.

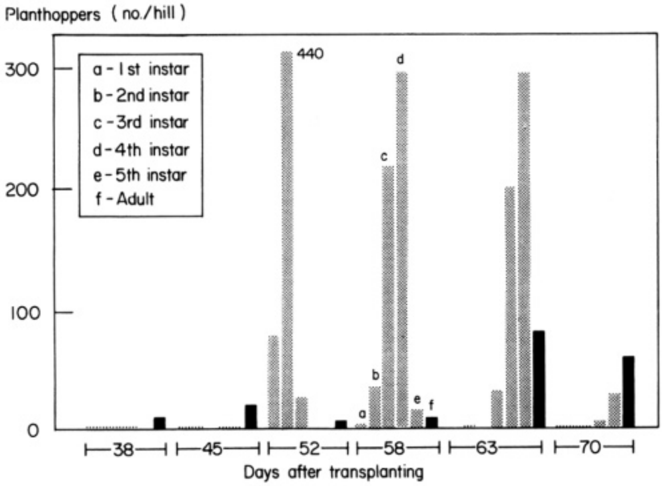


7. Density and composition of a field population of *Nilaparvata lugens* during a crop life. IRRI, 1971 wet season.

maturity, few macropterous adults were collected at the end of this large generation; they apparently had dispersed to new habitats (Fig. 7). The highest number of visible insects within one generation usually occurred when the population was largely in the nymphal stage. Hsieh (1972) found the majority of adults with either wing form were females (Fig. 9).

Hsieh (1972) monitored the adults caught on upright sticky boards at the perimeter of a field. Many adults were caught within the first 15 days after transplanting, but they evidently did not establish a breeding population. A second flight period at around 35 or 40 days, when slightly more adults were caught, started the generation sequence in Figure 7. Sticky-board catches peaked again just after the two adult-emergence periods, about 70 and 98 days after transplanting. Evidently those two flight peaks, even though lower than the first two, represent adults leaving the field (Fig. 9).

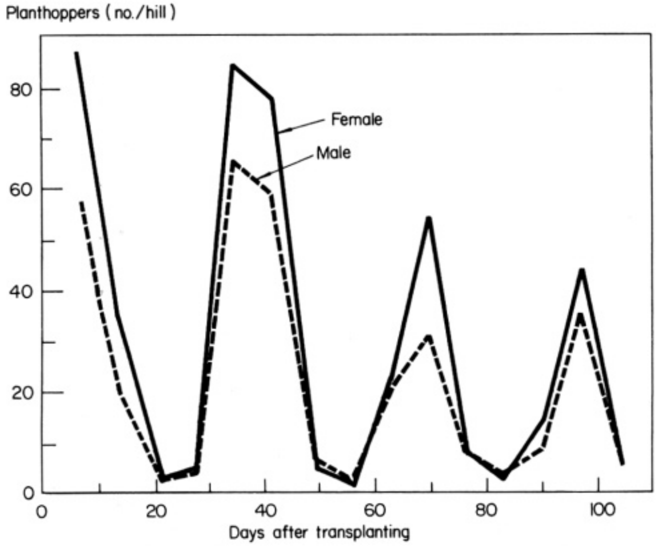
In 1976 at IRRI we attempted to construct life tables for the BPH. Egg, nymph, and adult densities were recorded three times each week. The data (Fig. 10, 11) revealed that the major adult immigration occurred between 20 and 30 days after transplanting. Oviposition followed immediately, and the density of the resultant nymphs and adults peaked at about 50 days. These data probably involved considerable sampling error, for all juvenile stages and adults do not peak at the same time. The emerging adults (more than 50% were female) were numerous. Evidently many soon emigrated, for the next batch of eggs was only slightly larger than the first. The second major



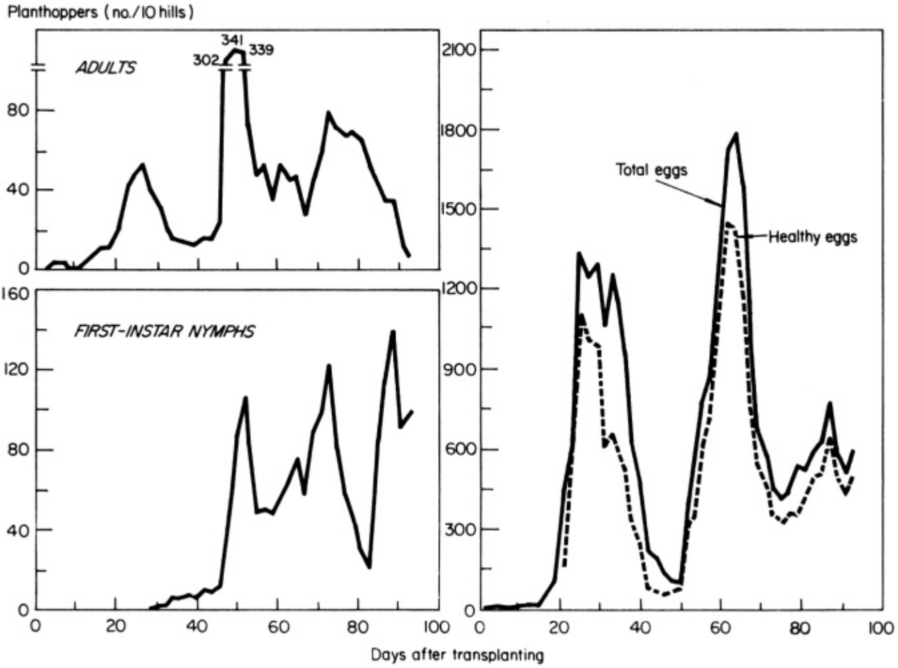
8. Populations in each instar of *Nilaparvata lugens* on rice variety IR20 treated with diazinon insecticide. IRRI, November-December 1970.

generation, as indicated by the density of its third- and fifth-instar nymphs and adults, was much smaller than the first. The reason is unknown.

Egg parasitism during the second oviposition period was about the same or lower than that during the first. For the whole crop period, egg parasitism



9. Numbers of macropterous adults of *Nilaparvata lugens* caught on vertical sticky traps (1 m^2) set on levees facing away from and around a rice field. IRRI. 1971 wet season.



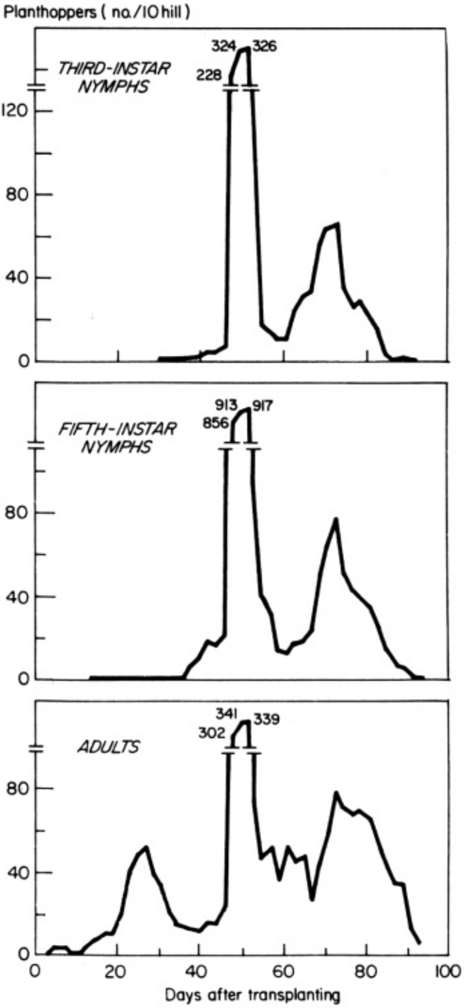
10. Egg, nymph, and adult densities of *Nilaparvata lugens* on rice selection IR1917-3-17 (3-point running av.). IRRI, 1976 wet season.

ranged from 0 to 71% and averaged 24%. Egg predation averaged only 1% (range of 0 to 20%). Adult parasitism was negligible, ranging from 0 to 10% and averaging 0.5%. The last peak in adult population initiated a small third generation that probably was not completed before harvest.

Because of imprecise and inaccurate sampling, and because of the problem of adult dispersion, few conclusions can be drawn regarding the mortality within each generation. The actual percentage of eggs that hatched was also unknown. Ho and Liu (1969) found that only 52% of eggs hatched. However, it does appear that young nymphs have high mortality, possibly from predation, especially in the second major generation.

A similar set of observations, except that no eggs were counted, was made in an upland rice field at IRRI in 1976. Even though sampling was initiated rather late, there evidently were at least two generations, the largest reaching a peak at 50 days after rice emergence (Fig. 12). It is not known why the insects failed to multiply beyond 60 days.

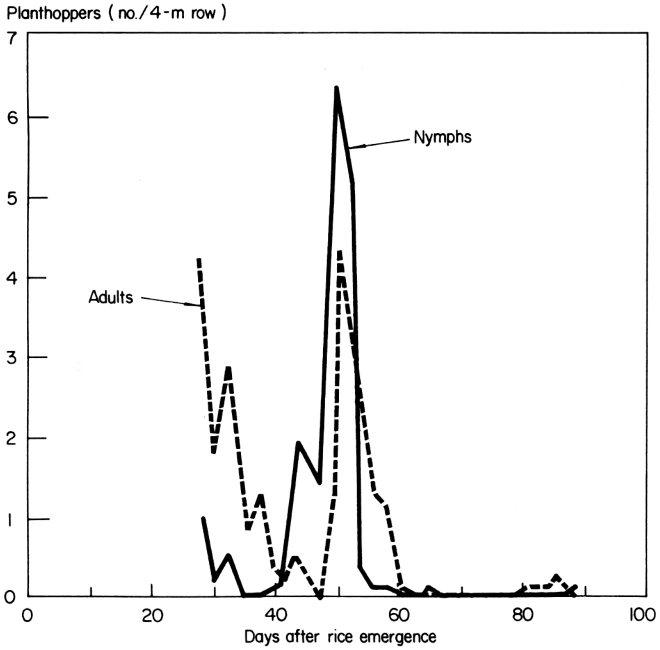
Data collected at IRRI on about 75 irrigated lowland crops over the last 6 years almost always show two or three generations per crop period and only rarely one or four. There may be a small generation during the first 40 days after transplanting, but normally it is negligible. Its peak density occurs at about 30 days. This generation, or even immigrant adults by themselves, can



11. Populations of third- and fifth-instar nymphs and adults of *Nilaparvata lugens* on rice selection IR1917-3-17 (3-point running av.). IRRI, 1976 wet season.

damage the plants if the dispersal flight is large when the crop is first transplanted, and many eggs are laid. Densities of the two major generations reach peaks at around 60 and 85 days after transplanting (Fig. 7). Sometimes the first peak is the largest, sometimes the second. Occasionally a fourth generation develops if the variety is medium or late maturing. The peak density of the fourth generation occurs beyond 100 days, and sometimes is the highest of the entire crop period (IRRI 1971).

There are several literature references to large invasions of newly planted crops by adults, which may damage the crop directly or soon give rise to large



12. Populations of *Nilaparvata lugens* on rice variety Kinanda in an upland field. IRRI, 1976 wet season.

nymphal populations that may kill the plants (Mochida et al 1977; Stapley 1976b; Varca and Feuer 1976). The adults may originate in other fields, or even in seedbeds (Otake and Hokyo 1976). The development of several generations between a crop's planting and harvest, and the occurrence of generation peak densities, have been noted or described by a few authors. Alam (1971) found three peaks per crop in two crops out of three. Pathak (1971) found either the second or third peak was the highest. The peak population generally occurred at or after panicle initiation. Gavarra and Raros (1975) noted peaks at about 60 and 90 days after transplanting. Mochida et al (1977) concluded that there were two generations per crop for short-duration varieties. Das et al (1972) claimed that four to five generations were completed in a cropping season. Grist and Lever (1969) report that in Vietnam there were three or four generations per year, probably meaning per crop. Some authors have reported that peak populations can develop in the middle of a crop's life span (Otake et al 1975; Stapley 1976b), but they more commonly develop toward the end, when the third generation peaks (Hinckley 1963a; Ngoan 1971; Kulshreshtha et al 1974; Anon. 1975a,c; Nishida et al 1976).

Surveillance. The time each generation peaks varies somewhat from crop to crop, possibly according to when the immigrant adults first invade the crop.

However, the peak in each generation can be predicted to some extent by monitoring the dispersing insects with sticky boards, and observing the size and composition of the field population on a per-hill basis. Dyck and Orlido (1977) demonstrated the usefulness of such monitoring to set times for application of insecticides. The strong population fluctuations during a crop's life, due to changing generations, also make it important to select sampling times carefully in field experiments. Treating or sampling at randomly selected times could produce erratic results. Surveillance of pest populations as a tool of effective pest control is gaining acceptance in several countries (Hinckley 1963a; Singh 1975; Yen and Chen 1977; Zotzmann 1976; B. Thomas, pers. comm.).

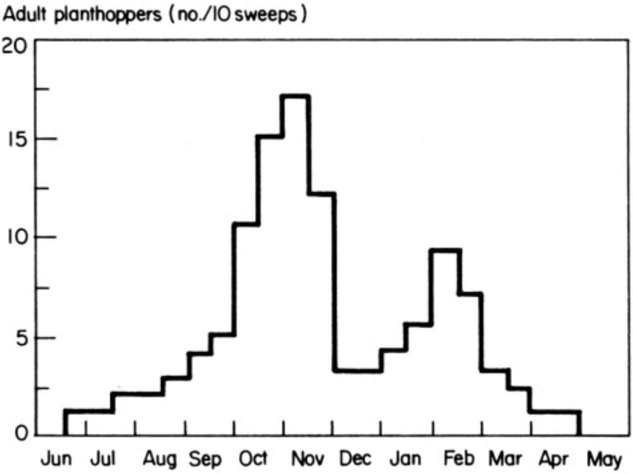
Fluctuations within a year

BPH are active throughout the year in the tropics (Pathak 1968; Ho and Liu 1969; Chiu 1970; Kulshreshtha et al 1974). If generation life is about 1 month, there could be 12 generations per year. In subtropical areas there may be 6 to 7 (Anon. 1977), 10 (Ho and Liu 1969), 11 (Chiu 1970), or 8 to 11 generations per year (Yen and Chen 1977).

Occasionally it has been reported that BPH populations appear to have only one major peak each year. That may be related to the cropping pattern. The period between June and September has been mentioned for areas north of the equator (Lei and Wang 1958; Israel 1969; Fernando 1975; Velusamy et al 1975; Anon. 1977; pers. comm. with N. V. Huynh), and March and April for those south of the equator (Hinckley 1963b).

However, two population peaks usually develop within 1 year, no doubt one for each major crop season (Chiu 1970; Misra and Israel 1970; IRRI 1973, 1974, 1975; Kalode 1974; Kisimoto and Dyck 1976; Diwakar 1975; Heong 1976; Yen and Chen 1977). That is confirmed by light-trap catches and by occasional field data. Sometimes no differences are observed between the two peaks (MacQuillan 1975). In most cases reported north of the equator, the largest peak comes during the last half of the year, during the second crop (Fig. 13; Table 3; Tao 1965; Chou 1969; Lin 1970; Misra 1971; Hoppe 1973; Hsieh and Yen 1975; Alam and Karim 1977; Hsieh 1977). However, in a 1-year study, Alam (1971) found the largest light-trap catch during the first half of the year. Also Ho and Liu (1969) stated that the insect density was greater in the first crop than in the second. N. D. Penny (pers. comm.) in Malaysia found that the greatest catch in a light trap was obtained in July, but that field visual counts were highest in December.

At IRRI we are trying to explain the changes in insect populations from season to season through a rather unusual experiment. Crops are planted almost every month, and the BPH population density and composition are measured weekly. When the data have been collected, the peak nymphal density for each generation for each crop is determined. The first-, second- and third-generation peaks occur approximately at 30, 60, and 90 days after

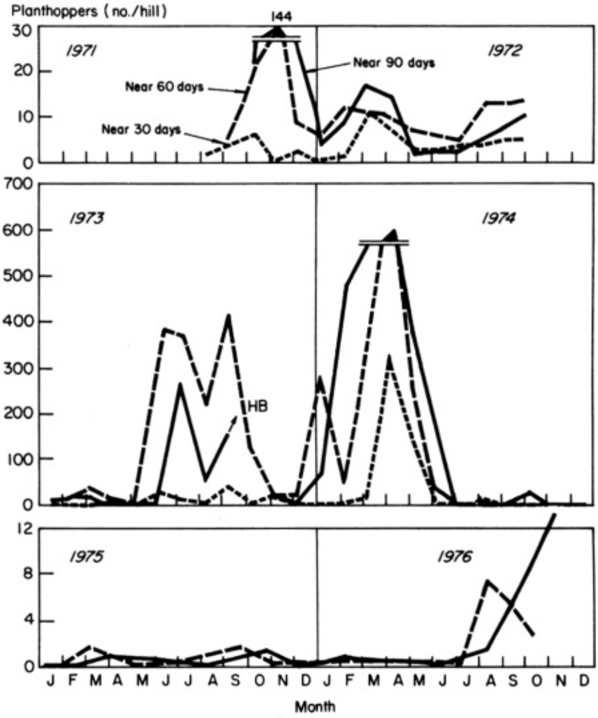


13. Seasonal occurrence of *Nilaparvata lugens* on rice, according to fortnightly observations. Cuttack, India, 1966–67.

transplanting. The peak population density of each generation from many crops has been plotted in Figure 14. The curves indicate the fluctuations in nymphal populations over time, with biases of crop age, generation number or stage, or adult movement excluded. Thus, the effects of season can be observed. In general it was found that there were usually two population peaks

Table 3. Numbers of adult *Nilaparvata lugens* caught in a light trap at Bangladesh Rice Research Institute, Joydebpur, Dacca, 1970–76.

Month	1970	1971	1972	1973	1974	1975	1976
January	–	9	0	0	0	0	8
February	–	2	0	0	14	3	22
March	–	15	3	0	53	47	27
April	92	0	0	0	6	668	51
May	44	0	0	39	27	225	369
June	131	205	0	45	93	122	97
July	193	31	4	67	314	45	102
August	180	29	0	25	1,795	86	684
September	8	1,314	0	8	1,357	254	913
October	408	1,581	341	11	2,726	235	2,381
November	452	1,414	936	134	2,672	3,976	57,875
December	8	0	571	14	49	86	61
Total for 48 weeks	–	–	1,855	343	9,106	5,747	62,590
Total for 52 weeks	1,516	4,600	1,855	361	9,853	6,163	67,497



14. Brown planthopper *Nilaparvata lugens* density on crops of the medium-maturing rice variety IR20 planted monthly or bimonthly at IRRI. Each curve is the insect generation maximum density on crops of nearly the same age, either 30, 60, or 90 days after transplanting. Data are for both nymphs and adults in 1971-72, but only for nymphs in 1973-76. HB = hopperburn.

each year, suggesting that something outside the crop was indeed influencing pest density. At IRRI there are two major crop-periods each year, approximately January-June and July-December. The periods correspond to a dry, hot season and a wet, cooler season. The presence of two population peaks per year strongly suggests that within a year's time period the major influence on insect populations is the surrounding rice-cropping pattern (IRRI 1973, 1975) and not climate, because there are two crop cycles per year but only one climatic cycle. Also, the season with the highest population density is not constant, again suggesting that the climatic nature of the season is not very important in irrigated rice culture. The influence of the cropping pattern probably is related to the size of the dispersing adult-planthopper population.

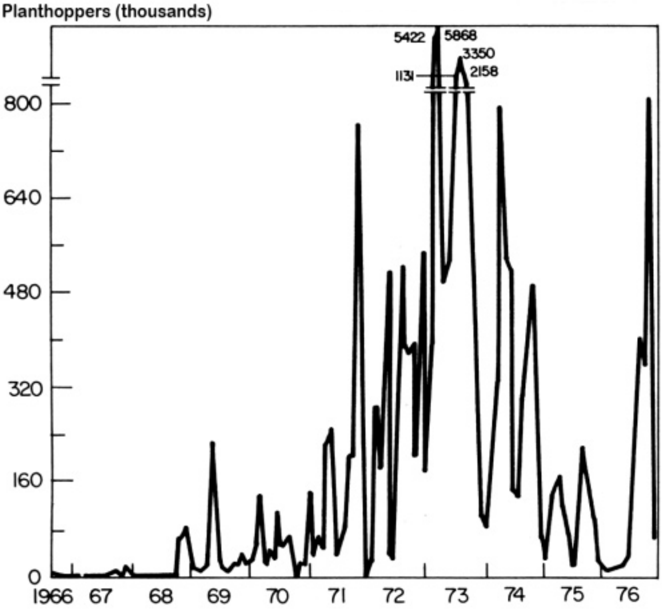
The existence of specific times of year when BPH may be abundant obviously implies that some benefit may be gained from surveillance and forecasting.

Fluctuations over the years

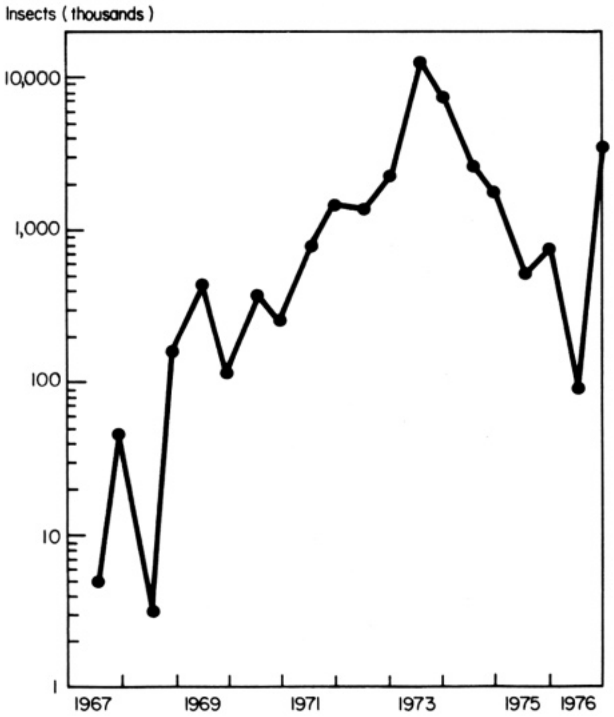
Because the BPH has only recently been a serious pest of tropical rice fields in Asia, there are no long-term records of insect numbers. That makes it difficult or impossible to determine what has actually caused this new pest problem.

Available data are from India, Bangladesh, and the Philippines. Kalode (1974, 1976) reported that light-trap catches in several states of India appear to have increased over the last few years. Catches in Bangladesh since 1970 have fluctuated widely, but considering the very large catch in 1976, the trend is toward higher pest densities (Table 3).

Figure 15 shows the trend in light-trap catches at IRRI during the past 10 years. There was a general increase in the catch size from 1966 to 1973. In 1973 the Philippines suffered severe crop damage from BPH. The pest population declined in 1974 and 1975, but sharply increased again in 1976. The $\log_{10}$ of the population increased gradually and steadily up to 1973 (Fig. 16), suggesting that the cause of the increase was operating with little deviation, which tends to rule out climate as the cause. A scan of records shows that no climatic parameter changed consistently over the years. If seasonal shifts in climate have no important effect on BPH, small changes in long-term climatic trends should have none either. The logical explanation of the increase, then,



15. Numbers of adult *Nilaparvata lugens* caught in 4-week periods in three light traps at IRRI, 1966–76.



16. Numbers of adult brown planthoppers *Nilaparvata lugens* caught in 6-month periods in three light traps at IRRI, 1967–76.

is that rice cultural practices, which have clearly been changing within the past 10 years, in some way encourage growth of the pest population. The components of modern rice culture that might be involved (IRRI 1975) are discussed in the earlier parts of this paper.

A survey of 100 farmers in Laguna province (i.e. around IRRI) showed that there has been almost a total change from traditional to high yielding varieties in the last 15 years. Also during this period the use of fertilizer increased steadily, and there was an increase in the area double-cropped to rice and in insecticide use.

A decline in light-trap catches at IRRI that occurred in 1974 and 1975 (Fig. 15, 16) was probably caused by the widespread growing of BPH resistant varieties around IRRI. And the sharp increase in catches in 1976 (Fig. 15, 16) may be related to a local change in insect biotype, making currently grown varieties more susceptible to the pest.

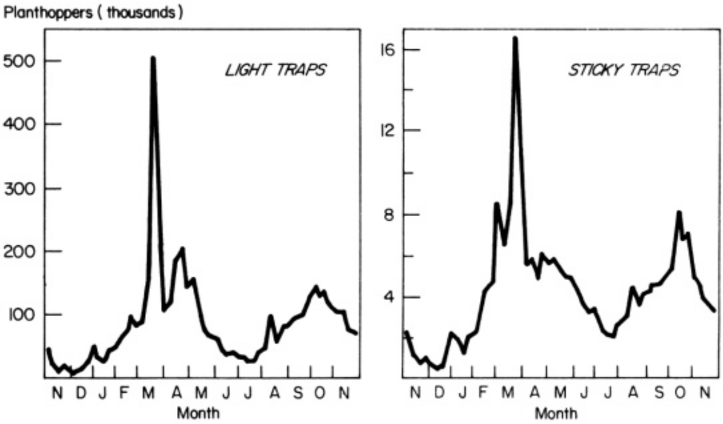
Inspection of Figures 14 and 15 reveals (with minor exceptions such as that in 1974) a rough correspondence between the trends in increase and decrease of pest populations. Despite the fact that light-trap data represent insect fluctuations for a much larger area than do field observations, the comparability of the two trends means that the long-term trends seen in light-trap records can also be observed in fields. Probably, however, field collections are secondhand indicators of changes in pest numbers over a period of years, since the size of the immigrant invasion would play a major role in determining field densities. We must continue light-trap records to maintain continuity of data and to provide for future trend analyses.

DISPERSAL OF THE BROWN PLANTHOPPER

Dispersal in relation to population dynamics

Brown planthoppers move from plant to plant within a field, and adult movement may increase near the end of a crop (Hsieh 1972). However, this section of the paper describes the movement from one field to another of flying macropterous adults. The dispersal permits adults to leave a maturing crop, probably at the end of the third generation, and invade a young crop. Adults may also spread out of a field after the first, or especially the second generation (Mochida et al 1977), but the greatest dispersal is expected while the crop is maturing. MacQuillan (1974, 1975) reported that according to sticky-trap catches maximum dispersal occurred just before harvest; adults were collected throughout the year, however. An experiment at IRRI, where the naturally occurring population was trapped in a field cage at 35 days after transplanting, indicated that dispersal during and at the end of a crop period affects pest density. Near harvest the caged population was much larger than that outside the cage. Assuming that the mortality of caged insects was similar to that of uncaged insects, it appears that the cage prevented dispersal, and the adults continued to breed inside the cage. Our data suggest that because of the two main crops per year at IRRI there are two major dispersal periods, one at the end of each cropping period (Fig. 17). However, dispersal from young crops could occur if the plants are unsuitable because, for example, of hopperburn (IRRI 1974).

Several sources have pointed out that the dispersing insects fly mainly in the early evening hours (IRRI 1972, 1973, 1974; Hsieh 1972; Hoppe 1973; Anon. 1975c; MacQuillan 1975; Kalode 1976, Varca and Feuer 1976). Hoppe (1973) and Kalode (1976) add that the flight occurs in the evenings of hot, humid days. The dispersal flights no doubt occur during the preoviposition period (Hoppe 1973). Figure 9 indicates that more females than males were caught in sticky traps at IRRI, but that probably only reflects the female-to-male ratio in the field. Flight is rather near the ground: catches on sticky boards at IRRI were greatest at 1 m height, less at 4 m, and much less at 8 m. Directional flight is regarded as unlikely, although analysis of sticky-trap records from all around IRRI suggested that more planthoppers flew into IRRI fields from surrounding fields than outward. However, that may only be caused by changing wind direction. Soedarmo (1976) thought that man may accidentally transport planthoppers with seedlings or on vehicles, and



17. Numbers of adult *Nilaparvata lugens* caught in 1-week period in 3 light traps and 12 sticky traps at IRRI, November 1973–November 1974.

that irrigation water and aquatic birds carry the insects. However, such agents of spread are not likely to be important.

Regarding reinfestation, adults apparently enter a field in waves (Fig. 9). However, only the second wave may lead to a nymphal hatch that can be measured (Fig. 7). It may be that seedlings right after transplanting are not preferred by the dispersing adults for oviposition.

Long-distance migration in tropical regions has been studied very little. Kisimoto and Dyck (1976) hypothesized that planthoppers move each year from tropical to subtropical to temperate regions of East Asia. Northward migration is passive, depending on the movement of air masses. Calora (1974) expected that BPH could migrate on air currents from one province of the Philippines to the next. However, Dyck (1974a) doubted that adults can disperse more than a few kilometers in the tropics. There is no need to assume migration because the BPH is always present in tropical areas. There is no known case of a large dispersal flight that is likely to have originated from a great distance.

Wing form

Most work on wing form has been done in Japan, and the resulting ideas have appeared in literature from tropical countries. According to several authors (Grist and Lever 1969; Ho and Liu 1969; Kulshreshtha et al 1974; Laosinchai and Hongsaprug 1974; Kalode 1976), low nymphal density and plentiful food supply cause the development of the brachypterous form; the opposite conditions cause the macropterous form to develop. Kalode (1976) adds that brachypterous forms develop under an optimal temperature regime.

As already mentioned, macropterous forms invade a field and begin the infestation (Anon. 1975c). The second generation may produce some brachypterous forms, which apparently are very fecund (Ho and Liu 1969; Heong 1976). Near the time of crop maturity, macropterous adults again dominate and disperse from the field (Fig. 7; Hsieh 1972).

Some findings vary somewhat from the usual descriptions in the literature. Hinckley (1963a) found that macropterous forms usually made up about 75% of the population, rarely less than 50%. Crowding did not appear to affect wing form. In a 1-year study at IRRI, Alam (1971) never found a high proportion of brachypterous females. Otake et a1 (1975) reported that in Sri Lanka the brachypterous rate increased at the end, not at the middle of the season. More research is needed to clarify the role of wing form in population dynamics.

DISTRIBUTION OF THE BROWN PLANTHOPPER IN RICE FIELDS

Very little research has been done in the tropics to characterize the field distribution of *N. lugens.* Hoppe (1973) and Kalode (1976) suggested that immigrant adults in a field are randomly distributed. The species usually is found near the base of the plants; Hoppe (1973) suggests that is a result of negative phototaxis.

During the crop, aggregation may develop. Otake and Hokyo (1976) noted that adult females often were aggregated in the field. The distribution corresponds to “a mathematical model of (a) negative binomial series with a common k.” Chen (1976) recently intensively studied the field distribution, and found that the aggregation index was 1.2888 for all instars of the nymphal stage; 0.8542 for brachypterous adults, and 1.8096 for macropterous adults.

In 1973, at IRRI on several occasions we counted the number of BPH on every hill in a few field plots and studied the distribution patterns. The insects were not distributed randomly within the field as a whole, nor within some of the plots (Gomez 1974). The magnitude of the sampling variance was positively correlated with insect density. There was a tendency for adults and a greater tendency for nymphs to be clustered on certain hills. Nymphal densities on adjacent hills were related. Nymphs tended to distribute themselves over tillers rather than over hills; and the number of tillers per hill partly, but not completely, explained the clustering behavior. The use of “hoppers per tiller” as a unit of measure and the effectiveness of using two or three hills as a sample unit need to be investigated (IRRI 1975). A unit involving hills may be needed in population studies, but a unit involving tillers could be suitable for research on insect damage (IRRI 1971).

SAMPLING THE BROWN PLANTHOPPER

Because complete enumeration of the total population is impossible in regular field studies, a sampling procedure must be devised. Current sampling procedures in ecological experiments are rather ad hoc, and there is little evidence of their accuracy or precision. The percentage coefficient of variation of planthopper estimates in IRRI experiments within 1 year ranged from 1 to 660 (Gomez 1974). As long as ad hoc methods are employed, we must use experimental results with caution.

Sampling individual hills

Sampling individual hills or groups of hills is basic to ecological studies in which the sample unit must be given in terms of a specific land area. (The number of tillers per square meter changes as a rice crop grows, but the number of hills per square meter does not.) Various techniques have been used to count insects on hills: visual estimates, aspirators (Heong 1975; Singh 1975; Otake and Hokyo 1976), striking a hill with or without a catching device (Dyck 1974b; Dyck and Pathak 1974; Anon. 1975c), Kittoor's glass-book technique (Dyck and Pathak 1974), and cages or bags for covering or removing a whole hill.

At IRRI we have used visual counting, including thorough hill-searching, rather extensively because it permits rapid counting without subsequent laboratory work. Both nymphs (as a group) and adults can be counted by experienced observers. The accuracy of visual counting probably decreases as pest density increases. Using 10 or 16 haphazardly scattered healthy hills per plot, we have sampled 1, 2, 3, or 7 times each week. However, healthy hills may give inflated estimates of population densities. Others have used 10 or 20 hills (Chelliah and Subramanian 1973; Mochida and Suryana 1976; Mochida et al 1977; Otake and Hokyo 1976). N. D. Penny (pers. comm.) sampled 100 random hills semiweekly. Hinckley (1963a) counted the insects on one stem on each of 10 hills, and Nishida (1975a) recorded the insects counted within a fixed time, possibly 3 minutes.

Mouth aspirators permit careful collection of nymphal stages in particular. We usually sampled 10 hills/plot each week (IRRI 1971). Although sampling is more tedious and slower than visual counting, the collections are immediately available for identification and counting. On the other hand, motorized suction machines permit rapid collecting but are not suitable for sampling young nymphs (Dyck and Pathak 1974). Alam (1971) collected insects from sample rows and MacQuillan (1968, 1974) sampled hills or 0.3-m-row units. Wan (1972) placed a metal cylinder around individual hills before sampling with a modified vacuum cleaner, and found that the method favored the collection of adult insects. Soehardjan (1973) employed a D-Vac suction machine to collect adults from 1-m^2 units.

Insects knocked off a hill that has been struck are usually counted visually after the pests fall onto the water surface. However, Misra and Samal (1975) constructed a cylindrical cage, into which the planthoppers are tapped from the plants. Gavarra and Raros (1975) each week sampled 30 hills, obtaining insects by holding the plants above a greased wooden paddle and striking them. Hinckley (1963a) clapped an ethyl acetate killing jar against the base of rice hills and ran it upwards, trapping the planthoppers. Wan (1972) says use of the method caught mostly nymphs and few adults.

Das et al (1972) selected three hills at random, cut off all tillers at points below the water line, and placed the tillers in plastic bags; later the collected material was sorted and the insects counted in the laboratory. A similar method is currently being tested at IRRI for life-table studies, but the bag is placed over the hill before the rice is cut.

Counting insects on only 10 or 20 hills/plot lacks precision. A quick calculation of the number of hills required for a precision level of 10 or 20% suggests that several hundred hills should be sampled. Using a formula given by Southwood (1966), Munroe (1974) calculated that 64 hills were required to obtain a 50% precision level, and 1,600 hills to get a 10% level. However, Chen (1976) recently calculated that 50 to 70 hills were adequate at any plant stage for intensive studies needing a 20% level, and 30 to 40 hills for extensive studies to meet a 30% precision level. Chen also developed a plan for sequential sampling at three crop ages; his plan was for use in the field to determine population densities and whether those densities were above or below economic thresholds.

Sweep net

The sweep net has been widely used to sample BPH from seedbeds and rice fields. Its main advantages are speed and convenience. Catches heavily favor adults, however, and are biased by the crop age and nature of the stand, the microhabitat of BPH, the sweeping technique used, and climatic factors. Sweeping can be useful, however, for extensive field surveys (Otake and Hokyo 1976), or when adult comparisons within short time spans are needed and sampling conditions remain uniform.

The number of sweeps per plot varies from 5 to 100 (Hinckley 1963a; Wan 1972; Dyck and Pathak 1974; Nishida 1975a; Mochida and Suryana 1976; Mochida et al 1977; Otake and Hokyo 1976). Bae and Pathak (1969) took sweep samples every 10 days between 0800 and 1000 hours but O. Mochida (pers. comm., CRIA-IRRI, Sukamandi, Indonesia) made sweeps weekly after 0900 or 1000 hours. N. D. Penny (pers. comm.) found it best to sweep at 1000 hours.

Mochida et a1 (1977) tried to correlate sweep net catches with directly counted field densities, and developed the following formulae:

$$Y = 1.2432X + 0.6963 \ (r = 0.8562)$$
$$X = 0.5896Y - 0.2050 \ (r = 0.8562)$$

where X is log [(no. adults + nymphs)/hill + 1] and Y is log [(no. adults + nymphs)/50 strokes of net + 1]. However, Otake and Hokyo (1976) found they could not correlate field counts and sweep samples of macropterous females. Wan (1972) suggested a pooling of net and direct counts.

Traps

The most commonly used traps are those with light (incandescent, fluorescent, or blacklight) as the attraction source (Wan 1972; IRRI 1973; Anon. 1977). Light traps depend on the positive phototactic response of the insects; physiological as well as abiotic environmental factors can influence the behavior (Leeuwangh 1968). The correspondence of light-trap catches to field samples varies from poor to good (Leeuwangh 1968 ; Alam 1971 ; Fig. 14, 15).

Airborne net-traps and yellow-pan water-traps have been used in Indonesia (Mochida and Suryana 1976) to catch dispersing, flying insects. Another trap for flying planthoppers is the sticky trap — boards or cylinders covered with sticky material (IRRI 1972; MacQuillan 1974, 1975). Hsieh (1972) found that sticky traps were useful even in rainy weather. At IRRI the sticky board 1 m above the ground gave a good catch. There was a good correlation between sticky-trap and light-trap catches (Fig. 17). Thus, both light and sticky traps can be used to monitor dispersing insects.

Quadrats

Wire quadrats are useful for counting population densities in seedbeds and broadcast-seeded fields (MacQuillan 1974; IRRI 1976). The quadrat may be 0.06 to 0.25 m^2 (Abraham 1957; O. Mochida, pers. comm.). However, sweeping with a net is probably an appropriate method of sampling seedbeds because the plants are small, and the populations are low and composed almost entirely of adults.

CONCLUSIONS

The density and composition of the BPH population in the field fluctuates dramatically within the lifetime of one crop, within 1 year, and over a period of years. The insect changes during a crop's life are influenced by crop age and the pattern of insect generations, which is rather distinct in a given field. Dispersing macropterous adults invade a field after planting, and two major generations usually develop before the crop matures. Insect density is highest when nymphs dominate the population, usually about 60 and 85 days after transplanting. Nymphal mortality may be high. Most dispersion of adults from the field takes place near crop maturity.

Within a year, there are usually two population peaks, one near the end of each crop season. Surrounding crops apparently influence pest density strongly, possibly by affecting the size of the dispersing population. A year's largest peak may occur in either the dry or the wet season.

Evidence to date suggests that the change to modern rice cultural methods within the past 10 years is the major factor in the upsurge in recent years of BPH populations and of the damage the insect causes. Components of those methods that have been shown to increase pest populations are many tillers per unit area, flooding fields, and applying high doses of nitrogenous fertilizer.

More evidence is needed to indicate whether critical roles in increasing pest populations are played by cropping patterns, high yielding varieties per se, weeds, natural enemies of BPH, climate, or insecticides. If indeed the main cause of the insect problem is man's modern methods of growing more rice, the BPH will probably remain a pest or become an even more serious pest. The solution is not likely to come from reversing the trends of modern agriculture, but from improving our pest management skills.

Sampling the BPH is difficult because of the uneven distribution that develops in the field. Use of the number of tillers per hill appears to be an important step toward improving sampling methodology. We have reviewed the current methods of sampling BPH and discussed the advantages and disadvantages of each. There is little evidence so far to indicate what exactly is the best method for any particular purpose. In ecological studies it is important to sample all stages of the insect on some kind of a hill basis. Traps are useful for monitoring dispersal.

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OUTBREAKS AND MIGRATION

Forecasting brown planthopper outbreaks in Japan

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Outbreaks in Japan of the brown planthopper *Nilaparvata lugens* (Stål) were more frequent in the last decade than in the one before. The number of insects and the frequency of outbreaks are usually higher in the regions southwest of Japan than elsewhere. It is important to measure population levels of the immigrating insects in June and July to forecast the levels of the outbreaks in subsequent generations. Traps and field surveys are reliable, but patrol-type surveys are essential in forecasting for large areas.

Generally, insecticide applications are timed to kill the nymphs that are produced by the immigrating adults, before the brachypterous females of the next generation appear. When the immigrant population is low, the level of the brachypterous female population should determine insecticide applications. If insecticide application is necessary, it should be timed to kill the younger nymphs of the second generation after they hatch.

ALTHOUGH HEAVY INFESTATIONS have occurred in tropical Asian countries only in recent years, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) has been one of the most important pests of rice in Japan over a long period. It is said that famines in earlier days were caused by rice failures that resulted from either serious outbreaks of the blast disease or of insect pests, especially the BPH, or unusual cold weather during the rice plant's reproductive stage, or both.

Forecasting of the time of the insect's appearance and its numbers in the coming rice season requires knowledge of the insects' overwintering situation in temperate countries. The BPH and the whitebacked planthopper *Sogatella furcifera* Horvath have been observed to overwinter in Japan only in small numbers at isolated locations near hot springs [Ministry of Agriculture and Forestry (MAF) 1965, 1967]. But in July 1967, a weather ship happened to meet a mass flight of rice planthoppers on the Pacific Ocean far from Japan (Asahina and Tsuruoka 1968). That incident threw considerable light on the

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complex pattern of the BPH. Since then, surveys on sea or on land have suggested that there are transoceanic long-distance migrations of the planthoppers to Japan during the *baiu* (rainy) season in June and July (Kisimoto 1971, 1972; Iijima 1973; Itakura 1973; Hirao 1974; Mochida 1974). However, the origin of the migrating planthopper has not been definitely clarified.

Japan has more data on the bionomics and physiology of the BPH related to the overwintering problem than data related to forecasting problems. In general, diseases and insect pests are forecast on long- and short-term bases. Before the migration of BPH to Japan was discovered, long-term forecasting was based on the assumption that both species of planthoppers overwintered in Japan as diapausing eggs in the gramineous winter grasses. The data on long-term forecasting so far published are meaningless. This paper therefore focuses on the short-term forecasting of the BPH, with special reference to outbreaks in Japan.

Because of the regular or intensive insecticide applications in Japan, an "outbreak" in that country is difficult to define. But when the pests are abundant, farmers often fail to suppress them. As used in this paper, the word "outbreak" means a large-scale occurrence of pests or severe damage of rice plants. Damage is indicated by hopperburn.

OUTLINE OF GENERAL FORECASTING WORK

The 1940 large-scale outbreaks of the BPH and whitebacked planthopper led the Japanese Government to establish in 1941 a nationwide plant-protection system called "Forecasting Work of Disease and Insect Pest Occurrence." The work is carried out according to the general and detailed rules for the enforcement of disease and insect outbreak forecast work for ordinary crops in Japan (MAF 1971). In addition, a plant protection law was established in 1950. The rules for forecasting work are revised every few years on the basis of experimental results.

Systematic forecasting has been well developed. According to the 1975 census, there are 192 prefectural forecasters in 47 prefectures and 484 local forecasters at 265 observatory stations. Every forecaster belongs to a prefecture and is under the administrative control of the prefectural governor. However, the Division of Plant Protection, Ministry of Agriculture and Forestry, directs the technical work of the forecasters, subsidizing all or a part of their expenses. Every observatory station has traps and model fields for use in forecasting; representative rice varieties are grown in the model fields with the cultivation practices common in the region concerned. No insecticides or fungicides are applied in a model field. The local forecasters present to the prefectural forecasters survey results based on the overall information taken from the traps, from the model field, and from survey patrols of the farmers' fields. The prefectural forecasters periodically deliver forecasting information or extraordinary warnings or alarms to the office concerned. They publish annual reports.

The rules to be followed in surveys for forecasting the occurrence of the whitebacked planthopper and the BPH are specified. Planthopper catches in the light trap (a bow-frosted bulb with double filament) are to be recorded daily throughout the rice-growing season. A sticky trap (80 × 25 cm) at the plant-top level and a net trap (1 m in diameter) more than 10 m high are also recommended for catching immigrating adult insects from April to July. During that period, a sweep net (37 cm in diameter) with a handle (1 m long), or a suction catcher, if available, is used to determine the density of adult and nymph populations on gramineous grasses around the paddy fields.

To record the population density, samples are taken from the nursery beds with 20 strokes of the sweep net. In the paddy fields, plants are pushed aside and the insects on the plants are counted or the plants are tapped and the insects that fall into the paddy water are counted. It is well to use a sweep net at the same time.

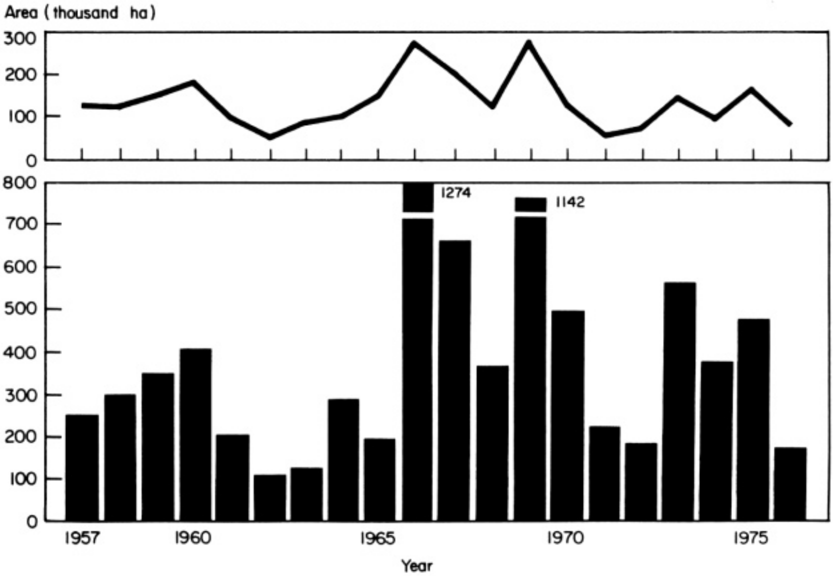
The rice fields of a region are evaluated twice during July and August, and, finally, in mid-September; the degree of insect occurrence is recorded according to the following scale : none : 0 adults and nymphs found per hill with push-aside or tap-and-count method (0 insects found/20 strokes of sweep net), rare: 1–10 adults and nymphs (1–100 insects/20 strokes of net), medium: 11–50 (101–300), abundant: 51–100 (301–700), severe: over 101 (over 701); hopperburn may accompany this rating.

Forecasting of the planthopper in Japan is conducted under these rules. In addition, sampling methods are tried to make the results accurate.

OUTBREAKS IN RECENT YEARS

An outbreak of the BPH was recorded in 697; from that time until World War II, more than 100 small or large outbreaks occurred occasionally, causing miserable famines in old days (Suenaga and Nakatsuka 1958; Hirashima 1965).

The yearly records show that the frequency of the occurrence of the BPH outbreaks has varied considerably in the past 20 years (Fig. 1). The outbreaks occurred more frequently in the last decade than in the one before. There was no periodicity in the outbreaks. The 1966 outbreak was the largest both in area involved and in severity of damage; the 1969 outbreak was next (MAF 1968; Hirao 1976). In 1966 the BPH was found on 1,274,000 ha of 3,149,000 ha of paddy fields in Japan and severely damaged 780,500 ha, reducing yields to 348,900 t. In 1969. 1,142,000 ha were affected. Less severe outbreaks occurred frequently in 1967, 1970, 1973, and 1975, but none during the previous decade. The outbreaks of the BPH were always accompanied by outbreaks of the whitebacked planthopper, except in 1972, when an outbreak of only the whitebacked planthopper occurred, affecting 830,000 ha. Generally, damage from



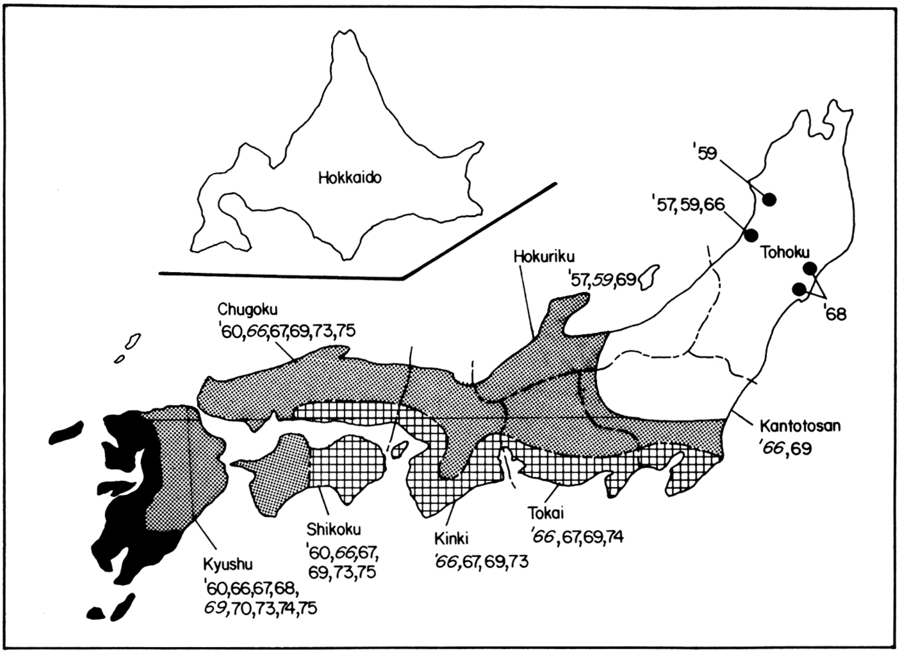
1. Areas affected by the brown planthopper during a 20-year period. Histogram = Japan; solid line = Kyushu.

the whitebacked planthopper is much less severe than that from the BPH.

Areas where the BPH occurs usually extend northward to the central part of the Japanese mainland (lat 36°N); the whitebacked planthopper occurs further north (lat 44°N). That fact is attributable to the difference in the migratory abilities of the two species. The geographical patterns of the BPH abundance and of the frequency of outbreaks are distinct (Fig. 2).

The largest light-trap catches, which reflect roughly the number of insects, were always seen in the southwestern regions, especially Kyushu, and in the southern region along the Pacific coast. Outbreaks occurred frequently in three regions, Kyushu, Shikoku and Chugoku. For instance, in the past 20 years there were 9 years of outstanding outbreaks in Kyushu, in contrast to 4 years in Kinki and only 2 years in Kanto-Tosan. Even in Kyushu, the insect population and severity of damage are usually much larger in the western coastal region and in the southern region, where the paddy fields, if left unsprayed, suffer from hopperburn almost every year. The area affected in Kyushu in the last decade varied from 80,000 to 290,000 ha, accounting for 29 to 80% of 360,000 ha of rice fields in Kyushu (Fig. 1).

Outbreaks of the BPH were recorded in three localities in Tohoku (Fig. 2), in the northern part of the mainland, where outbreaks of the whitebacked planthopper occasionally occur. Outbreaks of the BPH in Akita Prefecture in 1959 and in Miyagi and Iwate prefectures in 1968 were the first ever recorded there; the affected areas covered several thousand hectares (Watanabe 1960; Ito et al 1969; Yoshida and Hasegawa 1969).



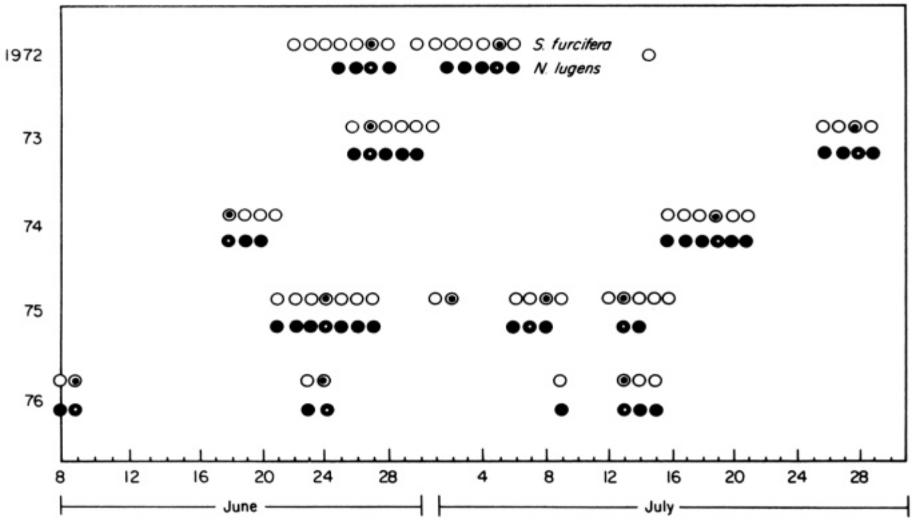
2. Geographical distribution of brown planthopper populations, based on light-trap catches and outbreak frequencies in 1957-1975. Italics indicate year of severest outbreaks in an area. Darker areas have higher population densities.

The geographical distribution of the BPH over the country is attributable to transoceanic movement of insects from the west or the southwest into Japan. The reason for the frequent outbreaks in the last decade is uncertain. Transoceanic migration may link the recent outbreaks in Asian countries to those in Japan.

There is no periodicity in the BPH outbreaks. Therefore, intensive and extensive forecasting work is important in predicting the insect occurrence and resultant hopperburn especially in the southwestern and southern parts of the country, where the BPH occurs much more abundantly and frequently than in other north and northeastern regions.

FORECASTING OUTBREAKS

The rice plants normally are transplanted in mid-June in the southwestern regions. The *baiu* (rainy) season is from early June to late July. Planthopper migrations usually last for about a month from mid-June to mid-July (Fig. 3). Earlier immigrations, especially of the whitebacked planthopper, are occasionally seen in the coastal region of the west and south of Kyushu facing the East



3. Immigrating waves of the planthoppers in Chikugo in recent years.

China Sea in late April or May; population density is low. The BPH usually goes through four generations in a paddy field, multiplying abundantly as the generations advance until harvest. Hopperburn usually occurs after heading in the generations later than the third. Many entomologists state that it is important to know the dates and frequency of immigration waves and their density, to forecast the population of subsequent generations.

Catching the immigrants

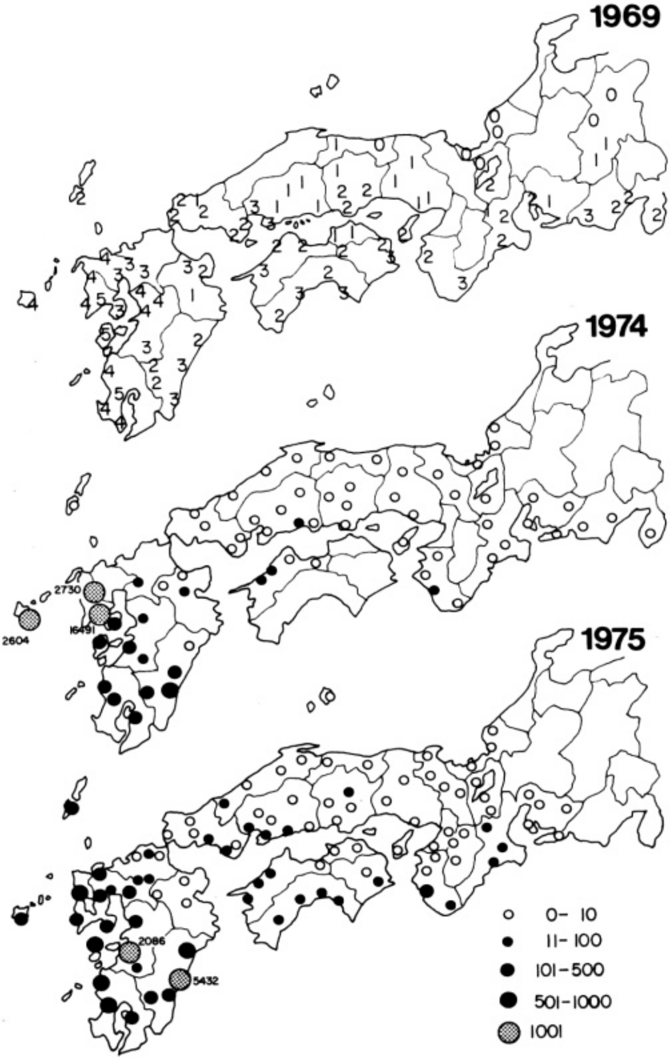
Light traps. Light traps are commonly used to record the seasonal fluctuations of insect numbers. Figure 4 shows the light-trap catches of the BPH during immigration. A large number of immigrants were trapped in 1969 and severe hopperburn occurred widely in the same regions. The same phenomenon was observed in other outbreak years (Yamashita and Nagai 1968).

According to the historical records (Hara et al 1967), the largest light-trap catches were 0.2 million BPH together with 1.31 million whitebacked planthoppers caught per trap at Taniyama on the night of 9 July 1966, and 0.14 million BPH and 1.28 million whitebacked planthoppers at Sendai on the night of 11 July of the same year. In addition, 0.38 million BPH at Sendai and 3.01 million whitebacked planthoppers at Izumi were trapped in a 6-day period beginning on 7 July 1966. The trapping stations were in Kagoshima Prefecture at the southern tip of Kyushu. The year 1966, of course, was unusual.

According to the light-trap record for the past 20 years at the Kyushu National Agricultural Experiment Station, Chikugo, Fukuoka, the average BPH catch during immigration periods was 406 (2,149 in 1969—24 in 1963). Kuno

(1968) indicated a high correlation between the density of immigrants in the field and the total number of adults in the light trap near the field during the immigration period. Similar results are shown in recent data (Fig. 5).

It is difficult to standardize the relationship between the number of insects caught in a light trap during the immigration period and the occurrence of hopperburn in subsequent generations, because the environments in which



4. Light trap catches of planthopper immigrants up to July 20. Figures for 1969 indicate logarithm values; for 1974 and 1975, the symbols are defined in the legend.

Table 1. Brown planthopper immigrants up to 20 July and hopperburn. Kyushu National Agricultural Experiment Station, Chikugo.

Year	Insects trapped (no.) by		Density[b]	Hopperburn[c] (rating)
	Light trap	Net trap[a]		
1968	204	7	0.038 (0.010–0.159)[d]	+
1969	2149	197		++
1970	177	21		++
1971	98	7		0
1972	31	9		+
1973	89	25	0.013	+
1974	97	10	0.036	++
1975	266	8	0.041	++
1976	191	6	0.012	+

[a] Average of 2 traps. [b] Highest number of adults/hill in a field. [c] ++ = overall; + = patch; 0 = none. No insecticides used. [d] After Kisimoto (1975).

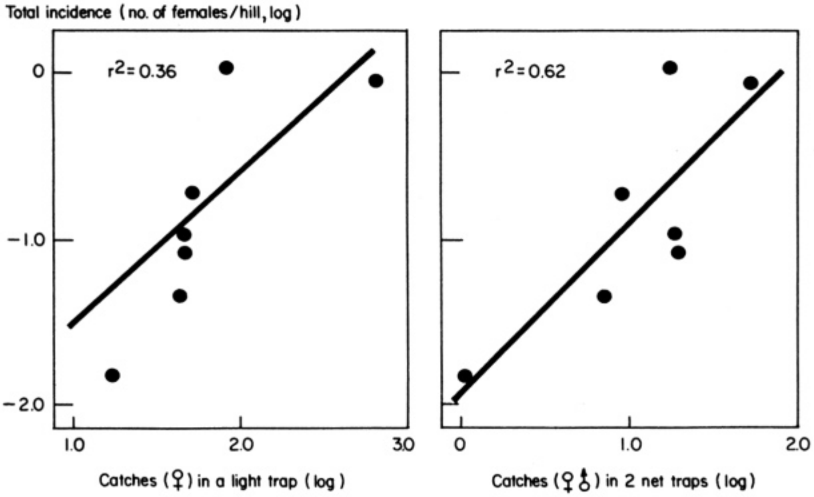
the generations develop, temperatures in the fall, and farming practices differ from place to place and year to year. However, it may roughly be said that a catch of more than 500 BPH during the immigration period results in a severe outbreak of hopperburn before heading and that a catch of 100 to 500 results in hopperburn of the whole field after heading, while light hopperburn occurs in October, when the catch is around 100. Roughly, a catch of 50 may be a threshold for hopperburn. Hopperburn occurred almost every year unless insecticides were applied in the field (Table 1).

It appears that light traps are useful for catching immigrant insects and forecasting subsequent outbreaks of hopperburn, especially when immigrant density is high. The area a light trap can forecast for has not been determined for any pest.

Other traps. A net trap is reliable (Fig. 5). But I recommend the use of two or more net traps for accuracy. Yellow-pan water and sticky traps could catch more males than females, probably because the sexes differ in activity. Since yellow-pan water and sticky traps reflect the population trends of the planthoppers after the insects have become established in a field, their use can substitute for visual counting.

Kisimoto (1974, 1975) suggested that catches of more than 10 individuals in a net trap or of more than 50 in a yellow-pan water-trap during immigration means the occurrence of hopperburn in the fall, and that catches of from more than 100 to several hundreds forecast severe outbreaks of hopperburn before heading (Fig. 6).

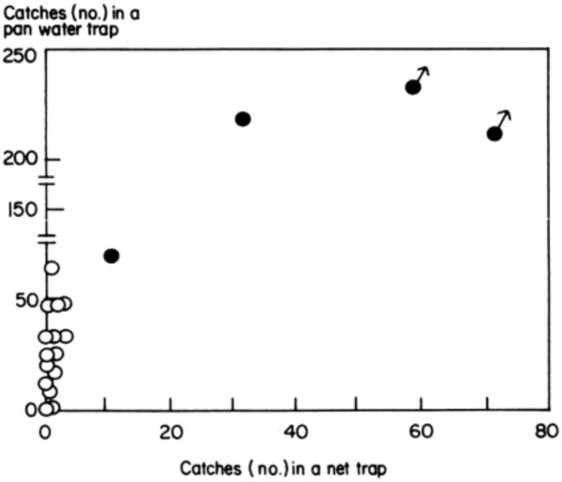
Visual counting. BPH immigrates before the maximum tillering stage of rice plants. It is therefore easy to count visually, hill by hill, without consuming much time or disturbing the insects. The distribution of BPH adults is random in this generation (Kisimoto 1965; Kuno 1968). The density of the immigrants is low (Table 1). Roughly, more than one individual male or female per 100 hills might cause hopperburn in the fall. When plant growth is more advanced,



5. Correlation of immigrating brown planthopper catches in traps and field populations near the traps.

the tap-and-count and push-aside methods are recommended for counting nymphs.

Net sweeping. Net sweeping is commonly used to determine the population density of insects. Net sweeping in the field is unreliable during the immigration period, because plants are short and the planthopper inhabits the lower



6. Correlation of immigrating brown planthopper catches between light trap and net trap (Kisimoto 1974). The black circles with arrows indicate flights that eventually caused hopperburn.

part of rice plants close to the surface of the irrigation water. The results vary significantly between investigators or with weather conditions. Net sweeping and the push-aside methods are the only ones applicable to nursery beds.

Survey patrols. Each trap has merits and demerits. Light traps do not work in the daytime; net traps do not function under calm conditions. Planthopper catches are often significantly different even in light traps 200 or 300 m apart. The area covered by traps is uncertain. To remedy such deficiencies, visual counting by survey patrols as frequently as possible is necessary for checking insect density. Planthopper populations should be forecast from a broad base.

Establishment of the immigrants in a field

The adults of the second generation appear about 1 month after the immigration (allow 2 weeks for the egg period, including a few preoviposition days for the immigrant, and another 2 weeks for a nymphal period) (Suenaga 1963; Kisimoto 1969; Hirao 1972). They begin to appear in late July or mid-August, depending on the time of immigration. Most females are brachypterous but males are macropterous. The brachypterous females have a higher rate of reproduction (Kisimoto 1965) and, thus, are the sources of the subsequent generations that cause hopperburn. It is important to know the population of second-generation brachypterous females to forecast fall outbreaks of hopperburn.

In that generation, visual counts, including those that use tap-and-count and push-aside methods, are meaningful only for field surveys. The brachypterous females, unlike the macropterous immigrants of the previous generation, concentrate in certain areas. When there are more than 30 or 40 females/ 100 hills, hopperburn occurs first where the females can aggregate (Kisimoto 1969). About 20 females/100 hills are considered to be a threshold for hopperburn in the fall. If there are more than 200 females/100 hills, nymphs from the eggs they lay cause serious outbreaks before heading. Such was the case in 1969 and 1970.

Little is known about how environment affects the reproductivity of the BPH in a field. Suenaga (1963) said that continuing temperatures of above 30°C are unfavorable for nymphal growth under experimental conditions. However, such continuous high temperatures do not prevail even in midsummer in Japan.

As mentioned (Fig. 3), the time of the immigration has varied from year to year and from area to area. When the immigration occurs early, as in mid-June, or when high temperatures prevail in September, the BPH is able to extend itself into one more generation (the fifth) in October. That occurred in 1975, when severe outbreaks occurred in southwestern Japan. near harvest time. On the other hand, unusually low fall temperatures limited reproduction. My observations indicate that hopperburn occurs earlier on the early maturing varieties than on the late-maturing ones, even with similar population densities, probably because the rice plants' tolerance to the BPH is reduced as the plant approaches maturity. Such facts should be considered in forecasting.

The forecasting work begins with determining the times and frequency of occurrence of the immigrants by traps and field surveys. More than two kinds of traps are recommended for use, and field surveys of the population density are unavoidable in large-area forecasting. From the levels of the immigrant population thus obtained. the levels of outbreaks and resultant hopperburn in the subsequent generations can be predicted.

GENERAL CONCEPTS OF CHEMICAL CONTROL

The population peaks of successive generations of the BPH are rather clear. Nagata et al (1973) developed measures to control them. Insecticides should be applied 20 to 25 days after immigration, when the immigrant density is high. Insecticide applications kill nymphs produced by the immigrants before the nymphs become adults and lay eggs. If application is delayed, the eggs laid by the brachypterous females are not affected and become the source of outbreak in later generations. When immigrant density is low, insecticide applications should be timed to kill nymphs of the second generation after most eggs have hatched.

There are no efficient ovicides or insecticides that have long residual effect to control the BPH. When there are two or more waves of immigration within a short period, as in 1975 and 1976, the later insect stages follow erratic patterns. Such conditions make control of BPH with a single application of insecticides difficult.

For effective BPH control insecticide application should be properly timed on the basis of the results of forecasting work.

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Brown planthopper migration

R. Kisimoto

The growth of populations of *Nilaparvata lugens* and *Sogatella furcifera* in Japan starts from immigrants transported from the south by a warm and humid maritime air mass. Inflow of the air mass is induced by a depression or depressions traveling northeastwards along the frontal system, which appears in the rainy season called *bai-u* in the Far East. When a depression emerges in the Chinese continent between 25 and 35°N and proceeds rapidly northeastward along the Japan Islands, a mass immigration of *N. lugens* and *S. furcifera* occurs. There are more *S. furcifera* than *S. lugens* in most cases. When the route digresses to the north or south, a minor immigration of only *S. furcifera,* or of *S. furcifera* accompanied by *N. lugens,* occurs.

Migration surveys on the East China Sea, in which three net traps were set up on a boat, showed that of more than 60 species of small insects that were traveling in the rainy season, *S. furcifera* was the most numerous, followed by *N. lugens* then by *Laodelphax striatellus,* the small brown planthopper. All the insects were concentrated within 200 to 300 km south or north of the front where southwest winds prevail.

A general survey of the immigrant density was carried out soon after a typical mass immigration in 1969, which covered the whole of Japan. An insect net sweep of 50 strokes was taken as a sampling unit. The density in logarithmic scale decreased linearly with distance from the west coast of Kyushu Island.

Among various traps tested, a parallel use of a net trap and a yellow-pan water trap was the most adequate for estimating the time and the density of immigration. Catches of 10 *N. lugens* by a net trap and 50 by water trap are tentatively designated as the threshold above which hopperburn will appear within two to three generations.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* (Stål) is an important pest of the rice plant. It is characterized by its high migratory ability and its high reproductivity on modern, susceptible rice varieties. Many small insects, such as aphids, leafhoppers (Jassidae), and flies, can be carried over long distances by wind; but the planthoppers (Delphacidae) have higher migratory ability. Among the planthoppers that infest rice and other cereal crops or gramineous

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weeds, *Sogatella furcifera* seems to have the highest migratory ability, *N. lugens* the next highest. Immigrant masses of *S. furcifera* sometimes invade fields of young seedlings and injure them seriously, but their offspring rarely cause damage later. *S. furcifera* is not sedentary enough to build up populations that injure rice as does *N. lugens.*

The growth of BPH population begins with immigrants. In the rapid increase of population that follows, the short-winged form plays an important role. When a certain population density is attained, the host plant withers (Kisimoto 1976a, b). Immigration–over a long distance or a short one—depends on the flight of the long-winged adult. Several processes constitute the migratory phenomenon: takeoff, traveling, landing, and short-distance flying before settling down to a preferred habitat. Techniques for collecting flying insects or estimating the density of migrating insects are also important in the study of migration.

LONG-DISTANCE MIGRATION

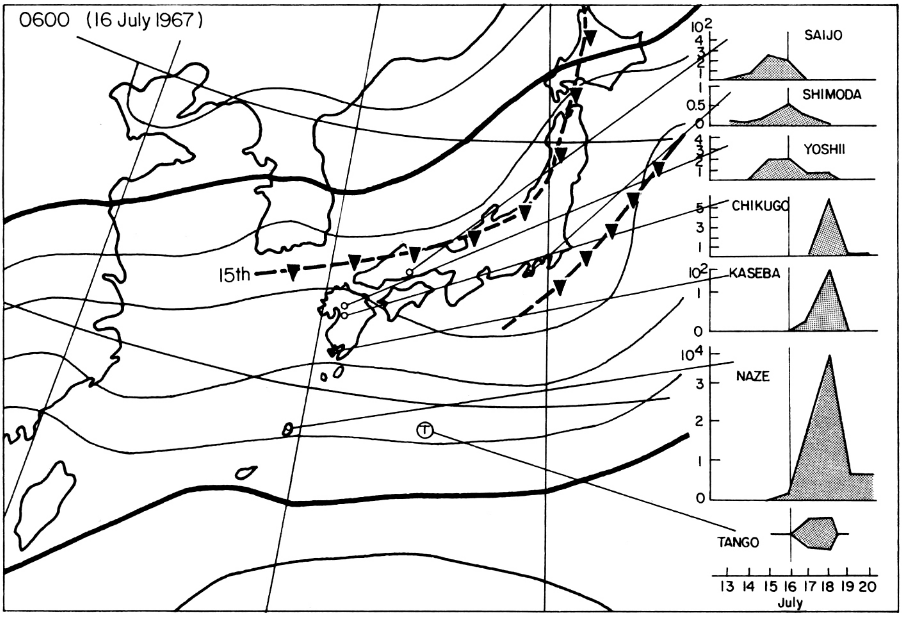
Whitebacked planthopper and BPH infest rice grown in tropical Asia, in temperate Asia up to the northern region of the Chinese continent, and in Korea and Japan. The whitebacked planthopper is much more widely distributed than BPH; it covers areas northeast of China, Vladivostok, U.S.S.R., and Hokkaido, Japan.

There has been long-standing disagreement about the modes of overwintering of the two species. In Japan the species have no apparent resting state in which to survive a severe winter after the rice plant dies and no alternative host plant. Yet, in the rainy season they suddenly appear in light traps or paddy fields, sometimes in large numbers. Until recently, the features of their migration were not understood, partly because their small size renders visual observation difficult, and partly because most surveys have used light traps, which function only on calms. But Tsuruoka's observations opened a new dimension in the discussion (Asahina and Tsuruoka 1968), and the many facts that have accumulated show that planthoppers migrate long distances—several hundred kilometers or more.

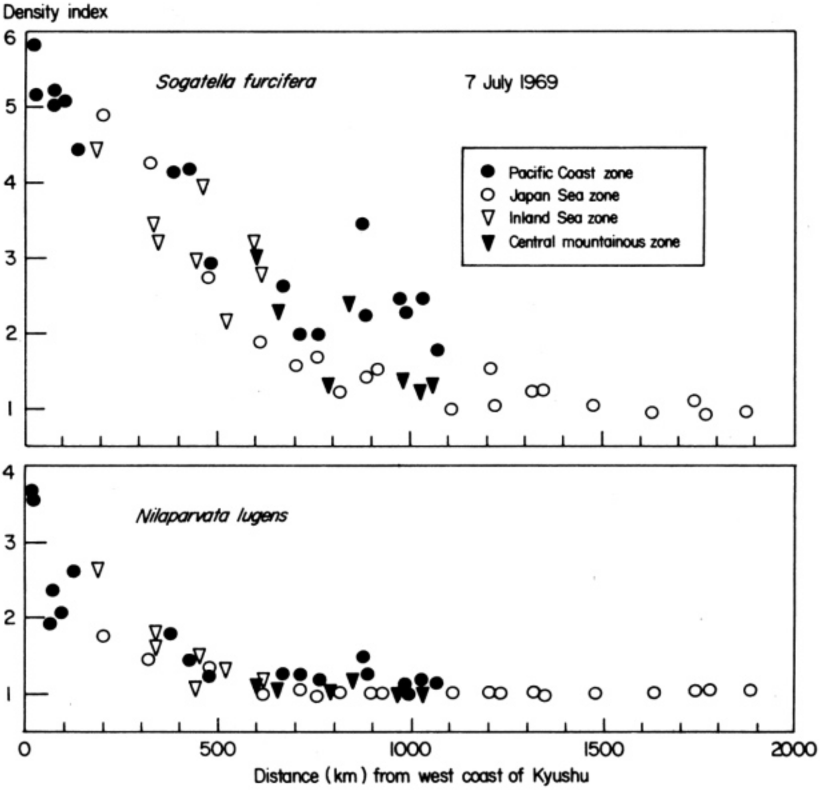
At Tango, an ocean weather station 135°E, 29°N, about 500 km south of the Japanese mainland, Asahina and Tsuruoka (1968) reported that two whitebacked planthoppers flew into a light on board the ship on 15 July, and several thousands the next day. Throughout the day of 17 July the weather ship was in the midst of masses of swarming *S. furcifera* and a small proportion of BPH. The swarms were observed until 0600 on 18 July, when the wind, until then southwesterly, became west-northwesterly or northwesterly and the number of planthoppers apparently decreased. Tsuruoka supposed that the air at the station at 2100 of 16 July came from south of 20 N, east of the Philippines. However, light trap records in western Japan showed distinguishable catches from 13 to 14 July (Fig. 1). Catches were much larger in western Japan, particularly in Kyushu and the southern islands, but interestingly catches were obtained 2 to 3 days earlier in the central Pacific coast zone than in Kyushu or at Tango. It seems plausible that those widely separate catches came from the same mass of migrating planthoppers.

In Chikugo, a southwesterly south wind started to blow at 1100 of 13 July and lasted until 1900 of 17 July, mostly at speeds of 20 to 30 km/hour, making light-trapping unfeasible. A distinguishable catch was then obtained on the calm night of 18 July. A cold front over the northern part of the Japanese mainland slowly moved southward and approached the Japanese islands on 15 July. The broad weather pattern seemed associated with light-trap catches of planthoppers moving stepwise from north to south, and Tango seemed to be the midst of such movement on 16 to 17 July.

In 1968, Tsuruoka (Asahina and Tsuruoka 1968) observed several hundred planthoppers, most of them BPH between 2130 and 2230 of 6 July at Tango, when a southwesterly wind, 24.2 to 24.6°C, blew at 4 to 7 m/sec. After the passage of a cold front at 2230, the temperature dropped 1 C and the number of planthoppers suddenly decreased. Distinguishable light-trap catches, mainly of BPH were observed in the central and western Pacific Coast zone; they were particularly large in southern Kyushu on 5 and 6 July. In 1969, Kisimoto



1. Synoptic map for 16 July 1967, when a mass of planthoppers was found at the Ocean Weather Station, Tango (T). Light trap records showing simultaneous catches at various stations are shown on the right. The broken line shows the front's position on 15 July



2. Relationship of prefecture's average density index to prefecture's distance from the west coast of Kyushu. Density index: 1 = no planthoppers; 2 = 1–5; 3 = 6–25; 4 = 26–125; 5 = 126–625; 6 = more than 625.

(1976b) reported a large-scale immigration of whitebacked planthopper and BPH on 25 and 26 June.

All facts strongly suggest that an area stretching more than 2,000 km from west to east is involved in the planthopper migration assuming the nearby continent to the west to be the migration source.

A general survey covering the whole of Japan, coordinated by the Section of Plant Protection, Ministry of Agriculture and Forestry, was carried out on 7 July 1969. Three typical immigration peaks, all involving whitebacked planthopper and BPH were observed from 25 June to 7 July (Kisimoto 1976b). Depending upon the number of pest-forecasting inspectors, 50 to 150 fields were sampled in each prefecture. Fifty sweeps with a 36-cm-diameter insect net were made on each paddy field. The planthopper densities were categorized on a logarithmic scale according to the number of insects collected (Fig. 2). The average density index for each prefecture is shown along with the distance of the prefecture's medium point from the west coast of Kyushu. Each prefecture was categorized as belonging to one of four zones: the Kyushu and Pacific coast zone, Japan Sea coast zone, inland sea zone, and central mountainous zone. All the Tohoku and Hokkaido districts were placed in the Japan Sea coast zone because the wind favoring the immigration of planthoppers in these areas seemed to come through the Japan Sea. Nagano, Gifu, and Kyoto prefectures, wide and heterogeneous, were each divided into two zones, and Hokkaido into four.

It is apparent from Figure 2 that the density index for both whitebacked planthopper and BPH decreases linearly with distance from the west Kyushu coast. That of BPH for a given locality is about one-half or one-third that of the whitebacked planthopper which means that actual populations of BPH are 1/25 to 1/125 those of the whitebacked planthopper. A few whitebacked planthoppers were collected as far as north as Hokkaido, and BPH as far as Yamagata and Ibaragi, which an autumn survey had shown to be the eastern limit of hopperburn-injury zone. From 26 June to 5 July 1969, Mochida (1974) collected 2,669 whitebacked planthoppers and 2,739 BPH on the East China Sea — almostthe same numbers. The migratory ability of the white-backed planthoppers appears to be much higher than that of BPH.

In a second general survey of the same type carried out 16 to 17 July, the same linear relation between distance and density index was found for both species, but the density of BPH was much lower than that in the previous study because substantial immigration of BPH had ended by 5 July (Kisimoto 1976b).

Tsuruoka also collected many planthoppers at Tango from August to October in 1967 and 1968 (Asahina and Tsuruoka 1968). The planthoppers were believed to be carried by north or northwest winds converging in the autumnal fronts that appear in the transitional period from summer to autumn in temperate East Asia. Itakura (1973) confirmed that by observation at Tango in 1973. In these cases, the planthoppers and other small insects were considered to have emigrated from western Japan.

COLLECTION OF MIGRATING INSECTS ON THE EAST CHINA SEA

Since 1969 survey voyages for collecting migrating insects have been made during the rainy season in the East China Sea. *S. furcifera* and *N. lugens* were the most numerous of the insect species collected (Table 1). Insects were caught in three 1-m-diameter tow nets 1.5 m deep; those flying into lights were collected by an aspirator. The third largest catch was that of *Laodelphax striatellus,* the small brown planthopper which is distributed widely in subtropical and temperate Asia, but in the Philippines is found only in mountainous areas (Kisimoto 1975). *Nilaparvata muiri* is distributed on the Chinese continent, Japan, and Korea. The densities of several predaceous mirid bugs, particularly *Cyrtorhinus lividipennis* and *Tytthus chinensis,* were comparable, but the density of *Tytthus chinensis* in tropical Asia seemed extremely low (R. Kisimoto,

Table 1. Migrating insects collected on the East China Sea.

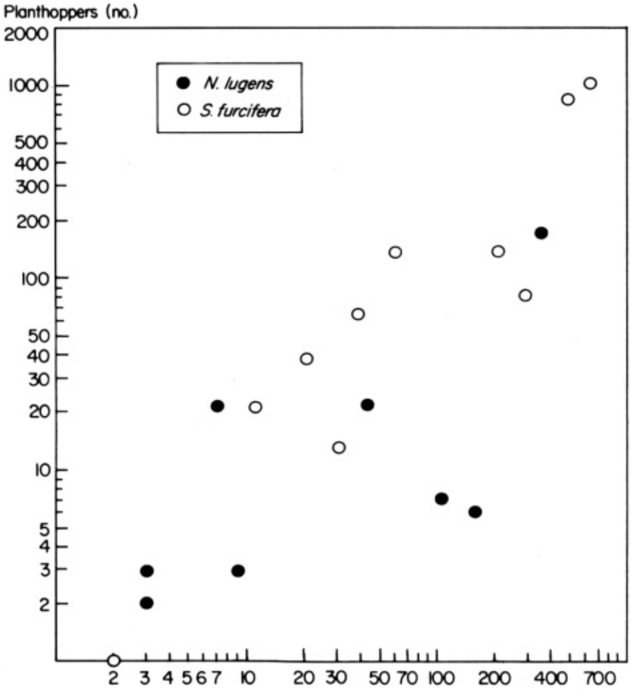
Species	Insects collected (no.)		
	9–18 July 1969 (R. Kisimoto)	22 June–2 July 1971 (R. Kisimoto)	25 June–1 July 1973 (T. Iijima)
S. furcifera	2010	98	618
N. lugens	650	10	129
L. striatellus	96	45	46
S. panicicola	61	11	64
N. muiri	9	0	0
P. propinqua	2	0	5
Other delphacids	4	0	2
Cyrtorhinus lividipennis	47	6	41
Tytthus chinensis	25	0	28
N. cincticeps	6	0	0
N. virescens	0	0	2
Other jassids	22	4	0
Others	161	12	53
Total	3093	186	988

unpubl.). Only a few *Nephotettix cincticeps* and other *Nephotettix* species were collected, although they multiply widely on rice in the area from which they were believed to have migrated. *Nephottetix* species seem to have a weaker migratory ability.

The correlation between numbers of whitebacked planthoppers or BPH caught in the East China Sea and on Chikugo by tow nets during the same period is shown in Figure 3. Catches showed large yearly fluctuations but were highly correlated.

METEOROLOGICAL FACTORS INDUCING IMMIGRATION

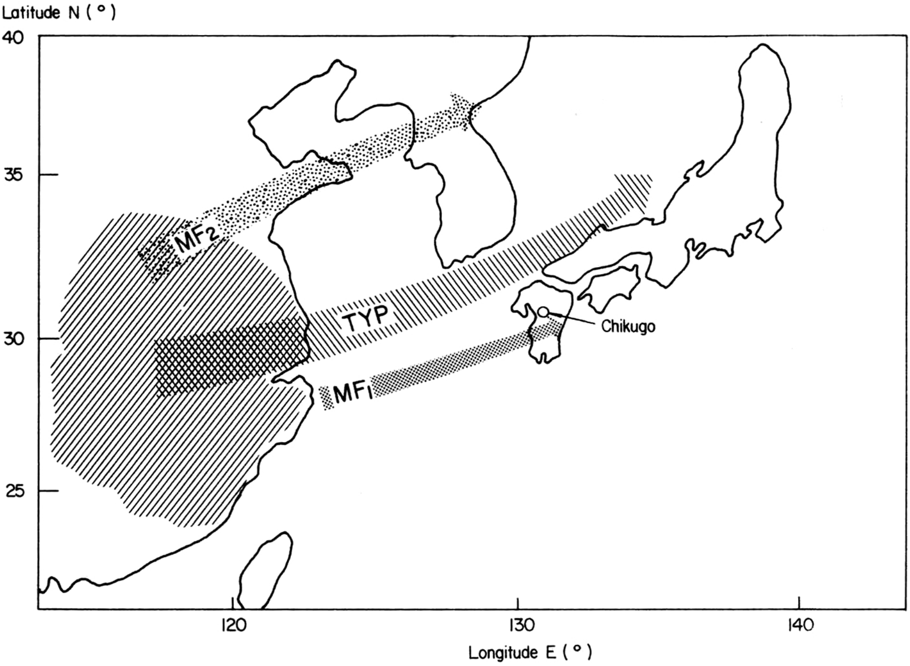
Kisimoto (1976b) analyzed broad weather patterns inducing long-distance immigration into Japan. The inflow of warm and humid air from the south favored the sudden appearance of planthoppers. The air flow was associated with the passage of a depression along the frontal zone called *bai-u* in temperate East Asia. The 40 immigration peaks of planthoppers from 1967 to 1972 were categorized into mass or minor immigrations according to the density of the trapped insects. Seven categories of broad weather patterns were used in the analysis (Kisimoto 1976b). Most immigrants were induced by a depression or successive depressions that emerged from the central part of the Chinese continent between 25°N and 35°N and proceeded eastward through a range between the observation point at Chikugo and about 600 km north (Fig. 4). This route was categorized as typical. Warm and humid southwest winds blew 19.3 hours at an average speed of 32.9 km/hour. When the route digressed a little to the north or south, minor immigrations occurred. In the final stage of the rainy season, southwesterly winds sometimes lasted 3 or 4 days, and in most cases inducing minor immigrations, but sometimes mass immigrations



3. Correlation between simultaneous planthopper catches (male and female) on the East China Sea and on land (Chikugo) during rainy seasons. 1960–72

as in 1967. Only the whitebacked planthopper appeared in one-half of the minor immigrations. Maximum wind speed averaged 23.1 km/hour for minor immigrations of both planthoppers and 16.6 km/hour for those without BPH. The latter type of immigration tended to occur at the beginning of the immigration season when temperatures were lower.

Typical mass catches by the tow net at sea or on land, or collections by aspirator at sea were often observed in a warm sector, 200 to 300 km south of a cold front (Kisimoto 1971) (Fig. 5, 6). But north of the frontal zone planthoppers were often collected as far as 400 to 500 km away. Itakura (1973) analyzed the relation between frontal systems and migrating insects at Tango, and found that during the *bai-u* season insects were at points within 100 km south and 400 km north of a front, and in autumn 100 to 400 km north and 300 km south. Unstable air currents, showers, and turbulence in the frontal system seem to induce the landing of insects traveling along with the air mass.



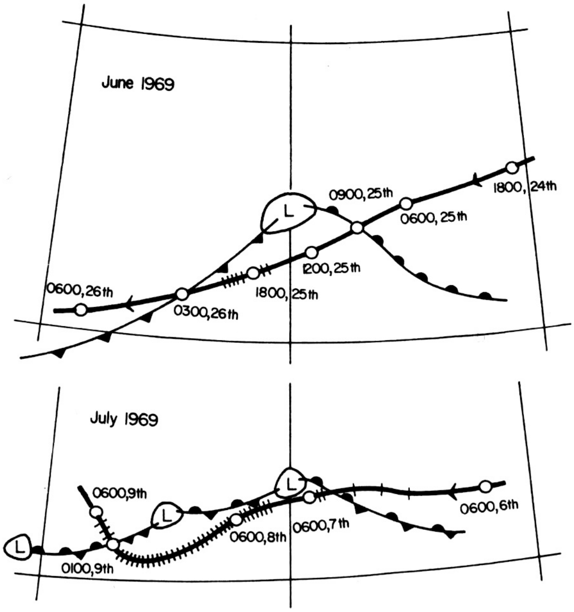
4. Paths of depressions associated with typical mass immigrations (TYP) and with minor immigrations of both *S. furcifera* and *N. lugens* (MF_2) and of *S. furcifera* alone (MF_1).

FLIGHT BEHAVIOR OF PLANTHOPPERS

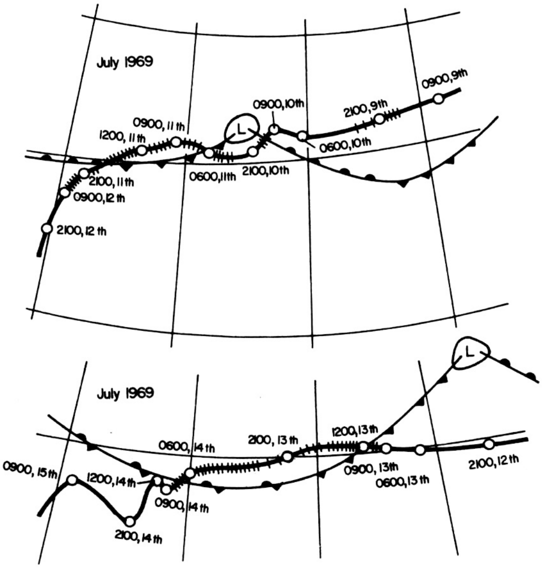
After a teneral period of 22 to 23 hours at 27.5°C (Ohkubo 1973), long-winged adults of *N. lugens* tend to take off spontaneously. An insect ready to take off, goes up to the top of a host-plant leaf, then takes off and flies upward. If wind is blowing, it drifts. This flight behavior seems to be quite different from the sporadic flight of the insect when disturbed (Ohkubo and Kisimoto 1971).

Takeoff periodicity surveyed by a Johnson-Taylor suction trap showed a typical crepuscular bimodal curve during summer and early autumn. Takeoff was most frequent at light intensities of 1 to 200 lux, with the maximum observed at 100 lux. This light intensity occurs within a quarter of an hour of sunset or sunrise. Takeoff frequencies were fundamentally the same at dawn and at dusk and were unaffected by temperatures above 20°C.

When temperatures went down in autumn, the bimodal curve was modified; when they were higher than 22°C, the bimodal peaks were found at 50 to 1,000 lux. When the dawn temperature was 13°C, takeoff was observed only at dusk at 18°C and at 50 to 4,000 lux. In late autumn, when dawn temperature was 13°C and dusk temperature was 12°C, takeoff was observed only in the daytime. The temperature threshold for takeoff was estimated as 17°C. Winds higher than 11 km/h in the open air inhibited takeoff.



5. Position of observation point Chikugo in relation to the frontal system. Good catches by tow nets are indicated by short bars on the track showing the position of Chikugo moving westward. Numbers on open circles mean the hour and date when Chikugo was located. ○-○-○ = position of Yoko-maru, ▼▼ = frontal system.



6. Position of the survey ship Yoko-maru relative to the frontal system on the East China Sea.

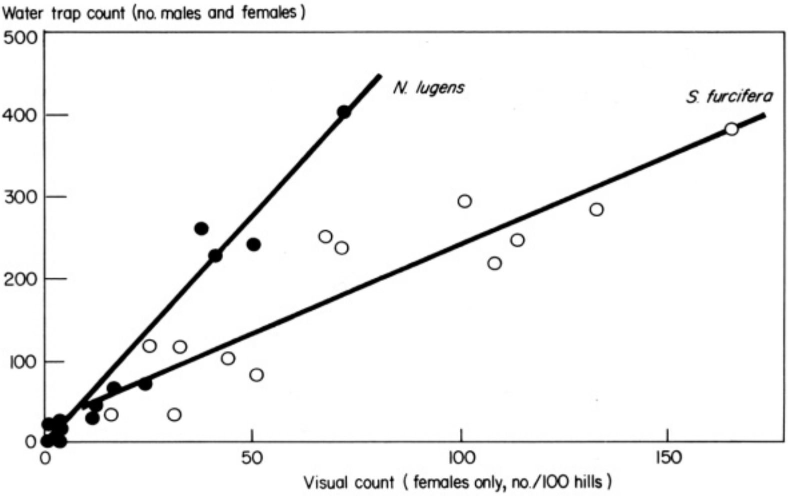
Takeoffs of *N. cincticeps* formed a unimodal distribution pattern at dusk; dawn takeoff was sporadic. Light intensity for takeoff was 0.1 to 20 lux—much lower than that for BPH (*N. cincticeps* is considered to be an unlikely long-distance migrant). Winds higher than 12 km/h clearly inhibited takeoff.

In tethered flight in the laboratory, a few BPH began continuous wingbeating at 10°C, and one-half of the individuals, both male and female, started to do so at 16.5°C. The temperatures are much higher than those for aphids. Winds do not favor the continuation of wingbeating, which decreased linearly with increased wind velocity. No wingbeating was expected at 5.6 m/second. In a series of velocity-increasing experiments, 15 individuals stopped wingbeating at 5.5 m/second; on the average in a velocity-decreasing series, they started to do so at 5.1 m/second.

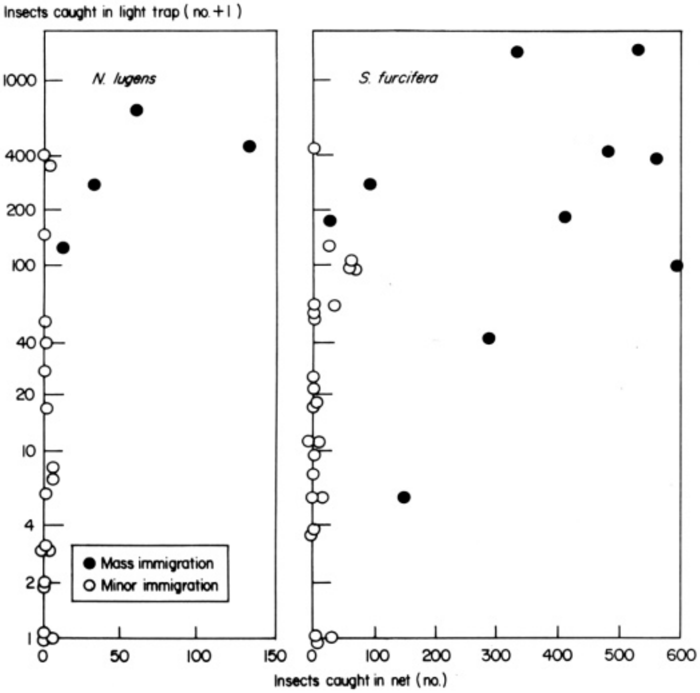
High humidity favors a longer flight period, as well as the ability to endure longer fasting. Most BPH in the experiment kept up wingbeating for more than 10 hours at 85% relative humidity; the longest wingbeating lasted 23 hours. The period of wingbeating was about one-half as long as the life span without food. Wingbeating clearly induces a decrease in body weight in the first 2 to 3 hours; in 5 to 6 hours it consumes 20% of the original body weight in both male and females.

VARIOUS TRAPS FOR ESTIMATING PLANTHOPPER DENSITY

In addition to visual counting in the paddy field, the light trap, the yellow-pan water trap, and the tow net have been used to help estimate insect densities.



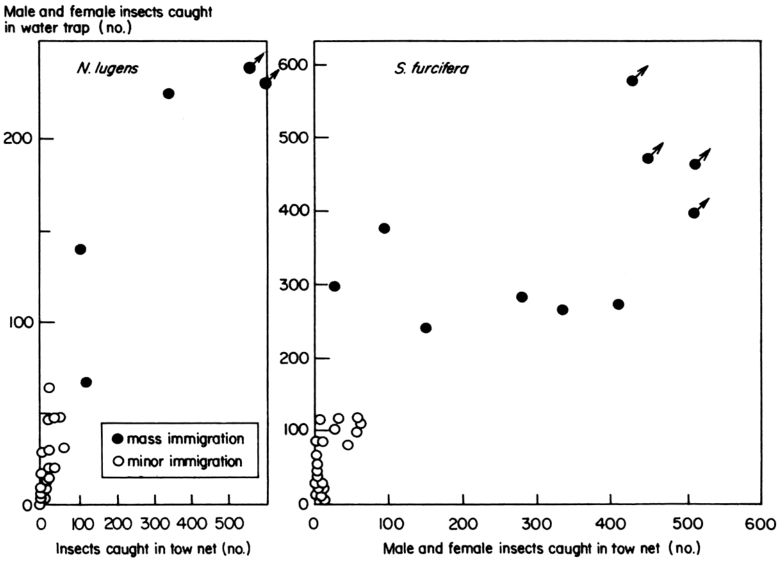
7. Correlation between number of females per 100 hills recorded from a visual count and number of males and females caught by a water trap set in the same paddy field within 3 days of the count.



8. Correlation between planthopper catches in two net and in light trap for each immigration peak, 1968–72

Traps depend on insect flight behavior and different ones may give different results. The tow net seems to be the most direct method of collecting flying insects, but it functions only when wind is blowing. Density estimated by the tow net shows the average trend of immigration in a relatively broad area. Low cost and easy handling favor its extensive use in wild or remote areas, or at sea. The yellow-pan water trap is also easy to handle, and has yielded fairly good correlation between the number of females counted visually and the number of planthoppers caught by water trap (Fig. 7). The correlation coefficient is very high. Efficiency of the pan-water trap is higher with BPH than with whitebacked planthopper and in both species but particularly in BPH the male is much more attracted to the trap than is the female (Kisimoto 1976a,b).

The light trap is one of the most widely used tools in estimating insect density, but it functions only on calm night. Catches by net and by light trap are not linearly correlated (Fig. 8). On the whole, the combined use of the net and the water trap seems to provide the best estimates of immigrant density. Catches of more than 10 BPH individuals by net and of more than 50 by water trap should be considered evidence of an important immigration that will ordinarily cause hopperburn after the crop's heading stage (Fig. 9).



9. Correlation between catches in tow net and in water trap. ♂ means that the actual figure is far from where it should be but is placed there to shorten the scale.

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Economic thresholds, nature of damage, and losses caused by the brown planthopper

K. Sogawa and C. H. Cheng

The brown planthopper is primarily a phloem feeder. A single female adult discharges 13 μl or more honeydew per day during sustained feeding.

Rice plants infested by the brown planthopper before maximum tillering stage have fewer panicles per unit area and fewer grains per panicle, while plants infested after the heading stage have lower percentages of ripened grain and gram weight. The heavily infested plants exhibit the characteristic symptom commonly referred to as hopperburn. Their leaves show a remarkable decline of protein nitrogen and an increase of free amino nitrogen, although the total nitrogen remains comparable to that in the healthy leaves

Based on the assessment of the yield loss caused by the brown planthopper, a control threshold of 20 to 25 planthoppers per hill has been tentatively recommended in tropical countries. The critical economic injury level may be much lower—2 to 5 planthoppers per hill.

SPORADIC BUT CATASTROPHIC outbreaks of the brown planthopper (BPH) have been recorded throughout the history of rice cultivation in Japan (Suenaga and Nakatsuka 1958; Miyashita 1963). Since about 1970, epidemics have occurred frequently in several tropical countries. With the spread of high yielding rice varieties and of intensive cultivation, the BPH has become the most destructive of rice pests because of the severe direct damage it causes and because it is a vector of grassy stunt disease. The feeding damage is commonly referred to as hopperburn. It first appears as browning of plants in patches in the middle of paddy fields. In severe cases the patches spread rapidly. The ecology of the BPH population has been studied in detail with special reference to causes of hopperburn damage (Kisimoto 1965). However, basic and practical studies of the feeding damage caused by the insect are still meager. This paper presents available information about the planthopper feeding and hopperburn damage and discusses the possible causes of hopperburn. It also deals with the

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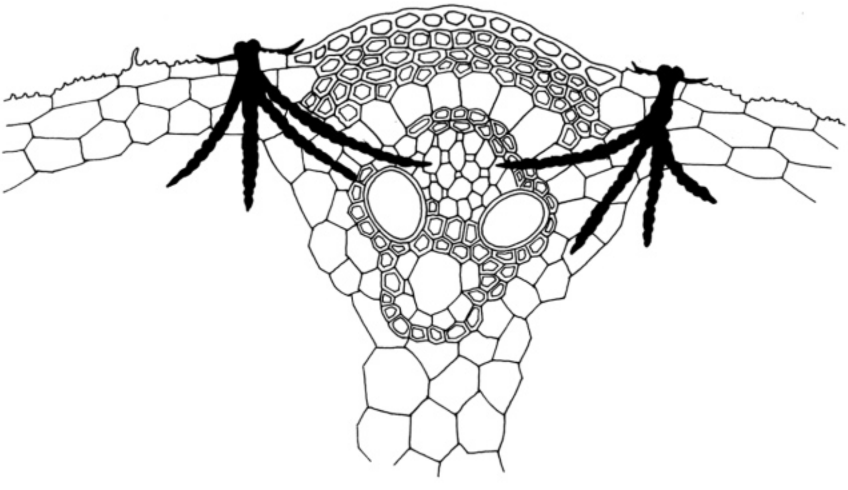
relationship between insect infestation and rice yield with special reference to the assessment of yield losses and economic thresholds.

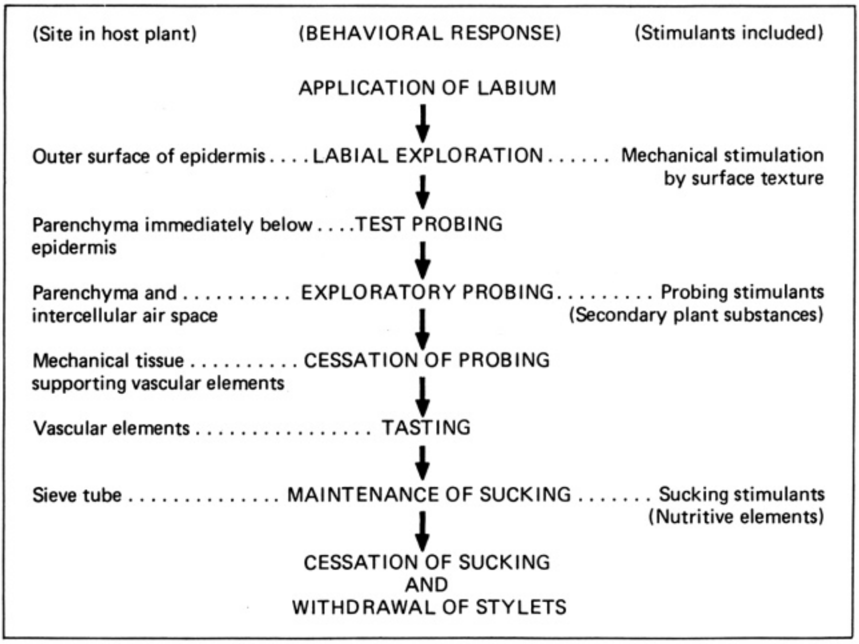
FEEDING BEHAVIOR OF THE BROWN PLANTHOPPER

The BPH, like other hemipterous insects, has mouth parts specialized for the intake of plant sap. It has an outer pair of mandibular and an inner pair of maxillary stylets, which are bundled together to form a piercing and sucking organ 650 to 700 μ long. The BPH is a typical vascular feeder; it primarily sucks the phloem sap by "stylet-sheath feeding" (Miles 1972); it secretes a coagulable saliva that forms a tubular lining (the stylet sheath) (Fig. 1). The highly localized feeding process is composed of a series of gustatory responses to specific botanical stimuli and several intermediary behavioral reactions induced spontaneously or according to the internal demands of the insect (Sogawa 1976; Fig. 2).

The feeding process can be divided into two main behavioral phases—stylet probing and sucking—according to the effects on the rice plant. The probing is done in the parenchyma outside the vascular bundles, and is associated with the secretion of the coagulable saliva. Generally the stylets are repeatedly inserted 100 to 400 μ into the parenchyma through a single point of entry, its course being shifted with each insertion. Consequently stylet sheaths are deposited in a forking pattern in the plant tissues (Fig. 1). The stylet sheaths are made mainly of stable lipoproteinaceous material and remain within the plant tissues after withdrawal of the stylets (Sogawa 1973b). The cellular contents of the epidermis and parenchyma lacerated by the insect stylets show



1. The stylet sheaths formed within the leaf sheath of a rice plant by two brown planthoppers.



2. Feeding process of the brown planthopper.

plasmolysis, but the cells are not emptied. The injury does not extend to cells beyond those penetrated (Sogawa 1973a), nor does it produce any external local symptoms. It has been shown that P^{32} absorbed from roots is accumulated at the sites of insect feeding, indicating abnormally enhanced metabolic activities there (Santa 1959). No accumulation occurs in plant tissues pricked artificially with a pin. Occasionally, necrotic lesions and occlusion by the salivary secretion are also recognized in the vascular tissues, especially in the phloem (Sogawa 1973b). Cagampang et al (1974) found that the upward flow of sap tends to be slower in the plants infested by the BPH than in uninfested plants only when the plants are cut above the feeding sites. It could be assumed that downward flow of the phloem sap is obstructed to a greater extent than the upward flow. The BPH probes much more frequently and consequently deposits more stylet sheaths in resistant rice varieties than in susceptible varieties (Sogawa and Pathak 1970; Karim 1975), but damage to the resistant varieties is less, indicating that the probing has little harmful effect upon the functioning of the plant and that the stylet sheaths are relatively inert.

When the stylet enters vascular tissues, the BPH ceases probing and salivation, and begins to suck. During sustained feeding, the insect excretes a large amount of “honeydew.” Suenaga (1959) estimated that the sap intake of a third- or fourth-instar nymph is about 6 to 11 mg/day. Sogawa (1970) recorded the total daily excretion by a female adult on a rice seedling (var. Norin 8) as about 13 μl of honeydew containing about 270 γ of sugars and 12 γ of amino acids.

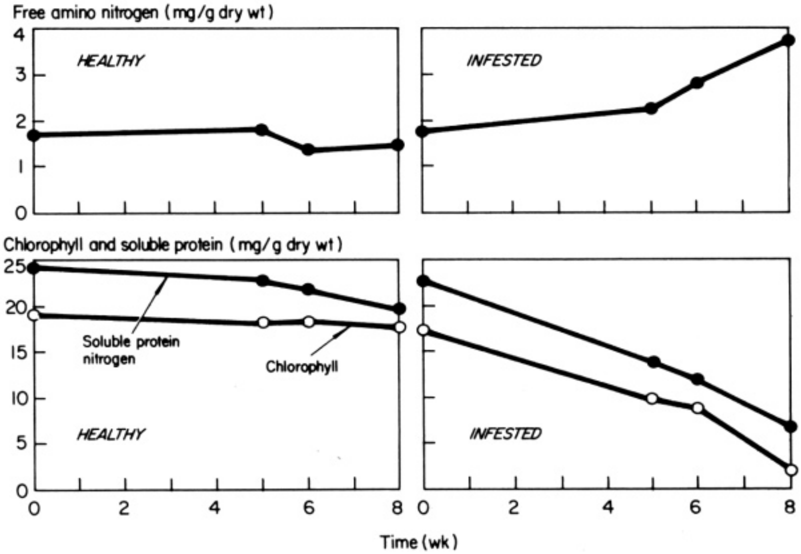
In another experiment, a female ingested about 14 to 31 mg/day on 40- to 60-day-old plants of susceptible varieties (Saxena 1976). Although critical analysis of the BPH feeding is still too limited to permit the evaluation of the damage from feeding, it seems possible that the drain of fluids and nutrients by the intensive sucking is largely responsible for hopperburn. It has been tentatively estimated that the sustained sucking of 10 to 20 female adults per rice tiller might cause nitrogen deficiency in the plants within a short period. Because the BPH takes a large quantity of sugars from the phloem, the function of a planthopper colony on rice plants is considered as that of an extra "sink" for photosynthates, which interferes with the normal partition of the products. The amount of insect feeding and the severity of damage to different rice varieties are positively correlated; BPH ingest much less from the resistant varieties than from the susceptible varieties (Sogawa and Pathak 1970; Karim 1975; Saxena 1976). Moreover, biotypes that break down host-plant resistance are apparently able to ingest plant sap from the "resistant" varieties (Saxena 1976), and induce hopperburn damage in "resistant" as well as in susceptible varieties. It seems reasonable to consider hopperburn damage as being mainly caused by the removal of phloem sap.

NATURE AND MECHANISM OF HOPPERBURN DAMAGE

The first symptom of hopperburn injury appears on rice plants as yellowing of the older leaf blades. It extends progressively to all above-ground parts of the plants, which turn brown and die. Symptoms appear more slowly if only the leaf blades or leaf sheath are exposed to planthopper feeding than if entire plants are exposed (Cagampang et al 1974). The development and physiological activities of the roots are also drastically reduced in infected plants.

The quantitative changes in the biochemical constituents of rice plants, brought about by the infestation of the BPH, have been studied. The water contents of rice plants decreased from about 84% to 72% (Santa 1959), and from 76% to 62% during ingestion (Cagampang et al 1974). Wilting symptoms differed from those of plants under drought stress, in which the leaf blades dry up with little loss of green color. However, the chlorophyll content of the leaf blades of the BPH-infested plants declined with the decline in moisture content (Cagampang et al 1974).

As chlorosis increased the protein in the leaves decreased steadily : chlorotic leaves had 33% less protein than healthy leaves; brown leaves had 73% less (Sogawa 1971). Similarly, soluble protein nitrogen declined from about 22 to 7 mg/g of dry weight in the leaf blades, and from 10 to 7 mg in sheaths as infestation progressed, whereas the total nitrogen in the infested leaves remained comparable with that in the healthy ones (Cagampang et al 1974; Fig. 3). On the other hand, the total free amino acid content of chlorotic leaf blades is

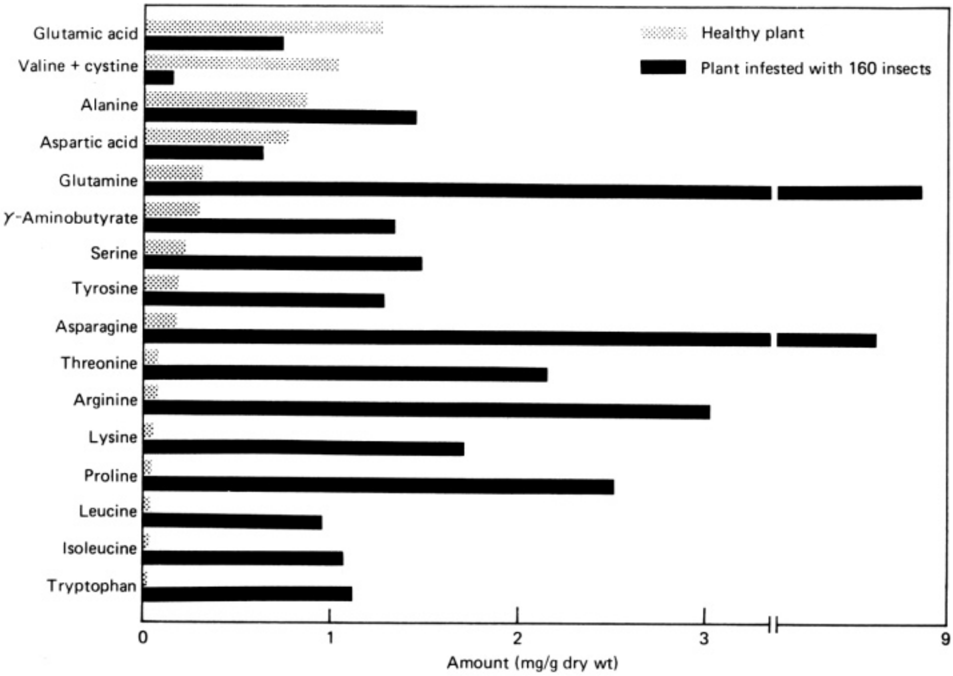


3. Changes in chlorophyll, soluble protein nitrogen, and free amino nitrogen contents in leaf blades of 8-week-old TNl plants infested with 80 brown planthopper adults (right) and of healthy plants (left).

more than four times that of healthy leaves, and that of brown leaves is about 1.8 times that of healthy ones (Sogawa 1971). When the rice plants were exposed to different populations of the BPH, the free amino acid content in leaf blades increased in step with the insect population. For example, 50-day-old plants each infested with 80 or more BPH had three to four times as much free amino acid content, as the healthy plants, and the leaf blades of the heavily infested plants had 30 times more arginine, asparagine, lysine, proline, and tryptophan than those of the healthy ones (Cagampang et a1 1974; Fig. 4).

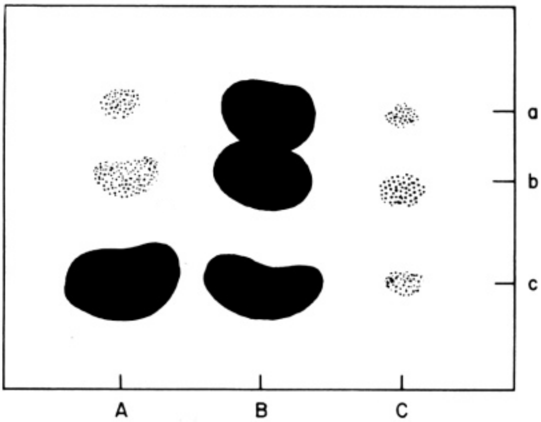
The healthy and chlorotic leaves differed little in total sugar content but the amounts of such reducing sugars as fructose and glucose increased markedly in the chlorotic leaves (Sogawa 1971 ; Fig. 5). A striking reduction of starch content also occurred in the culms of infested plants (Santa 1959). An unusual increase in the iron content of leaves of infected plants was considered the result of a deterioration of physiological activity of the root system (Santa 1959; Fig. 6).

The leaf blade of the rice plant generally has a higher potential for protein synthesis and maintains a higher level of protein nitrogen content than other portions of the plant. However, leaf blades of infested plants have significantly reduced protein content, and accumulate free amino acids and amides. Such changes, however, may be only a part of a complex of metabolic changes associated with hopperburn. A similar change in nitrogen constituents occurs in rice leaves detached from their root system (Kiuchi and Watanabe 1969; Oritani and Yoshida 1969). In that case, it is considered that the protein

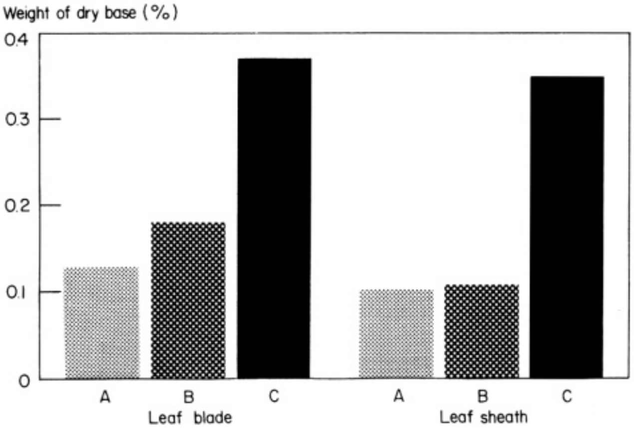


4. Effect of infestation of adult brown planthoppers on composition of free amino acids in plants.

degenerates because of a deficiency of root-produced cytokinins, which play an essential role in ribonucleic acid and nitrogen metabolism in the leaf blades (Yoshida et a1 1970), and that the resultant amino acids and amides accumulate



5. Paper chromatogram of soluble sugars in the leaf blade of a healthy rice plant (A), and in the chlorotic (B) and brown (C) leaf blades of a BPH-infected plant (Sogawa 1971). a, Fructose; b, glucose; c, sucrose.



6. Iron content of leaves of healthy and BPH-infested rice plants. A = healthy plant, B = plant at periphery of a hopperburn patch, C = plant in the center of a hopperburn patch.

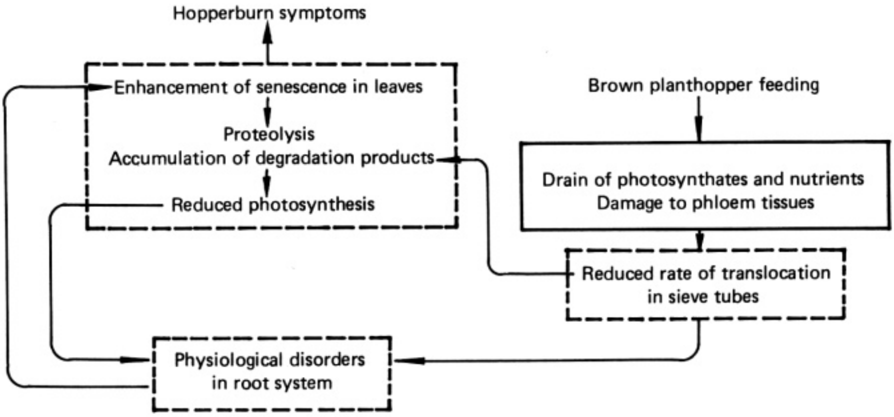
in the leaf-blade tissues because translocation systems are not functioning. The systemic nature of hopperburn damage has led to speculation that during feeding, the BPH injects a phototoxic saliva into the rice plant (Hisano 1964). Cagampang et al (1974), however, suggested that such a phytotoxin, if involved, is not systemic because ingestion at a restricted site does not cause widespread symptoms. There is no experimental evidence that indicates that the insect injects a toxin while feeding.

We suggest that a more probable cause of hopperburn damage is the reduction in the rate of translocation of photosynthates to the root system, which results from the drain of phloem sap and the physiological disruption of active transportation in the phloem by sustained feeding. Disturbance of the physiological activities of the root system enhances leaf senescence. The proteolic products, such as amino acids and amides, will be accumulated in the leaves. The possible relationships of BPH feeding and plant response are illustrated in Figure 7.

Further critical studies of BPH feeding and of physiological reaction of rice plants to insect feeding are needed to determine quantitative relationships between phloem-sap drain and the development of hopperburn symptoms or yield reduction.

ASSESSMENT OF YIELD LOSS

The effects of insect infestations on plant growth and yield are generally complex and variable. The time of insect attack in relation to plant growth, intensity of injury (or the population density of insects), duration of the attack, and environmental factors affecting both insect activities and plant growth



7. Possible relationships between BPH feeding and the development of hopperburn symptoms in rice plants.

control the relationship between an insect infestation and its effect on yield (Bardner and Fletcher 1974).

On the other hand, the factors governing rice yield include the number of panicles per unit area, number of grains per panicle, percentage of ripened grain, and weight of 1,000 grains (Matsushima 1960). Plants infested by the BPH before maximum tillering usually have fewer panicles per unit area and fewer grains per panicle; a planthopper attack after the heading stage affects the percentage of ripened grain and grain weight.

The BPH severely damages rice plants in the postflowering stage in most rice areas (Cheng 1976a; Lee and Park 1976; Kisimoto 1976; Kulshreshtha 1974; Velusamy et al 1975). For instance, under natural conditions in Japan the BPH migrates into paddy fields between late June and mid-July and multiplies almost exponentially during two or three insect generations. The hopperburn usually occurs on rice plants nearing maturity. The yield loss due to hopperburn varies greatly according to when hopperburn occurs. When the plants suffer hopperburn within 30, 40, and 50 days after heading, the yield losses are estimated at about 80 or 90, 50, and 10%, respectively (Kisimoto 1976). Besides the yield loss, higher percentages of dead, immature, and broken grains have been recorded in the infected plants (Chou 1969; Hisano 1964; Kawada 1951 ; Tao and Yu 1967). But in tropical areas where rice grows throughout the year in continuous and staggered plantings the hopperburn tends to occur at any stage (Fernando 1975; Mochida and Dyck 1976).

The methods adopted by various workers for assessing yield loss caused by the BPH can be broadly classified into three categories : (1) comparing yields of pest-infested crops with those of pest-free crops; (2) comparing yields of crops infested with insect populations of different sizes at the same growth stage, or of crop infested with populations of similar size at different growth stages; and (3) comparing yields of crops that have suffered different degrees of damage.

Comparison of yields of pest-infested crops with those of pest-free crops

Tao and Yu (1967) compared the grain yields of crops treated with insecticides to control the BPH and those of crops exposed to natural infestation in the Chia-yi area, Taiwan, in second rice crops from 1962 to 1966. Treated plots had about 37% more rice yields than the infested plots. In another series of experiments in central and southern parts of Taiwan during the last few years, the yield reduction in the naturally infested plants ranged from 17 to 65%, averaging 44% (Table 1). The method is applicable only in areas where the BPH is sufficiently abundant to cause yield reduction. Also, the BPH population trends in the infested plots during the experiment must be known to ensure correct evaluation of the effects of the insect infestation on rice yield.

Comparison of yield based on growth stages and insect populations

It has been observed in Japan that if rice plants at the tillering stage are attacked by about 10 planthoppers/hill for a week, the lower leaves turn yellow and die, and yield eventually decreases by 10 to 40%. If the plants at the heading stage are infested by 10 to 50 planthoppers for 10 to 14 days, they eventually show hopperburn damage and the yield is reduced by 20 to 50%. According to Bae and Pathak (1970), rice plants infested by 100 to 200 first-instar nymphs for only 3 days at 25 days or at 50 to 75 days after transplanting suffer 40 to 70% or 30 to 50% yield losses, respectively; if the same plants are attacked by 8 to 32 adults for the same period. the yield decreases by 30 to 70%. A "control threshold" of 20 to 25 planthoppers/hill that has been recommended for tropical countries (Mochida and Dyck 1976) may be too high. A different experiment has shown that 2-week infestations by 5 to 25 or more nymphs per tiller at 26–39 and 40–53 days after seeding caused 8 and 70% or more yield losses, respectively (IRRI 1974). Yen and Chen (1976) reported that the tolerance to the BPH of rice variety Tainan 5 at different growing stages varies greatly. Grain

Table 1. Effect of insecticide application on rice grain yield (Cheng 1976a).

Year	Grain yield (t/ha)		Yield loss (%)
	Treated plots with insecticide[a]	Control plots	
1969	5.78	3.57	38
1970	4.39	2.34	47
1971	4.46	2.60	42
1972	5.01	4.13	17
1975	3.62	1.26	65
Mean	4.49	2.50	42

[a] Average yield from the treatments with insecticides recommended for controlling the brown planthopper.

Table 2. Yield losses of rice caused by the brown planthopper.

Type or variety[a]	Plant stage[b]	Insect density (no./hill)	Insect stage	Duration of infestation (days)	Yield loss (%)	Reference
Japonica	Tillering	Several	Nymph and adult	7	10	Suenaga 1959
		10	Nymph and adult	7	40	
	Heading	10	Nymph and adult	10	50	
		50	Nymph and adult	14	80	
TN1	25 DT	100	1st-instar nymph	3	40	Bae and Pathak 1970
		200	1st-instar nymph	3	70	
		8	Adult	3	30	
		16	Adult	3	60	
		32	Adult	3	70	
	50–75	100	1st-instar nymph	3	30	
		200	1st-instar nymph	3	50	
		8	Adult	3	30	
		16	Adult	3	40	
		32	Adult	3	55	
IR22	26–39 DS	25/tiller	Nymph	14	≥ 85	IRRI 1973
	40–53 DS	225/tiller	Nymph	14	≥ 79	
Tainan 5	Tillering	20	Adult	14	75	Chen 1976
	Booting	40	Adult	14	90	
	Milky	160	Adult	14	20	

[a] All are susceptible to the brown planthopper [b] DT = days after transplanting. DS = days after seeding.

yields were reduced by 40 to 60% when plants were infested at the tillering stage by 20 to 40 insects/hill for 2 weeks; grain yields were reduced by about 75 to 90% when plants were infested at the booting stage by the same number of insects. When the plants were infested at the milky stage by 80 insects/hill yield was not significantly reduced. Even an infestation by 160 insects/hill caused only 20% decrease in grain yield (Table 2). The data indicate significant differences in the relative susceptibility of rice plants at different growth stages, and in the relative intensity of damage caused by constant population of insects during given periods. In spite of large variations, the experiments show that rice plants are most sensitive to the damage by the BPH during the active tillering and booting stages. That provides practical information for the timing of pest control. However, it is necessary to evaluate the cumulative damage caused by varying insect population densities throughout the rice growth period under natural conditions at various localities to determine the control threshold for the BPH.

Lee and Park (1976) reported that hopperburn usually appears on a plant 40 to 60 days after it was infested by a single pair of adult insects per hill under experimental conditions. If a pair of adults are confined on a plant within 54 days after transplanting. the plant is burned and yields no grain; yield loss is 30% or less when insects are confined more than 80 days after transplanting (Table 3). Kisimoto (1975) pointed out that 10 to 20 brachypterous female adults per hill in August will cause limited hopperburn and if the density is

Table 3. Rice yield losses associated with time of infestation by the brown planthopper and with density of planting (Lee and Park 1976).

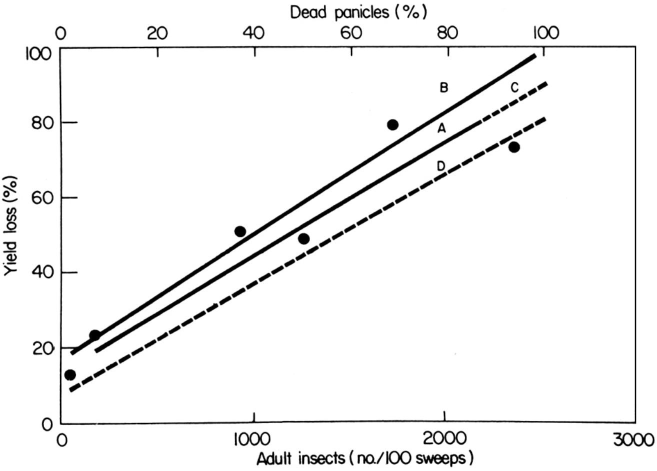
Time of infestation		1 hill/pot		4 hills/pot	
Date[a]	DT[b]	Yield (g/hill)	Yield loss (%)	Yield (g/hill)	Yield loss (%)
July 1	46	0	100	0	100
July 10	56	0	100	1	100
July 20	66	6	81	9	70
July 30	76	12	61	12	61
August 5	81	21	30	22	27
August 10	86	21	19	25	17
August 15	91	28	6	29	3
No infestation		30	0	30	0

[a] Date of transplanting: May 17. [b] Days after transplanting.

increased from 30 to 50 insects/hill, the field will be severely hopperburned. It has also been estimated that the progeny of one brachypterous female that is released 1 month after transplanting are able to kill 8 to 11 hills after heading.

In Japan Nomura (1949) and Suenaga (1959) studied the relationship between number of adults per 100 net sweeps and percentage of loss of grain yield in the field (Fig. 8). They determined the relationship at the tillering stage by walking diagonally across the field. The following equation gives: Yield loss = number of insects collected × 3.0 + 10.

Kisimoto (1975) reported that when 50 to 100 insects are caught by a water-pan trap during immigration of the BPH into paddy fields, and 30 to 50 brachypterous females of the second generation are found per 100 hills by



8. Relationship between population density of the brown planthopper and yield loss. A: Nornura (1949); B: Chubu-Kinki Agric. Exp. Stn. (1952). C: Kyushu Agric. Exp. Stn. (1957); D: Kanto-Tosan Agric. Exp. Stn. (1952). Source: Suenaga 1959.

Table 4. Relationship between degree of damage by the brown planthopper and rice yield loss (Suenaga and Nomura 1970).

Damage	Plant appearance	Panicle damage[a] (%)	Yield loss (%)
Slight	No withering; little sooty mold	25	10
Low	Little withering; much sooty mold; hopperburned areas	40	35
Medium	Withering of lower leaves; severe sooty mold; 60% lodging at the edge of hopperburned areas	45	50
High	Considerable withering; 80% lodging within hopperburned areas	70	65–70
Severe	Completely withered; few fully developed panicles in center of hopperburned area	90	> 80

[a] Number of panicles with less than 70% ripened grains.

visual count, hopperburn will occur where the brachypterous females are found. In such a case, a control program should operate during the nymphal stage of the third generation. When more than 150 immigrants are trapped, earlier control is recommended to prevent severe hopperburn.

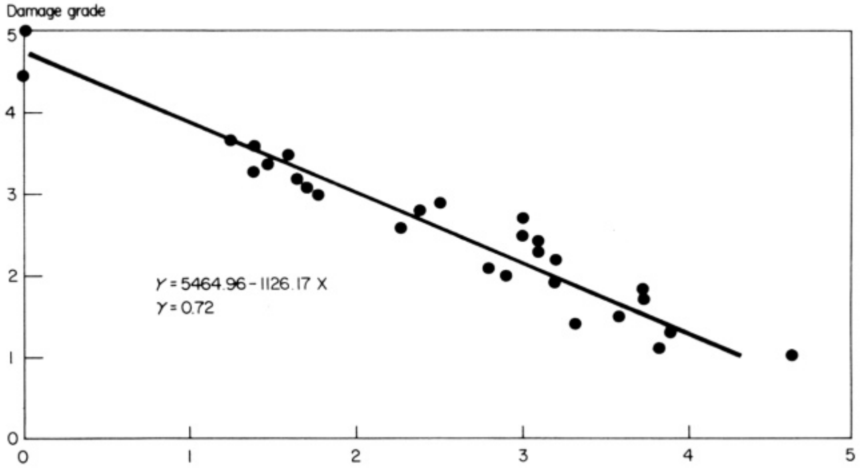
Crops that have suffered different degrees of damage

Rice entomologists commonly assess yield loss on the basis of degree of damage caused by the BPH. According to Nomura (1949), the lodging percentage of infested plants is used as a basis for assessing grain reduction due to the BPH. Plants with 100, 80, and 60% lodging had grain yields reduced by more than 80, 70, and 50%, respectively. Unhealthy-looking plants infested with a large number of planthoppers suffered from 20 to 30% yield loss.

Gifu Statistics and Survey Office in Japan (1966) and Suenaga and Nomura (1970) based five grades of damage on the appearance of infested plants. The worst infestation caused about 80% yield loss; slight infestation caused about 10% yield reduction (Table 4). Using those damage categories, a regression line, $Y = 5465 - 1126X$, was developed for assessing yield loss resulting from the BPH infestation. It indicates that every one-grade increase in damage results in a yield loss of about 1.1 t/ha or 20% of total production (Fig. 9). Similarly, rice loss is also estimated by using an index calculated from the following equation :

$$\text{Damage index} = \frac{[(1A + 2B + 3C + 4D)/4T]\ 100}{T \times 4}$$

where *A* indicates the number of tillers with the upper two leaves undamaged and the rest withered; *B,* the number of tillers with all except the flag leaf withered; *C,* the number of tillers with all leaves withered but with panicles still alive; *D,* the number of tillers with leaves, stems, and panicles all withered; and *T*, the total number of infested tillers. The percentage of yield loss in each



9. Relationship between the damage grade (see Table 4) and rice grain yield (Cheng 1976a).

damage index is calculated in Table 5. With this procedure, the damage indexes recorded in Taiwan in the first and second rice crops of 1975 were 5.9 and 15.3, and those of 1976 were 2.4 and 6.3, respectively (Department of Agriculture and Forestry, Taiwan 1974, 1975).

Nomura (1951) also tried to assess yield loss on the basis of the percentage of dead panicles, degree of panicle damage, and degrees of lodging of infested plants (Table 6). The yield loss is expressed with a multiple-regression equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$$

where X_1 is percentage of panicles dead. X_2 is degree of panicle damage, and X_3

Table 5. Relationship between damage index and yield loss (%). Department of Agriculture and Forestry, Taiwan 1972.

Damage index [a]	Yield loss (%)
10	10
20	20
30	25
40	35
50	40
60	50
70	55
80	60
90	65
100	70

[a] Damage index = [(1*A* + 2*B* + 3*C* + 4*D*)/4T]100; A. tillers (no.) with 2 upper leaves undamaged, all other leaves withered; *B*. tillers (no.) with all leaves withered except flag leaves, *C*. tillers (no) all leaves withered, panicles alive; *D*, tillers (no.) with leaves, stems, and panicles all withered; *T*. total no. of infested tillers.

Table 6. Relationship between plant damage caused by brown planthopper and rice loss (Nornura 1951).

Dead panicles[a] (%)	Panicle damage[b]	Lodging[c]	Grain loss (%)
100	70	50	80
100	50	40	70
70	50	40	65
70	40	30	55
50	40	30	50
50	20	20	40
30	20	20	30
10	10	10	20
5	5	5	15

[a] $\frac{\text{No. dead panicles} \times 100}{\text{Total no. panicles}}$ [b] Damage index: 0 = no damage; 100 = panicles and grains 100% empty; damage index/all panicles investigated. [c] 0 = plants stand upright; 100 = –panicle ends touch the ground.

is degree of lodging of the infested plants. Nomura calculated the yield loss due to the BPH according to the following equation:

$$Y = 10.898 + 0.126X_1 + 0.470X_2 + 0.306X_3.$$

The method mentioned above is generally believed to be adaptable to those areas where the BPH infestations occur mainly after heading. Yield loss caused by the BPH before the heading stage could be assessed through the methods used for assessing yield loss from whitebacked planthopper infestation (Gifu Statistics and Survey Office 1966).

ECONOMIC INJURY LEVEL FOR THE BPH

The economic injury level (EIL) is the lowest population density that will cause injury sufficient to justify artificial control measures (Stern et al 1959). It is a basic criterion for economic control. However, it must be recognized that the EIL is a dynamic parameter, varying with a number of factors. For a given plant variety and a particular geographical area, the EIL changes with a change in (1) the market value of the crop; (2) the cost of artificial control measures; and (3) the environmental factors, such as tolerance of the plant and feeding of the insect (Michael and Pedigo 1974; Pedigo 1972).

Recently several rice entomologists have attempted to determine the EIL for the BPH. They usually caged pests at constant densities on potted plants at various stages of growth for certain periods, or applied insecticides to check insect populations when the target populations reached certain population levels. As pointed out, the relationship between insect population levels and rice yield losses varies greatly depending on the stage at which the plant is infested and the rice variety used. Before an accurate EIL was developed, a crude control threshold based on observations and experience had been proposed as

Table 7. Relation of brown planthopper population densities to grain yield and net return. Chiayi Agriculture Experiment Station, Taiwan, 1976, 2nd crop.

Insect population[a]	Tainan 5			TN1		
	Insecticide application (kg/ha)	Grain yield (t/ha)	Net return (NT $/ha x 1000)	Insecticide application (kg/ha)	Grain yield (t/ha)	Net return (NT $/ha x 1000[b])
Weekly spray	12	5168	44 43	12	6170	49.79
10/hill	2	4370	47.76	3	5298	51.88
20/hill	2	4222	46.05	3	5187	50.72
40/hill	1	4091	45.80	2	4938	49.53
80/hill	0	3834	44.09	1	4607	47.12
160/hill	0	3672	42.23	0	4089	49.93

[a] Treated with 75% Orthene W.P. at 0.8 kg/ha when the number of insects per hill reached its target population level. [b] Net return: value of rough rice minus cost of insecticide and of its application. Cost, 11.5 NT $/kg for Tainan 5 rice and 10 5 NT $/kg for TN1 rice Cost for application: 450 NT $/ha, 75% Orthene W.P. 800 NT $/ha.

a rough guideline for practical pest control operations (Yen and Chen 1976). In the Philippines (Custodio et al 1974) the recommended threshold is 1 adult, hill up to 20 days after transplanting (DT); 10 nymphs/hill from 20 to 40 DT, and 20 adults or nymphs/hill thereafter. About 20 and 25 planthoppers/hill, a generally accepted threshold in several tropical countries, seems to be too high to minimize yield loss, because grain yield in plots that reached the EIL were reduced at 15–20% (Cheng 1976b: Table 7). Available data indicated the control threshold for the BPH should be about 10 insectsihill.

In Japan, the economic threshold for the BPH has also been determined by predicting whether the insect population would be able to reach a “tolerance-density” or cause loss by reaching the “tolerance-level of damage”, so that the BPH could be controlled before the population passed the “tolerance-density’’ level. Sugino (1975) calculated population levels for the first generation of the planthoppers that he considered could cause a yield loss greater than the “tolerance-level of damage” (3.5% of total grain production) during later generations. Those population levels are reached when (1) the number of insects in the generation preceding the one that has the highest population peak in from 2 to 5/hill, (2) when the highest number of insects/hill is about 5 during the second generation after immigration (first 10 days of August), or (3) when the number of brachypterous female adults reaches 0.25–0.33/hill in the second generation after immigration (first 10 days of August). Kulshreshtha and Kalode (1976) suggested that the threshold of economic injury for the insect up to 70 days after planting, based on the growth pattern of populations of the BPH in India, is between 2 and 5 nymphs and adults per hill.

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CHEMICAL CONTROL

Chemical control of the brown planthopper

E. A. Heinrichs

The most commonly practiced method of controlling the brown planthopper (*Nilaparvata lugens* Stål) is through the application of insecticides. Of the various leafhopper and planthopper species that attack rice, the brown planthopper is one of the most difficult to kill. Biotypes with differential responses to various sources of genetic resistance vary in their susceptibility to insecticides. Several methods of applying insecticide have been developed but foliar sprays are still the most commonly used. Proper timing and placement of insecticides are important in achieving effective control. Insect resistance to insecticide, which has occurred in limited cases, is expected to increase with increased use of insecticides in the tropics. Resurgences of the brown planthopper that result in total yield loss occur when certain insecticides are excessively used. Resurgences are more common when insecticides are applied as a foliar canopy spray than when they are broadcast.

CONTROL OF THE BROWN PLANTHOPPER *Nilaparvata lugens* (Stål) has depended primarily on the application of insecticides. In Taiwan, more than 50% of the insecticides applied to rice are directed at the brown planthopper (BPH) (pers. comm. with C. Y. Hsieh, Joint Commission on Rural Reconstruction, Taiwan). The evolution of the chemical control of the BPH is exemplified by the experience in Japan where the insect has had economic significance for many years.

Available records of leafhopper and planthopper outbreaks in Japan begin in the 7th century. The average time interval between recorded outbreaks has decreased from 22.5 years in the old period to 5.6 years in the middle and to 1.4 years in the recent period (Miyashita 1963). Unfortunately, no such data are available for the tropics.

The evolution of chemical control since the later part of the middle period has been recorded by Suenaga and Nakatsuka (1958) and Matsuo (1961). The use of whale oil, found effective in 1670, had spread throughout the country by 1840. Kerosene began to replace whale oil in 1897. DDT dust was the first post-World War II insecticide to replace kerosene and it was soon replaced by

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BHC. Organophosphorus insecticides were first used in 1952. Diazinon and malathion soon replaced parathion. Since 1964 carbamate insecticides have been used in Japan. A similar evolution is occurring throughout tropical Asia.

The use of insecticides for the control of the BPH is not always effective and can produce undesirable side effects.

This paper discusses some reasons why farmers sometimes find insecticides ineffective in controlling BPH, and some of the solutions research has provided for increasing the effectiveness of chemical control.

INSECTICIDE EVALUATION AND RECOMMENDATIONS

The toxicity of new insecticides to the BPH is first determined in the laboratory. Promising compounds are further tested in the field. Outside of Japan, most of the companies that synthesize and develop insecticides commercially are in Europe and the United States where the BPH does not occur. As a result, most of the basic testing to determine the suitability of the compounds for use against the BPH is conducted not by the manufacturer but by national or regional (state or province) experiment stations in Asian nations.

Insecticides have been extensively tested in Japan and a large number have been identified as effective against the BPH (Iwata 1970). Numerous insecticides were reevaluated in the field in Taiwan (pers. comm. with C. H. Cheng, Chia-yi Agricultural Experiment Station, Chia-yi, Taiwan, and C. C. Chen, Taiwan Plant Protection, Taichung, Taiwan). Carbofuran granules and acephate, BPMC, Hokbal, MIPC, and propoxur sprays were found to be most effective. Field evaluations have been conducted in India (Chelliah and Subramanian 1972), Korea (pers. comm. with J. S. Park, Institute of Agricultural Sciences, Office of Rural Development, Suweon, Republic of Korea) and Malaysia (Lim 1971; MARDI 1976).

Laboratory and field evaluations in the Philippines have identified several insecticides effective against the BPH. Before being field tested, the insecticides are subjected to four laboratory tests at the International Rice Research Institute (IRRI): 1) direct contact toxicity with Potter's spray tower, 2) residual contact toxicity of foliar sprays, 3) paddy-water application, and 4) root-zone application.

Table 1 shows the result of a retest of Philippine recommended insecticides applied as foliar spray. Most of the insecticides are effective at 1 day after treatment, but at 7 days their effectiveness begins to drop, indicating short residual activity, even in the greenhouse. Perthane has the longest residual activity.

Control with foliar sprays is generally poorer in the field than in the laboratory; it varies between 40 and 80% (Table 2). When insect populations are large, 80% control is not sufficient and repeated applications are necessary.

The synthetic pyrethroids are the most recent class of insecticides developed for agricultural use. At low rates they reportedly are active against the lepi-

Table 1. Knockdown and residual effects of Philippine recommended insecticides applied as foliar spray for control of brown planthopper *Nilaparvata lugens* **IRRI greenhouse, 1977.**

Insecticide [a]	Mortality [b] (%)		
	1 DAT	7 DAT	14 DAT
Perthane	100 a	60 a	10 cde
Carbophenothion	100 a	42 abc	10 cde
Metalkamate	100 a	18 c	20 abcd
Azinphos ethyl	98 a	50 ab	37 a
Monocrotophos	98 a	20 c	6 de
Acephate	98 a	18 c	8 de
MIPC	95 a	22 c	18 abcd
Chlorpyrifos	70 b	18 c	23 abcd
BPMC	58 b	22 c	10 cd
MTMC	22 d	28 bc	16 abcd

[a] All insecticides were applied at 0 75 kg a.i./ha, except carbofuran which was applied at 0.25 kg a.i./ha. [b] Mean of four replications, each consisting of 10 Insects caged on a treated plant, adjusted using Abbott's formula DAT = days after insecticide treatment when insects were placed on treated plants. Mortality was determined at 48 hours after caging. For each DAT a fresh group of insects was used. In any column, means followed by the same letter are not significantly different at the 5% level (DMRT).

dopterous species. Greenhouse tests indicated that when applied as foliar spray they are no more effective than carbofuran (Table 3).

Laboratory evaluation of insecticides applied in paddy water indicate that carbofuran, which has the longest residual activity. most effectively controls BPH (Table 4). It is also the most effective when applied to the root zone (Table 5).

Table 6 summarizes the results of experiments at IRRI to determine the suitability of insecticides for use as direct contact spray, as foliar spray, and

Table 2. Field evaluation of insecticides for the control of the brown planthopper. IRRI, 1976 wet season.

Insecticide [a]	Brown planthoppers[b]					
	Before 1st insecticide application (no.)	Four days after 1st insecticide application (no.)	Control (%)	Two days after 2nd insecticide application (no.)	Control (%)	Average control (%)
Metalkamate	2678	304	89	67	78	84
Monocrotophos	3502	659	81	192	70	76
Carbofuran	2914	835	71	431	48	59
Carbophenothion	2892	1785	38	375	79	59
BPMC	3182	1644	48	353	79	59
Acephate	3091	1414	54	588	58	56
MIPC	2318	1124	52	571	49	51
Methyl parathion	2991	2153	28	737	66	47
Endosulfan	2903	1935	33	1059	45	39
Control	2481	6183		5129	–	–

[a] All insecticides were applied at 0.75 kg a.i./ha, except carbofuran which was applied at 0.25 kg a.i./ha. A total volume of 1,022 liters of water plus insecticide was sprayed per hectare. The nozzle was held 5–7.5cm from the water surface. [b] Collected with a D-Vac suction machine. Second application was 5 days after the first. Percentage of control was based on population count 4 days after first application.

Table 3. Knockdown and residual effects of insecticides applied as foliar spray at low rates against the brown planthopper. IRRI greenhouse, 1976.

Insecticide[a]	Formulation[b]	Concentration[c] (%)	Brown planthopper mortality[d] (%)		
			1 DAT	7 DAT	14 DAT
Carbofuran	20 F	0.02	100 a	100 a	100 a
		0.004	100 a	82 b	21 b
		0.0002	47 b	6 def	18 bc
NRDC 149	10 EC	0.02	100 a	26 cd	18 bc
		0.004	30 bcd	11 cdef	13 bcd
		0.0002	9 ef	11 cdef	5 cde
WL 41 706	30 EC	0.02	97 a	30 c	13 bcd
		0.004	20 cde	9 cdef	3 de
		0.0002	15 def	8 def	7 bcd
NRDC 161 (Decis)	2.5 EC	0 02	92 a	14 cde	16 cde
		0.004	12 def	11 cdef	20 b
		0.0002	5 fg	8 def	14 bcd
WL 43775	30 EC	0.02	48 b	14 cde	11 bcd
		0.004	10 ef	8 def	7 bcd
		0.0002	12 def	0 f	12 bcd
Perthane	45 EC	0.02	38 bc	7 def	5 cde
		0.004	12 def	5 def	5 cde
		0.0002	10 ef	5 def	8 cde

[a]Applied at the rate of 12.5 ml solution per 45-day-old plant. [b]F = flowable, EC = emulsifiable concentrate. [c]0.02 = 0.4 kg a.i./ha; 0.004 = 0.08 kg a.i./ha, 0.0002 = 0.004 kg a.i./ha. Carbofuran is a carbamate, perthane an organophosphate, and the others pyrethroids. [d]Mean of 4 replications, each consisting of 15 insects caged on plants; adjusted using Abbott's formula. In a column means followed by a common letter are not significantly different at the 5% level. DAT = days after treatment, when insects were placed on treated plants

Table 4. Effect of paddy water application of insecticides at 1 kg a.i./ha on control of the brown planthopper. IRRI greenhouse, 1976.

Insecticide	Formulation[a]	Brown planthopper mortality[b] (%)		
		1 DAT	7 DAT	14 DAT
Carbofuran	3 G	100 a	92 a	26 b
Metalkamate	3 G	100 a	48 c	26 b
Disulfoton	5 G	100 a	31 c	—[c]
FMC 27289	5 G	100 a	5 d	19 b
Diazinon	10 G	66 bc	13 cd	8 c
BPMC	4 G	62 bcd	32 c	30 b
MTMC	5 G	59 bcd	13 cd	0 d
Aldicarb	10 G	59 bcd	0 d	17 b
Padan	10 G	56 cde	0 d	—[c]
Dyfonate	5 G	48 bcde	26 c	0 d
Chlorfenvinphos	10 G	14 efgh	0 d	11 c
Triazophos	5 G	14 efgh	0 d	0 d
Chlordimeform	5 G	10 fgh	0 d	—[c]
Perthane	5 G	10 fgh	0 d	0 d

[a]G = granules. [b]Means of three replications; each consisting of 10 insects caged on a treated TN1 plant; adjusted using Abbott's formula. DAT = days after treatment, when insects were caged on treated plants. Mortality was determined at 48 hours after caging. In a column, means followed by a common letter are not significantly different at the 5% level. [c]Plants were hopperburned.

Table 5. Evaluation of insecticides applied in the root zone at 1 kg a.i./ha for control of brown planthopper. IRRI greenhouse. 1976.

Insecticide	Formulation[a]	Brown planthopper mortality[b] (%)			
		1 DAT	12 DAT	26 DAT	32 DAT
Carbofuran	20F	100a	73a	16a	24a
FMC27289	48EC	100a	60a	27a	24a
Methamidophos	50EC	50 b	13 bcd	29a	–[c]
AC64475	5G	43 bc	60a	13a	15a
Methomyl	20EC	23 cd	20 bc	13a	–[c]
Carbofuran	3G	13 d	60a	29a	32a
Acephate	75SP	10 de	8 bcd	22a	–[c]
Methomyl	50DP	5 de	5 cd	15a	13ab
Metalkamate	3G	0 e	12 b	11a	8ab

[a] F = flowable, EC = emulsiflable concentrate, G = granules, SP = soluble powder, DP = dispersible powder. Flowable and emulsifiable concentrates were injected into the root zone with a syringe, and granules were placed in gelatin capsules and injected by hand. [b] Mean of four replcations, each consisting of 10 Insects caged on a treated TN1 plant; adjusted using Abbott's formula Mortality was determined at 48 hours after caging. DAT = days after treatment, when Insects were caged on treated plants. In a column, means followed by a common letter are not significantly different at the 5% level. [c] Plants dead due to brown planthopper burn.

as applied to the paddy water or to the root zone (E. A. Heinrichs, and S. L. Valencia, unpubl. data). Insecticide activity varies with the type of application. Few insecticides are effective when applied to paddy water or the root zone. Carbofuran's effectiveness in all four tests, however, indicates its versatility against rice pests. Many insecticides are ineffective as a direct contact spray in Potter's spray tower but are effective as a residual contact foliar spray. The pyrethroids are all highly effective as contact poisons.

Results of insecticide evaluation programs have been used as a guide in developing control recommendations for BPH in various Asian countries. At least 31 different insecticides are recommended throughout Asia, not only because of their effectiveness but also because of their commercial availability and safety. BPMC, carbaryl, carbofuran, and diazinon are the most widely recommended. Carbamates are primarily recommended in Japan where insects have been found resistant to the phosphates.

SELECTIVE TOXICITY

Species

The BPH generally is more difficult to kill with insecticides than are other hoppers in rice fields. In both laboratory and field tests at IRRI, the green leafhopper *Nephotettis virescens* Distant was much more sensitive to insecticides than the BPH. Choi and Lee (1976) and Fukuda and Nagata (1969), who studied the toxicity of several insecticides to the BPH, the whitebacked planthopper *Sogatella furcifera* Horvath, and the small BPH *Laoddphax striatellus* Fallen, found the BPH to be the least susceptible.

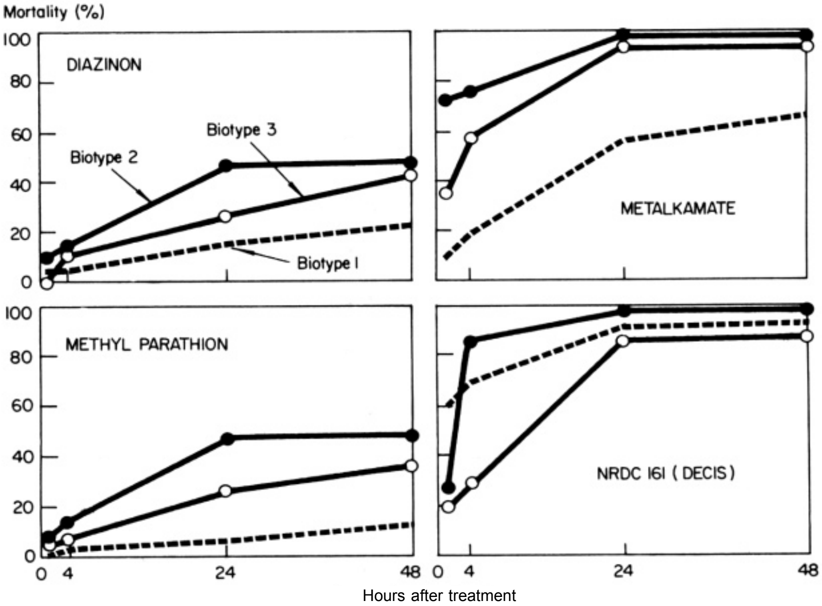
Table 6. Activity of insecticides against the brown planthopper as tested by four application methods. IRRI laboratory. (E. A. Heinrichs and S. Valencia, unpubl.)

Insecticide [a]	Activity [b]			
	Contact toxicity	Foliar spray	Paddy water	Root zone
Carbamates				
BPMC	+	+	-	-
Carbaryl	-	+	+	-
Carbofuran	+	+	+	+
Metalkamate	+	+	+	-
Methomyl	+	-	+	-
MIPC	+	+	+	-
MTMC	+	+	-	-
Padan	-	-	-	-
Organophosphates				
Acephate	-	+	+	-
Azniphos ethyl	-	+	-	-
Carbophenothion	-	+	-	-
Chlorfenvinphos	-	-	-	-
Chlorpyrifos	-	+	-	-
Diazinon	-	+	-	-
Methyl parathion	-	-	+	-
Monocrotophos	+	+	-	-
Vamidothion	-	+	-	-
Organochlorines				
Endosulfan	-	+	-	-
Perthane	-	+	-	-
Pyrethroids				
NRDC 149	+	+	-	-
NRDC 161	+	+	-	-
WL 43467	+	+	-	-
Permethrin	+	+	-	-

[a] Applied as a 0.01% spray in the contact toxicity test in Potter's spray tower, 0.04% spray equal to 0.75 kg a.i./ha in the foliar spray test, and at 1.0 kg a.i./ha in the paddy water and root-zone tests. [b] + = effective; mortality counts of 80% or higher; - = not effective. Mortality readings in the contact toxicity experiments taken at 48 hours after treatment. Readings in the foliar spray, paddy water, and root-zone experiments were at 1, 7, and 14 days, respectively, after brown planthoppers were caged on treated plants.

Stage and sex

The age of adult insects influences their sensitivity to insecticides (Sugimoto and Yamazaki 1970). The susceptibility of adults was studied at 1 to 13 days after emergence. The mortality of females at 3 hours after treatment was lowest—15% at 4–5 days; it was 67% at 1 day and 94% at 13 days. Uebayashi and Osaki (1968) studied the susceptibility to several insecticides of the BPH at various stages; they ranked the adult male to be more susceptible than the adult female, which was more susceptible than nymphs of the 4th or 5th instars. Studies by Fukuda and Nagata (1969) indicated no difference between males and females.



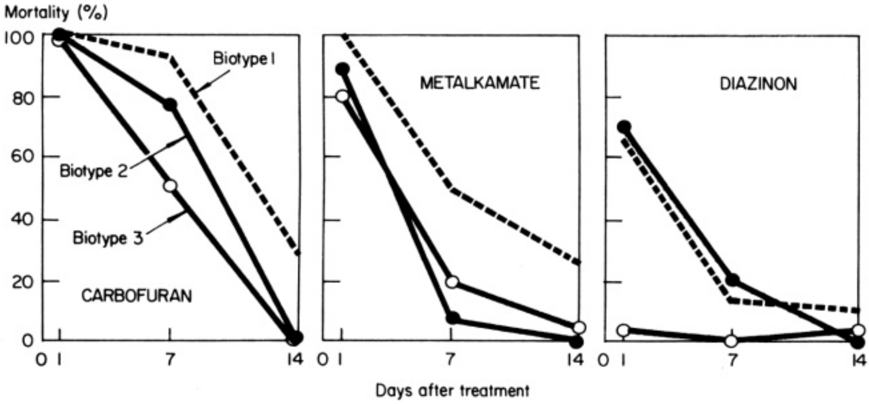
1. Mortality of three brown planthopper biotypes treated with 0.04% contact spray in a Potter's spray tower at indicated hours after treatment. IRRI, 1977 (E. A. Heinrichs and S. Valencia, unpubl. data).

Insecticide classes

Studies in Japan (Fukuda and Nagata 1969) indicated that carbamates are the most toxic of the compounds tested, while the organophosphate and chlorinated hydrocarbon insecticides are the least. In general, organophosphates have more selective toxicity to the various hopper species; carbamates and chlorinated hydrocarbon insecticides are not selective. Choi and Lee (1976) reported similar results.

Biotypes

Three BPH biotypes with differential reactions to genetic resistance from various sources have been selected in the greenhouse at IRRI (1976). Studies in 1976 indicated that the biotypes vary biologically (IRRI 1977). Their responses to insecticides differ, depending on the method of application and the insecticide. Biotypes 2 and 3 are generally more susceptible than biotype 1 to insecticides sprayed directly on the planthoppers as a contact poison in a Potter's spray tower (Fig. 1). When insecticide granules are applied to paddy water, biotype 3 is distinctly less susceptible than biotype 1 to the carbamate insecticides carbofuran and metalkamate, and to the phosphate insecticide diazinon (Fig. 2).



2. Knockdown and residual activity against three brown planthopper biotypes of insecticide applied as granules at 1 kg a.i./ha. IRRI laboratory, 1977 (E. A. Heinrichs and S. Valencia, unpubl. data).

FIELD APPLICATION

Application methods

To make chemical control of BPH more economical, application methods have been refined. Foliar sprays have been most commonly used in the tropics, and dusts most commonly used in Japan. Sprays and dusts are readily washed off the plants by the frequent monsoon rains in the tropics; thus, they have been replaced to some extent by easy-to-apply granules. Because of their effectiveness and wide-spectrum activity, systemic granular insecticides have gained popularity in recent years. New approaches to the use of chemicals against the BPH are being developed.

Seed treatment. Treatment of seeds with insecticides was first tested at IRRI in 1968 in a direct-seeded crop (IRRI 1968). It was further tested in 1971 in the greenhouse, in an upland field, and in a lowland field (IRRI 1972). Carbofuran at 1 kg a.i./ha provided protection against BPH caged for 3 weeks on treated plants in the greenhouse and in the upland field test, but it was ineffective in the lowland field. Soaking seeds in a carbofuran solution for 12 hours before planting was ineffective even at 5,000 ppm, which is equivalent to 4 kg a.i./100 kg seed. Seed treatment thus has not proven to be an effective means of control except, possibly, for short periods in the nursery.

Placement in furrows. An alternative to seed treatment was placing the insecticides 2 to 3 cm below the seed in upland rice before planting (IRRI 1974). Carbofuran or lindane + MTMC, so applied, followed by a side-dressing at 55 days after seeding (DS), each at 2 kg a.i. ha, controlled BPH up to 58 DS. Hopperburn in the carbofuran-treated plot was 1%; in the plot with lindane + MTMC it was 4%; the untreated control was 93% hopperburned at 66 DS.

Seedling soak and root coat. Soaking seedlings in a 1,300 ppm carbofuran solution for 24 hours before transplanting provided almost 100% control for up to 40 days in an air-conditioned insectary; in the field, however, such treatment was ineffective (IRRI 1972). In field studies in 1972 (IRRI 1973) some control of BPH for less than a week was obtained when seedlings were soaked 24 hours in a 1,000 ppm carbofuran solution. Adding 29, methyl cellulose in the solution as an adhesive increased mortality, but was not enough to provide more than 5 days of control.

Foliar sprays. For BPH control in the tropics insecticides are most commonly applied as foliar spray. Because the insect feeds at the base of the plant near the water level, and outbreaks generally occur after a dense canopy has been formed, control with a canopy spray is difficult. In Malaysia, the BPH was completely controlled at 3 days after spraying when the spray pattern was directed toward the plant bases; control was only 57% when the spray was directed to the canopy (Heong 1975). Studies at IRRI in 1977 (E. A. Heinrichs and G. B. Aquino, unpubl.) indicate that insecticides vary in effectiveness depending on place of application. Control by metalkamate increased by 20% and that by Perthane by 30% when the insecticides were applied to the plant bases instead of on the canopy. For monocrotophos, there was no such difference. In previous studies (IRRI 1968) the effectiveness of monocrotophos sprays in controlling the BPH was attributed partly to the systemic action of the insecticide. Movement of a systemic insecticide down to the leaf sheath would make application of sprays to the base of the plant less necessary.

Phosphamidon and dichlorvos were applied as high-volume ground sprays, and ultra low-volume aerial sprays to a 70-day-old rice crop in Indonesia in 1970 (Singh 1975). Both insecticides were effective against BPH when applied as ground sprays, but only dichlorvos was effective when applied as aerial spray. The lack of effectiveness of the phosphamidon aerial treatment was attributed to the failure of the spray to reach the bases of the plants. Because of the fumigant action of dichlorvos, its placement at the plant bases was not essential.

It is laborious and time consuming to spray the base of every plant with a single-nozzle sprayer. To shorten application time, IRRI developed a six-row sprayer with drop nozzles (Fig. 3). Its use provides more effective control than does the use of canopy sprays.

Granular broadcast. Broadcasting of granules has become a popular method of BPH control. It has several advantages over foliar sprays and dusts. It is less laborious and more rapid than foliar sprays and requires no equipment. Granules penetrate the dense canopy and reach the area where the planthoppers feed; they have longer residual activity (Takai 1971).

Granules were first used in Japan about 15 years ago (Okamoto 1970). Early work at IRRI (Pathak et al 1967) with a granular combination of carbaryl and gamma-BHC applied at the rate of 3 kg a.i. ha controlled the BPH and produced yields twice those of treatments with a 0.04% endrin foliar spray.

3. Six-row sprayer for applying insecticide to the base of the rice plants. IRRI, 1977.

which failed to reach the feeding site. Gamma-BHC, however, was more effective against the stem borers than against the BPH. With the development of diazinon granules, simultaneous control of stem borers, leafhoppers, and BPH was achieved (Bae and Pathak 1969). Diazinon is still widely recommended. In certain countries carbofuran granules are more popular than diazinon because their residual and systemic activity makes them effective against most rice pests (IRRI 1975).

The action of granular insecticides in paddy fields has been described by Koyama and Tsurumachi (1968), Toyoda (1970), and Koyama and Tsurumachi (1971). Koyama (1971) classified the mode of action of granules into three groups: 1) a fumigation effect as insecticide vapor rises from the paddy water, 2) a systemic effect caused insecticides taken up by the roots to be moved through the stem to the leaves, and 3) a direct systemic effect through the stem and leaves that come in contact with the insecticide. The fumigation vapors act as a contact poison; the systemics kill the insect when it sucks the plant sap. Insecticides in the first group have a high vapor pressure, those in the third group have high water-solubility, and those in the second have intermediate characterisitics. Toyoda (1970) applied BPMC, MIPC, and diazinon in a paddy with no standing water and achieved a quick knockdown of the BPH. The result indicates that certain granular insecticides might be effective under upland conditions because of the fumigation effect.

Microgranules that readily stick to the leaves were developed to act as insecticides of the third group. Koyama (1971) reported that microgranules are more effective than ordinary granules, but tests at IRRI indicated that they have no advantage over ordinary granules (IRRI 1974). Both effectively controlled BPH nymphs. but neither controlled the grassy stunt virus vectored by the BPH.

Root-zone application. Because microbes and chemicals rapidly degrade the insecticide in the paddy water and rains wash it off the rice plants, three or four applications are generally required to provide season-long control of rice pests. Thus the concept of root-zone application in which the insecticide is placed in a protected area near the roots was developed.

In field tests, carbofuran, which was most effective in the root zone, controlled the BPH for up to 40 days when applied as 1 capsule/hill at the rate of 1 kg a.i./ha at transplanting (Pathak et al 1974). Plant residues, determined by gas chromatography, were much higher when carbofuran in gelatin capsules was applied in the root zone than when it was broadcast (Aquino and Pathak 1976). In Korea, Choi et al (1975) tested the effectiveness of root-zone application 3 days after transplanting (DT) and found that carbofuran and BPMC controlled the BPH for up to 80 days after treatment. Tests in Indonesia (Sama and van Halteran 1976) have also indicated that carbofuran and BPMC provide control but for a shorter period than in Korea. Because hand placement of encapsulated insecticide is laborious, IRRI engineers have designed equipment for root-zone application. A liquid band applicator was compared with the capsules for BPH control. At 45 DT, the two methods gave similar control (Table 7).

Soil incorporation. Incorporation of insecticide into the soil is a modified type of root-zone application, but it is not quite as effective as placing the insecticide in each hill. However, the method is much easier. A farmer only needs to spread the granules and incorporate them at the last harrowing. BPH generally build up slowly in a crop and reach their peak near harvest time. One root-zone application is not expected to provide control until harvest. One application at transplanting may prevent insect buildup to damaging levels, but it has not controlled late-season migrations from adjacent hopperburned areas in IRRI tests. Root-zone application appears to be most useful in locations

Table 7. Brown planthopper populations after carbofuran had been applied in gelatin capsules or with a liquid band applicator to the root zone of the rice variety IR20. IRRI, 1976 wet season.

Treatment [a]	Rate (kg a.i./ha)	Brown planthopper (no./10 sweeps)[b]	
		36 DT	45 DT
Capsule	2	9 a	1 a
Liquid applicator	2	8 a	6 a
Capsule	0.5	13 ab	34 b
Liquid applicator	0.5	32 b	71 b
Control		59 c	302 c

[a] 3% granules were used in the capsule treatment and 20% flowable in the liquid application. Insecticide was applied once at 5 days after transplanting (DT). [b] In a column, means followed by a common letter are not significantly different at the 5% level.

where BPH infestations begin early in the crop season and migration from adjacent fields does not occur.

TIMING

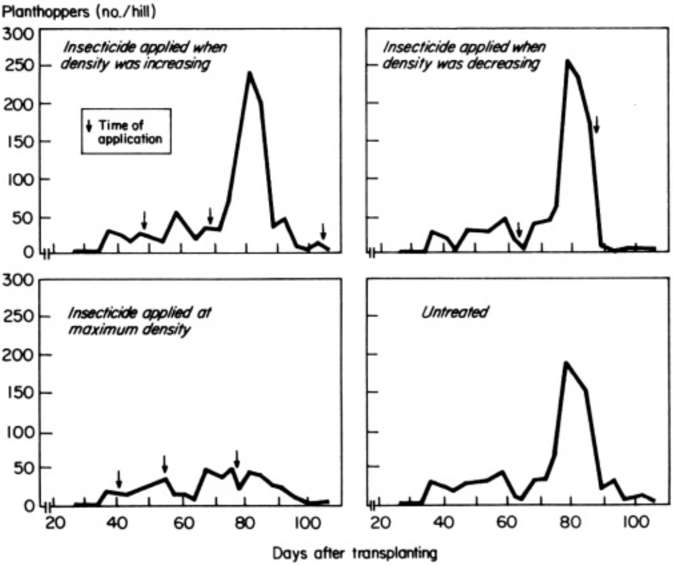
Proper timing of insecticide application can minimize costs. In the tropics where planthoppers are active throughout the year, generations usually overlap. The presence at the same time of several stages of the insect complicates control. Eggs inside the plant are difficult to kill, and most insecticides lack sufficient residual activity to kill the nymphs that hatch from eggs several days after application and whose population often increases thereafter.

In Japan and Korea, where the BPH annually immigrates, early generations have little overlap and control is rather easy. But if treatment is delayed until late in the season, repeated applications are necessary. Studies in Japan by Nagata et al (1973) indicated that when the insecticide was applied at the proper time, only one application per crop was necessary. MIPC granules broadcast on 7 August to control adult brachypterous females of the second generation, or on 3 September to control females of the third generation, reduced the planthopper population to an extremely low level, and kept it at that low level throughout the crop period. However, application on 15 August during the oviposition period, or on 27 August before nymphal hatch was complete, increased the BPH population and caused hopperburn in early October.

In Korea, BPH immigration dates are used to determine time of insecticide application. Studies in Korea (pers. comm. with J. O. Lee, Institute of Agricultural Sciences, Office of Rural Development, Suweon, Republic of Korea) indicate that the BPH population increases rapidly about 5 weeks after migration, and insecticide application is scheduled just before the increase. Lee also studied the relationship between stage of plant growth at the time of initial infestation and yield losses. One pair of BPH per hill beginning on 1 July caused 100% loss; infestation beginning on 15 August caused only 3% loss.

In the tropics, where continuous and staggered plantings are common, timing is much more difficult. When insect populations are high in mature crops, the insects may migrate to the nursery at harvest. Heavy populations can inflict severe damage on young plants, and cause transmission of the grassy stunt virus. When a migratory population is absent in the Philippines, buildup within a crop is gradual and hopperburn generally occurs near harvest.

In an experiment at IRRI, MIPC was applied as foliar spray 1) during hatching when nymphal density was increasing, 2) at peak nymphal density when third instar nymphs were predominant, 3) and when nymphal density was rapidly decreasing and the adult population was increasing (IRRI 1973). Only the application at maximum nymphal density in each generation provided control (Fig. 4). Thus, three applications were required. Control in the first treatment was poor because eggs that had not been killed hatched and the insecticide did not remain effective long enough to kill the newly hatching



4. Density of brown planthopper nymphs on IR20 in relation to timing of insecticide (MIPC at 0.04%) application. IRRI, 1972 wet season.

nymphs. In the third treatment, the insect population increased because oviposition took place before the treatment and nymphs hatched after the insecticide was no longer active.

From tests in Taiwan conducted by C. H. Cheng, Chia-yi Agricultural Experiment Station, Chia-yi, one application of carbofuran granules at 64 DT provided control and gave a yield equal to that obtained with three applications and double that in the control plots (pers. comm. with C. Hsieh, Joint Commission on Rural Reconstruction, Taipei, Taiwan). That one application coincided with the maximum nymphal population stage of the second generation.

NOVEL MEANS OF CHEMICAL CONTROL

Insecticides are commonly known to kill insects by their action as a contact or stomach poison, or by fumigation. Research in recent years has identified some novel approaches to BPH control that are of great interest. Chemicals that act as feeding and oviposition inhibitors, ovicides and as insectistatic compounds have been identified.

Feeding inhibition

Sogawa (1971) evaluated more than 50 amino acid derivatives to determine their ability to inhibit BPH feeding. Several aromatic amines occurring in plants suppressed BPH feeding. Further studies by Kurata and Sogawa (1976) indicated that solutions containing 100 ppm of phenethylamine hydrochloride, tyramine hydrochloride, or hordenine sulfate inhibited feeding by 55, 73, and 73%, respectively.

Chlordimeform, whose chemical structure is similar to that of aromatic amines, suppressed feeding by the BPH at 10 ppm and above (Hirata and Sogawa 1976). Mortality at 10 ppm was similar to that of starved planthoppers.

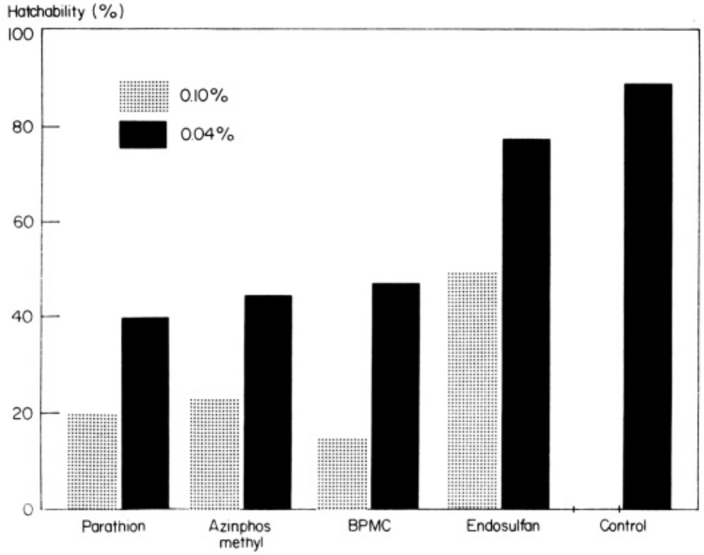
Inhibition of oviposition, and ovicides. Chlordimeform granules applied to paddy water suppress oviposition (Moriya 1976). Wettable powder applied to the paddy water at 18 ppm decreased oviposition by 90%. Nagata and Moriya (1975) found that contact and oral toxicity of chlordimeform were negligible, but that dipping roots in a chlordimeform solution inhibited oviposition.

Nagata and Moriya (1975) also found that dipping roots in a 10 ppm chlordimeform solution reduced hatching by 50%. Hatching nymphs escaped from the plants and starved to death. Ito and Saito (1973) tested the ovicidal activity of several systemic insecticides applied as root dips. Paraoxon, the most toxic, caused 88% egg mortality at 4 ppm. Studies by Toyoda (1968) and Israel et a1 (1968) indicated that insecticides were selectively toxic to BPH, whitebacked planthopper, and green leafhoppers, and that their selectivity differed. Toyoda found propoxur, MIPC, and MPMC applied to paddy water to be the most effective ovicidal agents against the BPH. Lethal doses were similar to those used in normal farming practices.

Preedasuvan and Pura (1973) sprayed several insecticides at rates of 0.08, 0.04, and 0.10% on plants containing BPH eggs. Egg mortality increased with insecticide concentration. Among the most effective ovicides were BPMC, azinphos methyl, and parathion (Fig. 5). Laboratory studies have indicated the potential of certain insecticides as BPH ovicides. The effectiveness of such ovicides in the field has not been determined.

Insectistatic compounds

Agents that diminish insect populations by suppressing growth and reproduction rather than by causing rapid mortality (as do conventional insecticides) are called insectistatics (Levinson 1975). In Japan, isoprothiolane, a fungicide recently developed to control blast, reportedly has insectistatic properties against the BPH (Miyake 1975). Newly hatched nymphs placed on plants growing in water treated with isoprothiolane slowly died between the third- and fifth-instar stages. Most were dead within 2 weeks of hatching. When third-instar nymphs were reared on treated plants, adults that emerged had short life spans and low oviposition rates. Both adults and nymphs had low probing frequency on treated plants. Isoprothiolane, however, is not promising as a compound for control of BPH when population densities are high (pers. comm. with J. Hirao, Kyushu National Agricultural Experiment Station, Japan). Additional field research will indicate the applicability of insectistatic compounds for BPH control.



5. Effect of two concentrations of insecticides sprayed on infested plants on the hatchability of brown planthopper eggs. Laboratory study (Preedasuvan and Pura 1973).

RESISTANCE TO INSECTICIDES

Most data on the resistance of BPH to insecticides have come from Japan where insecticides have been extensively used for many years. Benzene hexachloride (BHC) has been widely used since 1949 (pers. comm. with K. Ozaki, Kogawa Prefectural Experiment Station, Takamatsu, Kogawa, Japan).

In 1967, planthoppers collected from locations within the Hiroshima prefecture had a maximum of ninefold resistance (Kimura et al 1973). In 1967, poor field control with BHC dusts in Kyushu prefecture was linked to resistance (Nagata and Moriya 1969). Topical doses of BHC in the laboratory increased resistance sevenfold in only five generations.

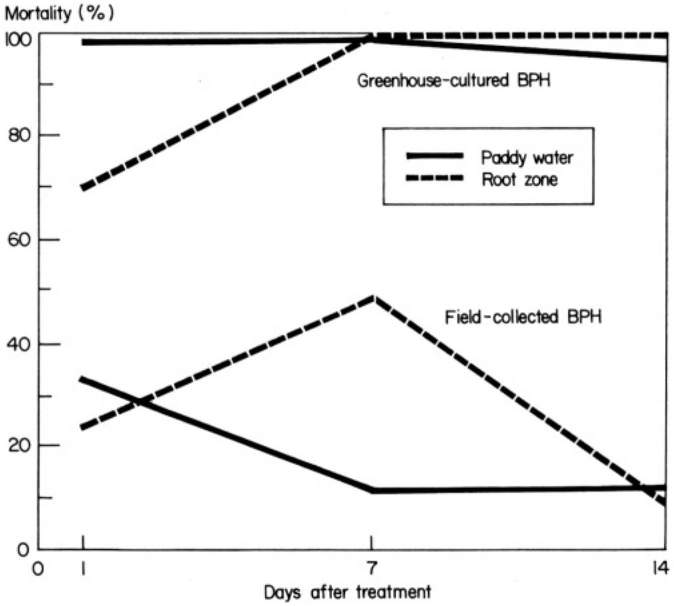
Studies on the seasonal fluctuation of resistance to gamma-BHC in Fukuda prefecture indicated that the third generation had 14 times greater resistance than the migrant population, and the fourth generation had 19 times more resistance (Nagata and Moriya 1974). The fluctuation was considered due to the alternating effects of the selective pressure of BHC and the replacement of resistant populations, which could not overwinter with susceptible populations migrating from distant areas where insecticide resistance did not occur. Cross resistance to dieldrin and fenitrothion was observed in the BHC-resistant strain.

In Japan, organophosphorus insecticides are said to have provided poorer field control in 1967 than in previous years (pers. comm. with K. Ozaki). Studies by Ozaki indicated that the BPH had developed resistance to fenthion, fenitrothion, diazinon, and malathion. Hence, the use of organophosphate insecticides has decreased throughout Japan. K. Ozaki (pers. comm.) also reported an increase in tolerance for the carbamate insecticides carbaryl and MPMC. Asakawa (1975) reported that carbamates are still effective and will continue to be so because of the annual migration of susceptible BPH.

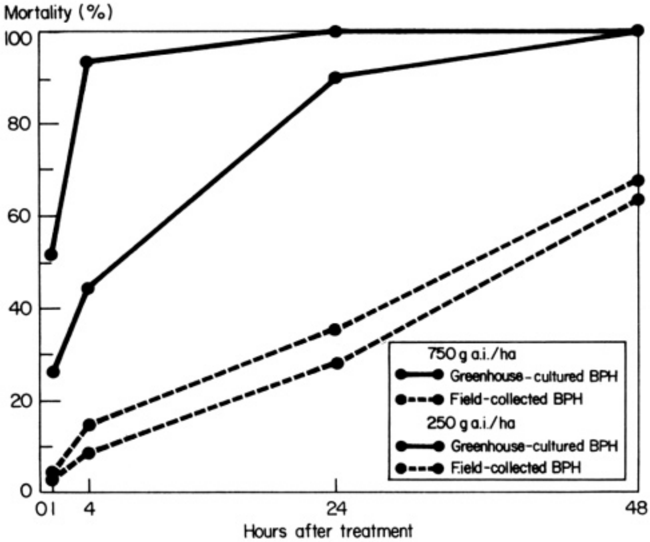
Reports of BPH resistance to insecticides in the tropics are rare, most likely because of the low level of insecticide use. At IRRI, the effectiveness of diazinon markedly declined in 1969 (IRRI 1970) after it had been used continuously for 10 successive crop seasons (about 3 years). Studies indicated that the loss of effectiveness was due to increase in resistance to the insecticide and to microbial degradation (IRRI 1971).

About 50 BPH generations had been exposed to diazinon at IRRI. The IRRI population was the only one with resistance that was five times greater than that of populations from other locations in the Philippines (IRRI 1972). The progeny of field-collected resistant planthoppers lost their resistance after several generations without exposure to diazinon.

Sethunathan and Pathak (1971) found diazinon to be inactivated by microbial degradation in 3 to 5 days of incubation with water from a rice field that had received several diazinon applications. Degradation in water from an untreated



6. Mortality of the greenhouse-cultured and field-collected brown planthopper as affected by paddy-water and root-zone applications of carbofuran at 1 kg a.i./ha. IRRI greenhouse, 1976.



7. Mortality of greenhouse-cultured and field-collected brown planthoppers as affected by carbofuran applied as a direct-contact spray with the Potter's spray tower. IRRI Laboratory, 1977. (E. A. Heinrichs and S. Valencia, unpubl.)

rice field was nonsignificant. Further research, however, indicated that the occurrence of diazinon-resistant strains was more important than microbial degradation in rendering diazinon ineffective against the BPH. In studies in Taiwan (T. Y. Ku, Plant Protection Center, Taichung, Taiwan, unpubl.), found that the BPH in the Taichung area developed a 13-fold resistance to ethyl parathion and 4-fold resistance to BPMC. No resistance to monocrotophos, acephate, vamidothion, or carbofuran was observed.

In 1976, after several years of use, carbofuran’s effectiveness against the BPH at IRRI declined. Applications of 2 kg a.i./ha at 14-day intervals failed to control the insect. The responses of field-collected insects to paddy-water and to root-zone applications of carbofuran at 1 kg a.i./ha were compared with the response of a susceptible greenhouse culture. The field-collected planthoppers showed an extremely low mortality (Fig. 6). To determine whether the resistance was genetic, further studies were conducted after rearing the field-collected insects for four or five generations. In the test for direct contact toxicity the field population was still distinctly more resistant to carbofuran than the susceptible greenhouse culture (Fig. 7). Probit analysis indicated a sevenfold resistance.

The BPH can develop resistance to insecticides within a relatively short time. With increase in continuous cropping and in use of insecticides in the tropics, BPH resistance to insecticides poses a real threat to rice production.

BROWN PLANTHOPPER RESURGENCE

In insecticide trials on experiment stations and in farmers' fields, hopperburn commonly occurs in treated plots while untreated areas remain relatively free of infestation. The phenomenon is most common when foliar sprays are applied but can occur in plots where granules have been broadcast.

Foliar sprays

BPH resurgence after treatment with foliar spray has been reported at IRRI (IRRI 1968, 1971, 1973, 1974, 1975, 1977). In seven experiments, the average hopperburned area in the most severely damaged treated plots was 94%, while that in the control plots was 18%.

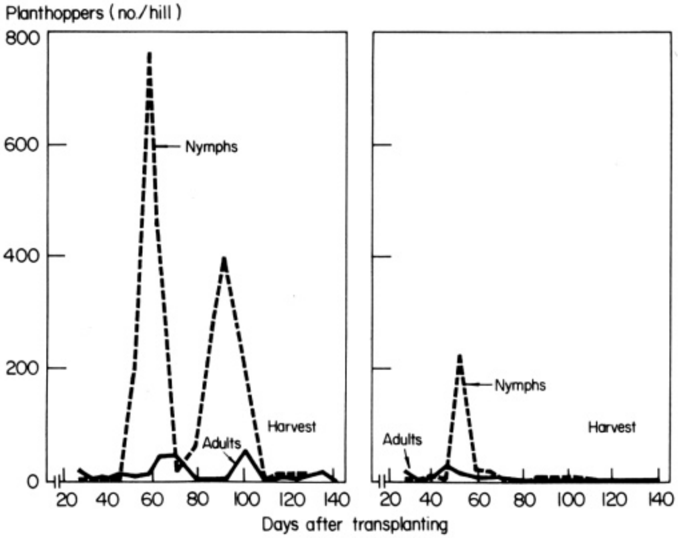
When carbofuran was applied as a foliar spray, by soil incorporation before transplanting, as broadcast granules, and by root-zone application, BPH resurgence was most common with foliar sprays (E. A. Heinrichs and G. B. Aquino, IRRI, unpubl.). Insecticides vary in resurgence activity (R. S. Rejesus and F. O. Cariño, IRRI, unpubl.). Methyl parathion has consistently caused planthopper resurgences; acephate, BPMC, metalkamate, and Perthane have not.

BPH outbreaks in upland fields are rare, but resurgences occur when certain insecticides are applied as foliar sprays. In 1976 (IRRI 1977) hopperburn occurred on a poor-tillering, upland rice variety with inadequate nitrogen where a synthetic pyrethroid, NRDC 161 (Decis), methyl parathion, or diazinon was applied (Table 8).

Table 8. Effect of foliar sprays on brown planthopper populations and damage in upland rice variety Kinanda.[a] IRRI, 1976 wet season.

Insecticide[b]	Brown planthopper (no./11-m row)[c]		Hopperburn (%)
	94 DS	Resurgence ratio	117 DS
NRDC 161 (Decis)	6,733 ef	16.40	100 d
Methyl parathion	2,468 ef	6.00	75 c
Diazinon	1,919 def	4.67	55 b
Azinphos ethyl	718 cde	1.75	4 a
Monocrotophos	374 bcd	.91	1 a
Carbaryl	336 bc	.82	3 a
Methomyl	164 abc	.40	1 a
BPMC	178 bc	.43	0 a
Acephate	156 abc	.38	1 a
Endosulfan	157 abc	.38	0 a
MIPC	133 abc	.32	0 a
Vamidothion	55 ab	.13	3 a
Perthane	29 a	.07	0 a
Control	411 bcd	–	4 a

[a] In a column, means followed by a common letter are not significantly different at the 5% level. [b] All insecticides were sprayed at 0.75 kg a.i./ha. Plots received 3 applications at 49, 77, and 94 days after seeding (DS). [c] Collected with a D-Vac suction machine. Resurgence ratio = number of planthoppers after two insecticide applications at 94 DS divided by the number in the untreated control.



8. Change in brown planthopper populations in plots of IR20 treated with diazinon granules (2 kg a.i./ha) at 18, 38, 56, 76, 97, and 118 days after transplanting (left) and in untreated plots (right). IRRI, 1971 dry season.

Granules

IRRI Annual Reports (IRRI 1970, 1971, 1972, 1975, 1976) describe numerous resurgences after the broadcast of granules in paddy water. In 11 experiments, hopperburn of the most severely damaged treatment averaged 75%; that of the untreated plots was 14%. Diazinon has commonly caused resurgences (Fig. 8; IRRI 1972). In 1976, IRRI plots treated with 2 kg a.i. carbofuran/ha at 14-day intervals were hopperburned while untreated plots remained relatively undamaged (R. S. Rejesus and G. D. Salinas, unpubl.). The BPH population of the treated plot was four times that of the untreated plot.

The mechanisms of planthopper resurgence have not been determined. A combination of factors may be involved. We might consider these possibilities:

- failure of sprays to reach the plant bases where the planthoppers feed, lack of residual effects to kill hatching nymphs, and resistance to the insecticide;
- decrease in populations of natural enemies (Toyoda and Yoshimura 1967; pers. comm. J. H. Stapley);
- changes in the chemical nature of the rice plant, affecting planthopper nutrition ; and
- stimulation by the insecticide of planthopper oviposition, feeding, or hatching.

CONCLUSIONS

The proper use of insecticides can provide effective control of the BPH. There is much more to chemical control, however, than simply, applying chemicals.

Several years' experience with highly toxic organic insecticides has made extremely clear the need for a more thorough understanding of the biology, ecology, and behavior of the pest and a better knowledge of the action of insecticides to maximize insecticidal effectiveness.

In most Asian countries the BPH has only recently become a pest, and many countries need to develop effective and economical means of controlling it. Chemical control may prove effective and economical, but not without investment in research. A long-lasting solution can be achieved only through the development of interdisciplinary national programs where the applied-research entomologist works closely with the chemist, ecologist, physiologist, biological control specialist, agronomist, and plant breeder.

Several research areas deserve immediate attention :

- *Evaluation of insecticides.* Evaluation of insecticides must be a basic part of every nation's research program. Imported field test data from other countries can be used in making initial recommendations, but there is no substitute for in-country testing under conditions peculiar to the particular country.
- *Insecticide application.* Methods that allow foliar sprays to reach the insect at its feeding site at the base of the plant must be developed.

The literature indicates the importance of time of application in relation to the life cycle of the planthopper. Additional research should be conducted in the tropics to determine whether it is possible to base timing on the life cycle of the insect. Easy monitoring methods for farmer use in determining proper application time should be developed.

- *Insecticides' mode of action.* Insecticides applied as foliar sprays should be evaluated to determine their effectiveness as systemic insecticides that move from the upper leaf area down to the lower leaf sheath area where the BPH feeds. The ovicidal, antifeedant, and repellent action of insecticides should be evaluated, and development of additional chemicals with such types of action should be considered.
- *Resurgence.* There is an urgent need to determine the role of insecticides in BPH resurgences. The evaluation program should eliminate insecticides that stimulate BPH populations to increase to outbreak levels.
- *Resistance to insecticides.* As insecticide use increases we can expect the BPH populations to develop insecticide resistance. Because of the high cost of developing insecticides, fewer may be developed in the future. Ways preventing the development of resistance to insecticides and of increasing the active life of the currently available must therefore be sought.

Insecticides have not been a panacea. It is distressing to note that in Japan abnormal increases in BPH populations occurred when insecticide applications reached a high level after 1957 (Miyashita 1963). The problems experienced in Japan, where insecticides were extensively used in rice-insect control for over two decades, are today confronting nations throughout Asia. The battle between the farmer and the BPH will continue. A thorough understanding of the BPH ecology and integration of control by insecticides with that by varietal resistance, and biological and cultural control will increase man's chances of winning the battle.

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VARIETAL RESISTANCE

Screening methods and sources of varietal resistance

Seung Yoon Choi

The methodology of mass screening rice at the seedling stage and the sources of resistance to the brown planthopper that have been identified are discussed

The insect can be efficiently mass-reared on the susceptible varieties on 40- to 50-day-old potted plants or on seedling mats. Many countries have adopted the basic screening procedures developed by the International Rice Research Institute.

A large number of varieties or lines that are sources of genetic resistance to the insect are available in the rice germplasm. However, their resistance in one country does not necessarily hold true in other countries.

THE INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI) initiated studies on varietal resistance to the brown planthopper (BPH) in 1966. Since then, it has developed and documented efficient mass-screening techniques for evaluating tens of thousands of varieties from worldwide germplasm collections in the seedling stage in the greenhouse.

The basic techniques have been introduced in Japan (Kaneda and Kisimoto 1977), Korea (Choi et al 1977), Taiwan (Cheng and Chang 1977), India (Kalode and Krishna 1977). Thailand (Pongprasert and Weerapat 1977). Sri Lanka (Fernando et al 1977), Indonesia (Harahap 1977), and the Solomon Islands (Stapley et al 1977). With those techniques, the varieties from the germplasm collections and the bulk of those countries breeding materials have been satisfactorily screened in the seedling stage for resistance to the BPH.

This paper reviews the details of mass-screening techniques presently used and the resistant sources identified so far.

SCREENING METHODS

Mass-rearing of the brown planthopper

Mass-rearing of the BPH is essential to mass screening of varieties. The insect is mass-reared on the susceptible variety Taichung Native 1 or on other equally

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susceptible varieties that provide food and sites for oviposition. The original colony is started by caging a pair (♀♂) of adults (virus-free insects from areas harboring the grassy stunt virus) on the rice plant.

Two methods of mass-rearing are employed.

Rearing on old potted plants. Pathak and Khush (1977) at IRRI described this method, and most countries use it. The insects are reared on 40- to 50-day-old plants inside a 0.5- × 0.5- × 1-m cage. This standard cage uses a wooden or steel frame, bottom, and door. Its roof and a side wall are covered with glass, but the remaining two sides are covered with either fine-mesh wire screen or nylon cloth. The screen permits aeration and prevents condensation of moisture on the glass walls.

The potted plants are changed as needed. Each cage can accommodate several potted plants that usually support 2,000 to 3,000 late-instar nymphs. Eggs of about the same age are obtained by placing the plants overnight in a cage containing adult insects.

Rearing on seedling mats. Insects are mass-reared on seedlings in a transparent acrylic (plastic) cage. The top and three sides of the cage are covered with fine-mesh nylon cloth. Japan (Kaneda and Kisimoto 1977) and Korea (Choi et a1 1977) use this method. Choi et a1 (1977) have also described it. Seedling mats are prepared by placing the pregerminated seeds on moistened gauze on enameled trays. The mats can be easily cut into the desired size several days later when the seedlings have grown and their roots have become entangled in the gauze. The adult insects are caged on the seedling mats. The ovipositing insects are removed 1 or 2 days later and the seedling mats with eggs are taken out of the cages. A fresh seedling mat is put on one side inside the cage as nymphs appear. Each cage can accommodate one seedling mat (about 20 × 25 cm) that can support 1,000 to 2,000 late-instar nymphs.

Insects are reared in this method in insectaries at 26–27°C and with 15-hours light in Japan (Kaneda and Kisimoto 1977) and at 25–30°C and with 24-hours light in Korea (Choi et a1 1977).

Rearing on old potted plants and on seedling mats provide a continuous supply of test insects. The use of rice seedling mats is feasible in insectaries in the off-season in the temperate zone, but their efficiency is inferior to that of potted plants in the greenhouse. In Korea, the former method is used in summer, and the latter, during other seasons.

Screening procedures. In many countries, varietal screening for resistance to the BPH is usually conducted at the seedling stage in the greenhouse. Basic screening procedures standardized by IRRI (Pathak and Khush 1977) have been adopted in different countries.

The test varieties or lines are seeded in rows 5 cm apart in 60- × 45- × 10-cm seedboxes. Each line is planted in a 20-cm-long row along the width of the seedbox. A susceptible check variety (usually Taichung Native 1 or one of the equally susceptible varieties) and a resistant check variety (always Mudgo, except in certain biotype studies) are planted at random in each seedbox. At

7 days after seeding, the test plants are thinned to 20 to 30 seedlings per row. Initial evaluation uses only one replicate.

Sometimes germination is not uniform because the seeds germinate poorly or are infected with soil-borne disease. The problems can be overcome by pregerminating the seeds and disinfecting them with fungicides like phenyl mercuric acetate (Choi et al 1977).

The pregerminated seeds are planted individually at uniform spacing within each row. Although laborious, this method is superior to direct seeding in ensuring a uniform stand of seedlings and eliminating thinning work.

The seeded boxes are placed on a galvanized iron tray on a table inside a screened room. The screened room may be a section of a greenhouse. About 5 cm of standing water on the tray provides high humidity suitable for insect survival and eliminates the need for watering the plants, which may disturb the insects feeding on them.

If a screened room is not available, each seedbox may be put in a wooden cage covered with fine-mesh cloth (Choi et al 1977). In Taiwan, the seeded boxes are covered with a nylon net after infestation (Cheng and Chang 1977).

About 7 days after seeding at the one- and the two-leaf stage, the seedlings are infested by scattering a large number of insects on them. The heavily infested plants from the mass-rearing cage are gently tapped over the seedlings. The insects should be on the test varieties as uniformly as possible. Generally second- and third-instar nymphs are used for infestation. An average of 5 insects/seedling constitutes an optimum population to differentiate the resistant and susceptible lines.

The insects' preference or nonpreference for the test varieties is recorded. But the final rating for resistance is based on the extent of damage the different test varieties suffer. Up to 1975, a scoring system with a scale of 0 to 5 was used. In 1976, IRRI revised the scoring system (IRTP 1975). At present, plant damage is rated on the standard scoring system of 0–9 (Table 1).

The final damage rating is taken when about 90% of the plants of the susceptible check variety are killed—usually about 7 to 10 days after infestation.

Table 1. Standard for rating damage by brown planthopper (revised by IRRI-IRTP 1975; Pathak and Khush 1977).

Grade of damage	Symptom	Rating[a]
0	No visible damage	HR
1	Partial yellowing of first leaf	R
3	First and second leaves partially yellow	MR
5	Pronounced yellowing and some stunting	MS
7	Wilting and severe stunting	S
9	All test plants dead	HS

[a] HR = highly resistant; R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; HS = highly susceptible.

The varieties or lines that fall into grade 1 to 3 (or 0 to 2 under the former scoring system) are further evaluated for consistency of resistance in a repeat screening using the same technique, with four replicates per entry.

The selected lines or varieties are tested further to evaluate the nature and causes of their mechanisms of resistance.

SOURCES OF RESISTANCE

Since 1966, rice entomologists and breeders at IRRI have given much attention to the search for sources of resistant genes and the use of resistance in their breeding programs. Since then, screening for BPH resistance has been done on tens of thousands of varieties and lines from IRRI's worldwide germplasm collections and on its breeding lines. From these screening studies, a large number of varieties originating from indica rice were identified as resistant.

Using the mass-screening technique, many Asian rice-growing countries have also screened their available rice germplasm and breeding lines and incorporated the sources of resistance compatible with other desirable plant characters in their breeding programs.

More than 500 varieties or lines have been found resistant to the BPH (Table 2) in the Philippines (IRRI 1972, 1973, 1974, 1976; IRTP 1975, 1976a, b; Pathak and Khush 1977), Japan (Kaneda and Kisimoto 1977), Korea

Table 2. Resistant sources and their reaction to the brown planthopper in different countries.

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
AC-1613	India	R	–	–	–	–	–	–	–	–
ADR 52	"	–	–	–	–	–	–	R	–	–
ADT 4	"	–	–	–	MR	–	–	–	–	–
ADT 19	"	R	–	–	–	–	–	–	–	–
Anbaw C7	Burma	MR(R)	–	–	MR	–	–	–	–	–
Andaragahawewa	S. Lanka	R	R	–	R	–	R	S	–	–
Anethoda	Nigeria	R	–	–	–	–	–	–	–	–
ARC 1040	India	–	–	–	–	–	–	R	–	–
ARC 5757	"	–	–	–	–	–	–	R	–	–
ARC 5839	"	–	–	–	–	–	–	R	–	–
ARC 5918	"	–	–	–	–	–	–	R	–	–
ARC 5984	"	–	–	–	–	–	–	R	–	–
ARC 5987	"	–	–	–	–	–	–	R	–	–
ARC 6563	"	–	–	–	MR	–	–	–	–	–
ARC 6650	"	R	R	–	MR	R	MR	R	–	–
ARC 7320	"	–	–	–	–	–	–	R	–	–
ARC 7327	"	–	–	–	–	–	–	R	–	–
ARC 10410	"	–	–	–	MR	–	–	–	–	–
ARC 10550	"	S	S	–	S	S	S	R	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
ARC 10595	"	–	–	–	MR	–	–	–	–	–
ARC 10834	"	–	–	–	MR	–	–	–	–	–
ARC 10945A	"	–	–	–	–	–	–	R	–	–
ARC 11354	"	S	S	–	S	S	S	R	–	–
ARC 11704	"	–	–	–	–	–	–	R	–	–
ARC 13788	"	–	–	–	–	–	–	R	–	–
ARC 14203	"	–	–	–	–	–	–	R	–	–
ARC 14342	"	MR	S	–	R	S	MR	R	–	–
ARC 14394	"	MS	S	–	S	S	S	MR	–	–
ARC 14529	"	R	S	–	S	R	R	MR	–	–
ARC 14529A	"	–	–	–	–	–	–	R	–	–
ARC 14539B	"	–	–	–	–	–	–	R	–	–
ARC 14636A	"	–	–	–	–	–	–	R	–	–
ARC 14766	"	R	MR	–	S	R	R	R	–	–
ARC 14766A	"	–	–	–	–	–	–	R	–	–
ARC 14771	"	MR	S	–	S	R	S	MR	–	–
ARC 14988	"	–	–	–	–	–	–	R	–	–
ARC 15152	"	–	–	–	–	–	–	R	–	–
ARC 15570A	"	S	S	–	S	S	S	R	–	–
ASD 7	"	R	R	MR	MR	R	R	S	–	–
ASD 9	"	R	–	–	–	–	–	–	–	–
B441b/190/1/1/3	Indonesia	–	–	–	–	R	–	–	–	–
B2360-8-5-LR-4-3	"	–	–	–	–	–	R	–	–	–
B3753-5-Pn-4-1	"	–	–	–	–	–	R	–	–	–
B3753-8-Pn-2-3	"	–	–	–	–	–	R	–	–	–
Babawee	S. Lanka	R	R	–	R	S	S	MR	–	–
Bakatabe	Indonesia	–	–	–	MR	–	–	–	–	–
Bala	India	MR	R	–	MR	M	S	S	–	–
Balamawee	S. Lanka	R	R	–	R	R	–	R	R	–
Bangkok	"	MR	–	–	–	–	–	–	–	–
Batapolawee	"	–	–	–	–	–	–	–	R	–
Batia Sira	India	–	–	–	–	–	–	R	–	–
Bello	GOA?	MR	–	–	–	–	–	–	–	–
Berawee	S. Lanka	–	–	–	R	–	–	–	–	–
Berlin	Costa Rica	MR	–	–	–	–	–	–	–	–
Bhadoia 293	Pakistan	MR	–	–	–	–	–	–	–	–
Bir-co-yuan li	Taiwan	MR	–	–	–	–	–	–	–	–
BJ 1	India	MR	–	–	–	–	–	–	–	–
BKN 1105-18	Thailand	–	–	–	R	–	–	–	–	–
BKN 6806-46-60	"	–	–	–	R	–	–	–	–	–
BKN 6953-15-1	"	–	–	–	R	–	–	–	–	–
BKN 6960-28	"	–	–	–	–	R	–	–	–	–
BKN BR 1008-5	"	–	–	–	–	R	–	–	–	–
BKN BR 1009-8	"	–	–	–	–	R	–	–	–	–
BKN BR 1030-3-1	"	–	–	–	–	R	–	–	–	–
BKN BR 1030-28-1	"	–	–	–	–	R	–	–	–	–
BKN BR 1031-15-1-3	"	–	–	–	–	R	–	–	–	–
BKN BR 1088-81	"	–	–	–	–	R	–	–	–	–
BKN BR 1091-69-1	"	–	–	–	–	R	–	–	–	–
BKN BR 1094-55-2	"	–	–	–	–	R	–	–	–	–
Bogor-1	Indonesia	R	R	R	R	R	R	MR	–	–
Bogor-6	"	R	R	MR	R	R	MR	M?	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
Bogor-7	"	R	MR	–	MR	R	MS	M?	–	–
Bogor-8	"	R	R	R	R	MR	MR	M?	–	–
Bogor-12	"	R	R	R	R	R	MR	R	–	–
Bogor-14	"	MR	R	MS	R	MR	MS	M?	–	–
Bogor-16	"	R	MR	S	R	MR	MS	S	–	–
Bogor-18	"	R	R	R	R	S	R(M)	S	–	–
Bogor-20	"	R	R	R	R	R	MR	MS	–	–
Bogor-22	"	MR	R	–	R	R	MR	S	–	–
Bogor-25	"	MS	R	–	R	R	MR	S	–	–
Bogor-26	"	R	R	–	R	R	MR(M)	S	–	–
Bogor-29	"	R	R	–	R	R	MS	M	–	–
Bogor-31	"	R	R	–	R	MR	MS	M	–	–
Bogor-32	"	MR	R	R	R	MR	MR(M)	S	–	–
Bogor-34	"	M	R	–	R	MR	MR(M)	S	–	–
Bolibod	Philippines	MR	–	–	–	–	–	–	–	–
BR 43-11-2	Thailand	–	–	–	–	R	–	–	–	–
BR 51-118-2	"	–	–	–	–	R	–	–	–	–
BR 1030-3-1	"	R	R	R	R	R	MR	S	–	–
BR 1030-3-2	"	R	R	–	R	R	R	MS	–	–
BR 1030-11-2	"	R	R	R	R	MR	MS	MS	–	–
BR 1030-18-1	"	R	R	R	R	R	R	S	–	–
BR 1030-21-1	"	R	R	R	R	R	R	S	–	–
BR 1030-28-1	"	R	R	R	R	MR	MR	S	–	–
BR 1030-31-1	"	R	R	–	R	R	R	S	–	–
BR 1030-65-1	"	R	R	–	R	M	MR	S	–	–
BR 1030-76-1	"	R	R	–	R	R	R	S	–	–
C 33-18	"	–	–	–	MR	–	–	–	–	–
C 62-1-230	Taiwan	R	R	–	–	R	R	S	–	–
C 62-1-373	"	R	R	–	–	R	R	MS	–	–
C 84-35	S. Lanka	–	–	–	MR	–	–	–	–	–
C 409	Burma	MR	–	–	–	–	–	–	–	–
C 5298	India	MR	–	–	–	–	–	–	–	–
Cesariet	"	–	–	–	MR	–	–	–	–	–
Channinyakan	"	–	–	–	–	–	–	R	–	–
Cheenadi	S. Lanka	–	–	–	–	–	–	–	R	–
Chemban	India	–	–	–	–	–	–	MR	–	–
Chempan	"	–	–	–	–	–	–	MR	–	–
Chemparam Pandi	"	–	–	–	–	–	–	R	–	–
Chennellu	"	–	–	–	–	–	–	R	–	–
Cheriya Chittari	"	–	–	–	–	–	–	R	–	–
Che shau nan bir	China	MR	–	–	–	–	–	–	–	–
Chetteri	India	–	–	–	–	–	–	R	–	–
Chianung shen-yu 10	Taiwan	–	R	–	–	–	–	–	–	–
Chianung shen-yu 11	"	R	R	–	MR	R	S	S	–	–
Chiu shih tsi	China	MR	–	–	–	–	–	–	–	–
C 15402-1	U.S.A.	MR	–	–	–	–	–	–	–	–
C 18636-1	Indonesia	R	–	–	–	–	–	–	–	–
CNT 7246-11-2-2	Thailand	–	–	–	–	R	–	–	–	–
CNT 7255-42	"	–	–	–	–	R	–	–	–	–
CO 3	India	R	–	–	–	–	–	–	–	–
CO 9	"	MR	R	–	MR	R	R	MS	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
CO 10	"	MR(R)	–	–	–	–	–	–	–	–
CO 13	"	–	S	–	MR	–	–	–	–	–
CO 20	"	MR	S	–	–	–	–	–	–	–
CO 22	"	R	R	–	MR	R	–	–	–	–
Company Chittari	"	–	–	–	–	–	–	R	–	–
CR 57-29	"	MR	–	–	–	–	–	–	–	–
CR 94-13	"	R	R	–	R	R	MR	S	–	–
Ctg 408	Pakistan	MR	–	–	–	–	–	–	–	–
Dampata Podiwee	S. Lanka	–	–	–	R	–	–	–	–	–
Dd 21	Bangladesh	MR	–	–	–	–	–	–	–	–
Dd 48	"	MR	–	–	–	–	–	–	–	–
Dd 68	"	MR	–	–	–	–	–	–	–	–
Dd 91	"	MR	–	–	–	–	–	–	–	–
Dd 106	"	MR	–	–	–	–	–	–	–	–
DF 1	"	R	–	–	R	–	–	–	–	–
Dikwee	S. Lanka	R	R	–	MR	R	R	S	–	–
Dikwee 328	"	R	–	–	–	–	–	–	–	–
DJ 9	Bangladesh	R	–	–	R	–	–	–	–	–
DJ 29		R	–	–	–	–	–	–	–	–
DJ 66		MR	–	–	–	–	–	–	–	–
DJ 72	"	MR	–	–	–	–	–	–	–	–
Djawa Sredek	Indonesia	–	–	–	–	–	–	R	–	–
DK 1	Bangladesh	MR	–	–	–	–	–	–	–	–
DNJ 80	"	R	–	–	R	–	–	–	–	–
DNJ 174	"	MR	–	–	–	–	–	–	–	–
DNJ 177	"	MR	–	–	–	–	–	–	–	–
DS 1		MR	–	–	–	–	–	–	–	–
Dumali	Philippines	MR(R)	–	–	–	–	–	–	–	
DV 29	Bangladesh	MR	–	–	–	–	–	–	–	–
DV 86		MR	–	–	–	–	–	–	–	–
DV 88	"	MR	–	–	–	–	–	–	–	–
DV 110	"	MR	–	–	–	–	–	–	–	–
DV 114	"	MR	–	–	–	–	–	–	–	–
DZ 41	"	MR	–	–	–	–	–	–	–	–
DZ 98	"	MR	–	–	–	–	–	–	–	–
DZ 171		MR	–	–	–	–	–	–	–	–
Early No. 3 (PI 208449)	India	MR	–	–	–	–	–	–	–	–
EK 1240	"	–	–	–	R	–	–	–	–	–
EK 1236	"	–	–	–	R	–	–	–	–	–
EleSamba	S Lanka	–	–	–	–	–	–	–	R	–
Elwee	"	–	–	–	–	–	–	–	R	–
Ennapatta	India	–	–	–	–	–	–	R	–	–
Gadi	Indonesia	–	–	–	MR	–	–	–	–	–
Gangala	S Lanka	R	R	R	R	R	MS	M	–	–
Gambada Samba		MR	–	–	–	–	–	–	–	–
Gapita	Indonesia	–	–	–	–	–	–	R	–	–
Ginmasari	Japan	MR	–	–	–	–	–	–	–	–
Girasal	GOA	MR	–	–	–	–	–	–	–	–
GS531	India	–	–	–	–	–	–	MR	–	–
H 5	S Lanka	R	R	–	MR	R	MR	S	–	–
H 105	"	R(MR)	R	–	R	R	R	S	–	–
Hal Suduwee	"	–	–	–	–	–	–	–	R	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
Hamsa	India	MR	R	–	–	R	R	S	–	–
Hathiel	S. Lanka	R	R	–	MR	–	–	–	–	–
Hathiyal	"	–	–	–	–	–	–	R	–	–
Hattathawee	"	MR	–	–	–	–	–	–	–	–
Heenhoranamawee	"	MR	–	–	MR	–	–	–	–	–
Heen Rath	"	R	–	–	–	–	–	–	–	–
Heen Rathkunda	"	–	–	–	–	–	–	–	R	–
Heenukkullama	"	R	–	–	R	–	–	–	–	–
Hill sel x PN bmt 54V-103	U.S.A.	MR	–	–	–	–	–	–	–	–
Hondarawala	S. Lanka	MR(R)	–	–	–	–	–	–	–	–
Hondarawala 378b	"	R	–	–	R	–	–	–	–	–
Hondarawala 3786	"	R	–	–	–	–	–	–	–	–
Hondarawala 502b	"	MR	–	–	R	–	–	–	–	–
Hondarawala 5026	"	R	–	–	–	–	–	–	–	–
Horana Mawee	"	R	–	–	–	–	–	R	–	–
HR 12	India	–	–	–	R	–	–	–	–	–
HR 19	"	–	–	–	R	–	–	–	–	–
HR 106	"	–	–	–	MR	–	–	–	–	–
HR 1231-235-3	"	R	R	R	R	R	R	S	–	–
HR 1231-258-2	"	MR	R	R	R	R	R	S	–	–
Hsin hsin bir	China	MR	–	–	–	–	–	–	–	–
Hunykkulama	S. Lanka	R	–	–	R	–	–	–	–	–
Hwang mu	China	MR	–	–	–	–	–	–	–	–
IET 5085	India	R	MR	–	M	MR	S	MS	–	–
IET 5118	"	MR	MR	–	R	M	R	M	–	–
IET 5119	"	MR	MR	–	R	M	S	MR	–	–
IET 5120	"	R	MR	–	R	S	MR	MR	–	–
IET 5122	"	R	MR	–	R	MS	R	M	–	–
IET 5236	"	R	MR	–	MR	MA	S	MS	–	–
IR4-93	Philippines	R	–	–	–	–	–	–	–	–
IR8 M16	India	R	MR	–	S	MR	S	S	–	–
IR18	Philippines	–	–	–	MR	–	–	–	–	–
IR26	"	R	R	–	R	MR	MR	MS	–	MR
IR28	"	R	–	–	MR	R	–	–	–	M
IR29	"	R	–	–	–	R	–	–	–	–
IR30	"	R	–	–	MR	R	–	–	–	S
IR32	"	R	–	–	MR	R	R	–	–	R
IR34	"	R	–	–	MR	R	–	–	–	M
IR36	"	R	–	–	–	R	R	–	–	R
IR38	"	R	–	–	–	–	–	–	–	R
IR40	"	R	–	–	–	–	–	–	–	–
IR42	"	R	–	–	–	–	–	–	–	–
IR747B2-6	"	R	R	–	–	–	–	–	–	–
IR747-13-6-3	"	–	–	–	MR	–	–	–	–	–
IR781-144-1-IR8/2	"	–	–	–	–	–	–	R	–	–
IR789-63-1	"	R	–	–	–	–	–	–	–	–
IR1154-243	"	R	–	–	–	–	–	–	–	–
IR1154-243-1	"	R	MR	R	S	M	MR	S	–	–
IR1330-3-2	"	R	–	–	–	–	–	–	–	–
IR1513A-E597	"	R	R	–	–	MR	R	S	–	–
IR1514A-579	"	R	–	–	–	–	–	–	–	–
IR1514A-E597-1	Philippines	–	–	–	–	R	–	–	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
IR1514A-E597-2	"	R	–	–	–	–	–	R	–	–
IR1514A-E666	"	–	–	–	MR	–	–	–	–	–
IR1539-823-1	"	R	–	–	–	–	–	–	–	–
IR1539-823-4	"	R	–	–	–	–	–	–	–	–
IR1539-823-4-1	"	R	R	–	R	R	MR	MS	–	–
IR1541	"	–	–	–	R	–	–	–	–	–
IR1544-340-6	"	R	–	–	–	–	–	–	–	–
IR1561-228-3	"	R	–	–	–	–	–	–	–	–
IR1561-288	"	–	–	–	R	–	–	–	–	–
IR1614-138-4	"	R	–	–	–	–	–	–	–	–
IR1614-389-1	"	R	–	–	–	–	–	–	–	–
IR1628-632-1	"	R	R	–	–	R	MR	S	–	–
IR1632-93-2-2	"	R	R	–	–	R	R	S	–	–
IR1702-74-3	"	R	–	–	–	–	–	–	–	–
IR1702-158-3	"	R	–	–	–	–	–	–	–	–
IR1712-217-2	"	R	–	–	–	–	–	–	–	–
IR1712-238-3	"	R	–	–	–	–	–	–	–	–
IR1820-52-2	"	R	–	–	–	–	–	–	–	–
IR1857-1	"	R	–	–	–	–	–	–	–	–
IR1909-1-3-3	"	–	–	–	–	–	–	R	–	–
IR2003-97-7	"	R	–	–	–	–	–	–	–	–
IR2003-P16-7	"	R	–	–	–	–	–	–	–	–
IR2006-P12-12	"	R	–	–	–	–	–	–	–	–
IR2006-P111-6	"	R	–	–	–	–	–	–	–	–
IR2014-P136-10	"	R	–	–	–	–	–	–	–	–
IR2016-P7-4	"	R	–	–	–	–	–	–	–	–
IR2018-P43-2	"	R	–	–	–	–	–	–	–	–
IR2031-238-5	"	R	–	–	–	–	–	–	–	–
IR2031-352-3-2	"	–	–	–	–	R	–	–	–	–
IR2031-354-1	"	R	–	–	–	–	–	–	–	–
IR2031-724-2	"	R	–	–	–	–	–	–	–	–
IR2034-238-1-2-3	"	R	–	–	–	R	–	–	–	–
IR2034-289-1	"	R	–	–	–	–	–	–	–	–
IR2035-290-2	"	R	–	–	–	–	–	–	–	–
IR2035-487-3-3	"	–	–	–	–	R	–	–	–	–
IR2038-158-2	"	R	–	–	–	–	–	–	–	–
IR2039-119-1	"	–	–	–	–	R	–	–	–	–
IR2039-203-3-1	"	–	–	–	–	R	–	–	–	–
IR2039-269-1	"	R	–	–	–	–	–	–	–	–
IR2042-101-2	"	R	–	–	–	–	–	–	–	–
IR2049-104-2	"	R	–	–	–	–	–	–	–	–
IR2061-213-2-16	"	–	–	–	–	–	R	–	–	–
IR2061-214-3	"	R	–	–	–	–	–	–	–	–
IR2061-464-4	"	R	–	–	–	–	–	–	–	–
IR2061-465-1-5-5	"	–	–	–	–	–	–	–	–	R
IR2070-24	"	R	–	–	–	–	–	–	–	–
IR2071-1-1-1	"	–	–	–	–	–	–	–	–	R
IR2070-88	"	R	–	–	–	–	–	–	–	–
IR2071-135-3-3	"	–	–	–	–	R	–	–	–	–
IR2071-137-5-5-1	"	R	–	–	–	–	–	–	–	R
IR2071-251-1-1-3	"	–	–	–	–	R	–	–	–	–
IR2071-486-1-2	"	–	–	–	–	–	R	–	–	–
IR2071-586-5-6-3-4	"	–	–	–	–	–	–	–	–	R

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
IR2071-621-2-3	"	–	–	–	–	–	R	–	–	–
IR2151-957-5	"	R	–	–	–	–	–	–	–	–
IR2153-43-2-3	"	–	–	–	–	–	R	–	–	–
IR2153-381-8-1	"	–	–	–	–	–	–	–	–	M
IR2153-550-2-6	"	–	–	–	–	R	–	–	–	–
IR2172-64	"	–	–	–	–	–	R	–	–	–
IR2307-72-2-2-1	"	R	R	–	R	MR	MR	S	–	–
IR2307-10-1-2-3	"	–	–	–	–	–	–	–	–	R
IR2307-112-3	"	–	–	–	–	–	–	–	–	R
IR2307-247-2-2-3	"	–	–	–	–	–	–	–	–	R
IR2307-281-5-32	"	–	–	–	–	–	–	–	–	R
IR2328-27-3-6	"	–	–	–	–	R	–	–	–	–
IR2681-34-5	"	–	–	–	–	R	–	–	–	–
IR72771-119-3-1	"	–	–	–	–	–	–	–	–	R
IR2777-103-2-2-3	"	–	–	–	–	–	–	–	–	R
IR2796-125-3-2-2	"	–	–	–	–	–	–	–	–	MR
IR2798-86-6	"	–	–	–	–	R	–	–	–	–
IR2823-399-5-6	"	–	–	–	–	–	–	–	–	R
IR2863-38-1	"	–	–	–	–	R	–	–	–	–
IR2863-38-1-2	"	–	–	–	–	–	–	–	–	R
IR2863-39-2-1	"	MR	–	–	–	–	–	–	–	–
IR3634-62-2	"	–	–	–	–	–	–	–	–	MR
IR3941-25-1	"	–	–	–	–	–	–	–	–	R
IR4409-65-3	"	–	–	–	–	–	–	–	–	R
IR4409-80-2	"	–	–	–	–	–	–	–	–	R
IR4417-177-1-4	"	–	–	–	–	–	–	–	–	R
IR4422-29-6	"	–	–	–	–	–	–	–	–	R
IR4422-143-2-1	"	–	–	–	–	–	–	–	–	R
IR4427-16-2-4	"	–	–	–	–	–	–	–	–	R
IR4427-23-2-3	"	–	–	–	–	–	–	–	–	MR
IR4427-58-5-2	"	–	–	–	–	–	–	–	–	R
IR4427-118-5-2	"	–	–	–	–	–	–	–	–	MR
IR4427-279-4-1	"	–	–	–	–	–	–	–	–	MR
IR4432-28-5	"	R	–	–	–	–	–	–	–	–
IR4432-38-6	"	R	–	–	–	–	–	–	–	M
IR4432-52-6-4	"	R	–	–	–	–	–	–	–	R
IR4432-103-6-4	"	R	–	–	–	–	–	–	–	–
IR4492-7-2-1	"	–	–	–	–	–	–	–	–	MR
IR4531-6-1-1	"	–	–	–	–	–	–	–	–	R
IR4580-5-3	"	–	–	–	–	–	–	–	–	R
IR4707-7-3	"	–	–	–	–	–	–	–	–	R
IR4707-123-3	"	–	–	–	–	–	–	–	–	R
IR4816-70-1	"	–	–	–	–	–	–	–	–	R
IR5257-77-2	"	–	–	–	–	–	–	–	–	R
IR5311-46-3	"	–	–	–	–	–	–	–	–	R
IR5853-76	"	–	–	–	–	–	–	–	–	R
Iri 328	Korea	R	MR	–	R	R	MR	S	–	–
Iri 329	"	R	R	–	R	MR	R	S	–	–
JBS 34	India	–	–	–	R	–	–	–	–	–
JBS 1168	"	–	–	–	–	–	–	R	–	–
Kahata Keralla	S. Lanka	–	–	–	–	–	–	–	R	–
Kahata Samba	"	R	–	–	–	–	–	–	–	–
Kalimekri 391	Pakistan	MR	–	–	–	–	–	–	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
Kaluhan diran	S. Lanka	–	–	–	–	–	–	–	R	–
Kalu Hathiyal	"	–	–	–	–	–	–	R	–	–
Kaluheenati	"	–	–	–	R	–	–	–	–	–
Kalu Kuruwee	"	MR	–	–	–	–	–	–	–	–
Kalu Samba	"	R	–	–	–	–	–	R	–	–
Kam-Ban-Gan	Hongkong	–	–	–	MR	–	–	–	–	–
Kao sen yu 12	S. Lanka?	–	–	–	MR	–	–	–	–	–
Karayal	S. Lanka	R	–	–	MR	–	–	–	–	–
Karekagga	S. Lanka	MR	–	–	–	–	–	–	–	–
Karia	Fiji Is	MR	–	–	–	–	–	–	–	–
Karuth Vellathan	S Lanka	–	–	–	–	–	–	R	–	–
Ka ying 20	China	R	–	–	–	–	–	–	–	–
Kinko	Japan	MR	–	–	–	–	–	–	–	–
Kin shan zim	China	MR	–	–	–	–	–	–	–	–
Klewer	Indonesia	–	–	–	MR	–	–	–	–	–
Kodiyam	India	–	–	–	–	–	–	R	–	–
Kosatawee	S. Lanka	R	–	–	R	–	–	–	–	–
Kula Peruvela	"	–	–	–	–	–	–	R	–	–
Kuruhon darawala	"	R	R	–	R	R	–	–	–	–
LxH/2-281	India	–	–	–	–	–	–	R	–	–
Lal Basumati	Pakistan	–	–	–	–	–	–	R	–	–
Lampong peuteuj	Indonesia	–	–	–	R	–	–	–	–	–
Leb Mue Nahng	India	S	S	–	S	MS	S	M	–	–
Lekam Samba	S. Lanka	R	–	–	R	–	–	–	–	–
Lien chan shoa thou	China	MR	–	–	–	–	–	–	–	–
Loku Samba	S. Lanka	–	–	–	–	–	–	R	–	–
Lua Ngu	Vietnam	–	–	–	–	–	–	R	–	–
Lun yah tsan	Chlna	MR	–	–	–	–	–	–	–	–
M 302/Mas 24 (1900)	S. Lanka	–	–	–	MR	–	–	–	–	–
Madael	"	–	–	–	–	–	–	R	–	–
Madayal	S. Lanka	R	–	–	R	–	–	–	–	–
Madayal b	"	R	–	–	–	–	–	–	–	–
Mahadikwee	"	R	–	–	R	–	–	–	–	–
Malkora	"	MR(R)	–	–	–	–	–	–	–	–
Manoharsali	India	–	–	–	–	–	–	R	–	–
Mawee	S. Lanka	–	–	–	–	–	–	R	R	–
Mgl 2	India	R	R	–	R	–	–	–	–	–
MI 329	S. Lanka	R	–	–	MR	–	–	–	–	–
MR 329 b	"	R	–	–	–	–	–	–	–	–
Milketan 20	Philippines	–	–	–	MR	–	–	–	–	–
Milyang 30	Korea	R	R	–	R	MR	R	S	–	–
Milyang 34	"	–	R	–	–	–	–	–	–	–
Milyang 36	"	–	R	–	–	–	–	–	–	–
Moddai Samba	S. Lanka	–	–	–	–	–	–	–	R	–
MR 1523	India	–	–	–	–	–	–	R	–	–
MTU 9	Pakistan	MR(R)	–	–	MR	–	–	–	–	–
MTU 15	India	R	R	–	MR	R	R	S	–	–
MTU 16	"	–	–	–	–	–	–	R	–	–
Mudgo	"	R	R	R	R	R	R	S	–	–
Mudukmel	S. Lanka	–	–	–	–	–	–	–	R	–
Mudu Kiriyal	"	R	–	–	R	–	–	R	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
Muhudu Kiriyal	"	MR	–	–	–	–	–	–	–	–
Murunga 137	"	–	R	–	R	–	–	–	–	–
Murunga 307	"	–	–	–	R	–	–	–	–	–
Murunga-kayan	"	R	R	–	MR	–	–	–	–	–
Murunga-kayan 3	"	R	R	–	S	R	MR	S	–	–
Murungakayana 101 b	"	R	R	–	R	R	R	S	–	–
Murungakayan 104	"	R	–	–	–	–	–	–	–	–
Murungakayan 302	"	R	–	–	–	–	–	–	–	–
Murungakayan 303	"	R	R	–	–	–	–	–	R	–
Murungakayan 303b	"	R	R	–	–	R	MS	S	–	–
Murungakayan 304b	"	R	–	–	R	–	–	–	–	–
Murungakayan 307	"	–	–	–	R	–	–	–	–	–
Muthumanikam	"	R	R	–	R	R	MS	S	–	–
Nang Lay	Vietnam	–	–	–	–	–	–	R	–	v
Ngane Tia	Laos	–	–	–	–	–	–	R	–	–
Niao uao	Taiwan	MR	–	–	–	–	–	–	–	–
O. australiensis	Australia	R	–	–	–	–	–	–	–	–
O. brachyntha	?	R	–	–	–	–	–	–	–	–
Oenji Hore	Indonesia	–	–	–	R	–	–	–	–	–
Okshitmayin	Burma	R	–	–	–	–	–	–	–	–
O. latifolia	?	R	–	–	–	–	–	–	–	–
O. punctata	India	R	–	–	–	–	–	–	–	–
Ottaval	S. Lanka	MR	–	–	–	–	–	–	–	–
Ovarkaruppan	"	R	–	–	R	–	–	–	–	–
Ovarkaruppan b	"	R	–	–	–	–	–	–	–	–
Pakheng kang	Laos	–	–	–	MR	–	–	–	–	–
Palasithari 601	S. Lanka	R	R	–	R	S	S	S	–	–
Pandi	Indonesia	–	–	–	–	–	–	R	–	–
Pandorai	India	–	–	–	MR	–	–	–	–	–
Panneti	S. Lanka	R	–	–	R	–	–	–	–	–
Pantong 32	Malaysia	–	–	–	MR	–	–	–	–	–
Pappakee		MR	–	–	–	–	–	–	–	–
Parakulam	S. Lanka	–	–	–	–	–	–	R	–	–
Parduriwee	"	–	–	–	–	–	–	–	R	–
Pawakkulama B	"	R	–	–	R	–	–	–	–	–
Pelopor	Indonesia	–	–	–	R	–	–	–	–	–
Periamorungan B	S. Lanka	R	–	–	MR	–	–	–	–	–
PK-1		R	–	–	R	–	–	–	–	–
PK-1 b	"	R	–	–	–	–	–	–	–	–
Podimawee	"	R	–	–	–	–	–	–	–	–
Podowee	"	R	–	–	–	–	–	–	–	–
Podwi 48	"	–	–	–	–	–	–	R	–	–
Ptb 9	Indla	–	–	–	R	–	–	–	–	–
Ptb 12	"	–	–	–	–	–	–	MR	–	–
Ptb 18	"	R	R	–	R	R	–	–	–	–
Ptb 19	"	R	R	R	R	R	MR	R	–	–
Ptb 20	"	R	–	–	–	–	–	–	–	–
Ptb21		R	R	–	R	R	MS	MS	–	–
Ptb 27	India	R	–	–	–	–	–	–	–	–
Ptb 28	"	–	–	–	–	–	–	R	–	–
Ptb 33	"	R	R	R	R	R	R	R	–	–
Ptb 39	"	S	S	–	S	S	S	M	–	–
Pulot Etam	Malaysia	–	–	–	MR	–	–	–	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
Pusmaraga	S. Lanka	MR	–	–	–	–	–	–	–	–
Radin Bilis	Indonesia	–	–	–	–	MR	–	–	–	–
Rata-thavalu	S. Lanka	–	–	–	–	–	–	–	R	–
Rathkunda"		MR	–	–	–	–	–	–	–	–
Rathu Heenati"		R	R	–	R	–	–	R	–	–
Rathu Heenati b"		R	–	–	–	–	–	–	–	–
Rathu Hondarawala		–	–	–	–	–	–	–	R	–
RD4	Thailand	R	R	R	R	R	R	S	–	–
RD9 "		R	MR	–	R	MR	MR	S	–	–
RDRI	India	–	–	–	R	–	–	–	–	–
Rexoro x Zenith	USA.	MR	–	–	–	–	–	–	–	–
Ro wuan shun 21-3	China	R	–	–	–	–	–	–	–	–
RP 4-10 (T90 x IR8)	India	–	R	–	–	–	–	–	–	–
RP 9-6 "		R	R	–	–	R	R	S	–	–
Rusty Late	China	MR	–	–	–	–	–	–	–	–
S 2204	China	–	–	–	–	–	–	R	–	–
Samba	S. Lanka	R	–	–	MR	–	–	–	–	–
Saraya"		MR	–	–	–	–	–	–	–	–
Senawee	S. Lanka	R	–	–	R	–	–	R	–	–
Seratoes Hari	Indonesia	MR	–	–	–	–	–	–	–	–
Seruvellai	S. Lanka	R	–	–	R	–	–	–	–	–
Siam7	Thailand	–	–	–	–	–	–	R	–	–
Sigadis	Indonesia	R	–	–	–	–	–	–	–	–
Sinna Karuppan	S. Lanka	R	–	–	R	–	–	–	–	–
Sinnakayam B"		R	–	–	R	–	–	–	–	–
Sinnanayam 398"		–	–	–	–	–	–	R	–	–
Sinna Sivappu"		R	–	–	R	–	–	R	–	–
Sinna Suappu"		R	–	–	R	–	–	–	–	–
Sinnavellai "		R	–	–	–	–	–	–	–	–
Shinchiku-iku No. 74	Taiwan	MR	–	–	–	–	–	–	–	–
SLO 12	India	R	–	–	R	–	–	–	–	–
SPT 721-40	Thailand	–	–	–	–	R	–	–	–	–
SPT 7202-35"		–	–	–	–	R	–	–	–	–
SPT 7215-20"		–	–	–	–	R	–	–	–	–
SPT 7329-18-1"		–	–	–	–	R	–	–	–	–
SPT 7342-20-1"		–	–	–	–	R	–	–	–	–
Sudhu-balawee	S. Lanka	MR(R)	–	–	–	–	–	–	–	–
Sudu Heenati"		–	–	–	MR	–	–	–	R	–
Sudu Hondarawala"		R	–	–	R	–	–	–	–	–
Sudunisamba"		–	–	–	R	R	–	–	–	–
Suduru Samba"		R	R	R	R	R	R	R	R	–
Sudurvi "		MR	–	–	–	–	–	–	–	–
Sudurvi 305"		R	R	–	R	R	–	R	–	–
Sudurvi 306"		–	–	–	R	–	–	–	–	–
Sulai "		MR	–	–	MR	–	–	–	–	–
Suweon 271	Korea	–	R	–	–	–	–	–	–	–
Suweon 272"		–	R	–	–	–	–	–	–	–
Su Yai 20	China	–	–	–	R	–	–	–	–	–
T 3	India	–	–	–	–	–	–	R	–	–
T 5"		–	–	–	MR	–	–	–	–	–
T 10"		–	–	–	–	–	–	R	–	–

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Table 2 continued

Variety and line	Origin	IRRI (Philippines)	Korea	Japan	Taiwan	Thailand	Indonesia	India	S. Lanka	Solomon Islands
T 16	″	–	–	–	–	–	–	R	–	–
T 26	″	–	–	–	–	R	–	–	–	–
T 27	Philippines?	–	–	–	–	–	–	R	–	–
T 1406	India	–	–	–	–	–	–	R	–	–
T 1415	″	–	–	–	–	–	–	R	–	–
T 1421	″	–	–	–	–	–	–	R	–	–
T 1425	″	–	–	–	–	–	–	R	–	–
T 1426	″	–	–	–	–	–	–	R	–	–
T 1432	″	–	–	–	–	–	–	R	–	–
T 1437	″	–	–	–	–	–		R	–	–
T 1471	″	–	–	–	–	–	–	R	–	–
T 1477	″	–	–	–	–	–	–	MR	–	–
Ta 11	″	–	–	–	MR	–		–	–	–
Ta 68	″	–	–	–	MR	–	–	–	–	–
Ta-lee	China	MR	–	–	–	–	–	–	–	–
Ta-Tsao	″	MR	–	–	–	–	–	–	–	–
Ta-yang-tsin	″	MR	–	–	–	–	–	–	–	–
Td 55	Thailand	MR	–	–	–	–	–	–	–	–
TG 37	Indonesia	–	–	–	–	R	–	–	–	–
Thailand x Norin	India	MR	–	–	–	–	–	–	–	–
Thirissa	S. Lanka	R	–	–	R	–	–	–	–	–
Thurmaswee	″	–	–	–	–	–	–	–	R	–
Tibirewewa	″	R	–	–	R	–	–	–	–	–
Tibiriwewa b	″	R	–	–	–	–	–	–	–	–
Tjere Ornas	Indonesia	–	–	–	MR	–	–	–	–	–
TR 26	India	R	S	–	M	R	S	S	–	–
Triveni	″	S	S	–	MR	R	MS	S	–	–
Tunkura walawee	S Lanka	MR	–	–	–	–	–	–	–	–
Ucp 31	Pakistan	MR	–	–	–	–	–	–	–	–
Ucp 34	″	MR	–	–	–	–	–	–	–	–
Ucp 37	″	MR	–	–	–	–	–	–	–	–
Ucp 38	″	MR	–	–	–	–	–	–	–	–
Ucp 188	″	MR	–	–	–	–	–	–	–	–
Ulme	Portugal	MR	–	–	–	–	–	–	–	–
Umsum	Korea	–	–	–	–	–	–	R	–	–
Valsarachampara	India	–	–	–	–	–	–	R	–	–
Vellai-Langayan	S. Lanka	R	–	–	R	–	–	R	–	–
Vellanlangalayan	″	–	R	–	–	–	–	–	–	–
Vellathil Chera	India	–	–	–	–	–	–	R	–	–
Vellachnipan	″	–	–	–	–	–	–	MR	–	–
Velutha Chera	″	–	–	–	–	–	–	MR	–	–
VI/1806 1 Mas 24(800)	S. Lanka	–	–	–	MR	–	–	–	–	–
Vanam	″	–	MR	–	–	–	–	–	–	–
W 1252	India	–	–	–	–	R	–	–	–	–
W 1256	″	–	–	–	–	R	–	–	–	–
W 1259	″	–	–	–	–	R	–	–	–	–
W 1263	″	–	–	–	–	R	–	–	–	–
WX 318-5-4-49-61-1	Korea	MR	R	–	R	R	R	S	–	–
WX 325-30-17-2	″	MS	MR	–	MR	S	MS	S	–	–
Yakadawee	S. Lanka	–	–	–	–	–	–	–	R	–
Yen tu	China	MR	–	–	–	–	–	–	–	–
Yodaya ty	Burma	MR	–	–	–	–	–	–	–	–
Yo shun pai ku	China?	MR	–	–	–	–	–	–	–	–
Yuan li	″	MR	–	–	–	–	–	–	–	–

(Song et a1 1972; Choi 1975; Choi et al 1977), Taiwan (Cheng and Chang 1977), Thailand (Pongprasert and Weerapat 1977), Indonesia (Harahap 1977), India (Kalode and Krishna 1977), Sri Lanka (Fernando et al 1977), and the Solomon Islands (Stapley et a1 1977). Varieties resistant in a country were not, however, necessarily resistant in other countries. For example, the varieties ASD7 and Mudgo are resistant in the Philippines (IRRI), Japan, Korea, Taiwan, Thailand, and Indonesia, but susceptible in India.

The different reactions could be due to the presence of different populations of BPH in different locations and countries. In the future, the sources of resistance so far identified should be retested against the different biotypes to tackle the development of biotypes capable of surviving on the resistant plants.

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Varietal resistance to brown planthopper in India

M. B. Kalode and T. S. Khrishna

The brown planthopper has assumed great importance in rice and all efforts are being made to identify resistant varieties and to understand host-plant resistance and utilize it in India's breeding programs. A mass-screening technique resulted in the identification of resistant or tolerant cultivars among 15,000 entries. Materials from Northeast India and Kerala offer great potential.

Studies of the host-plant-Insect interactton showed that in most resistant varieties an antibiosis type of mechanism was involved. There was a correlation between the resistance at seedling stage and that at other stages. Six-or seven-day-old nymphs caused more damage than those at other stages of development.

Preliminary genetic data indicate that resistance is predominantly qualitative. Both dominant and recessive genes for resistance seem to be involved.

Through an effective breeding program a number of resistant breeding lines have been evolved and are under test in endemic areas. The differential reactions of lines in the multilocation tests suggest the occurrence of biotypes.

IN SEVERAL RICE-GROWING tracts of India, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) has assumed importance in recent times.

Extensive damage by BPH in India was first observed in Kerala during 1973. Subsequently reports were received from Andhra Pradesh, Bihar, Haryana, Orissa, Punjab, Tamil Nadu, and Uttar Pradesh (Kalode 1974; Kulshrestha et al 1974).

Although timely application of insecticides provides effective control, large-scale chemical control is difficult and expensive. Repeated sprayings upset the natural balance between the insect and its natural enemies. The logical approach to BPH control would be to use host-plant resistance as part of an integrated pest-management program. Efforts are in progress to tackle the BPH problem from various angles. The advances in developing resistant varieties are briefly discussed.

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Resistance to BPH in rice is being investigated at the All India Coordinated Rice Improvement Project (AICRIP), Hyderabad, Central Rice Research Institute (CRRI), Cuttack; Rice Research Station, Pattambi; Rice Research Station, Maruteru; Andhra Pradesh Agricultural University (APAU), Hyderabad; Agricultural University, Pantnagar; and a few other research centers in the country. The approach includes

- screening of varieties from different sources to identify donors,
- studies on the mechanisms of resistance,
- investigations on the genetics of resistance,
- a program for the transfer of genes for resistance to varieties possessing good agronomic characteristics, and
- biotype studies.

SCREENING FOR RESISTANCE

Screening methodology adopted

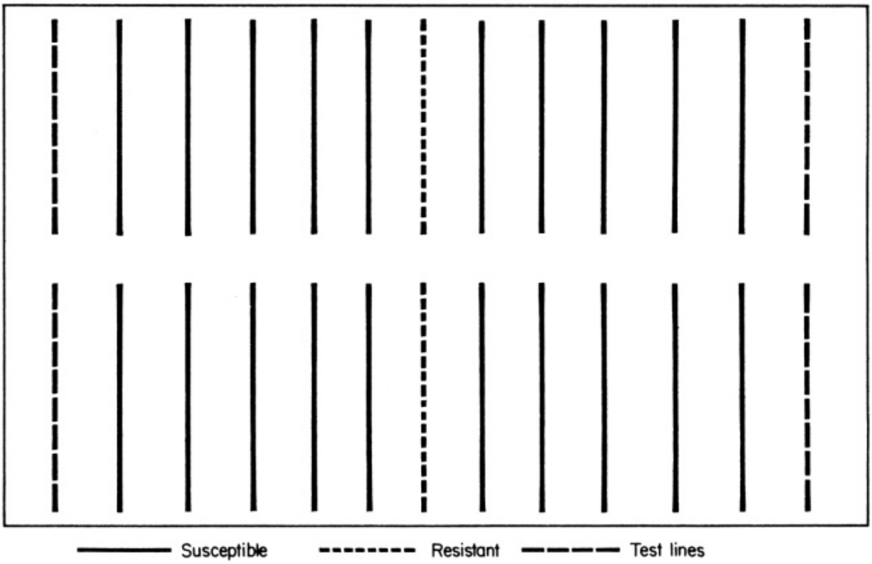
Mass-screening tests were conducted under controlled greenhouse conditions at the national headquarters of AICRIP, Rajendranagar, Hyderabad. Elsewhere screening was carried out in the laboratory or the cultivars were exposed to natural populations of BPH in the field.

The mass screening in the greenhouse is used to discard susceptible lines and identify possible resistant cultures. In early screenings, it was observed that test lines planted at either end of a tray was more likely than others to escape insect attack. Various methods and designs for planting test rows were evaluated and a modified layout that minimized the chances of escape (Kalode et al 1975) was devised. The method involved the infestation of 7- to 10-day-old seedlings of test entries grown in puddled soil in wooden trays (50 x 40 x 8 cm). Each tray accommodated 20 test rows, each with 15 seedlings; 2 middle rows of a resistant check, and 4 susceptible border rows of TN1 (Fig. 1).

The wooden trays were placed in water in 7.5 cm deep trays to maintain a humidity suited to the insects and to keep away ants. Sufficient numbers of first- or second-instar nymphs were released on test entries so that each seedling was infested with at least 5 to 10 nymphs. When more than 90% of the susceptible-check seedlings were dead, the entries were scored for damage on a 0-to-5 scale: 0 = no apparent damage, 1 = initiation of wilting or yellowing in one leaf, 2 = initiation of wilting or yellowing in all leaves, 3 = complete wilting of 50 to 70% of the leaves, central leaf surviving, 4 = all leaves wilted, stem green, 5 = plant dead.

Test lines with damage scores below 3 were retested (randomized and replicated 4 to 5 times). An entry with an average score ranging from 0 to 1.5 was rated resistant; 1.6 to 3.0, moderately resistant; and above 3, susceptible.

A total of 15,026 varieties and breeding lines have been screened at Hyderabad since 1974 (Table 1).



1. Layout for mass screening of rice lines for resistance to the brown planthopper in India.

Evaluation of germplasm from different sources

Assam varieties. Nine hundred and fourteen cultivars from Northeast India were evaluated for BPH resistance; 69 were found resistant or moderately resistant in replicated tests. About 15 varieties showed a high level of resistance.

Table 1. Reactions of rice cultivars to the brown planthopper at All India Coordinated Rice Improvement Project (1974-76).

Cultivar source	Entries (no.) with damage score (%)			Total
	0–1.5	1.6-3.0	3.1-5.0	
Assam	39	30	845	914[b]
Coimbatore	24	72	410	514[a]
Pattambi	30	7	264	301[b]
AICRIP	4	5	558	567[b]
APAU	1	0	43	44[b]
IRRI	29	44	590	663[b]
National Screening Nursery (NSN)	17	88	3,075	3,180[a]
International Rice Observation Nursery (IRON)	0	8	372	380[b]
Elite breeding material from AICRIP	38	26	86	150[b]
Breeding material from AICRIP	353	890	6,084	7,327[b]
CRRI, Cuttack	0	9	219	228[b]
Pattambi	12	31	75	118[b]
Kapurthala	0	0	190	190[b]
APAU	31	3	416	450[b]

[a] Based on a single test. [b] Based on single and replicated test.

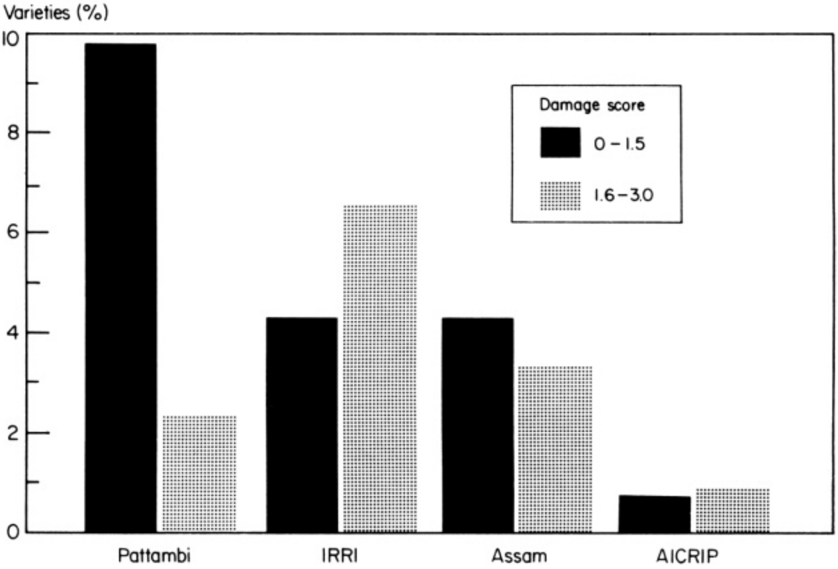
The distribution of the resistant cultivars from Northeast India showed that most had been collected from the hilly tracts of Assam, Meghalaya, and Manipur.

Germplasm from IRRI. Of 663 cultivars from IRRI, 73 exhibited varying degrees of resistance. Twenty-nine showed a high level of resistance, they were earlier found to be resistant or moderately resistant to biotype 1 at IRRI (Pathak 1976).

Germplasm from Pattambi and Coimbatore. About 301 entries from the Rice Research Station, Pattambi, and 514 from the Agricultural College and Research Institute, Coimbatore, were evaluated. Ninety-six entries from Coimbatore and 37 from Pattambi had damage scores under 3 in preliminary tests. Of those 30 from Pattambi and 24 from Coimbatore had scores ranging from 0 to 1.5. The reactions of entries from Pattambi have been confirmed in replicated tests; those from Coimbatore are still being confirmed.

Germplasm from AICRIP and Andhra Pradesh Agricultural University (APAU). A total of 567 traditional tall varieties from the AICRIP collection and 44 from the APAU collection were also tested. Seven from the AICRIP collection and one from APAU were resistant.

From such limited evidence, any conclusion about the relative contributions of germplasm from various Indian sources to resistance to the BPH has restricted value (Fig. 2). However, the evaluations give a broad view of promising sources. Materials from Kerala and Northeast India were most promising. The



2. Relative percentages of the varieties tested at AICRIP having resistance to the brown planthopper *Nilaparvata lugens.*

Table 2. Cultivars showing high resistance to the brown planthopper in greenhouse tests (All India Coordinated Rice Improvement Project).

Variety	Source	Damage score[a] (0–5 scale)
ARC 5987	Assam	1.0
ARC 10550	"	0.6
ARC 10945A	"	0.9
ARC 11354	"	0.6
ARC 14203	"	0.8
ARC 14342	"	0.4
ARC 14394	"	1.0
ARC 14529	"	0.2
ARC 14529A	"	0.3
ARC 14636A	"	0.5
ARC 14766	"	0.3
ARC 14766A	"	0.7
ARC 14988	"	0.7
ARC 15152	"	0.3
ARC 15570A	"	0.6
Chennelu	Pattambi	0.9
S 2204	"	0.9
T 27	"	0.9
T 3	"	1.0
Company Chittari	"	0.9
T 10	"	1.0
Ennapatta	"	0.9
5352	"	0.7
T 1415	"	0.5
T 1421	"	0.9
T 1437	"	0.8
T 1471	"	0.9
Lua Ngu	IRRI	0.6
Ptb 19	"	0.7
Sinnanayam 398	"	0.8
ARC 5839	"	1.0
ARC 7327	IRRI	1.0
Ngane Tie	"	1.0
ARC 6650	"	1.1
Loku Samba	"	1.1
ARC 7320	"	1.1
ARC 1040	"	1.2
Gapita	"	1.2
Kalu Samba	"	1.2
Sinna Sivappu	"	1.2
Kalu Hathiyal	"	1.2
Batia Sira	"	1.2
Madael	"	1.2
Balamawee	"	1.3
ARC 10834	"	1.3
Horana Mawee	"	1.3
Mudu Kiriyal	"	1.3
ARC 5757	"	1.3
Sudurvi 305	"	1.3
Umsum	"	1.3
Hathiyal	"	1.4
Rathu Heenati	"	1.4
Senawee	"	1.5
Mawee	"	1.5
Djawa Sredek	"	1.5
Nang Lay	"	1.5
Ptb 28	AICRIP	1.5
ARC 5918	"	1.0
Manoharsali	"	1.2
JBS 1168	"	1.1
Mtu 16	APAU	1.0

[a] Based on replicated test. 0 = no damage, 5 = plants killed.

increased contributions of IRRI germplasm is due to the earlier screening at IRRI for biotype I. The donors showing relatively high levels of resistance are listed in Table 2.

Screening for resistance at other centers. Screening of entries at CRRI revealed BPH resistance in the greenhouse in the cultivars Ptb 33, Ptb 21, Ptb 10, TKM 6, Murungakayan, ARC 5984, ARC 7239, ARC 18529, ARC 14729, ARC 14736, ARC 15223, ARC 15264, ARC 15821, ARC 12627, ARC 15284, ARC 14766, ARC 14529, ARC 10176, AC 131, AC 199, AC 357, AC 1224, AC 1619, AC 3070, and MNP 76. In addition, 20 cultivars derived from crosses involving Ptb 10, Ptb 18, Ptb 21, and Panbira have shown a high level of resistance (Prakasa Rao and Das 1976, unpubl.).

Evaluation of breeding material

Besides the general screening, a program was initiated at AICRIP to evaluate breeding lines developed at AICRIP and other locations, including the International Rice Observational Nursery (IRON).

Among the 3,180 National Screening Nursery entries tested so far, 17 were resistant (scoring 0 to 1.5); 88 exhibited moderate degrees of resistance (1.6 to 3.0).

Eight entries out of 380 cultures from IRON showed moderate resistance.

In the AICRIP breeding materials, 391 out of 7,476 selections had scores below 1.6, and 916 had scores ranging from 1.6 to 3.0. The material came from more than 40 cross-combinations; selections from crosses RP 31–49–2/Leb Mue Nahng, Vijaya/Ptb 21, Sona/Manoharsali, and ARC 5984/Pelita were very promising.

Two hundred and twenty-eight breeding lines from crosses involving resistant donors such as Ptb 10, Ptb 18, Ptb 21, and Panbira from CRRI, Cuttack, were tested against the BPH. Nine showed moderate degrees of resistance.

Of 118 breeding lines from Pattambi, 12 showed a high level of resistance while 31 lines were moderately resistant in a preliminary test. Among 450 selections from APAU involving crosses Sona/Manoharsali and Jaya/Manohar Sali, 31 were promising, with damage scores of less than 1.5, while 3 had moderate resistance (Lakshminarayana 1976, unpubl.).

Evaluation of BPH-resistant donors against other pests of rice

Current emphasis is on the development of lines with multiple resistance. Cultivars already identified as resistant or moderately resistant to BPH were tested by infestation in the greenhouse for the reaction to the whitebacked planthopper (*Sogatella furcifera*) and to gall midge (*Orseolia oryzae*) (Table 3). Fifty varieties possessed multiple resistance; among them, 14 were resistant or moderately resistant to all three insect pests. Twenty-six varieties were resistant to the whitebacked planthopper and the BPH; 10 lines had resistance to the gall midge and the BPH.

Studies by Sastry and Prakasa Rao (1975) at CRRI identified Ptb 18, Ptb 21, Leaung 152, TKM 6, and W 1263 as resistant to planthoppers, leafhoppers, gall midges, and stem borers.

STUDIES OF HOST-PLANT-INSECT INTERACTION

Preference or nonpreference

Ptb 33, Ptb 21, ARC 6650, and MR 1523, which possess varying degrees of resistance, and susceptible TN1, were grown in wooden flats, and first- and second-instar nymphs were released on 1-week-old seedlings; each seedling was originally infested by about 10 nymphs. The insect counts on different varieties after 24 hours showed significant differences (Table 4). TN1 attracted the most nymphs (17.9), Ptb 33 the fewest (9.6); Ptb 21, ARC 6650, and MR 1523 attracted 12.0, 12.2, and 13.5 nymphs respectively. These differential responses suggest the possible presence of some attractant in the susceptible variety and its absence in the resistant cultivars, or the presence of repellents in the resistant

Table 3. Rice cultivars with multiple resistance to insects (Kalode et al 1976, unpubl.).

Variety	Source	Reaction to[a]		
		BPH	WBPH[b]	Gall midge
ADR 52	Pattambi	R	R	R
Vellathil Chera	″	R	R	R
Pandi	″	R	R	R
Chennellu	″	R	R	R
T 1425	″	R	R	R
T 1471	″	R	R	R
Ptb 19	″	R	R	R
Ptb 21	″	R	R	R
Channinyakan	″	R	MR	R
Chemban	″	MR	R	R
T 1426	″	R	MR	R
Velutha Chera	″	MR	R	R
MR 1523	CRRI	R	MR	R
ARC 11704	Assam	R	MR	R
L x H/2-281	Pattambi	R	R	S
Lal Basumati	″	R	R	S
Valsarachampara	″	R	R	S
5332	″	R	R	S
IR 781-144-1-IR8/2 yukara x TN1 4C952	″	R	R	S
Eswaramangalam	″	R	R	S
Cheriya Chittari	″	R	R	S
Ptb 33	″	R	R	S
Kodiyam	″	R	R	—[c]
ARC 14539B	Assam	R	R	S
ARC 14766A	″	R	R	S
Podwi 48	IRRI	R	R	S
Sulai	″	R	R	S
Chemparam Pandi	Pattambi	R	MR	S
Kula Peruvela	″	R	MR	S
Siam 7	″	R	MR	S
T 1406	″	R	MR	S
Chetteri	″	R	MR	S
ARC 15570A	Assam	R	MR	S
ARC 14529	″	R	MR	S
Vellai Langayan	IRRI	R	MR	S
Gangala	″	R	MR	S
ARC 13788	Assam	R	MR	S
Chempan	Pattambi	MR	R	S
CS 531	″	MR	R	S
T 1477	″	MR	R	S
T 10	″	R	S	R
T 16	″	R	S	R
T 1421	″	R	S	R
T 1432	″	R	S	R
Karuth Vellathan	″	R	S	R
Parakulam	″	R	S	R
ARC 5984	Assam	R	–	R
Ptb 12	Pattambi	MR	S	R
710	″	MR	S	R
Vellachnipan	″	MR	S	R

[a] BPH = brown planthopper, WBPH = whitebacked planthopper, R = resistant, Mr = moderately resistant, S = susceptible. [b] Based on single test. [c] No test.

Table 4. Preference and antibiosis reaction of the brown planthopper on selected rice varieties (Kalode et al 1976, unpubl.).

Variety	Nymphs settled (av. no.)	Adults at 14th day (%)	Females 20 days after release (%)	Progenies (no.)[a]
Ptb 33	9.6	18	13	200
MR 1523	13.3	20	9	189
Ptb21	12 0	15	9	197
Leb Mue Nahng	13.5	37	31	1300
ARC 6650	122	53	45	3105
TN1	17.9	61	52	7401

[a] Thirty-five days after infestation. [b] 24 h after release.

types. Similar observations were reported at IRRI and in Korea (Karim 1975, Choi 1974).

Antibiosis

To identify varieties possessing a high level of antibiosis, freshly hatched nymphs (10 per plant) were caged on 30-day-old plants, and their life cycle was studied. Survival and development of nymphs and population buildups on each variety were noted regularly.

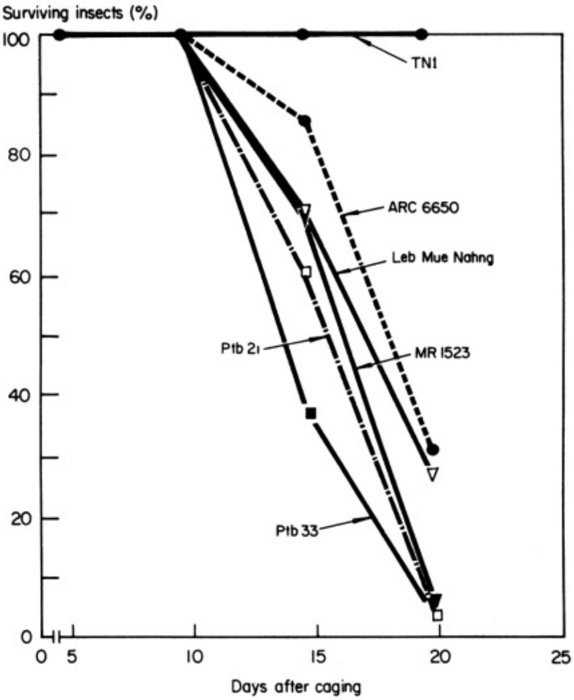
Survival of nymphs on resistant and susceptible cultivars. Survival of nymphs 15 days after they were caged on resistant and susceptible cultivars varied significantly (Fig. 3). On the 20th day after caging, 97.8% were alive on susceptible TN1; the survival rate was as low as 2.8, 3.3, and 4.8% on Ptb 33, Ptb 21, and MR 1523, respectively. The survival rates were intermediate on Leb Mue Nahng (26.1%) and ARC 6650 (29.2%). Survival was affected only after 10 days of caging. Mortality was high immediately before the adult stage was reached or shortly thereafter (Kalode et al 1976).

Population buildup of the brown planthopper on resistant and susceptible varieties. The population buildup from 100 original nymphs (from 10 replications) on Ptb 33, Ptb 21, and MR 1523 was significantly lower (189 to 200 nymphs) than that on TNl (7,401). Leb Mue Nahng and ARC 6650 were comparatively favorable to the insect (Table 4).

Other evidences of antibiosis included lower rates of nymphal development, lower production of females, and feeble development of adults. Similar effects had been reported by Sogawa and Pathak (1970) in populations reared on the variety Mudgo and on different rice varieties by Karim (1975).

Honeydew experiment

Honeydew deposition by leafhoppers and planthoppers has been used as a tool to measure the insects' food intake and the resistance of the host plant to insect attack (Sogawa and Pathak 1970; Karim 1975; Viswanathan 1975, unpubl.). In the current investigations, honeydew was collected on filter paper from 10



3. Survival of brown planthopper on selected rice varieties.

prestarved female adults that had been confined on each resistant cultivar for 24 hours. The amount of honeydew excreted was estimated by spraying filter paper with a 0.2% ninhydrin solution and reading the concentration with the help of a spectrophotometer after spots on the filter paper were dissolved in 80% ethanol.

Insect feeding on resistant cultivars Ptb 33, Ptb 21, MR 1523, and ARC 6650 was restricted (Table 5). Insects on Leb Mue Nahng and TNl excreted more heavily. The data also indicate a possible correlation between insect survival, population buildup, and honeydew excretion. Lower survival rates and less population buildup were thus associated with less feeding on the resistant varieties. The differences observed in honeydew excretion might be used as an indirect index of the degree of resistance. A similar possibility was earlier suggested by Sogawa and Pathak (1970), Choi (1974), and Karim (1975).

Effect of insect age on interaction with resistant and susceptible varieties

The time required by insects of different ages on a susceptible cultivar such as RP 31-49-2, RP 9-6, RP 9-4, or TNl and on a resistant cultivar. MR 1523, to destroy it was studied. The relatively shorter time taken by 6- to 7-day-old nymphs to destroy the susceptible varieties, compared with that taken by insects

Table 5. Total amino acid concentration in honeydew excreted by brown planthopper (10 females) fed on various rice varieties for 24 hours (Krishna, unpubl.).

Test variety	Total amino acid concentration (absorbance at 540/μ)
Ptb 21	0.34
Ptb 33	0.16
ARC 6650	0.47
MR 1523	0.24
Leb Mue Nahng	1.50
TN1	1.65

in other stages of growth, indicated their greater feeding requirement. The resistant variety MR 1523, although it recorded a slightly higher damage score with 6- and 7-day-old nymphs (3.0) than with adults (1.0) or 1- and 2-day-old nymphs (1.8) never suffered complete damage (Kalode et a1 1976, unpubl.).

Effect of different numbers of nymphs on resistant and susceptible varieties of different ages

Two rice varieties, TNl (susceptible) and MR 1523 (resistant), were caged with different numbers of nymphs and the extent of damage to MR 1523 was noted when all TN1 plants had been killed. The 10-, 15, and 20-day-old MR 1523 plants retained their resistance (0.5 to 1.3) even with increasing insect numbers (5 to 15, 15 to 25, and 25 to 35 insects/plant, respectively) while TNl plants were killed at all levels of insect population and at all plant ages.

In another experiment, Ptb 33, Ptb 21, Umsum, MR 1523, ARC 6650, and Leb Mue Nahng were infested at various ages (10, 30, 45, or 60 days after planting) with about equal numbers of insects (10, 30, 40 or 60 nymphs/plant, respectively). Results indicated that plant age did not influence the degree of resistance expressed (Kalode et a1 1976, unpubl.).

GENETICS OF RESISTANCE

Studies in India of the genetics of resistance to the BPH are few. Resistance to the BPH in Leb Mue Nahng was found to be qualitative and under single-gene control (Prasada Rao et a1 1976).

In studies of the genetics of resistance, 120 crosses were made in 1975. F_1 hybrid plants and F_2 materials were tested for reaction to the BPH by mass screening.

The results generally indicate that Ptb 33, ARC 6650, ARC 14636B, ARC 7080, and Lua Ngu possess dominant genes for resistance, whereas Ptb 21, MR 1523, Umsum, Leb Mue Nahng, ARC 14394, and ARC 15694 have the recessive gene for resistance (Krishna, unpubl.).

BREEDING FOR RESISTANCE

With the identification of four genes for resistance to the BPH (*Bph 1, bph 2, Bph 3,* and *bph 4*) (IRRI 1976), efforts to transfer the genes to varieties with desirable agronomic bases were most successful. The use of such varieties could control the BPH effectively in some countries (Freeman 1976).

Efforts to develop resistant cultivars with good agronomical backgrounds in India were successful. Some studies at AICRIP and CRRI on different crosses in successive generations have resulted in the identification of some resistant cultivars (Table 6). Entries in the RP 825 series seem to be resistant at IRRI to all three biotypes.

Table 6. Breeding lines resistant to or tolerant of the brown planthopper in studies in India.

Designation	Cross	Source
RP 1045-6-10-1 [a]	RP 31–49–2× Leb Mue Nahng	AICRIP
RP 1045-6-10-2 [a]	–do–	–do–
RP 1045-6-7-1 [a]	–do–	–do–
RP 1045-6-7-4 [a]	–do–	–do–
RP 1045-23-2-1 [a]	–do–	–do–
RP 825-24-7-1 [a]	Vijaya × Ptb 21	–do–
RP 825-24-7-1-1 [a]	–do–	–do–
RP 825-41-1-1	–do–	–do–
RP 825-71-4-4	–do–	–do–
RP 825-71-4-11	–do–	–do–
RP 825-71-4-11-1	–do–	–do–
RP 825-82-1-6-6 [a]	–do–	–do–
RP 825-82-4-1-6	–do–	–do–
RP 825-4-1-11 [a]	–do–	–do–
RP 1015-7-1 [a]	Sona × Manoharsall	–do–
RP 1015-29-7-1 [a]	–do–	–do–
RP 974-113-4-15 [a]	Sona × RP 9-4	–do–
RP 919-24-7-1-1 [a]	Sona × RP 8-8	–do–
RP 919-7-4-1-1	–do–	–do–
RP 899-3-6-9	IR8 × Tadukan	–do–
RP 899-3-6-9-1	–do–	–do–
CR 157-392-107-175	Vijaya × Ptb 10	CRRI
CR 157-392-11-4	–do–	–do–
CR 157-392-41-112	–do–	–do–
CR 157-389-12-47	–do–	–do–
CR 157-389-43-135	–do–	–do–
CR 157-392-21-185	–do–	–do–
CR 157-295	–do–	–do–
CR 157-389-43-120	–do–	–do–
CR 94-MR-1550-1075-690	(Ptb 21 × Ptb 18) × IR8	–do–
CR 94-MR-1550 white-90	–do–	–do–
S 11-52-626	IR20 × Panbira	–do–
S 11-78-629	–do–	–do–
CR 57-MR 1523	IR8 × Ptb 21	–do–
CR 57-11-2 [a]	–do–	–do–
CR 95-13-3 [a]	IR8 × Leaung 152	–do–
BPP 1235 [a]	IR8 × W 12787	APAU

[a] Lines presently under test in brown planthopper resistant variety trial.

Table 7. Reaction of selected rice varieties to the brown planthopper at different locations in India (preliminary report, International Rice Brown Planthopper Nursery. 1976).

Designation	Damage reaction[a] at		
	Cuttack	Hyderabad	Pattambi
Co 9	MR	S	S
Chianung-Sen-Yu 11	S	S	MR
Dikwee 2328	S	S	MR
Murungakayan 101 b	S	S	MR
Gangala	MR	S	S
Ptb 19	R	MR	R
Ptb 21	R	MR	R
Ptb 33	R	R	R
ARC 6650	R	R	R
Kentjana	S	S	MR

[a] R = resistant, MR = moderately resistant, S = susceptible

BIOTYPES

IR26 was resistant to the BPH in the Philippines and several other countries. However, it was susceptible at Kerala and AICRIP (Hyderabad) in India, and in Sri Lanka. The different reactions could be caused by different BPH populations in different areas. Data on the reaction of cultivars to the BPH at three locations in India are in Table 7. Varietal reactions show differences at different locations. Further critical supporting evidence is necessary. However, some of

Table 8. Brown planthopper damage to selected rice varieties from the Assam Rice Collection tested by the All India Coordinated Rice Improvement Project and the International Rice Research Institute.[a]

Designation	INDIA (AICRIP, Hyderabad)	PHILIPPINES (IRRI)[b]		
		Biotype 1	Biotype 2	Biotype 3
ARC 6650	2.0	3	1	9
ARC 7080	1.2	9	9	5
ARC 10550	0.6	9	9	9
ARC 14636	2.7	9	9	9
ARC 14342	0.4	7	7	9
ARC 14394	1.0	9	9	9
ARC 15570 A	0.6	9	9	9
ARC 14529	0.2	7	9	9
ARC 14766	0.3	5	9	1
ARC 14988	0.7	9	9	9
ARC 15152	0.3	9	9	9
ARC 15694	0.5	9	9	9
ARC 15831	1.8	9	9	9
Ptb 33 (check)	2.0	1	1	3

[a] Damage based on 0–9 scale: 0 = no damage, 9 = plants killed. [b] Personal communication with M. D. Pathak, 1976.

the ARC cultures that showed higher levels of resistance in earlier studies (Khrishna et al 1976) at Hyderabad (AICRIP) were tested at IRRI against three biotypes (Table 8). The data suggest that the biotype at AICRIP is entirely different from any of the three biotypes identified at IRRI.

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Breeding for resistance to brown planthopper and grassy stunt virus in Indonesia

Z. Harahap

The brown planthopper (BPH) *Nilaparvata lugens* Stål has been a major rice insect pest in Indonesia since 1975. Pelita I-1, one of the popular varieties grown by farmers, was heavily damaged by BPH and heavy losses from grassy stunt virus (GSV) usually followed.

Damage by BPH has been significantly reduced by growing the BPH-resistant rices IR26, IR28, IR30, and IR34. To date IR26 is the leading BPH resistant variety grown by farmers.

Since late 1976, IR26, IR28, IR30, and IR34 became susceptible to BPH in North Sumatra. IR32, however, grown adjacent to those varieties, showed resistance. A new biotype of BPH has apparently developed in North Sumatra.

An active breeding program is underway to Incorporate into improved varieties resistant to BPH and GSV as well as to other insect pests and diseases. A modification of the single-seed-descent, bulked-hybrid method is used to cope with the rapid expansion of hybridizations and the limited mass-screening facilities. Several lines resistant to BPH and GSV are being tested throughout the main rice-growing areas in Indonesia. Some of the lines are resistant to BPH biotype 2.

BEFORE 1970, THE BROWN PLANTHOPPER (BPH) was considered a minor pest of rice in Indonesia. In 1954 insignificant hopperburn was reported on Sigadis at Genteng Station, East Java. In 1960 hopperburn was observed near Karawang, West Java, on about 10 ha of Bengawan and other local varieties. Then between 1968 and 1972 localized hopperburn occurred on IR5 and C4-63 in many fields in East and Central Java. In 1973 BPH outbreaks occurred in many rice-growing areas of Indonesia, especially on Pelita I-1, IRS, and C4-63 in Bali, East Java, Central Java, and North Sumatra.

The government immediately released and widely distributed resistant varieties such as IR26, IR28, and IR30. In a short time, IR26 became popular in hopper-affected areas. Later, IR34 was released. Because the resistant varieties lack the eating qualities preferred by Indonesians and because they are sus-

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ceptible to sheath blight and “brown panicle,” some farmers were reluctant to grow them. IR30 is susceptible to bacterial leaf streak and IR34 lodges easily.

In the Banyuwangi area of East Java, hopperburn was significantly reduced through intensive control measures, including the growing of resistant varieties, application of recommended insecticides, and adoption of strictly enforced regulations on time of planting. Other crops were grown when rice could not be planted. IR26 has been the leading resistant variety grown. In April 1977 hopperburn was insignificant in the area and IR26 was still resistant.

In other areas of East, Central, and West Java, the disappearance of hopperburn caused by the use of resistant varieties encouraged farmers to again grow Pelita I-1, a high yielding variety that has preferred eating qualities but is highly susceptible to the BPH, grassy stunt virus, and tungro virus. Consequently, serious outbreaks of hopperburn were observed in parts of East and Central Java in March 1977. In West Java, where Pelita I–1 and traditional varieties were still the leading varieties, severe hopperburn occurred in late 1976 and early 1977.

In parts of North Sumatra, IR26 was widely planted starting in 1973. Considerable areas were later planted to IR28, IR30, and IR34. The destruction by hopperburn in late 1976 and early 1977 of about 15,000 ha of rice in North Sumatra, including fields of IR26, IR28, IR30, and IR34, indicated that a new biotype of the BPH had developed in North Sumatra. However, IR32 in adjacent fields showed strong resistance.

The government is expected to recommend soon either IR32 or IR36, or both, for release in North Sumatra.

The BPH today is one of the most destructive and dangerous rice pests in Indonesia. Associated with it is the grassy stunt virus, of which it is a vector. Heavy losses from the grassy stunt virus have followed the BPH epidemics. Efforts of Indonesian rice breeders to incorporate resistance to BPH and the grassy stunt virus into our leading varieties are briefly reviewed in this report.

BREEDING OBJECTIVES

The incorporation of resistance to the BPH, the grassy stunt virus, and tungro virus into improved-plant type varieties are major breeding objectives of the national rice varietal improvement program of Indonesia. Such varieties as Pelita I-1, C4-63, Adil, Makmur, and Gemar are being crossed and, in some cases, backcrossed to an array of resistant donor parent varieties.

Crosses used in the BPH program

Tables 1 and 2 list some of the important crosses that are being used to develop improved varieties resistant to BPH biotypes 1 and 2.

The parental sources used for incorporating biotype-1 resistance into improved-plant type varieties include advanced-generation breeding lines from IR2031, IR2061, IR2153, B2360, and B2361 (Table 1). Donor parents of

Table 1. Bogor crosses carrying resistance to BPH biotype-1 gene.

Cross no	Combination	Generation	Test site
B3063	IR2061-228-3-9/Pelita I-1	F_3	Pusakanegara
B3065	IR2061-228-3-9/Makmur	F_3	Kunmgan-Pusakanegara
B3066	IR2061-228-3-9/B541b-Kn-91-3-1	F_3	"
B3067	IR2061-228-3-9/Adil	F_3	"
B3313	B2360-6-1-2/8541b-Kn-19-3-4	F_3	Pusakanegara
B3318	B2360-6-5-1/Makmur	F_3	"
B3355	B2361-1-LR-4/B541b-Kn-19-3-4	F_3	"
B3356	B2361-1-1-LR-4/Makmur	F_3	"
B3389	Segon Beureum/IR2061-213-2-16	F_3	"
B3390	Segon Beureum/IR2153-159-1-4	F_3	"
B3391	Segon Beureum/IR3265-193-3-3	F_3	"
B3188	IR2031-238-5-2-5/Makmur	F_2	Kuningan
B3189	IR2031-238-5-2-5/Gama 318	F_2	"
B3195	IR2031-354-2-3/Gati	F_2	"
B3258	IR2153-26-3-5/Pelita I-1	F_2	"
B3261	IR2153-26-3-5/8541b-Kn-19-3-4	F_2	"
B3263	IR2153-159-1-4/Pelita I-1	F_2	"
B3215	IR2061-2-16/Jogo	F_3	Muara
B3216	IR2061-2-16/Cempo	F_3	"
B3217	IR2061-2-16/Bandang Salak	F_3	"
B3218	IR2061-2-16/Si Rumbia	F_3	"
B3307	B2360-6-1-2/Jogo	F_3	"
B3308	B2360-6-1-2/Lumut	F_3	"
B3309	B2360-6-1-2/Si Rumbia	F_3	"

biotype-2 resistance include CR94-13 and advanced breeding lines from IR2070, IR2071, and B3753. Other important hybridizations listed in Tables 1 and 2 include crosses between BPH-resistant varieties and such traditional varieties as Arias (upland); N. Tinuwu (stem borer resistant); Kewal (bulu); Lumut. Segon Beureum, and Jerak (high elevation); Balap Merah, Jogo, Cempo, Bandang Salak, and Si Rumbia (lowland); and Kencana, a bulu/indica hybrid variety of the traditional plant type developed at Bogor by Dr. H. Siregar in the 1940's. The traditional varieties are important sources for the development of improved rainfed and upland varieties.

BACKCROSS PROGRAM

Backcross programs have been started to transfer BPH resistance genes to such popular varieties as Pelita I-1 and Makmur. The F_2 plants of promising combinations B3063 (IR2061-228-3-9/Pelita) and B3065 (IR2061-228-3-9/Makmur) were infested with BPH in the greenhouse. Surviving resistant plants were transplanted to the field and selected plants were crossed back to Pelita I–1 and Makmur.

The second backcrosses have now been made. Also, tests of some BPH-resistant F_2 progenies of B3063 and B3065 were obtained at the Muara, Mojosari, and Kendalpayak stations in the 1976–77 wet season. Many of these F_3 lines gave resistant reactions to the grassy stunt virus at the Mojosari and Kendalpayak stations.

Table 2. Bogor crosses carrying brown planthopper resistance to biotype-2 gene.

Cross no.	Combination	Generation	Test site
B2589	IR2157-3/IR946-33-2-4//Pelita I-1	F_5	Muara
B2791	Pelita I-1//CR94-13/IR20	F_4	"
B3238	IR2070-132-3-3/Makmur	F_3	Pusakanegara
B3239	IR2070-132-3-3/Gama 318	F_3	Singamerta
B3240	IR2071-77-3-3/Pelita I-1	F_3	Kendalpayak
B3241	IR2071-7-3-3/Gata	F_3	"
B3242	IR2071-77-3-3/Gati	F_3	Singamerta
B3243	IR2071-77-3-3/Adil	F_3	Kendalpayak
B3244	IR2071-77-3-3/Makmur	F_3	"
B3252	IR2157-10-190-3-5/Pelita I-1	F_3	Singamerta
B3508	IR2071-669-3-6-5/C4-63Gb	F_3	Muara
B3515	IR442-2-58/Kencana	F_2	"
B3518	CR94-13/Kencana	F_2	"
B3520	IR2071-636-5-5/Kencana	F_2	"
B3541	It72071-636-5-5/Gernar	F_2	"
B3586	Arias/IR36	F_2	"
B3593	N. Tinuwu/IR36	F_2	"
B3594	Jerak/IR36	F_2	"
B3596	Remaja/IR36	F_2	"
B3603	Pelita I-1/Arias//IR2070-178-2-3-4	F_2	"
B3609	Lumut/IR2070-178-2-3-4	F_2	"
B3611	Gemar/IR2070-178-2-3-4	F_2	"
B3615	Balap merah/IR2071-178-2-3-4	F_2	"
B3650	IR2071-669-3-6-5/Kewal	F_2	"

Modified single-seed-descent bulk method

Because of the rapid expansion of hybridizations and because of limited facilities for mass screening of thousands of pedigree lines for resistance to diseases and insects, and other traits, a modified single-seed-descent bulked-hybrid method is being used. The F_2 through F_6 of many crosses are routinely transplanted at 5- × 5-cm plant spacing or at a population of approximately 6,000 plants/ 20 m^2. The tall and late-maturing plants are discarded, and four or five seeds from each remaining plant of each population are harvested. The seeds are bulked and used for growing the next generation.

Whenever a BPH epidemic occurs in a suitable area on one of the substations or in a farmer's field, the bulked hybrid populations are seeded in infested areas and surviving plants are transplanted at close or normal spacings. No insecticides are used.

Bulked hybrid populations and pedigree lines are screened in the field for reaction to the BPH, gall midge, neck blast, bacterial leaf blight, grassy stunt virus, and cold tolerance (by growing at high elevations), and for elongation ability. The very late-maturing photoperiod-sensitive genotypes required for tidal-swamp rice culture can also be identified by growing at close or conventional plant spacings.

BPH screening program at Pusakanegara

Severe hopperburn occurred during the 1976–77 wet season in the area surrounding the Pusakanegara station, so about 150 of the $F_2 - F_3$ bulk populations carrying BPH and grassy stunt virus resistance were planted on the station at 5- × 5-cm spacing. Land, 0.3 ha or less, was required. Most of the susceptible plants were killed by BPH. Some of the surviving plants from promising crosses were harvested and their seed were planted in a pedigree nursery the next season. The remaining plants were also harvested and their seed were bulked, as described earlier. Those populations will be mass-screened again in the dry season of 1977.

Screening for resistance to BPH biotype 2

At Bogor and Sukamandi pedigree lines and bulked hybrid are being screened in the greenhouse for resistance to a BPH biotype-2 colony from North Sumatra. Field screening for biotype 2 resistance in farmers' fields was recently initiated in North Sumatra in cooperation with the Extension Service and North Sumatra University.

Horizontal resistance

The Kencana variety is a possible source of horizontal resistance to the BPH. Bogor entomologists have classified it as moderately resistant to moderately susceptible to both biotypes 1 and 2. It appears in several crosses listed in Table 2. Dr. I. N. Oka recently screened small F_2 populations of the crosses Kencana/Pelita I-1 and Kencana/Gati (B9c-Md-3-3) for resistance to both biotypes. He classified the F_2 populations of both crosses as varying from moderately resistant to susceptible plants. Further studies are necessary to determine if Kencana possesses general resistance to BPH.

The screening method for bulk populations described earlier might be suitable for use in identifying general resistance if the bulk populations are screened for several generations. If possible, the major gene resistance should not be present in populations being screened for general resistance.

YIELD TRIALS AND PROMISING LINES

During the 1975–76 wet season, advanced yield trials of lines resistant to the BPH, grassy stunt virus, and rice tungro virus were conducted at the Muara, Pusakanegara, Mertoyudan, and Singamerta stations of CRIA in Java. The trials consisted of 12 entries with randomized block design, 4 replications, 3- × 5-m plots, 25- × 25-cm spacing, and fertilizer rates of 120 kg N/ha + 60 kg P_2O_5/ha.

Both B3753-7-Pn-4-1 and B3753-8-Pn-2-2 produced higher yields than Pelita I-1 probably because they were resistant to BPH biotype 2 (Table 3). B1014b-Pn- 18-4 and B 1991 b-Pn-43-4-1 produced fairly good yields and matured earlier than Pelita I-1. They are resistant to BPH biotype 1. B1014b-Pn-18-1-4 appeared to be resistant to the narrow brown leaf spot disease (*Cercospora*).

In the dry season of 1976, preliminary yield trials of lines resistant to the BPH and grassy stunt virus were conducted at the CRIA stations in Genteng,

Table 3. Agronomic data and disease reactions of 12 promising lines in advanced yield trials grown at 4 sites in Indonesia. Wet season, 1975–1976.

Cultivar	Grain yield (kg/ha)			Ht (cm)	Maturity (days)	Reaction[a] to		
	Min	Max	Av.			Brown planthopper[b]	Grassy stunt virus[c]	Rice tungro virus[d]
B462b-Pn-1-3	2723	4275	3454	109	120	S	–	MR
B441b-126-2-3-1	2770	4617	3603	116	122	S	S	MR
B459b-Pn-132-3-5	2878	4797	3690	103	119	I	–	MR
E461b-Pn-3-2-5	2620	3903	3294	106	121	S	–	MR
B462b-Pn-31-2	3127	4753	3904	112	123	S	–	–
BKN 6809-74-40	3223	4013	3388	107	118	R	S	–
BKN 6809-74-6	2033	4312	3196	103	118	R	S	–
B1014b-Pn-18-1-4	3247	4457	3775	97	112	R/I	–	–
B1991b-Pn-43-4-1	2903	4330	3674	85	122	I	–	–
B3753-7-Pn-4-1	3384	5410	4527	101	126	I	R	–
B3753-8-Pn-2-2	2847	5034	4194	111	127	I	–	–
Pelita I-1	2435	5139	3975	118	128	S	S	S

[a] R = resistant, MR = moderately resistant, S = susceptible, I = intermediate. [b] Readings from Entomology Department, Bogor. [c] Results from field screening at Kendalpayak, E. Java. [d] Results from field screening at Lanrang, S. Sulawesi.

Kendalpayak, and Mojosari. The trials consisted of 49 entries with lattice design, 3 replications, 1- × 5-m plots, 25- × 25-cm spacing, and fertilizer rates of 120 kg N + 60 kg P_2O_5/ha.

The yield and agronomic data for the more promising entries are in Table 4. Heavy infestations of the grassy stunt virus at Kendalpayak and Mojosari stations were responsible for the very low yields of susceptible lines. B2360-8-

Table 4. Agronomic data and reactions to grassy stunt virus and the brown planthopper of 13 cultivars grown in yield trials at 3 sites. Dry season, 1976.

Cultivar	Yield (kg/ha) at			Average			Reaction[a] to	
	Genteng	Kendalpayak	Mojosari	Yield (kg/ha)	Ht (cm)	Maturity (days)	Grassy stunt virus(%) at Molosari	Brown planthopper (rating) from Entomology Department Bogor
B2360-8-5-LR-4-3	6447	7133	4154	6044	98	129	8	R
B2360-8-5-LR-5-5	5380	6233	3674	5096	96	123	5	I
B2360-11-3-2-2	6013	7367	3820	5401	106	130	3	R
B2360-11-3-2-6	5593	7233	4100	5809	105	127	7	I
B2360-11-3-2-9	5333	7433	4180	5622	100	130	3	R
IR26	4580	3809	2010	3466	91	138	11	I
IR28	3313	1733	2560	2502	87	114	3	I
IR30	3447	1435	2687	2522	86	117	8	I
IR32	4087	2032	4594	3571	98	143	7	R
IR34	5360	5310	4506	5055	111	133	0	I
IR36	4080	5067	3006	4031	84	120	6	R
C4-63Gb	3750	400	1660	1936	90	127	87	S
Pelltal-1	4353	167	360	1623	104	139	95	S

[a] S = susceptible, R = resistant, I = intermediate.

Table 5. Twenty promising lines being tested in advanced yield trials at 41 sites. Wet season. 1976–77.

Cultivar	Amylose content (%)	Plant height (cm)	Maturity (days)	Reaction[a] to		
				Brown planthopper[b]	Grassy stunt virus[c]	Rice tungro virus[d]
B1014b-Pn-18-1-4	26.7	91	128	R/I	–	–
B1187b-Pn-50-2	20.3	108	133	I	–	–
B1991b-Pn-43-4-1	24.3	79	125	I	–	–
B2360-8-9-5	29.0	99	128	I	R	–
B2360-2-9-3	24.0	109	114	I	R	S
B2360-6-7-1	28.0	95	121	I	R	R
B2360-6-9-5	28.0	98	130	I	R	–
B2360-8-5-LR-4-3	26.4	95	112	R	R	R
B2361-1-1-LR-4-5	26.7	91	130	R	R	R
B3753-7-Pn-4-1	25.4	101	126	R	R	–
B3753-8-Pn-2-2	29.0	111	127	R	R	–
IR1514A-E597-2	25.7	111	85	R	R	R
IR1909-1-3-3	28.0	94	131	R	R	S
IR2061-213-2-16	24.3	116	125	R	R	R
IR2071-486-1-2	16.0	–	140	R	R	R
IR2071-621-2-3	15.6	108	122	R	R	R
IR2153-43-2-3	24.0	84	116	R	R	MR
IR2172-64	29.0	84	125	R	S	–
IR32	30.0	88	149	R	R	MR
IR36	25 0	84	120	R	R	R

[a] S = susceptible, MR = moderately resistant, R = resistant, I = intermediate. [b] Readings from Entomology Department, Bogor. [c] Results from field screening at Kendalpayak, East Java. [d] Results from field screening plots at Lanrang, South Sulawesi.

5-LR-4-3 produced the highest average yield of 6 t/ha. Lines yielding higher than IR34 were three sister lines of B2360-11 and one sister line of B2360-8-5. IR34 was the highest yielding IRRI variety (5 t/ha), followed by IR36, IR32, and IR26. The early maturing varieties IR28 and IR30 produced relatively low yields (2.5 t/ha). The low yield of IR26 was caused by a rather heavy infection of grassy stunt virus. IR28 matured very early (114 days) while IR32, the variety with the longest growth duration, matured in 143 days. Pelita I-1 and C4-63 were very susceptible to grassy stunt virus and produced practically no grain at Kendalpayak station.

Although the three sister lines of B2360-11 had previously been classified as resistant to the BPH in the greenhouse, they showed severe hopperburn in the yield trials of Mojosari in the 1976-77 wet season. During the same season, 20 promising lines resistant to BPH and grassy stunt virus were planted at 41 sites throughout the main rice-growing areas of Indonesia.

Two groups of lines, early- and late-maturing, were tested. Lines from IR2071, IR2153, IR2172, and B3753 resistant to BPH biotype 2 were included. IR32 was used as check variety for the late-maturing group and IR36 for the early maturing group. The promising lines are listed in Table 5. The data from the 41 trials will be completed by May or June 1977.

It is expected that after the second season of multilocation testing, to be conducted in the 1977 dry season (July seeding), some of the lines can be proposed for varietal release. At present, IR32 has been approved for release as a variety resistant to the BPH biotype 2 and IR36 is being considered for release.

In addition to the promising lines listed in Table 5, several very promising lines from IR4744 (RPW6-13/IR1721-11-6-8-3-2//IR2061-464-2), which are resistant to both the BPH and gall midge, are also under evaluation. The lines were selected from a group of lines of IR4744 sent to Indonesia for gall midge screening in 1975–76. The lines resistant to gall midge were identified by the Entomology Department, and have since been screened three or more times in the greenhouse and in the field. Several appear to have potentials as new varieties.

Status of varietal resistance to brown planthopper in Japan

C. Kaneda and R. Kisimoto

Methods of mass-rearing brown planthoppers (BPH) and of screening for varietal improvement and genetic studies were described.

Three BPH colonies, originating from catches in 1975 in Fukuoka and Konosu, and in 1976 at Chikugo, were tested for racial difference. A set of differential varieties reacted Identically to the colonies, which were considered similar to the biotype 1 at IRRI.

The growth in population of a wild colony of BPH on BPH-resistant rice was studied in the field and in the greenhouse using lines nearly isogenic for *Bph 1* gene. The colony kept on resistant lines for three generations in the field and for four generations in the greenhouse infested caged plants of the resistant lines in the field as severely as did the colony caged on susceptible varieties. In other experiments, as much as 74% and 92% of the 2 colonies reared for 4 generations on Mudgo and ASD 7, respectively, survived on these varieties. When these colonies were kept on Mudgo and ASD 7 for 10 generations and then on the susceptible variety Nihonbare for 4 generations, they did not recover their nonpreference for the resistant varieties.

Backcrossing is being adopted to incorporate *Bph 1* and *bph 2* into Japanese rice. Studies with F_2 plants with *Bph 1* suggested that the resistant gene *Bph 1* is significantly associated with longer culm, while studies with F_2 plants with *bph 2* gene, originating from IR1154-243, showed no relationship between BPH resistance and culm height, grain fertility, or threshability

Since there is more reason for suspecting degradation of the antibiosis in hybrid llnes than in donors of BPH resistance, breeding lines of a single cross and its first and second backcrosses were tested. Survival percentage was not necessarily higher, but the mean body weight of surviving insects increased nonsignificantly with repeated backcrossing.

The linkage relationship of *Bph 1* is being studied with other agronomic traits in cross-combinations involving many marker genes on 10 different chromosomes.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* Stål., the most serious insect pest of rice in Japan, cannot overwinter in the country. It is believed to immigrate every year from late June to July (Kisimoto 1976). BPH multiply on rice for three or four generations and finally cause “tsubo-gare,” or hopperburn, in maturing rice. As we bring hopper-resistant rice varieties into practical use,

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information on the area from which the insect migrates, the predominant biotypes of that area, changes of biotypes, etc. becomes essential. The role of the International Rice Brown Planthopper Nursery (IRBPHN) in providing such information is important to Japan.

SCREENING FOR VARIETAL RESISTANCE

At the Central Agricultural Experiment Station (CAES), Konosu, Japan, BPH are reared and screened in an insectary at 26 to 27°C and with 15 hours of light. In insect mass-rearing, young seedlings are grown in plastic trays (26 15 × 3.3 cm) without soil. Two trays are placed in a wooden-frame cage, 30 x 34 × 43 cm, with plastic plates for the top, the bottom, and the front cover, and with nylon mesh for the other three sides. About 2,000 to 3,000 nymphs can be reared in each tray.

In mass screening, 15 germinated seeds of each entry, after 2 days of incubation at 30°C, are planted in a half row (about 6.5 cm) in the tray. Usually 20 half-rows, including two replications of check rows, are grown in the tray's shallow soil. After 2 days in a lighted incubator, seedlings at the early second-leaf stage are each infested by about five second- and third-instar BPH nymphs. Susceptible plants are killed within 5 to 7 days after infestation.

In a short-term caging method (Kaneda 1975) designed to secure susceptible plants for further experiments, infestation is discontinued after 3 days. All nymphs are cleared off, and the plants are brought into a lighted incubator again. One or two days of nurturing would make clear the difference of varietal resistance. Susceptible plants recover from the suppressed growth after several days.

During the past 4 years of screening, we have found, in addition to those already recorded at IRRI and elsewhere, varieties that are highly resistant to the BPH. They are: Ptb selections (4, 7, 10, 12, 20, 28, 29, 30, 31, 34), HS 19, H 2871, and ADT 3 of India and Chhuthana of Khmer. Kaeu N. 632 and 651 of USSR are also resistant. Dozens of traditional varieties of Japan, China, and Southeast Asian countries, which were found moderately resistant, proved to have an antibiosis as weak as that of susceptible varieties (Kaneda et al 1977).

Some varieties in the 1974 IRBPHN that had been called resistant, such as CO 13, RP9-3, and RP9-4, proved to be susceptible in repeated tests. Similar observations were made in Korea (Choi 1975). The results of the 1976 IRBPHN suggested that the BPH colony at CAES is quite similar to biotype 1 at IRRI. The varieties and selections with resistance gene showed resistance, except for segregation in several selections.

RACIAL DIFFERENCES OF SEVERAL BPH COLONIES IN JAPAN

Until August 1976, CAES used a colony collected in Kagoshima in 1972 for screening germplasm and breeding materials. The insects used for the mass

Table 1. Suppression of seedling growth of selected rice cultivars by three colonies[a] of the brown planthopper (BPH) in Japan (Konosu 1976).

Cultivar	BPH resistance gene	Growth[b] (% of growth of uninfested check)					
		Seedling ht			Leaf age		
		A	B	C	A	B	C
Mudgo	*Bph 1*	68	50	53	97	99	100
IR26	"	71	71	74	97	95	97
$F_8$262	"	60	63	63	99	99	97
$F_6$324	"	66	64	70	97	97	99
ASD 7	*bph 2*	74	79	70	95	98	98
IR1154-243	"	57	72	63	86	95	97
IR32	"	67	81	67	92	95	92
IR36	"	72	83	64	100	100	100
CR 94-13	"	76	88	68	99	99	97
Rathu Heenati	*Bph 3*	66	75	75	100	100	100
Babawee	*bph 4*	50	60	53	84	94	92
Ptb 21	unknown	82	91	85	98	100	98
Ptb 33	"	77	82	17	100	100	100
Nihonbare	none	14[c]	14[c]	14[c]			
TN1	"	31[c]	28[c]	28[c]			

[a] Insect colonies: A = '75 Fukuoka, B = '75 Konosu. C = '76 Chikugo.

[b] Seedling ht = $\frac{\text{Ht of infested seedlings}}{\text{Ht of uninfested seedlings}} \times 100$. [c] Killed by BPH.

screening and other tests were not re-collected for the reproduction of the next generations. Screening for 4 years gave no indication of breakdown of varieties with *Bph 1* or *bph 2* genes for resistance. Since September 1976, a new colony, '75 Fukuoka, has been used. CAES tested three BPH colonies, including '75 Fukuoka, for their effects on 15 rice cultivars of different genetic backgrounds (*Bph 1, bph 2, Bph 3, bph 4,* and others). Entries were randomly arranged in a tray containing shallow soil; 10 seeds of each entry were planted in a row. In mass screening, the reactions of the varieties to the three colonies were generally identical; only the susceptible check varieties were killed. The '75 Konosu colony seemed weaker than the other colonies (Table 1) but since seedlings were not infested with exactly the same numbers of nymphs, the difference may not be essential. The experiment made clearer the similarity to biotype 1 of IRRI of the BPH that migrated to the Kyushu areas in 1975 and to the Kanto areas in 1976.

We consider it necessary to mention the yearly monitoring of the types of BPH migrating into Japan. Sampling immigrants early in the rice-growing season in western Japan will provide needed data.

BIOTYPES OF BPH

In the field, populations of a wild colony of BPH artificially released on a susceptible check variety, Nihonbare, and on susceptible lines in the two sets of nearly isogenic lines (Kaneda 1975) multiplied to such a degree that hopper-

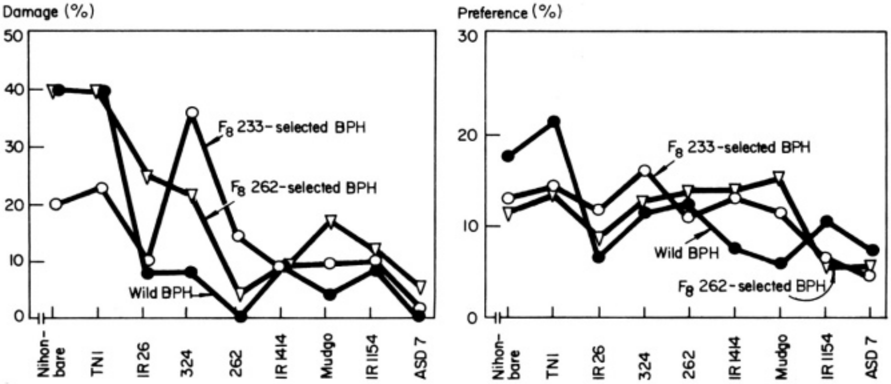
Table 2. Population growth of wild brown planthoppers (BPH) artificially released on two sets of lines nearly isogenic for *Bph 1,* and on a susceptible check.

Cultivar	Replicate	BPH population[a] (no.) 28 July	1st generation[b] (no.) 20 Aug	2nd generation[b] (no.) 26 Sept.	Damaged hills[c] (no.)			
					A	B	C	Total
Nihonbare	1	8	129	∞	38	22	4	64
S check	2	12	189	∞	34	35	21	90
F_8 262 (R)	1	0	6	25	0	0	0	0
	2	0	10	38	0	0	0	0
F_8 264 (S)	1	8	167	∞	74	23	0	97
	2	9	226	∞	63	23	7	93
F_8 223 (R)	1	0	11	23	0	0	0	0
	2	0	18	50	0	0	0	0
F_8 236 (S)	1	5	225	∞	59	19	3	81
	2	5	152	∞	54	13	2	69

[a] Number of short-winged females remaining from 27 insects introduced on 3 × 3 hills at center of plot on 24 July. [b] Number of short-winged females found in each experimental plot of 15 × 15 hills, ∞ means more than several hundreds. [c] A = completely withered hills; 13 = partly withered hills; C = no tillers withered but with sooty mold.

burn occurred in the third generation. On the other hand, on resistant lines carrying *Bph 1* from Mudgo, the multiplication was clearly suppressed but the pests were not exterminated; they stayed at a low but rather stable level for three generations until harvest (Table 2). The surviving adults were collected and kept for four generations in a glass house with ratoons of the test lines. In the next crop season they infested caged rice plants in a field of resistant lines, apparently as easily as wild BPH infested susceptible varieties.

After 10 generations of breeding on the resistant lines F_8 262 and F_8 233, each biotype colony was tested for its host preference, at 25°C in the laboratory, on two susceptible check varieties, five resistant cultivars carrying *Bph 1,* and two carrying *bph 2* (Fig. 1). Five plants of 9 cultivars, with 2 replicates (90 plants in a cage), were infested at the second leaf stage with 250 to 300 insects. Most of the insects were fifth-stage nymphs; some were adults. Preference was indicated by the average percentage of insects observed infesting each variety



1. Preference for and damage to rice lines F_8 262 and F_8 233 by three BPH biotypes.

during the first 3 days after the insects were introduced. The wild BPH population showed equal nonpreference for all resistant varieties but the selected biotypes showed impartiality for susceptible and resistant varieties carrying *Bph 1.* Nonpreference for lines carrying *bph 2* persisted. After 10 days of infestation, plant injury was determined on the basis of a scale of 0 (no visible damage) to 4 (completely withered). All resistant varieties were resistant to the wild BPH but in some cases, some of the resistant varieties carrying *Bph 1* showed as much susceptibility to feeding damage by F_8 262-selected and F_8 233-selected biotypes as did the susceptible checks. The differences in the inherent tolerance for damage among varieties caused rather variable results.

Selective breeding for biotypes infesting Mudgo and ASD 7 was carried out in the laboratory. Nymphs fed on Mudgo and ASD 7 had survival ratios of 46 and 31%, respectively, in the first generation, and 74 and 92% in the fourth generation. The preference of each colony for the resistant variety it fed on increased until it was as great as its preference for a susceptible check (Nihonbare); its preference for the other variety did not increase. At the 10th generation, a part of each colony was again released on Nihonbare to feed for two and four generations to determine if nonpreference for a resistant variety can be recovered. Preference, however, remained as high as that of a colony not so treated.

STATUS OF RICE BREEDING FOR BPH RESISTANCE

Efforts in breeding for BPH resistance had been concentrated on introducing *Bph 1* and *bph 2* genes into Japanese rice until 1976, when Rathu Heenati, Babawee, Ptb 33, and other cultivars were crossed with Japanese varieties to widen the genetic base of BPH resistance.

Breeding for *Bph 1*

Agronomic characteristics and factors related to BPH resistance of the primary parental lines derived from crosses between japonica varieties and Mudgo, have been described elsewhere (Kaneda 1976). The major defect of those parental lines was their rather low cross-compatibility with Japanese varieties. Their plant height, threshability, grain and table quality, and other traits were not as satisfactory as those of commercial varieties in Japan. Backcrossing was repeated and plant selection from the crosses was initiated in 1976.

Earlier studies with nearly isogenic lines suggested that the *Bph 1* gene is linked with some genetic factor or factors controlling greater culm height, which came from Mudgo. One of the primary parental lines, F_8 262, is about 4 cm taller than its susceptible counterpart, F_8 264.

The association between BPH resistance and culm height was also noticed in the B_1F_2 populations of Reiho/F_8 262//Reiho grown in 1976. A total of 167 F_2 plants, selected randomly from two populations of the cross, were analyzed for association between BPH resistance and maturity, culm height,

Table 3. Association between brown planthopper resistance (*Bph 1*) and culm height in random samples of F_2 plants of Reiho/F_8 262//Reiho.[a] Konosu 1976.

Culm ht (cm)	F_2 plants (no.) observed and expected (in parentheses)			
	Bph 1/Bph 1	*Bph 1/bph 1*	*bph 1/bph 1*	Total
70 or less	0 (2.5)[b]	7 (9.0)	9 (4.5)	16
71 to 80	5 (11.2)	39 (40.5)	28 (20.2)[c]	72
81 to 90	17 (10.0)	37 (36.0)	10 (18.0)	64
91 to 100	4 (2.3)	11 (8.5)	0 (4.2)	15

[a] Chi square for free recombination of resistance and culm height: $x^2 = 49.18$ ($P > 0.005$). [b] Category for F_8 262. [c] Category for Reiho.

grain fertility, threshability, grain quality, and leaf character (japonica type or indica type). Only culm height was significantly associated with BPH resistance. As shown in Table 3, none of 16 plants with culms less than 70 cm were homogeneous for the resistance, while none of 15 plants with culms over 90 cm were homogeneous for susceptibility.

In the other cross, F_6 324/Akitsuho^3, resistance was also associated, though not significantly, with taller culm or lower grain fertility.

In spite of such undesirable associations, CAES expects to have many promising lines in 1977, selected from different backcrosses. Table 4 lists the primary CAES breeding material for BPH resistance grown in 1977.

Table 4. Principal breeding material for BPH resistance at Central Agricultural Experiment Station, Konosu, Japan, in 1977.

Cross no.	Cross combination[a]
B_1f_1	
	Tsukushibare/Rathu Heenati//Tsukushibare, etc
	Tsukushibare/Babawee// Tsukushibare, etc.
	Tsukushibare/Ptb 21 or Ptb 33//Tsukushibare, etc.
BC F_2	
7605	A/Akitsuho^3, etc.
7607	B/Reiho^2, etc.
7611	C/Asominori^2, etc.
7613	Tsukushibare/C, etc.
F_3 lines	
7501	D/Tsukushibare
7503	A/Reiho//Asominori
7507	A/Akitsuho^2
7513	B/Tsukushibare, etc.
7520	A/Tsukushibare
7517	C/Asominori
7518	C/Tsukushibare
7519	C/Mizuho
F_4 lines	
7316	A
7407	A/Reiho
7408	A/Akitsuho

[a] A = F_6 324/Akitsuho, B = Reiho/F_8 262, C = Asominori/IR1154//Asominori, D = IR1414-67/Nihonrnasari^2//Tsukushibare.

Table 5. Characteristics of backcrossed F_1 plants, with or without *bph 2* gene, grown in greenhouse boxes, Konosu, Japan. winter 1975–76.

Cross no.	Population	Genotype	F_1 plants tested (no.)	Culm length[a] (cm)	Fertile grains [a] (no./ear)	Gram fertility (%)	Thresh-ability [b] (grade)
7517	4	*bph 2*/--	87	48.3 ± 6.13	18.1 ± 7.43	78	2.2
		--/--	97	47.3 ± 6.46	16.7 ± 6.22	76	2.3
7518	4	*bph 2*/--	74	48.4 ± 5.51	18.5 ± 6.51	71	2.7
			69	46.3 ± 5 42	16.8 ± 5 89	72	2.6
7519	3	*bph 2*/--	56	50.2 ± 5.24	18.0 ± 7.71	72	2.3
		--/--	90	49.5 ± 5.36	17.0 ± 6.19	68	2.8
Asominoro (check)			16	45.5	14.8	86	1-3
Mizuho (check)			16	42.1	11.1	66	2-4
IR1154-243 (check)			9	37.0	9.6	32	6-7

[a] x ± s. [b] International Rice Standard.

Breeding for *bph 2*

IR1154-243 was selected as the gene source of *bph 2* because of its short stature and earliness under temperate conditions. Besides, it seems more compatible with japonica rice than with indica rice.

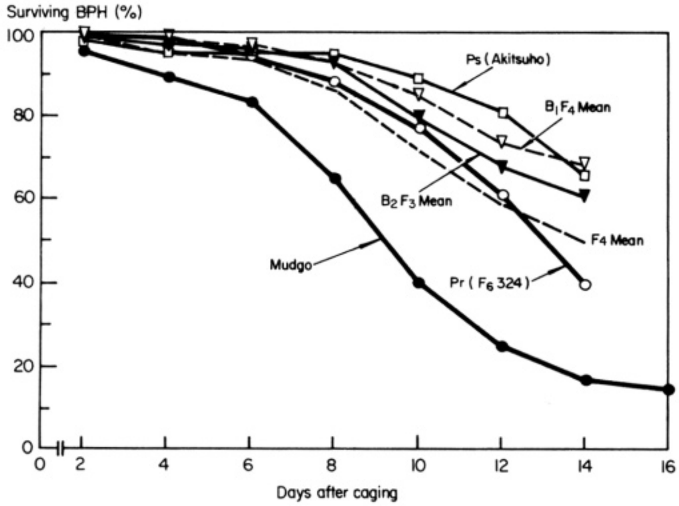
In contrast with what was done with *Bph 1* material, the backcrossed F_1 plants were grown without screening for BPH. Each F_1 plant grown in the greenhouse during winter was tested, using newly harvested F_2 seeds, for the retention of the *bph 2* gene. The presence of *bph 2* in B_2F_1 individuals did not affect culm height, grain fertility, number of grains per panicle, or threshability (Table 5; Kaneda et al 1977).

Also, the materials with *bph 2* seemed much more tolerant than *Bph 1* materials of the low temperatures and shading that cause low fertility of the grain in the winter crop produced in the greenhouse. Although resistant F_1 plants of *Bph 1* material suffered 70 to 80% sterility, *bph 2* material suffered only 22 to 29% sterility in the greenhouse during the 1975–76 winter.

We, therefore, consider breeding with *bph 2* to be much less difficult than breeding with *Bph 1,* although we have no data yet concerning the association of BPH resistance and grain quality, especially the high amylose content of IR1154-243.

EFFECT OF BACKCROSSING UPON ANTIBIOSIS

The primary CAES parental lines for BPH resistance do not retain the high levels of antibiosis retained by the donor parent Mudgo, though their reactions in the mass screening are as strong as Mudgo's. If the level of antibiosis is inevitably lowered by crossing with susceptible varieties, continued backcrossing, which is essential for breeding BPH-resistant japonica rice, would result in the selection of rices with little antibiotic effect on the BPH. In other words, rice varieties with more improved agronomic traits would not effectively hold down BPH populations.



2. Brown planthopper (BPH) survival on rice selections of different times of backcrossing compared with that on donor and recurrent parents (cf. Table 6).

Ten rice selections with different degrees of backcrossing, which were homogeneous for BPH resistance, were tested along with their donor and recurrent parents. Three second-leaf seedlings were caged with 10 second-instar BPH nymphs in glass test tubes. Insect survival, percentage of adults emerging, and mean body weight of insects surviving on the 16th day after caging, were used to determine the level of antibiosis.

As seen in Figure 2 and Table 6, insect survival was not necessarily higher for cultivars with more backcrosses in their backgrounds, and it varied even among lines of the same cross. The mean body weight of surviving BPH seemed to be increased by repeated backcrossing to japonica rice, although for some unknown reasons, it was much smaller on some single-cross lines than on their resistant parent F_6 324 (Kaneda and Jin 1977). However, variance analysis of body weight clearly differentiated the strong antibiosis of resistant breeding lines from that of susceptible parent. More tests are needed to dispel fears that repeated backcrosses to susceptible varieties may cause the degradation of antibiosis in rice selections.

Studies of the inheritance of *Bph 1*

Association of *Bph 1* with other agronomic traits is studied in the breeding process already described. In addition the research into the linkages between *Bph 1* and many marker genes has been conducted.

Five cross-combinations involving 10 marker genes on 6 chromosomes were analyzed by applying a “short-term caging method” to F_2 populations. After resistant and susceptible F_2 plants had been separated, they were transplanted

Table 6. Survival and development of BPH nymphs on rice selections derived from different doses of backcrossing to a japonica variety.

Test no.[a]	Cultivar	BPH survival (%) after caging for				Adult emergence (%)	Mean body wt (mg)
		8 days	10 days	12 days	14 days		
1	Mudgo	65	40	25	17[b]	3.7	0.96[b]
2	F_6 324	88	77	61	40[b]	36.0	1.15[b]
13	Akitsuho	95	89	81	66[c]	75.3	2.22[c]
3		90	81	70	61[c]	38.2	1.12[b]
4		86	77	65	59[c]	18.5	0.80[b]
5		81	57	42	30[b]	2.5	0.75[b]
	3–5 mean	86	71	59	50[c]	19.9	0 89
6		94	86	84	80[c]	49.0	0.91[b]
7		91	80	62	54[c]	27.4	1.16[b]
8		93	88	76	72[c]	46.6	1.05[b]
	6–8 mean	93	a5	74	69	41.0	1.04[b]
9		89	66	48	43[b]	31.0	1.24[b]
10		95	92	86	78[c]	51.8	1.12[b]
11		92	78	69	61[c]	46.0	1.18[b]
12		97	80	69	60[c]	40.0	1.22[b]
	9–12 mean	93	79	68	61	42.2	1.19

[a] 3–5 = F_4 lines of F_6 324/Akitsuho; 6–8 = F_4 lines of F_6 324/Akitsuho^2. 9–12 = F_3 lines of F_6 324/ Akitsuho^3. All of these lines are homogeneous for BPH resistance. [b] Significantly different from the maximum. [c] Significantly different from Mudgo, the donor of antibiosis.

in groups to the field, and observed for segregation in the marker characters. The linkage group and the marker genes, which seemed independent of *Bph 1,* are: *lg* (liguleless) and d_{11} (dwarf) of II ; *g* (long glume) of IV, *bl* (brown-spotted leaf), *tri* (triangular spikelet). and gh_2 (gold hull) of X; and *gl* (glabrous leaf) of XII, *la* (lazy habit) and *sp* (short panicle) of VIII; and *ch* (chlorina) of XI.

Six other crosses involving 13 marker genes on 8 chromosomes were tested in F_3. *Dn* (dense panicle) and dp_2 (depressed palea) of VII, *dt* (tillering dwarf), *Sp* and *la* of XIII, gh_2 and d_w (dwarf) of X seemed independent of *Bph 1. Cl* (clustering of spikelets) and *dp* of I, *lg* of II, lux (lax panicle) of III, gh_2 of VI, and *dl* (droopy leaf) of XI are still to be studied.

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Varietal resistance to the brown planthopper in Korea

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Since 1971, varietal screening for resistance to the brown planthopper has been conducted successfully using the mass-screening techniques developed by IRRI. Many varieties and lines from foreign collections have been identified as resistant, with resistance reactions identical to those of IRRI. Some factors of insect resistance were investigated. It was found that the resistant varieties are nonpreferred for feeding, but not always for oviposition. On resistant varieties, brown planthoppers suffered high mortality, had a slower rate of growth, and laid fewer eggs, from which fewer adults developed. Such effects might be attributed to less feeding on the resistant than on susceptible plants.

Study of the inheritance of resistance to the brown planthopper showed that the resistance in IR2061 seemed essentially the same as that in Mudgo, i.e. controlled by a single dominant gene.

No hopper-resistant varieties have been released, but many promising lines with hopper resistance are in advanced-generation trials. Their resistance-gene sources are mainly IR747B2-6 and Mudgo, with that of a few being H105. We are continually endeavoring to diversify resistance-gene sources.

THE BROWN PLANTHOPPER *Nilaparvata lugens* is now one of the key pests on rice in the countries of the Far East and Southeast Asia. In Korea, outbreaks have been sporadic and frequently severe. In 1975, we observed a severe outbreak in the southern part of the Republic of Korea. Severe losses of rice yield resulted : 24.1% in the Tongil variety, and 38.3% in Akibare (Park and Lee 1975).

In recent years, resistant varieties have received increasing attention because of growing awareness of the shortcomings of chemical pesticides. It has been well documented that varietal resistance can be a practical method for controlling insect pests. The control need is critical in Korea, because conventional rice varieties are all highly susceptible to the brown planthopper.

It is important that the available rice germplasm be screened for resistance to the pest and that resistance compatible with other desirable plant characters

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be incorporated into new varieties. Since 1971, Korean rice breeders and entomologists have paid great attention to discovering resistant sources, and to their use in Korea's breeding programs.

Fortunately, significant progress has been made in developing varietal resistance to the brown planthopper. Some lines showing high resistance will be commercialized in the near future.

SCREENING FOR RESISTANCE

In 1971, techniques of mass screening for varietal resistance to the brown planthopper were first introduced into Korea from the International Rice Research Institute (IRRI). Mass screening of seedlings was conducted in the greenhouse or laboratory, or sometimes in the screenhouse. Field screening is practically impossible in Korea because of fluctuations in annual migrations and the difficulty of obtaining sufficient insect populations for testing.

Mass rearing of test insects

The original colony of the test insects is started by one pair of adults. They are mass-reared on such susceptible rice varieties as Tongil, Yushin, and Jinheung, which provide the insects with food and sites for oviposition. Two methods are used in mass rearing; one uses 40- or 50-day-old potted plants inside a wooden cage covered by fine-mesh nylon cloth; the other uses rice seedlings placed in a transparent acrylic (plastic) cage. Details of both methods have been described by Choi (see Choi this volume). In the latter method, seedling-mats are prepared by placing the pregerminated seeds on gauze in enameled photographic trays. Two or three days later the seedlings are caged with adult insects. After 2 days, seedling-mats that contain eggs are taken out of the cages, after first removing the ovipositing insects. The plants or seedling-mats are transferred to another cage to await egg hatching. The method provides a continuous supply of test insects. The use of rice seedling-mats is feasible in the laboratory in the off-season, but rearing efficiency is inferior to that of potted plants in the field or greenhouse.

Screening procedures

Test varieties are seeded in rows spaced 4 cm apart in 40- × 51- × 10-cm polyethylene seedboxes. Each cultivar is planted in a 15-cm row across the width of the seedbox. A susceptible check variety (usually TNl, or Tongil, Yushin, or Jinheung) and a resistant check variety (always Mudgo) are planted at random in each seedbox.

The seeds are usually pregerminated by soaking in water at 30°C. For the first 10 hours the seeds are disinfected with fungicide phenyl mercuric acetate (PMA) in a water solution; then they are soaked again in water, which is replaced several times. Individual seeds are spaced uniformly within each row. The method, although laborious, gives a more uniform stand of seedlings than direct seeding. Twenty test varieties are accommodated in each seedbox. The seeded boxes are placed in a concrete or iron tray containing 5 cm of standing water. The bottom of each seedbox has several small holes to admit water freely. The water standing in the tray provides the high humidity required for survival of *N. lugens,* and eliminates the need for watering that might disturb feeding insects.

The seedboxes are usually covered by a bottomless wooden cage (30 × 40 × 30 cm) covered with fine-mesh nylon cloth. The cage keeps the insect population constant, preventing insects from escaping during the screening.

Seedlings at the one-leaf stage are infested by scattering a large number of second- and third-instar nymphs on them, an average of five insects per seedling. Final readings are made 10 to 14 days after infestation when all susceptible check plants have been killed. The scoring system of 0 to 9 is used.

Resistance response of source varieties

About 2,000 varieties or lines from Korean varietal collections and foreign introductions have been mass-screened for resistance to the brown planthopper. A large number from IRRI were reidentified in Korea as resistant, and at present their resistance has been identical to that of reactions at IRRI. All the japonica varieties tested so far from the Korean collection have been identified as highly susceptible.

CAUSES OF RESISTANCE

The resistance of varieties to insects could be due to one or more factors; nonpreference, antibiosis, or tolerance. Tolerance responses are generally more influenced by environmental conditions than are nonpreference and antibiosis (Painter 1951; Pathak 1970). Studies, therefore, have stressed evaluation of varietal resistance to the brown planthopper in terms of nonpreference and antibiosis.

Preference for feeding and oviposition

Since 1971, investigations on the preference of brown planthopper for feeding and oviposition on different varieties of rice have been reported in Korea (Choi et al 1976; Song et al 1972). These results indicated that the brown planthopper exhibited distinctly different preferences for different varieties in respect to feeding and oviposition. With the resistant and susceptible varieties, feeding preferences of the brown planthopper nymphs did not always coincide with the ovipositional preference of adults.

Song et al (1972) carried out an experiment for evaluating the nature of resistance of rice varieties to the brown planthopper. The test varieties were sown in rows containing 10 seedlings per row, 4 cm apart, in 36- × 46- × 10-cm polyethylene seedboxes. At the one-leaf stage, about 800 third-instar nymphs were placed on the rice plants. In a separate experiment with the same method,

Table 1. Preference of brown planthoppers for feeding and oviposition on resistant and susceptible varieties of rice (Song et al 1972).

Variety	Feeding and ovipositional preference[a]		
	Nymphs (no./plant)	Eggs (no./plant)	Seedling reaction
Su-yai-20	6.5 a[b]	25.8 de[b]	S[c]
Suweon 213-1	5.3 ab	35.4 cd	S
Suweon 214	5.2 ab	22.9 de	S
Suweon 218	4.9 b	24.6 de	S
Suweon 215	4.8 bc	29.8 de	S
Jinheung	4.3 bcd	27.3 de	S
Suweon 217	4.1 bcde	26.3 de	S
H 105	3.4 cdef	56.3 bc	R
Vellailangalayan	3.2 defg	25.6 de	R
IR8	3.0 defgh	51.0 bc	S
Pankhari-203	2.8 efgh	24.0 de	S
DV-139	2.5 fgh	80.2 b	S
ASD-7	2.1 fgh	135.9 a	R
MGL-2	1.7 gh	58.5 bc	R
Mudgo	1.6 h	73.1 b	R

[a] 48 hours exposure. [b] In a column any two means followed by the same letter are not significantly different at the 5% level. [c] S = susceptible, R = resistant.

about 200 female adults were released on seedlings at the two-leaf stage. After 48 hours, the numbers of nymphs and of eggs on the seedlings of each variety were recorded.

As shown in Table 1, fewer nymphs were recorded on the resistant varieties Mudgo, MGL-2, and ASD-7, than on the susceptible varieties Su-yai-20, Suweon 213-1, etc. In contrast, the varieties Mudgo, MGL-2, and ASD-7 had a relatively large number of eggs despite a low feeding preference. Generally, there was low feeding preference for the resistant varieties. However, the insects caused no apparent damage to resistant varieties such as H105 and Vellailangalayan, which showed relatively high feeding preference. Song et al (1972) also conducted an experiment to ascertain the preferences of the brown planthopper for oviposition on resistant varieties. When female brown planthopper adults were placed individually in test tubes on the resistant variety ASD-7 and the susceptible variety Suweon 214, the numbers of eggs laid were significantly fewer on ASD-7 than on Suweon 214. When the two varieties were grown together in a test tube, brown planthoppers significantly preferred ASD-7 for oviposition (Table 2). When each test tube contained only ASD-7, the insects had to feed on it or starve, but the insects laid fewer eggs on it than on the susceptible variety Suweon 214. However, when each test tube contained both varieties, the insects frequently moved about from the resistant variety to the susceptible variety and vice-versa; presumably to one for feeding and to the other for oviposition.

There is additional strong evidence to account for differences in feeding and oviposition of the brown planthopper on resistant varieties. Choi et al (1976) conducted a laboratory experiment to evaluate the nature of resistance of the new rice varieties Milyang 21 and Milyang 23 to the brown planthopper.

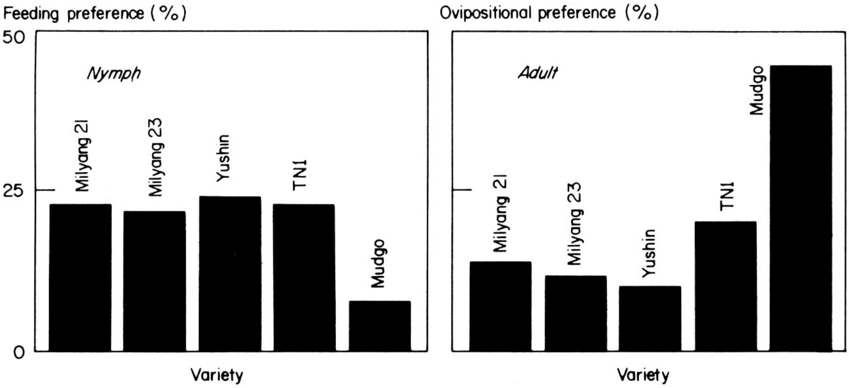
Table 2. Ovipositional preference of brown planthopper on rice varieties ASD-7 and Suweon 214 grown separately or together (Song et al 1972).

Variety	Eggs[a] (no./female)					Eggs (total no./female)
	1 Di	2Di	3Di	4Di	5Di	
			Grown separately			
ASD-7	5.5	2.3	10.3	0	0	17.8
Suweon 214	12.5	19.3	10.1	2.5	19.9	64.3
			Grown together			
ASD-7	18.1	12.4	5.4	14.2	12.3	62.4
plus						
Suweon 214	3.5	6.1	1.0	2.5	6.1	19.2

[a] Di = days after infestation.

According to our results (Fig. 1), nymphs preferred to feed on the susceptible varieties Milyang 21, Milyang 23, and Taichung Native 1 rather than on Mudgo. For oviposition, however, the adults preferred Mudgo rather than the susceptible varieties. Similar findings were also reported for small brown planthoppers (*Laodephax striatellus*) (Choi et al 1974, 1976), whitebacked planthoppers (*Sogatella furcifera*) (Choi et al 1973c), green rice leafhoppers (Choi et al 1973a) and zig-zag leafhoppers (Choi et al 1973b).

There is some evidence that contradicts the previous findings. Lee et al (1971) tested the preference of the brown planthopper for oviposition on varieties of rice in a paddy field screenhouse (39.6 m^2). The plants were exposed to about 10,000 brown planthopper adults 28 days after transplanting. After 7 days, eggs on 5 randomly selected plants of each variety were counted. A significantly higher number of eggs was found on the susceptible varieties than on the resistant variety Mudgo (Table 3).



1. Preference of brown planthopper nymphs and adults for feeding and oviposition on the seedlings of some varieties (Choi et al 1976).

Table 3. Ovipositional preference of brown planthopper on rice varieties or lines in a paddy field screenhouse (Lee et al 1971).

Source[a]	Varieties and lines tested (no.)	Egg-masses (no./15 hills)	Eggs (no./egg-mass)	Eggs (no./hill)
Tongil lines	12	82 2 ± 26.1	6 6 ± 0.6	36.3 ± 11.7
Japonica varieties	15	99 6 ± 30.1	6 3 ± 0.6	40.6 ± 11.2
IR1317 lines	8	97 5 ± 26.5	6.6 ± 0.7	44.0 ± 14.0
Other IR lines	11	108.8 ± 37.9	6.3 ± 0.5	44.7 ± 12.4
TN1 (check)		126	7	56
Mudgo (check)		8	6	3

[a] Varieties or lines susceptible to the brown planthopper.

Survival and development

When plants contain factors preventing insects from feeding on them, or are toxic to insects, the phenomenon is commonly known as antibiosis. At present, such a form of resistance appears to be desirable, and possibly has a more permanent basis for maximum effectiveness. Emphasis has, therefore, been placed on identifying varieties exhibiting antibiosis.

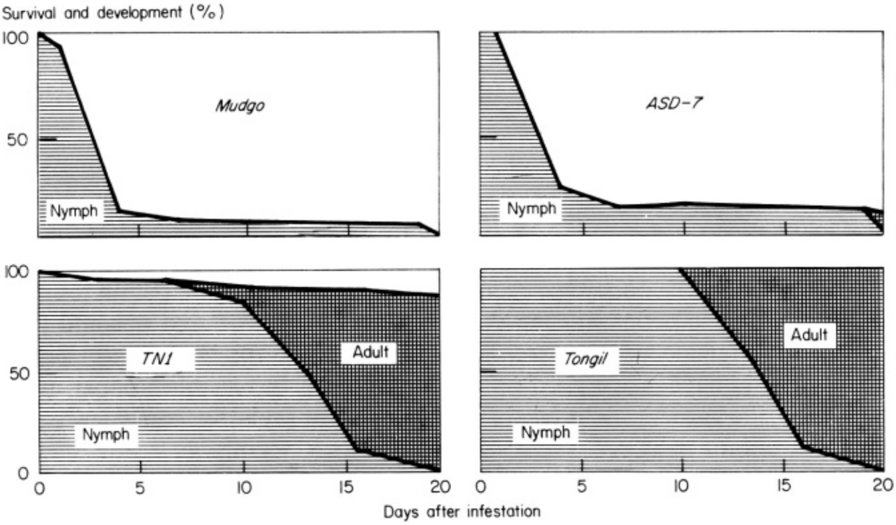
Lee and Park (1976) identified some lines that have been bred in Korea with promising resistance to the brown planthopper. First-instar nymphs caged on the new lines suffered high mortality, and fewer insects developed into adults than those that developed from nymphs on the susceptible varieties Tongil and Yushin (Table 4). Similar results were reported by Choi (1975) and Lee and Park (1976).

Song et al (1972) conducted a series of experiments to evaluate the nature of resistance of several varieties, studying several biological effects on the brown planthopper. The first-instar nymphs were caged on 10- to 14-day-old seedlings

Table 4. Rate of adult emergence of brown planthopper when first-instar nymphs were confined on seedlings of resistant and susceptible varieties or lines (Lee and Park 1976).

Variety or line	Insects infested (no.)	Adults emerged (no.)	Adult emergence (%)
Resistant lines[a]			
KR108-335-6	30	0	0
KR 87-56-4	20	1	5.0
KR 78-87-4	17	1	5.9
YR901-16-1	32	3	9.4
HR632-9-4	10	1	10.0
HR529-45-3	30	6	20.0
YR 92-91-3	38	12	31.6
HR529-42-5-2	19	6	31.6
Susceptible varieties[b]			
Yushin	14	12	85.7
Tongil	24	22	91.7

[a] Newly bred lines in Korea. [b] Leading varieties from indica japonica crosses.



2. Survival and development of first-instar brown planthopper nymphs on 10- to 14-day-old seedlings of resistant (Mudgo and ASD-7) and susceptible (TN1 and Tongil) varieties (Song et al 1972, 1974).

of the resistant varieties Mudgo and ASD-7, and on the susceptible varieties TN1 and Tongil (Suweon 213-1). After caging on Mudgo. nymphs suffered high mortality. and few nymphs became adults; while on TN1 and Tongil, nymphal survival was high and all nymphs became adults (Fig. 2).

In additional, but separate, experiments some biological interactions between the insects and the varieties were studied (Table 5). The varieties did not in any way affect the egg period and hatchability. However, the nymphs caged on resistant plants had a longer nymphal life than those on susceptible lines. The nymphal span was extended by about I week on resistant varieties. The lowest adult emergence was recorded on Mudgo (5.3%); the next lowest (11.2%) on ASD-7. High numbers of adults emerged on TN1 (87.1%), on Suweon 214 (96.8%), and on Tongil (100%). It is also apparent from the results that resistant

Table 5. Biological effects of resistant and susceptible rice varieties on the brown planthopper [a] (Song et al 1972).

Variety	Egg period (days)	Hatchability (%)	Nymphal period (days)	Adult emergence (%)	Female adults life span (day)	Eggs (no./female)
Mudgo	8.3	92.0	20.0 a	5.3 a	0.5 a	0 a
ASD-7	7.2	94.2	20.0 a	11.2 b	0.8 a	0 a
TN1	8.5	90.4	13.7 b	87.1 c	13.4 b	46.6 b
Suweon 213-1	7.8	91.4	14.0 b	100 d	14.4 b	203.4 c
Suweon 214	8.2	92.6	13.4 b	96.8 cd	21.2 c	245.7 c

[a] In a column. any two means not followed by the same letter are significantly different at the 5% level.

varieties affect the longevity of adult insects. Large numbers of eggs were recorded in susceptible varieties, while no eggs were found on Mudgo or ASD-7, where the adults fed and died before egg-laying.

Feeding ability on resistant plants

It has been documented that insects sucking the plant sap excrete honeydew, and the amount of honeydew excretion is positively correlated with the amount of food ingested. The quantity of honeydew excreted can be used as a criterion for the quantitative assessment of insect feeding (IRRI 1968).

An estimate of the honeydew excreted by the brown planthopper on resistant and susceptible varieties was reported by Song et al (1974) and Lee and Park (1976). Five female adults were caged for 24 hours on individually potted plants. The honeydew dropped onto and was absorbed by filter paper in the bottom of the cage. A quantitative determination of relative honeydew excretion was obtained by treatment within ninhydrin. Results revealed that the relative amount of honeydew excreted by female adults of brown planthopper was much less after feeding on the resistant varieties Mudgo and Vellailangalayan than after feeding on the susceptible varieties TNl, Suweon 213-1, and Suweon 214.

Utilizing the ninhydrin method, Lee and Park (1976) investigated the relative amount of honeydew excreted by brown planthoppers fed on some selected Korean lines. It was also apparent from their results that brown planthoppers excreted less honeydew when feeding on resistant plants than on susceptible varieties (Table 6).

GENETICS OF RESISTANCE

Resistance derived from IR2061-214-2-3-6

Limited numbers of hybrid materials were checked for the inheritance of resistance to hoppers. As shown in Tables 7, 8, and 9, Mudgo and IR2061-214-

Table 6. The relative amounts of honeydew excreted by 5 female brown planthopper adults when caged on selected resistant lines (Lee and Park 1976).

Variety or line	Amt. of honeydew (cm^2)[a]
Resistant lines[b]	
KR108-335-15	0.09
KR 87-56-4	0.17
HR529-42-5-2	0.19
KR 78-87-4	0.39
HR529-45-3	1.00
Susceptible varieties[c]	
Yushin	5.3
Milyang 22	2.5
Tongil	4.4
Jinheung	5.8
TN1	5.1

[a] 24-hour excretion. [b] The newly bred lines in Korea. [c] Leading Korean varieties.

Table 7. Reactions[a] to the brown planthopper of parent and hybrid materials (Kim and Heu, unpubl.).

Variety or cross	Rices (no.)[a]				X^2	P
	R	M	S	Total		
Parents						
Mudgo	302			302		
IR2061	146			146		
Co 22	190	6	3	199		
ASD-7	170	16	21	207		
IR4	186	52	24	262		
Ptb 18	190	2	10	202		
Muthumanikam	152	7	24	183		
Vellai-ilangalayan	99	11	38	148		
WX126			466	466		
F_2's						
Mudgo/WX126	602	18	203	823	0.059	0.75-0.90 (3:1)
WX126/Mudgo	429	7	153	589	0.326	0.50-0.75 (")
IR2061/WX126	742	16	248	1006	0.085	0.75–0.90 (")
Co 22/WX126	235	10	76	321	0.266	0.50–0.75 (")
WX126/Co 22	188	8	64	260	0.022	0.75–0.90 (")
ASD-7/WX126	124	15	425	564	2.734	0.05–0.10 (1:3)
WX126/ASD-7	61	13	214	288	2.242	0.10-0.25 (1:3)
IR4/WX126	1503	529	4187	6219	2.319	0.10-0.25 (")
Ptb 18/WX126	450	32	403	885		(")
WX126/Ptb18	323	23	318	664		(")
Muthumanikam/WX126	148	15	143	306		(")
Vellai/WX126	185	21	64	270	0.180	0.50-0.75 (3:1)

[a] R = resistant, M = moderately resistant, S = susceptible.

2-3-6 showed clear resistance responses while the others had a few susceptible individuals (Kim and Heu, unpubl.). Whether that was caused by impurity of the insect population or by incomplete penetrance of the resistant gene was not checked. Although the F_2 data of the crosses involving those resistant parents are presented in Table 7, the segregation ratios in their successive progenies were not studied except in the crosses involving IR2061.

Linkage relationship of the resistance from IR2061

Tests were conducted to find linkage relationships between the resistance to the brown planthopper of IR2061 and the marker genes of linkage-testers established by Takahashi (1964). As shown in Table 10. the resistance seems

Table 8. Reactions to the brown planthopper in BC_1 F_2 (Kim and Heu, unpubl.).

Cross	Reaction[a]			X^2	P
	Seg	S	Total		
Mudgo/$WX126^2$	38	28	66	1.516	0.10-0.25
IR2061/$WX126^2$	24	19	43	0.528	0.25-0.50
Co 22/$WX126^2$	24	19	43	0.528	0.25-0.50

[a] Seg = segregating, S = susceptible.

Table 9. Reactions[a] to the brown planthopper in F_2's of R|R crosses (Kim and Heu, unpubl.).

Cross	Rices (no.)				Susceptible plants (%)
	R	M	S	Total	
Mudgo/ASD-7	176	5	13	294	4.5
ASD-7/Mudgo	201	2	6	209	29
Mudgo/Ptb 18	141	2	5	148	34
Mudgo/Co 22	277	1	8	286	2.8
Mudgo/IR2061	248	0	0	248	0

[a] R = reststant, M = moderately resistant, S = susceptible

to be associated with the purple-stigma (Ps) marker, which belongs to the linkage group V (Heu and Suh, unpubl.). Because the markers Ps and I-Bf are loosely associated (with 42 units of C.O. value) according to (Takahashi 1964) the resistance seems to be loosely associated with the I-Bf marker.

BREEDING FOR RESISTANCE

Breeding lines

Breeding for the brown planthopper resistance in Korea was started in 1971, when an IRRI trainee brought back some F_2 and BC_1F_1 seeds, mainly of crosses involving Mudgo, which were designated as KR lines. Some BC_1F_1 seedlings of the KR lines were distributed to Korea's three crop experiment stations during the summer of 1971 and were used as sources of resistance in hybridization work. In the same year, several hundred KC lines introduced from IRRI were grown, and some of them were utilized as resistance sources.

At the Suweon Crop Experiment Station, many KC lines were tested at first, but most were soon dropped because of unacceptable plant type. Many

Table 10. Linkage relationship of the resistance to brown planthopper in IR2061 and marker characters (Heu and Suh. unpubl.).

Character	Segregation				X^2	P
Purple stigma		Ps	t	Total		
(Ps)	CK	81	22	103		
Group V	Surv	25	17	42	9.051	0.005
	R	(33)	(9)			
	(3.1)	(31.5)	(10.5)		5.365	.01-025
Inhibitor for		I-Bf	Bf	Total		
brown fullow	CK	243	71	314		
(I-Bf)	Surv	140	59	199	5.628	.01-025
Group V	R	(154)	(45)			
	(3:1)	(149.25)	(49.75)		2.293	10–.25

[a] CK = segregation which did not screen for hoppers'. Surv = segregation of survived plants; R = ratio from the check

Table 11. Crosses and lines for the resistance to the brown planthopper Suweon Crop Exp. Stn., unpubl.).

Cross	F_1 crosses	F_2		F_3 and adv[a]		OYT[b]		YT[c]	
		Crosses	Families	Crosses	Lines	Crosses	Lines	Crosses	Lines
IR747B_2-6									
IR26	–	7	247	1	9	–		–	
IR29	–	5	84	–	–	–		–	
IR30	–	1	9	–	–	–		–	
IR747	1	2	10	1	127	–		–	
IR1541	–	2	76	–	–	–		–	
IR2061	18	24	637	1	212	–		–	
IR2071	6	11	253	–					
IR2151	3	5	94	1	24				
IR2153	2	1	10	–	–				
IR2181	2	2	21	2	119				
IR3255	–	1	2	–	–				
Mudgo									
KC45	–	–	–	1	67	–		–	
KC50	–			11	814	1	8	–	
KC59	–			2	76	–		–	
KR77	1								
KR36								1	2
Mudgo	1								

[a]Adv = advanced generations. [b]Observational yield trials. [c]Yield trials

crosses were made with those KC lines having a male desirable plant type; some were carried to advanced generations (Table 11; Suweon Crop Exp. Stn. 1976, unpubl.). Among the crosses with KR lines, only two progressed to the yield-trial stages. Many IRRI lines were utilized as parents in crossing for resistance, but as shown in Table 11, only limited numbers of resistant lines were selected.

At the Honam Crop Experiment Station, the KR lines were intensively screened and many of them progressed to the observational yield trial stage. Among them, only two lines advanced to yield trials (Table 12; Honam Crop Exp. 1976. unpubl.). In the Honam area, damage caused by brown planthopper and whitebacked planthopper is observed almost every year. Consequently, varieties to be released for the area must have resistance to hoppers.

At the Youngnam Crop Experiment Station, emphasis was placed more on the screening for the small brown planthopper and the green rice leafhopper (*Nephotettix cincticeps*), which respectively serve as vectors for the stripe virus and the dwarf virus. Since 1975, when the brown planthopper outbreak was widely observed, even in the Suweon area, screening for brown planthopper resistance was intensified (Table 13; Youngnam Crop Exp. Stn. 1976, unpubl.). Among many advanced lines. the most promising are Milyang 30. 34, and 36, which derive their resistance from IR946. Early hybrid generations of those lines were screened mainly for stripe virus and not for brown planthopper. Nevertheless, the hopper resistance was carried to the advanced genera-

Table 12. Crosses and lines for resistance to the brown planthopper (Honam Crop Exp. Stn., unpubl.).

Cross	F_1 crosses	F_2 crosses	F_3 and adv[a]		OYT[b]		YT[c]	
			Crosses	Lines	Crosses	Lines	Crosses	Lines
IR747B$_2$-6								
IR26	6	12						
IR28	12	4						
IR29	16	5						
IR34	3	–						
IR747	–	–			1	1		
IR2061	16	22						
IR2151	1	6						
IR2153	–	4						
Mudgo								
IR1857	–	1						
IR2034	–	1						
IR2035	2	2						
IR2562	–	2						
Mudgo	–	–	1	5				
KR 36	4							
KR 77	–	14						
KR 78	–	–	2	147				
KR108	1	15	16	674	1	37	1	2
KR109	–	–	7	149	1	5		
HR515			11	524	1	7		
HR517	–	–	1	44	–	–		
HR1225	–	–	–	–	1	1		
HR1271	–	1	–	–	–	–		
HR2131	36	26	–	–	1	7		
HR2132	3	–	–	–	1	1		
HR2138	3	–	–	–	1	2		
Iri 328	3	–	–	–	1	1		
Iri 329	6	–	–	–	1	1		
CR 94–13								
IR32	2							
IR36	3							
H *105*								
Mil. 30	5							

[a] Adv = advanced generations. [b] Observational yield trials. [c] Yield trials.

tion. Consequently the improved lines were used as parents in many crosses for resistance to both the brown planthopper and to viruses.

In 1976, for the first time, advanced yield trials were made with the following lines: Suweon 271 and 272 bred in Suweon; Iri 328 and 329 bred in Honam; and Milyang 30, 34, and 36 bred in the Youngnam Crop Experiment Station (Table 14). The resistance of the first four originate from Mudgo, and of the latter three from H105.

Resistance source

Although many varieties and lines from IRRI were used as sources of resistance, their ancestry can be traced back to the four varieties–IR747B$_2$-6, Mudgo, CR94-13, and H105. Because the resistance gene of IR747B$_2$-6 is the same as that of Mudgo (Martinez and Khush 1974), most of the lines bred in Korea

Table 13. Crosses and lines for resistance to brown planthopper (Youngnam Crop Exp. Stn. unpubl.).

Cross	F_1 crosses	F_2 crosses	F_3 and adv[a] crosses	OYT[b] crosses	YT[c]	
					Crosses	Lines
IR747B_2-6						
IR26	–	1	5			
IR28	8	7	–			
IR29	8	4	–			
IR30	5	12	–			
IR34	8	–	–			
IR747	–	–	3	19		
IR2061	26	8				
Mudgo						
IR1539	–	–	2	11		
IR2035	–	–	2	–		
WX 318	10	–	–	–		
KC 58	–	–	1	3		
CR 94-13						
IR32	3					
IR2071	7					
H 105						
IR4	–	–	1			
Mil. 30	47					
Mil. 34	10					
YR 983					1	3
BC34-8						
BC 34-8	10	–	1	3		

[a] Adv = advanced generations. [b] Observational yield trials. [c] Yield trials.

Table 14. Advanced lines tested for their performance and resistance to brown planthopper.

Designation	Pedigree	Cross
Suweon 271	Wx318-5A-4-4-1	IR1317/IR833//Tongil^2///KR36
Suweon 272	Wx318-5A-6-16	"
Iri 328	HR1231-117-1	Wx126-48/KR108-2
Iri 329	HR1231-258-2	"
Milyang 30	YR1010-17-5	YR983/YR675
Milyang 34	YR1010-42	"
Milyang 36	YR1010-17-5-2	"

have the resistance gene *Bph1* only. Anticipating the outbreak of new biotypes. crossing started very recently using Babawee and Rathuheenati, but screening against biotypes other than biotype 1 is not yet being conducted in Korea.

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Varietal resistance to the brown planthopper in the Solomon Islands

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Trials were conducted on the Guadalcanal Plains in 1976–77 to assess agronomically desirable lines of lowland rice (*Oryza sativa* L.) for resistance to the brown planthopper *Nilaparvata lugens* Stål. Resistance was evaluated on the basis of hopperburn damage and the size of planthopper populations. One hundred and nineteen varieties from Bangladesh, Sri Lanka, Indonesia, and the Philippines were screened. The varieties IR2307-281-5-3-2, IR2071-137-5-5-1, IR2071-586-5-6-3-4, IR2071-588-1-1-1, IR4409-80-2, IR4417-177-1-4, IR4492-7-2-1, and IR4707-123-3 were selected as the most suitable for local conditions but none were considered totally resistant to the Guadalcanal brown planthopper biotype.

RICE-GROWING WAS INITIATED in Guadalcanal in 1960. From the outset, the brown planthopper (BPH) was recognized as a major limiting factor (Khush 1974; Nishida 1975). This was evident from trials from 1960 to 1966 by the Solomon Islands Department of Agriculture and the Commonwealth Development Corporation. Large-scale commercial production of dry rice by Guadalcanal Plains Ltd. started in 1965 on 1,200 ha and changed to irrigated rice in 1971 covering 320 ha. The BPH was controlled by aerial spraying until the introduction from the International Rice Research Institute (IRRI) of varieties carrying genes for BPH resistance. By 1974, all previously resistant varieties (IR1514A-E666, IR1516-228-3-3, IR1539-523-1-4, IR1541-76-3-3, and IR1416-389-1-1) had proved susceptible to BPH attack (Stapley 1974). This study reports our continued efforts to control the BPH in rice on Guadalcanal.

VARIETY TRIALS

In 1976 a total of 119 rice lines and varieties from Bangladesh, Sri Lanka, Indonesia, and the Philippines (IRRI) were screened in cages and in the field for BPH resistance. Screening in cages was done according to established IRRI

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procedures (IRRI 1976), with IR747-B2-6-3 as the susceptible check instead of TNl. For field screening, 1- × 3-m varietal plots were set up in commercial rice bays. A number of plots with susceptible varieties were included to attract the BPH in large numbers.

Rice lines from Bangladesh, Sri Lanka, and Indonesia, and some lines from the Philippines were susceptible (Table 1). Of the IRRI varieties tested, IR26, IR28, and IR30 (all with the dominant *Bph 1* gene) were susceptible; but IR1628-632-1, IR32, and IR36 (with the recessive *bph 2* gene) were tolerant. BPH populations on IR32 and IR36 were lower than those on IR1628-632-1. IR38 was resistant. In cage and field screenings, IR34 was tolerant of the biotype existing on Guadalcanal in 1976. Yet at IRRI, it is susceptible to biotype 2. The biotype issue remains confusing, but in general, lines with the dominant *Bph 1* gene are susceptible to the existing biotype while some lines with the recessive *bph 2* are resistant.

In 1974, observations were made on experimental plots to assess varietal resistance to the BPH. Twelve varieties were planted in a randomized block design in 4- x 6-m plots with four replicates. When hopper damage was observed, the plots were uniformly sprayed with MIPC insecticide (2-isopropyl

Table 1. Reactions of selected rice varieties to the brown planthopper (BPH), Metapona, 1976.

Variety or line	Origin	Grade of damage[a]		
		Trial 1	Trial 2	Trial 3[b]
Biplab	Bangladesh	4	—	—
B 462c/PM/31/2/1	Indonesia	—	6	—
B 796c/MR/12/2/5	"	—	7	—
B 796c/MR/143/2/5	"	—	6	—
B1742c/MR/51/1	"	—	6	—
B2931b/11/9/3/1	"	—	3	1
IR22	Philippines	—	3	3
IR24	"	—	2	1
IR26	"	3	2	2
IR28	"	4	7	4
IR30	"	8	6	1
IR32	"	1	4	1
IR34	"	4	7	1
IR36	"	1	4	1
IR38	"	1	1	–
IR262-9	"	9	3	—
IR747-B2-6-3	"	—	6	3
IR1561-228-3-3	"	—	3	2
IR1623-632-1	"	—	5	3
IR2006-P3-33-2	"	5	—	—
IR2061-465-1-5-5	"	2	2	1
IR2071-137-5-5-1	"	1	—	—
IR2071-586-5-6-3-4	"	1	—	—
IR2071-588-1-1-1	"	1	—	—
IR2153-43-2-5-4	"	7	—	—
IR2153-381-1-8-1	"	4	6	2
IR2307-10-1-2-3	"	1	1	1

continued on opposite page

Table 1 continued

Variety or Line	Origin	Grade of damage[a]		
		Trial 1	Trial 2	Trial 3[b]
IR2307-84-2-1-2	Philippines	8	–	–
IR2307-112-3	"	1	1	1
IR2307-211-6-6-2	"	6	2	1
IR2307-217-2-3	"	7	–	–
IR2307-247-2-2-3	"	1	1	1
IR2307-281-5-3-2	"	1	1	1
IR2688-33-4-2-3	"	8	–	–
IR2771-119-3-1	"	1	1	1
IR2777-103-2-2-3	"	1	–	–
IR2796-44-2	"	3	–	–
IR2797-80-2-2	"	7	–	–
IR2797-125-3-2-2	"	3	–	–
IR2823-103-5-1	"	9	–	–
IR2823-399-5-6	"	1	–	–
IR2843-26-3-2	"	8	–	–
IR2863-38-1-2	"	1	–	–
IR3351-38-31-1	"	7	–	–
IR3464-126-1-3	"	8	–	–
IR3525-46-1-4	"	7	–	–
IR3634-62-2	"	3	–	–
IR3941-25-1	"	1	–	–
IR4409-65-3	"	1	–	–
IR4409-80-2	"	1	–	–
IR4417-177-1-4	"	1	–	–
IR4422-29-6	"	1	–	–
IR4422-143-2-1	"	2	–	–
IR4427-16-2-4	"	2	–	–
IR4427-19-6-1	"	4	–	–
IR4427-23-2-3	"	3	–	–
IR4427-58-5-2	"	1	–	–
IR4427-118-5-2	"	3	–	–
IR4427-279-4-1	"	3	–	–
IR4427-315-2-3	"	7	–	–
IR4427-367-5-2	"	7	–	–
IR4432-38-6	"	4	–	–
IR4432-52-6-4	"	1	–	–
IR4437-46-3-3	"	1	–	–
IR4442-165-2-4	"	6	–	–
IR4492-7-2-1	"	2	–	–
IR4531-6-1-1	"	2	–	–
IR4531-6-1-3	"	6	–	–
IR4531-9-1-1	"	6	–	–
IR4580-5-3	"	1	–	–
IR4707-7-3	"	1	–	–
IR4707-123-3	"	1	–	–
IR4816-70-1	"	1	–	–
IR5257-77-2	"	1	–	–
IR5311-46-3	"	1	–	–
IR5853-76	"	1	–	–
GPL 2S (IR1416-138-3-1)	Solomon Islands	9	6	3
BG32-2	Sri Lanka	5	2	1
BG34-8	"	5	7	1
BG94-1	"	4	2	1
BG94-2	"	5	–	–
A 16-14	"	4	2	1
TN1	Taiwan	9	–	–

[a] Grade 0 = 0; 1 = 1-100 BPH, 2 = 100-250 BPH, 3 = 251-500, 4 = 500-750, 5 = 750-1000, 6 = 1001-2000, 7 = 2000-4000, 8 = 4000-8000, 9 = 8000. [b] Trial 3 was sprayed every 3 or 4 weeks.

Table 2. Variety trial (irrigated rice) at Metapona, late 1974.

Variety/line	Brown planthoppers (no./sq m at 40 days)	Days to maturity	Yield (t/ha)
IR747B2-6-3	4166	91	1.7
IR1416-138-3-1	3333	[a]	[a]
IR1614-138-1-1-3	2778	[a]	[a]
IR1561-228-3	5000	[a]	[a]
IR1416-389-1-1	4166	[a]	[a]
IR26	2778	120	3.8
IR1628-632-1	3722	109	5.9
IR2035-255-2-3-1	4444		[b]
IR1416-138-3-1 (selection)	6666	112	3.9
IR2061-464	3333	95	4.4
IR2061-214-3-3-28	4722	91	4.2
IR661-1-1-140-3	4166		

[a] Yields could not be measured because of severe 'hopperburn, [b] The crop lodged.

phenyl-N-methyl carbamate). Other observations were made in the commercial fields. In particular, studies were made of the relationship of location, age of plantings, and varieties grown to the size of BPH populations.

At 30 days the plots were heavily and uniformly attacked by BPH. Certain cultivars would have failed completely had they not been sprayed with MIPC on the 40th day. That one spray effectively eliminated the BPH and some plants recovered. Shortly afterwards, all plots were invaded by the predators, *Cyrtorhinus lividipennis* and *C. chinensis.* As a result, all the rice plots survived until harvest. The results from this trial are shown in Table 2.

Fluctuations of populations of the BPH and its predators on three varieties (IR28, IR1628-632-1, and IR36) in commercial fields at Metapona were observed during 1976. Large populations of the BPH developed on IR28, 30 days after sowing. They increased rapidly and were not controlled by *Cyrtorhinus.* In contrast, BPH populations on the relatively tolerant varieties, IR1628-632-1 and IR36, were initially low, and *Cyrtorhinus* maintained them at economically acceptable levels.

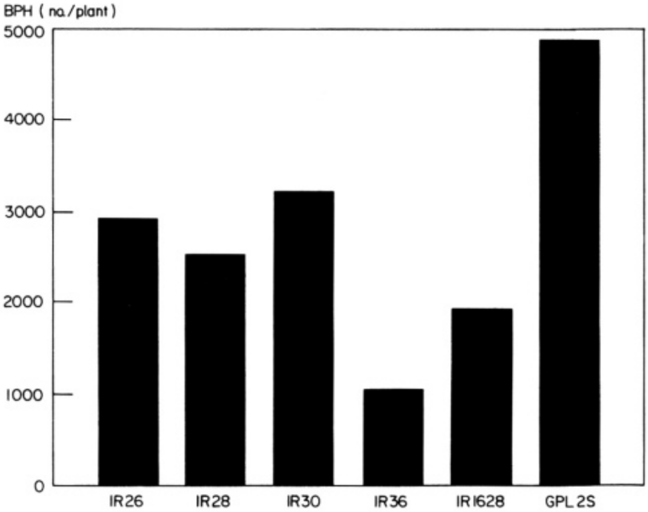
The maximum numbers of BPH during peak infestations of single plants in commercial rice fields before spraying are given in Fig. 1. The survival rate and population buildup of BPH were much lower on tolerant than on susceptible varieties.

BPH and *Cyrtorhinus* spp. populations in variety trials with and without insecticide treatment were determined from September to December 1976 (Table 3). The fields were sprayed with insecticides every 4 weeks. Maximum infestation by the BPH occurred 50 to 60 days after sowing, depending on the growth duration of each variety. *Cyrtorhinus* controlled BPH populations on tolerant varieties without insecticide sprays, but was unable to do so on susceptible varieties which had large numbers of the insect. On the resistant variety IR38, pest populations were too small to attract significant numbers of predators.

Table 3. Population development of the brown planthopper (BPH) and *Cyrtorhinus* (C) on selected rice cultivars.

Variety/line	Cultivar reaction to BPH[a]	Insects (av. no /sq m)							
		With insecticides[b]				Without insecticides			
		7 DAS[c]		50-60 DS[c]		7 DS[c]		60-60 DS[c]	
		BPH	C	BPH	C	BPH	C	BPH	C
BG 33-2	S	41.0	0	3083.0	63.3	46.7	0	4577.3	86.7
BG 34-8	S	25.6	0	1116.6	52.2	26.6	2.2	27401.7	159.9
BG 94-1	S	81.1	1.0	1166.6	55.6	86.7	1.1	766.6	193.3
GPL2S	S	52.2	0	8165.9	118.9	166.7	22.3	11659.9	199.4
IR24	S	41.1	0	8165.9	117.8	55.6	0	8221.4	35.6
IR262-9	S	33.3	0	10115.7	103.3	17.8	8.9	13987.5	46.7
IR1561-228-3-3	S	218.9	2.0	2999.7	74.4	188.9	19.9	4206.2	28.9
IR1628-632-1	T	33.0	0	3216.3	44.4	22.2	0	966.6	217.8
IR2061-465-1-5-5	T	22.2	0	1333.2	63.3	24.4	0	164.4	31.1
IR2153-381-1-8-1	T	174.4	2.0	116.7	25.6	222.2	2.0	31.1	22.2
IR2307-10-1-2-3	T	141.1	2.0	116.7	33.3	133.3	1.0	141.1	53.3
IR2307-112-3	T	111.1	2.0	549.4	36.7	146.7	6.7	68.9	2.2
IR2307-211-6-6-2	T	14.4	0	116.7	18.9	11.1	4.4	64.4	24.4
IR2307-247-2-2-3	T	166.7	1.0	216.6	29.9	144.3	15.6	146.7	31.1
IR2307-281-53-2	T	188.9	2.0	2949.7	58.9	168.9	2.2	86.7	55.6
IR2771-119-3-1	T	166.7	2.0	266.6	27.8	122.2	2.0	146.7	77.8

[a] S = susceptible, T = tolerant. [b] Orthene 75 SP applied at 4 weeks interval. [c] DS = days after sowing



1. Maximum number of brown planthoppers recorded on single plants in commercial rice fields.

DISCUSSION

Our experiences during the past year have shown that BPH can be successfully controlled in commercial rice production only by giving due attention to varieties, biological control, and the use of selective insecticides. Not one of these factors alone effects acceptable control.

Our search for varieties that have resistance to the BPH continues; no line tested in the Solomon Islands so far is immune or highly resistant to attack. But, we feel that even if lines with high resistance should be found, intensive cultivation may select BPH biotypes that have the ability to overcome that resistance.

Cyrtorhinus spp. is able to effectively control the BPH only if it enters the rice fields before panicle initiation and while BPH numbers are relatively low, as when such tolerant varieties as IR1628-632-1 and IR36 are grown. On varieties that allow large BPH populations to develop rapidly, correspondingly large numbers of *Cyrtorhinus* become established, but the crop can nonetheless be badly damaged.

Our approach to BPH control is, therefore, the growing of tolerant or resistant varieties or both, careful maintenance of predators, and the judicious use of selective insecticides. These approaches, we feel, can be developed and integrated into an effective system of brown planthopper control.

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Varietal resistance to the brown planthopper in Sri Lanka

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Two characteristics that emerge from seedling screening for *Nilaparvata lugens* resistance in Sri Lanka by the method described by Pathak (1971) are the frequent inconsistency of results, and the absence of a gradation of symptoms of damage leading to plant death. To illustrate these points, Ptb 33, which generally demonstrates a high level of resistance, may in some experiments have a survival range of 45 to 65% within four replications, and plant death is often observed as sudden wilting and not as progressive yellowing. Those features need further investigation.

Twenty varieties from Sri Lanka's indigenous rice collection of 985 varieties have been found resistant to *N. lugens.* Some are being studied in greater detail to elucidate the basis of their resistance, while others are being used in the current breeding program.

Studies on the effect of stage of plant growth on responses to *N. lugens* infestations indicate that seedling susceptibility or resistance does not necessarily continue until the later stages of plant growth.

Resistance to *N. lugens* in the seedlings of Ptb 33 and TR 26 was carried over into the 30- and 60-day-old plants. The seedling resistance noted in Iri 329, Jyoti, and Milyang 30 was lost in the later stages of plant growth. On the other hand, varieties such as Mudgo, Ptb 21, and Suduru Samba, which were susceptible in the seedling stage, proved resistant in later stages. The physiology and biochemistry of the rice plant vary with its growth stage, and findings of this nature are to be expected, at least with certain biotypes of an insect species. Such variability of resistance to an insect species, although not previously recorded for *N. lugens,* has been described for *Chilo suppressalis.* Resistance to *C. suppressalis* was present in Chianan 2 and Taitung 16 during the vegetative stage, but was lost when the plants flowered (Pathak 1972). *N. lugens* is a pest mainly of maturing rice plants Our findings emphasize the need for screening older rice plants for resistance, particularly to the biotype found in Sri Lanka.

N. lugens from Sri Lanka showed plant reactions and insect survival and development markedly different from those of the Philippines biotypes. Most of the rice varieties found resistant to the Philippine biotype originated in Sri Lanka, where for several hundred years they had been exposed to the *N. lugens* populations.

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Ptb 33 has to date been used as the principal donor parent for *N. lugens* resistance in our breeding program. Although its high level of resistance is transferable, its poor plant type and photoperiod sensitivity require several seasons to ensure combination of such resistance with other desirable agronomic characteristics. Resistance to *N. lugens* in Ptb 33 is controlled by a single dominant gene.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* (Stål) was first recorded as a pest of rice under the name *Nilaparvata greeni* (Distant) in the Kulutara District, Sri Lanka, in 1912. Since then, sporadic outbreaks of the pest have occurred in several areas, mainly in southwestern Sri Lanka. In the late 1960's and early 19703, BPH incidence increased in most rice-growing areas, and in 1973 an extensive outbreak in the eastern province in the Ampari District affected more than 50,625 ha.

In field tests at the peak of the attack in 1973–74, all popular commercial varieties, including the recently introduced IR26, were highly susceptible and suffered hopperburn. Only one variety, known to local farmers as "H 501" (a misidentification), survived to maturity at the highest pest intensities and appeared to be a nonpreferred variety. Since then, the search for varietal resistance to BPH has continued in Sri Lanka as a major research effort at the Central Agricultural Research Institute (CARI), Peradeniya, and Central Rice Breeding Station (CRBS), Bathalagoda.

SCREENING TECHNIQUES

The methods of culturing *N. lugens* and of screening for resistance to the insect at the Bathalagoda station essentially followed those described by Pathak (1971). At CARI, the screening techniques were generally the same, but the BPH cultures were raised on rice seedlings, usually 4 to 6 days old. Adult insects were introduced on culture plants for 2 days, then withdrawn to oviposit on fresh culture plants. Bg 11-11 was initially used as the culture plant but it was so susceptible to the pest it had to be replaced with Bg 34-6, a somewhat more tolerant variety. Screening of lines followed the same procedure, but screening results had to be reported in terms of percentage of plants affected because BPH in Sri Lanka produced an "all-or-none reaction" "sudden wilting of green plants rather than the graded symptoms that precede plant death, observed with the Philippine biotypes.

Both 5- to 10-day-old seedlings and 30-day-old, and even 60-day-old, plants were screened in the laboratory. We argued that because considerable physiological differences exist between the 5- to 10-day-old seedlings and the older plants, screening only very young seedlings for resistance might give misleading results. We believe results have justified this thinking, but screening older seedlings presents a variety of practical problems.

Four 30-day-old plants of each of four varieties were grown in a 12- ×

12- × 12-inch pot. In the case of 60-day-old plants, 9 to 12 plants of one variety occupied a single pot. The test pots were placed one against the other and enclosed with a 45-cm-high, black, fine nylon mesh. After 30 days or 60 days of growth, plants were infested with first- and second-instar BPH nymphs.

Field screening was not reliable because sufficient pest populations rarely built up in the test areas.

SCREENING INDIGENOUS VARIETIES FOR RESISTANCE

The earliest laboratory screening of seedlings of varieties that, on the basis of the experience of workers in the Philippines and in India, were considered most likely to have resistance to BPH showed that IR26 was susceptible and Ptb 33 resistant.

Pathak (1971) screened 10,000 rice varieties for resistance to the Philippine strain of *N. lugens* and showed that 46 varieties, mainly from Sri Lanka and India, were highly resistant. The 985 accessions of local varieties collected from various parts of Sri Lanka were, therefore, screened in the hope that a wider range of resistance would be found. The cultures of *N. lugens* were from original collections made in the Amparai District, where large-scale BPH outbreaks had become almost routine.

In seedling screening, only 20 varieties showed more than 40% survival when the highly susceptible check Bg 11-11 had less than 10% survival (Table 1).

Table 1. Traditional Sri Lanka rice varieties showing over 40% plant survival in seedling screening of 985 varieties for resistance to ***N. lugens***

Sri Lanka acc. no.	Variety	Surviving seedlings (%)
248	Thunmaswee	40
445	Panduruwee	41
630	Rata-thavalu	40
633	Cheenadi	63
645	Mawee	79
666	Kaluhandiran	50
701	Mudukiriel	50
782	Moddai Samba	42
793	Elewee	40
1094	Suduru Samba	72
1188	Rathu Hondarawala	40
1251	Kahata Keralla	56
1253	Heen Rathkunda	80
1255	Sudu Heenati	80
1256	Ele Samba	60
1326	Hal Suduwee	43
1480	Yakada Wee	40
1487	Batapolawee	44
2095	Murungakayan 303	46
2201	Balamawee	69

Table 2. Replicated seedling screening for resistance to *N. lugens* of five selected traditional Sri Lanka rice varieties.

Variety	Surviving seedlings (%) (mean of 4 readings)
Sudu Heenati	84
Heen Rathkunda	37
Suduru Samba	50
Mawee	49
Cheenadi	5
Ptb 33 (check)	51
IR26 (check)	24
Bg 11-11 (check)	0

Of the 20, five were selected on the basis of desirable agronomic characteristics for further screening in tests replicated four times, with Ptb 33, IR26, and Bg 11-11 as checks. The results are in Table 2.

The BPH resistance of the local varieties Sudu Heenati, Heen Rathkunda, Suduru Samba, and Mawee, and the Indian variety Ptb 33 was superior to that of IR26.

Of nearly 500 local and introduced varieties screened in the seedling stage, as described by Choi (this volume), seven showed high levels of resistance (Table 3).

After the field screenings at Bathalagoda, it was concluded that although all the seven varieties (Table 3) showed consistently high levels of resistance to BPH in the greenhouse tests, Ptb 33 performed best at all stages of growth in the field.

SCREENING THE SECOND INTERNATIONAL RICE BROWN PLANTHOPPER NURSERY

The screening of the Second International Rice Brown Planthopper Nursery (IRBPHN) at CRBS, Bathalagoda, suggested that the Indonesian varieties

Table 3. Seven varieties of rice showing high levels of *N. lugens* resistance in seedling screening of about 500 Sri Lankan and introduced varieties at Central Rice Breeding Station, Bathalagoda.

Variety	Seedlings surviving (%) 10-12 days after infestation
Ptb 33	84
ARC 6650	78
Suduru Samba	77
Rathu Heenati	75
Heenrath Kunda	74
MR 1523	71
Sudhu Heenati	65
TN1 (check)	9

Table 4. Variation of susceptibility or resistance to *N. lugens* with stage of rice plant growth.[a]

IRRI no.	Variety	5 days old		30 days old		60 days old	
		Surviving plants (%)	Ratio of surviving plants to total no.	Surviving plants (%)	Ratio of surviving plants to total no.	Test plants (no.)	Weeks (no.) until 100% kill
60	RD4	100	22:22	0	0:2	8	4.5
61	RD9	86	12:14	0	0:2	7	4.0
49	IR8 M 16	60	12:20	0	0:3	9	4.0
55	IRI 328	61	14:23	50	2:4	9	3.5
57	IRI 329	77	17:22	0	0:2	9	3.0
58	Jyoti (Ptb 39)	82	22:27	0	0:4	9	5.0
59	Milyang 30	67	16:24	0	0:4	8[b]	3.0[b]
66	WX 325-30-17-2	45	9:20	0	0:4	—	—
54	IR2307 - 72-2-2-1	42	10:21	0	0:2	9	3.0
82	Gangala	48	10.21	0	0:4	9	6
36	Ptb 33	53	10:19	100	4:4	9	6
62	TR 26	48	10:21	100[b]	4:4[b]	8[b]	6[b]
9	Bogor 14	50	4:8	—[b]	—[b]	—[b]	—[b]
71	ARC 11354	50	4:8	—[b]	—[b]	—[b]	—[b]
74	ARC 14529	60	6:10	—[b]	—[b]	—[b]	—[b]
78	ARC 14771	71	10:14	—[b]	—[b]	—[b]	—[b]
79	ARC 15831	67	4:6	—[b]	—[b]	—[b]	—[b]
81	Babawee	57	8:14	—	—	—	—
8	Mudgo	14	3:22	100	4:4	15	6.0
28	Mudgo	0	0:19	0	0:4	4	3.0
48	Mudgo	0	0:15	75	3:4	9	3.0
68	Mudgo	0	0:18	100	4:4	9	5.0
88	Mudgo	0	0:14	100	3:3	9	5.0
67	ARC 6650	0	1:23	100	4:4	9[b]	5.0[b]
89	Muthumantham	8	1:12	75	3:4	—[b]	—[b]
93	Ptb 21 (Tekkan)	0	6:17	100	4:4	—[b]	—[b]
97	Sudurusamba	0	0:20	100	4:4	—	—
	TN1 all 5 accessions	0		0		9	4

[a] Varieties selected from second International Rice Brown Planthopper Nursery. [b] Not tested due to lack of seed.

Bogor 6, 8, 12, 18, and 20 were BPH resistant, but it was felt that the tests should be repeated for confirmation.

Screening at CARI, Peradeniya, of the same varieties at seedling stage. and at 30 days, and at 60 days old gave results that suggest that seedling resistance or susceptibility is not necessarily carried over to the later growth stages of the rice plant (Table 4).

Of the varieties tested at all three stages, only Ptb 33 and TR 26 had seedling resistance that correlated with resistance at the 30-day and 60-day stages. Nine varieties with seedling resistance were susceptible in the later stages. On the other hand, of the 10 entries that showed marked seedling susceptibility, 8 were resistant at 30 days old, and at least 3—(8)[1] Mudgo, (68) Mudgo, (88) Mudgo, and (67) ARC 6650—carried the resistance through to the 60-day-old stage.

In a recent test, 19 varieties were tested by the seedling screening method. IR32 (57.1%), IR4432-52-6-4 (62.5%), and IR2071-586-5-6-34 (66.7%) were

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[1] Numbers enclosed within parentheses are IRBPHN numbers.

resistant to BPH, but such varieties as IR28, IR34, and IR38 proved highly susceptible.

Numerous field screening of both indigenous and introduced varieties have been laid out, but only once did the test areas suffer BPH infestations severe enough to permit clear-cut and reliable evaluations. During the 1974 epidemic in the Amparai District, a replicated screening of the varieties Bg 94-2, Bg 90-2, Bg 66-1, and so-called H 501 was conducted in highly infested areas. The highest yields were obtained from Bg 94-2, a 3.5-month variety that matured early and escaped the third-generation BPH buildup. H 501 showed almost no signs of damage and supported an extremely low BPH population. All other varieties, including IR26, suffered severe hopperburn. Subsequently H 501 showed high seedling susceptibility in the seedling screening. But it seems possible that the variety would prove highly resistant if screened at later stages of growth.

BROWN PLANTHOPPER BIOTYPES

No detailed studies have been conducted to determine the biotype or biotypes of BPH found in Sri Lanka. However, some studies have been made of the survival and development of nymphs on specific rice varieties, of the period required for the nymphs to kill seedlings of certain varieties, and of the relative survival, with time, of certain varieties exposed to the nymphs. The studies confirm that the BPH found in Sri Lanka differs greatly from the biotypes found in the Philippines.

Three-day-old seedlings growing singly in test tubes were exposed to six first-instar BPH nymphs, and the number of days until the death of each plant was recorded (Table 5). The varieties Ptb 33, ARC 6650, Rathal 518,

Table 5. Number of days until death of seedlings of selected rice varieties exposed to 6 *N. lugens* nymphs.[a]

Variety	Days (no.) to death of					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Sudhu Heenati[b]	6	6	6	6	7	–
Bg 11-11[b]	14	5	8	9	12	–
IR36	7	10	10	10	12	10
IR38	11	8	11	7	7	7
ASD 7	10	10	10	10	7	7
Mudgo	10	10	11	10	11	11
Babawee[b]	10	10	13	16	–	–
Rathal 518[b]	20	16	20	16	20	–
Heenrathkunda	12	12	20	16	16	–
ARC 6650	20	20	15	20	20	–
Ptb 33	20	20	18	20	20	–
Sudurusamba	10	20	16	14	15	–

[a]In single-plant test-tube cultures, 6 nymphs/plant. [b]Only 5 plants were used in this test.

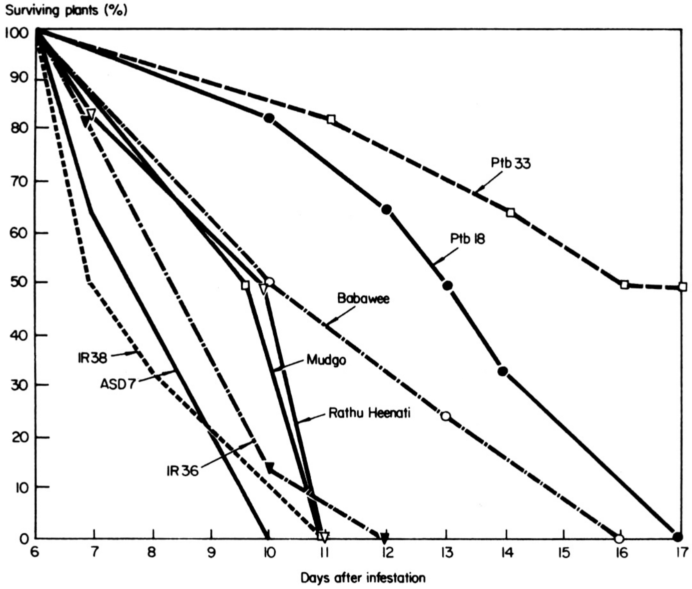
Table 6. Survival and development of *N. lugens* nymphs on 8 rice varieties.

Rice variety	Test nymphs (total no.)	Nymphs (no.) surviving to adulthood					Nymphal deaths (no.)
		Brachypterous (females)	Macropterous (females)	Brachypterous (males)	Macropterous (males)	Total	
Mudgo	35	18	0	0	12	30	5
ASD 7	18	4	0	0	9	13	5
Bg 34-6	54	29	2	0	13	44	10
IR8	30	17	0	0	6	23	7
Bg 11-11	59	19	0	0	15	34	25
Ptb 33	51	16	0	0	21	37	25
Sudhu Heenati	30	10	3	0	10	23	7
Suduru Samba	29	8	1	0	13	22	7

and Sudurusamba showed marked resistance to the pest, and ASD 7, Mudgo, IR36, and IR38, which had been found resistant to the Philippine races, were highly susceptible to the Sri-Lankan biotype.

Single first-instar nymphs were introduced on 3-day-old seedlings growing singly in test tubes. The number of nymphs that survived and the types of adults that developed were recorded (Table 6). If survival and development on Bg 11-11 are treated as an index of normal development on a susceptible variety, BPH developed normally on all the varieties, including ASD 7, Mudgo, and Ptb 33.

The rate at which certain rice varieties died or survived as single plants under attack by a fixed number of BPH nymphs in single test tubes was studied (Fig. 1). Seventeen days exposure to the pest, Ptb 33 showed 50% survival of



1. Effect of *N. lugens* infestation on rice varieties.

Table 7. Genetics of resistances to *N. lugens* in Ptb 33.

Cross or parent	Resistant	Susceptible	Total	X^2
TN1	0	16	16	–
Ptb 33	18	0	18	–
TN1/Ptb 33:F_1	44	0	44	–
TN1/Ptb 33:F_2	107	30	137	0.702(3:1)
TN1/Ptb 33/TN1 BCF1	10	10	20	0 (1:1)

seedlings. Other varieties resistant to the Philippine strain of BPH, such as Ptb 18, Rathu Heenati, Babawee, Mudgo, IR36, IR38, and ASD 7, suffered 100% mortality.

BREEDING FOR RESISTANCE

Breeding for BPH resistance in Sri Lanka was initiated in 1973 with IR26, H 105, Mudgo, and ASD 7 as donors for resistance. During the 1973–74 epidemic some of those varieties were found to be susceptible, suggesting biotype differences. With the discovery of new sources of resistance, the initial crosses were abandoned (Gunawardena et al 1975; Kudagamage 1976) and new crosses were made in 1975. Ptb 33 was used extensively as the resistant donor, and nearly 300 crosses were made. The crossing program was subsequently expanded with varieties such as Sudu Heenati, Suduru Samba, Heenrath Kunda, and MR 1523 as additional sources of resistance. The proportion of breeding material with BPH resistance continued to increase rapidly. During the last season almost 100% of the F_2 and F_3 and backcross materials had at least one resistant parent.

Ptb 33 consistently had the highest level of BPH resistance in our laboratory and field screenings. But because of its poor plant type and its sensitivity to photoperiod, several more seasons may be required to combine its high level of resistance with desirable agronomic and commercial traits.

In the last season about 1,000 B_1F_3 selections from 22 different backcrosses were evaluated for resistance. Preliminary data clearly indicate that the high levels of BPH resistance in Ptb 33 can be successfully transferred. About 100 F_2 and F_3 bulk populations were also grown and selections were made.

Genetics of resistance in Ptb 33

The genetics of BPH resistance was investigated in Ptb 33 and TN1. The F_1 plants of TN1 and Ptb 33 were resistant, indicating that the resistance is dominant. The F_2 and backcross data (Table 7) suggest that Ptb 33 has a single dominant gene for BPH resistance.

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Studies on varietal resistance to the brown planthopper in Taiwan

C. H. Cheng and W. L. Chang

Since the implementation of the screening program in 1968, about 3,000 rice varieties or lines from Taiwan's varietal collections and foreign introductions have been screened for resistance to the brown planthoppers and some 120 varieties have been identified as resistant. None of Taiwan's native varieties have been recorded as resistant to the brown planthopper. However, all the resistant varieties are of indica type and most are natives of India and Sri Lanka.

Resistance was mainly due to the insect's nonpreference of the plants or sheltering. The resistant plants also caused high mortality and lower population development of the insects. The effects of plant age, fertilizers, and temperature on varietal resistance to the brown planthopper were also investigated. The characteristics of insect resistance were not greatly affected by any of those factors.

The genetics of resistance to the brown planthopper has been intensively studied. One dominant and one recessive gene have been identified. Resistance to the brown planthopper can be incorporated into improved plant types, such as indica and japonica rice, in all selections. Several promising selections were identified. One of them was named Chianung Sen 11 in 1973. The resistant varieties can be used for minimizing pest populations and their damage.

Three biotypes of the brown planthopper have been developed in the insectary. They do not differ distinctly in morphological characters but do differ in the capability of causing plant wilting. The ability of biotype 2 to Infest plants with *Bph 1*-resistant genes is controlled by recessive genes while the ability of biotype 3 to Infest plants with *bph 2*-resistant genes IS governed by dominant genes.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* Stål, which arose from a sporadic pest, has become one of the most destructive insect pests of rice in Taiwan since 1961. It sucks the sap of the rice plant. The damage results in the plant's loss of vigor, reduction in tiller number, increase in unfilled grains, and, in severe cases, hopperburn (Cheng 1975). Heavy infestation usually occurs in the second crop of rice. An average of 85,413 ha, or about

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19% of the total area planted to rice, has suffered from the damage of BPH in the past 10 years.

Until recently the use of insecticide has been the most reliable method of controlling the insect. To be effective, control with insecticide requires three to six applications at an estimated cost of US$40 to US$80/ha. In 1973, however, a BPH-resistant variety, Chianung Sen 11, was developed and released for commercial cultivation in this island. The use of a resistant variety is a more economical way of controlling BPH on rice than the use of insecticides. This paper reviews some of the results obtained in studies being conducted at the Chiayi Agricultural Experiment Station in Taiwan.

SCREENING FOR RESISTANCE

Screening for varietal resistance to the BPH has been carried out at the Chiayi Agricultural Experiment Station since 1968. The greenhouse screening methods are similar to those reported by Choi (this volume). The varieties classified as resistant are further evaluated for consistency of resistance in both the laboratory and the field.

Field screening tests are conducted where BPH incidence usually is high. Each variety is planted in 50-hill plots (1 × 2.5 m) and replicated in a randomized complete block design. Subsequent management conforms to standard procedures in the area except that no insecticide is used throughout the season. The number of BPH settling on each hill and insect damage to the plants are recorded every 10 days after transplanting.

About 3,000 varieties or lines from Taiwan collections and foreign introductions have been screened for resistance to BPH since the implementation of a screening program in 1968 (Chow and Cheng 1971; Chang and Chen 1971; Cheng 1973). No japonica ponlai, Japanese or Korean japonica, native indica, mainland China indica, or upland rice has proved resistant to the BPH. Only varieties or lines from the International Rice Research Institute (IRRI) have shown any resistance to it. The resistant varieties are all indicas, most of them natives of India and Sri Lanka (Table 1).

The reactions of the selected resistant varieties to the BPH in the field were generally similar to those of seedlings in greenhouse tests. However, some varieties, for instance, Peta and Peloper, were classified as susceptible in the seedling stage but appeared to be moderately resistant in the reproductive stage in the field. A large number of insects were recorded on them at the mature stage but damage was slight (Chow and Cheng 1971). In breeding for resistance to the hoppers, these “field resistant” varieties are also important.

MECHANISM OF RESISTANCE

Nonpreference of resistant varieties by the brown planthopper

A series of experiments revealed that the BPH usually preferred the resistant

Table 1. Reactions of selected rice varieties from the IRRI world collections[a] to the three biotypes of the brown planthopper in the greenhouse, 1976.

Variety	IRRI acc. no.	Origin	Reaction to biotype[b]		
			1	2	3
ADT 4	8185	India	MR	S	S
Anbaw C7	6069	Burma	MR	S	S
Andaragahawewa	11974	Sri Lanka	R	–	–
ARC 6563	12276	India	MR	S	R
ARC 6650	12308	India	R	MR	R
ARC 10410	12453	India	MR	–	–
ARC 10595	21525	India	MR	–	–
ASD 7	6303	India	MR	S	S
Babawee	8978	Sri Lanka	R	R	R
Balamawee	7752	Sri Lanka	R	R	R
Balamawee	8919	Sri Lanka	R	R	R
Bakatabe	13507	–	MR	S	S
Berawee	8967	Sri Lanka	R	S	S
C 84-35	13497	–	MR	S	S
C 33-18	–	–	MR	–	–
Cesariet	–	–	MR	–	–
Chianung-shen-yu 11	26955	Taiwan	MR	S	S
Co 9	3690	India	MR	–	–
CR 94-13	–	India	MR	R	R
CO 13	4897	India	MR	–	–
CO 22	6400	India	MR	–	–
Dalwa Sanam (MTU 15)	6365	India	MR	–	–
Dampata Podiwee	15399	Sri Lanka	R	–	–
DF 1	8365	–	R	R	R
Dikwee	7814	Nigeria	MR	S	S
EK 1263	11057	–	R	S	R
EK 1240	3742	–	R	S	R
DJ 9	8511	–	R	–	–
Gadi	8219	–	MR	–	–
Gangala	7733	Sri Lanka	MR	R	R
Hathiel	7730	Sri Lanka	MR	–	–
Heenukkulama	11978	Sri Lanka	R	S	R
Hondarawala 378b	12076	Sri Lanka	R	R	R
Hondarawala 502b	15634	Sri Lanka	R	–	–
HR 12	19299	India	R	–	–
HR 19	4901	India	R	S	S
HR 106	3753	Sri Lanka	MR	S	S
Heenhoranamawee	15286	Sri Lanka	MR	–	–
Hunukkulama b	11974	–	R	–	–
H5	156	Sri Lanka	MR	S	S
H 105	158	Sri Lanka	R	S	S
IR5161-288	–	Philippines	R	–	–
IR1541-76-3	–	Philippines	R	–	–
IR1514A-E666	–	Philippines	MR	–	–
IR747-13-6-3	–	Philippines	MR	–	–
IR26	24154	Philippines	MR	S	R
IR28	30411	Philippines	MR	–	–
IR30	30413	Philippines	MR	S	R
IR32	30414	Philippines	MR	R	R
IR34	30415	Philippines	MR	–	–
IR38	–	Philippines	R	S	R
JBS 34	3732	–	R	–	–
Kaluheenati	7735	Sri Lanka	R	–	–
Kao shen yu 12	–	–	MR	S	S
Karayal	8911	–	MR	–	–
Kam-Ban-Gan	–	–	MR	–	–
Klewer	13375	–	MR	S	S

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Table 1 continued

Variety	IRRI acc. no	Origin	Reaction to biotype[b]		
			1	2	3
Kosatwee	11677	Sri Lanka	R	–	–
Kuruhonarawala	7731	Sri Lanka	R	R	R
Lampong peuteuj	13515	–	R	S	S
Lekam Samba	15412	Sri Lanka	R	R	R
M 302/Mas 24 (1900)	7833	Sri Lanka	MR	–	–
Madayal	12001	Sri Lanka	R	–	–
Mahadikwee	11956	Sri Lanka	R	–	–
MI 329	12089	–	MR	–	–
Mgl 2	–	India	R	–	–
Miketan 20	–	India	MR	–	–
Mudgo	6663	India	R	S	R
Mudu Kiriyal	15489	Sri Lanka	R	R	R
Murunga 137	1471	Sri Lanka	R	S	R
Murunga 307	3472	Sri Lanka	R	–	–
Murungakayan	8955	Sri Lanka	MR	–	–
Murungakayan 3	12071	Srl Lanka	R	S	S
Murungakayan 101 b	12072	Sri Lanka	R	R	R
Murungakayan 304b	12073	Sri Lanka	R	–	–
Murunaakavan 307	11096	Sri Lanka	R	–	–
Muthukanikam	15397	Sri Lanka	R	R	R
MTU 9	7919	India	MR	–	–
MTU 15	233	India	MR	–	–
Ovarkaruppan	11963	Srl Lanka	R	–	–
Oenji Hore	4189	Sri Lanka	MR	–	–
Palasithari 610	12069	Srl Lanka	R	R	R
Panneti	8937	Sri Lanka	R	S	S
Pantong 32	18343	–	MR	S	S
Pa kheng kang	12977	–	MR	S	S
Pandorai	13456	–	MR	S	S
Pawakkulama B	11938	Srl Lanka	R	S	R
Peolopor	5335	–	R	–	–
Periamurungan B	11935	Sri Lanka	MR	S	S
PK-1	15192	Srl Lanka	R	–	–

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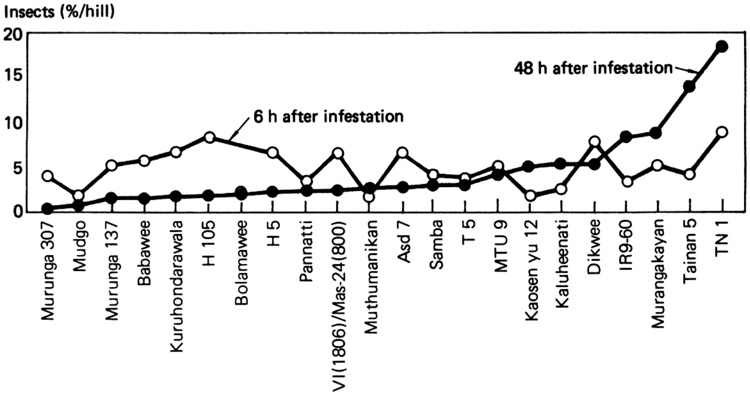
varieties less than they did the susceptible varieties (Fig. 1). In general, the variety preferred by the adult insect was also preferred by the nymphal insect (Table 2), and the variety that the insect preferred for feeding or for shelter was the one it also preferred for depositing eggs (Fig. 2). During the first 6 hours after infestation, the insects showed no distinct preference for any variety. However, they gradually migrated from resistant to susceptible varieties, and 48 hours after infestation, about 2 to 30 times more insects were recorded on susceptible varieties than on resistant ones. The reaction was even more distinct in the field. The BPH population usually increased rapidly on plants of susceptible varieties after the flowering stage; it remained very low or increased very slowly on resistant plants. More than 1,000 times as many insects were recorded on susceptible than on resistant varieties, although the plants were only 25 cm apart. Damage on resistant varieties was barely noticeable, while that on susceptible varieties was heavy (Chow and Cheng 1971).

Table 1 continued

Variety	IRRI acc. no.	Origin	Reaction to biotype[b]		
			1		23
Ptb 9					
Ptb 18	11052	India	R	–	
Ptb 19	6107	India	R	R	R
Ptb 21 (tekkan)	6113	India	R	R	R
Ptb 33	19325	India	R	R	R
Pulot Etam	13457	–	MR	–	–
Rathu Heenati	11370	Sri Lanka	R	R	R
Radin Bilis	13594	–	MR	S	S
RDRI	613	–	R	–	–
Samba	8903	–	MR	S	S
Seruvellai	8990	Sri Lanka	R	S	R
Senawee	15281	Sri Lanka	R	R	R
Sinna Karuppan	11731	Sri Lanka	R	–	–
Sinakayam B	11687	Sri Lanka	R	S	A
Sinna Sivappu	15444	Sri Lanka	R	R	R
Sinnasuappu	11697	Sri Lanka	R	S	S
SLO 12	6300	India	R	S	R
Sudu Heenati	15749	Sri Lanka	MR	–	–
Sudu Hondarawala	15541	Sri Lanka	R	R	R
Sudurvi 305	3475	Sri Lanka	R	–	–
Sudurvi 306	11098	Sri Lanka	R	S	R
Sulai	15421	Sri Lanka	R	S	R
Sulai	15239	Sri Lanka	MR	–	–
Su Yai 20	7299	China	R	–	–
T5	9832	India	MR	S	S
Thirissa	7734	Sri Lanka	R	R	R
Ta 11	8276	–	MR	–	–
Ta 68	8294	–	MR	–	–
Tjere Omas	13535	–	MR	S	S
Tibirewewa	11969	Sri Lanka	R	S	S
Vellailangayan	8956	Sri Lanka	R	–	–
VI /18061 Mas 24(800)	7815	Sri Lanka	MR	–	–

[a] About 3,000 rices were tested. [b] R = resistant. MR = moderately resistant. S = susceptible, – = no data



1. Preference of adult brown planthopper for selected resistant and susceptible varieties. CAES (Chia-yi Agricultural Experiment Station), 1972.

Table 2. Hosts preferred by *N. lugens* at various life stages or according to sex (Cheng 1973).

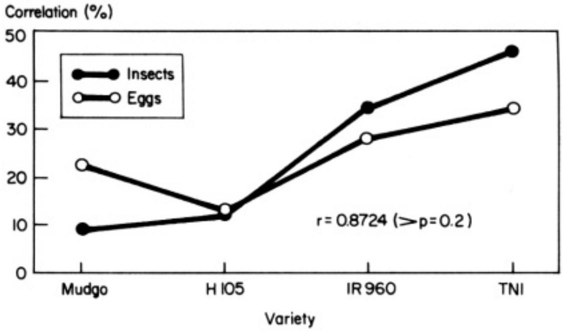
Variety	Insects[a] (%) on plant at				
	Instar			Adult stage	
	1st	2nd-3rd	4th-5th	Female	Male
Mudgo (R)	12.7	11.7	5.3	10.2	14.2
H 105 (R)	19.9	11.1	14.9	9.6	13.4
Samba (R)	20.2	12.5	20.8	13.9	12.7
TN1 (S)	47.3	64.7	59.7	66.3	59.7
LSD 5%	7.44	15.13	5.81	14.04	6.8
1%	10.69	21.21	8.35	21.27	10.31

[a] Differences among insect stages within a variety were not significant.

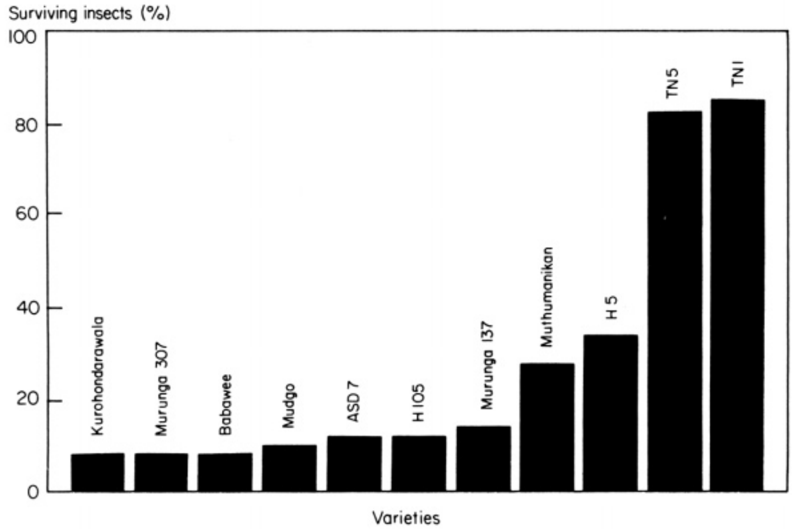
In greenhouse and field trials, the BPH exhibited strong nonpreference for the following varieties: Mudgo, Murunga 137, Murunga 307, Sudarvi 305, Sudarvi 306, Balamawee, Rathu Heenati, Heenukhulama, Babawee, Kuro-hondarawald, Ptb 18, Pawakhulama, SLO 12, Sinnakayam, Tibiriwewa, EK 1263, and Andaragawewa. In general, the degree of plant damage was closely related to the insect's preference for a host variety; the stronger the insect's preference of the plant, the more severely the plant was damaged. However, some varieties, e.g. Kaosen yu 12, MTU 9, ARC 6650, ARC 10595, and Sinnasuappu, even though they attracted larger numbers of insects, were damaged only slightly. Thus, besides a low degree of attraction for insects, a plant's tolerance for insect feeding probably is also an important factor contributing to its resistance (Cheng 1973).

Survival and population buildup on resistant and susceptible varieties

In the studies of survival and growth of the BPH on resistant and susceptible varieties, equal numbers of insects were caged with individual plants of selected varieties. In one such experiment (Fig. 3), 15 days after caging, the survival



2. Correlation between the settling preference and oviposition preference of brown planthopper for resistant and susceptible varieties.



3. Survival of first-instar brown planthopper nymphs 15 days after caging on selected resistant and susceptible rice varieties. CAES (Chia-yi Agricultural Experiment Station).

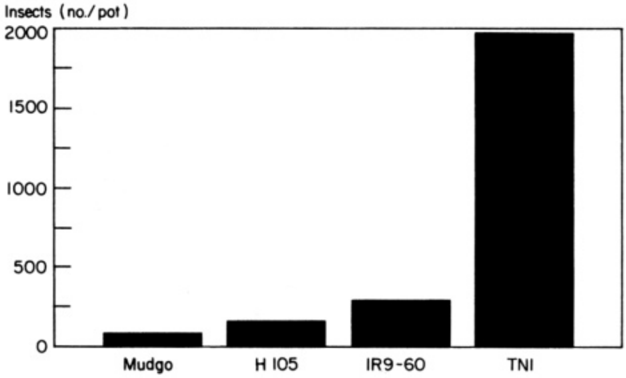
rate of nymphs caged with resistant varieties ranged from 8 to 38%, while that of nymphs caged with susceptible varieties ranged from 82 to 85%. Furthermore, the nymphs on resistant varieties generally took longer to become adults than those on susceptible plants. Varieties that exerted high mortality to first-instar nymphs also caused high mortality to other instars and adult insects. But the older instar nymphs had slightly higher mortality rates than the younger ones, and adults had higher mortality rates than nymphs (Table 3).

Antibiosis is also involved in the resistance to the BPH. That was demonstrated by the adverse effects of resistant plants on the increase of insect populations in the greenhouse. Thirty-day-old potted plants were caged separately, each with five pairs of newly emerged adults. The insect population

Table 3. Differences in survival between growth stages and sexes of brown planthoppers on some selected varieties[a] (Cheng 1973).

Variety	Surviving Insects[b] (%)				
	Instar			Adult stage	
	1st	2nd-3rd	4th-5th	Female	Male
Mudgo	14	24	4	16	0
H 105	42	40	32	28	20
TN1	88	90	84	78	72

[a] Ten Insects at each life stage caged with each variety, 10 replications. [b] Seven days after infestation.



4. Population of brown planthopper on selected resistant and susceptible varieties 50 days after 5 pairs of adults were caged with each pot. CAES (Chia-yi Agricultural Experiment Station), 1972.

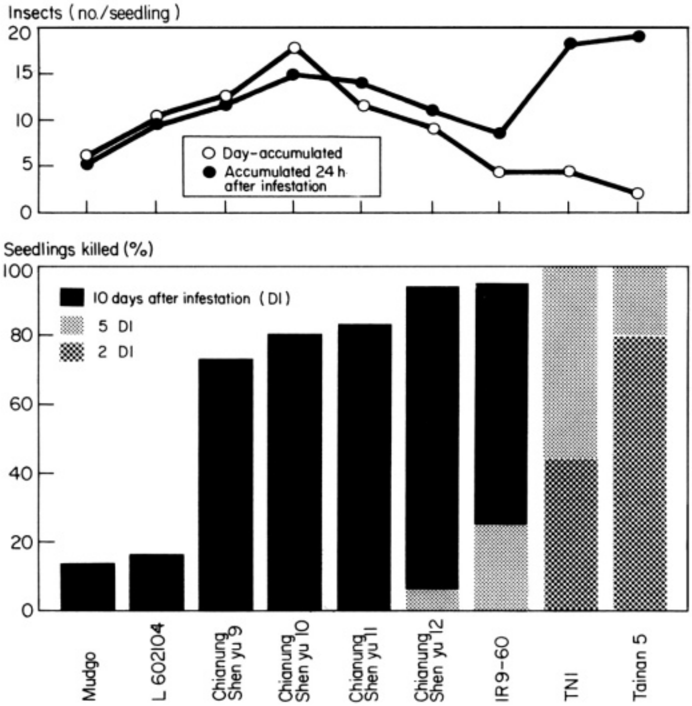
increased more than 200 times on a susceptible variety 50 days after caging, but only 6 to 30 times on resistant varieties (Fig. 4). The lower rate of population increase on resistant varieties seemed to have been caused by the high mortality of adults and nymphs, or by reduced fecundity.

Tolerance for the brown planthopper

To determine the tolerance of different rice varieties for BPH damage, large numbers of the insects were caged with potted plants. Resistant plants often were only slightly damaged while susceptible plants were killed. The low level of plant damage on resistant varieties was primarily due to the adverse effect of the plant on the insect, rather than to the ability of the plant to tolerate insect feeding (Cheng 1973). However, in mass screenings and in field experiments, some varieties exhibited little damage even though infested by as many insects as the susceptible varieties. Of seedlings of susceptible TN1 and resistant Chianung Shen yu 10, 24 hours after infestation, 18 and 15%, respectively, were infested (Fig. 5). All TN1 seedlings were dead 4 days after infestation, while only 80% of the seedlings of Chianung Shen yu 10 were dead 10 days after infestation. In terms of number of insects found on plants over a period of days, the tolerance for insect infestation of Chian Shen yu 10 was four times greater than that of TNI (Cheng 1973). The results of field experiments were similar. Although infested with large numbers of BPH, some varieties such as Peta, TKM 6, Lung-yu, Peloper, and Thirissa suffered only moderate damage, while hopperburn developed in susceptible varieties (Cheng 1973).

Effect of environmental factors

The effects of some environmental factors (e.g. plant age, fertilizer, and temperature) on varietal resistance to the BPH were studied at the Chiayi Agricultural Experiment Station during 1971 and 1972. Insects on the older plants of resistant



5. Brown planthopper damage to the seedlings of some resistant and susceptible varieties (lines) in relation to the host preference of the hopper and the resistance of rice.

varieties had significantly higher survival rates than insects on younger plants, showing that older plants were less resistant than younger ones (Table 4). However, the differences in resistance due to age were smaller in plants of a highly resistant variety than in plants of a susceptible variety. The BPH tended to prefer the older plants among 15-, 30-, 60-, and 90-day-old plants of resistant varieties. When varieties of the same age were caged together and infested with BPH, the numbers of insects settling on resistant and susceptible varieties differed significantly for 15-, 30-, and 60-day-old plants but not for 90-day-old plants.

Cheng (1971) reported that rice plants treated with nitrogen were strongly preferred by BPH. Hoppers feeding on a nitrogen-treated plant excreted more honeydew, and had a higher survival rate and greater population increase than those feeding on nitrogen-deficient plants. However, nitrogen application did not affect resistant varieties as significantly as it did susceptible varieties; the higher the variety's susceptibility, the greater was the effect. The effects of combinations of different fertilizer application rates on resistant (Mudgo) and susceptible (TN1) varieties were also investigated. Deficiency of any or all of three elements, nitrogen, phosphate, or potassium, greatly retarded plant development. The insects' preference of the affected plants, and the

Table 4. Relations of plant age to the survival of host preference of and damage by brown planthoppers on resistant (R) and susceptible (S) rice varieties (Cheng 1973).

Plant age (days)	Surviving insects (%)	Insects recorded (%) on		Damage grading[a]
		Varieties of same plant age together	Plants of all varieties and ages mixed together	
		Mudgo (R)		
90	32	22.5	13.4	1
60	24	12.4	7.7	1
30	15	12.9	0.8	1
15	16	11.9	0.2	1
		H105 (R)		
90	45	21.6	17.4	2
60	32	19.6	4.7	2
30	29	16.7	1.6	1
15	25	6.5	0.1	1
		IR9-60 (R)		
90	48	22.2	5.1	5
60	25	18.7	4.6	3
30	26	18.7	0.7	3
15	22	22.6	0.2	3
		TN1 (S)		
90	90	33.7	15.7	9
60	92	49.2	20.1	9
30	93	51.7	6.6	9
15	82	58.9	0.4	9
LSD	10.2	13.6	14.5	

[a] O = no visual damage, 9 = plant killed.

development of the insect populations decreased distinctly. Increasing the amount of nitrogen or phosphate in a complete fertilizer increased the life span and reproduction of BPH adults on both resistant and susceptible varieties. However, that difference did not change the relative susceptibility of the varieties (Table 5).

Studies of the effect of temperature on varietal resistance indicated that more insects were generally found on susceptible plants than on resistant varieties at any temperature tested. However, the differences declined with temperature and were not significant at 15°C (Table 6). The damage to plants of resistant varieties usually was more severe in winter screenings than in summer tests. The effect of lower temperatures on BPH survival was not as distinct as the effect on host preference. In a resistant variety, the survival rate at various intervals after infestation usually increased with decline of temperature (Table 7). However, on both the resistant varieties and susceptible TN1, fewer nymphs developed into adults at the lower temperatures than at the higher temperatures.

GENETICS OF RESISTANCE

Studies of inheritance in rice varieties resistant to BPH have been conducted at the Chiayi Agricultural Experiment Station since 1968. The method used

Table 5. Relation of fertilizer application to host preference, adult life span, population development, and plant damage of brown planthoppers on two rice varieties (Cheng 1973).

Fertilizer N[a]-P[b]-K[c]	Insects/ seedling[d]	Life span of female (days)	Insects (no. produced/ pair of adults)	Plant damage[e]
		TN1 (susceptible)		
0-0-0	1.4	6.8	55	9
0-2-2	1.5	13.6	76	9
1-1-1	12.4	7.9	77	9
2-1-1	15.3	12.6	77	9
3-1-1	15.1	14.3	117	9
2-0-2	1.5	4.8	0	9
1-2-1	10.7	15.7	121	9
1-3-1	18.0	16.0	177	9
2-2-0	3.7	10.9	69	9
1-1-2	8.3	15.7	149	9
1-1-3	11.9	13.7	91	9
2-2-2	11.1	13.4	169	9
3-3-3	16.1	14.3	129	9
		Mudgo (resistant)		
0-0-0	0.3	5.2	0	0
0-2-2	3.9	5.1	1	0
1-1-1	6.5	3.3	1	0
2-1-1	8.9	5.9	10	0
3-1-1	8.4	3.9	1	0
2-0-2	3.2	3.0	0	0
1-2-1	5.9	3.3	3	0
1-3-1	6.1	4.0	7	0
2-2-0	5.5	6.2	9	0
1-1-2	3.8	3.6	0	0
1-1-3	5.1	4.1	5	0
2-2-2	13.9	3.6	1	0
3-3-3	18.8	5.0	1	0

[a]Nitrogen. [b]Phosphorus. [c]Potassium. [d]For each variety, one pot per treatment; pots randomly arranged and infested with 200 newly emerged adults; 5 replications. [e]Plant damage, 0 = no visual damage, 9 = plant killed.

for screening rice varieties was used in the genetic studies. Rice seedlings in grades 0, 1, and 3 were classified as resistant while those in grades 5, 7, and 9 were classified as susceptible. The resistant check variety Mudgo, the susceptible check variety TN1, and both parents of the cross were also included in each flat. The resistance of Mudgo to the BPH was dominant (Chang 1970)

Table 6. Effect of temperature on the host preference of the brown planthopper[a] (Cheng 1973).

Variety	Insects(%)			
	15°C	20°C	25°C	30°C
Mudgo (R)	16.74	21.17	5.01	5.37
H105 (R)	25.74	18.69	16.82	16.30
Samba(R)	26.92	18.97	10.28	3.69
TN1 (S)	30.58	41.37	67.84	74.63

[a]Five replications each consisting of 20 nymphs.

Table 7. Effect of temperature on the survival of brown planthopper nymphs on resistant (R) and susceptible (S) rice varieties (Cheng 1973).

Days after infestation	Surviving nymphs (%)		
	Mudgo (R)	IR9-60 (R)	TN1 (S)
	15°C		
20	53	57	66
40	17	33	54
60	4	18	43
75[a]	2	7	40
	20°C		
15	60	90	92
20	38	30	92
25	14	66	90
30[a]	7	34	79
	25°C		
15	18	30	84
20[a]	12	21	83
	30°C		
15[a]	21	35	89
20	10	30	87

[a] Nymphs developed to adult stage.

and was controlled by a single dominant gene (Chen and Chang 1971). IR9-60, an early introduction from IRRI, possessed a recessive gene for resistance to the BPH (Chang and Chen 1971).

F_1, F_2, backcross progenies, and F_3 families of the susceptible resistant crosses showed that resistance to the BPH in rice varieties MTU 9, Sudurvi 306, Murunga 137, EK 1263, Sinnakayam, and Heenukhulama was conditioned by a single dominant gene while that in rice varieties Kaosen-yu 12, H5, Samba, Dikwee, ASD 7, IR9-60, Anbaw C7, Pannetti, and H105 was controlled by a recessive gene. It is not known whether the single genes for resistance in rice varieties MTU 9, Sudurvi 306, and Murunga 137 are identical to *Bph 1* of Mudgo. However, there is evidence that the recessive genes of IR9-60, Kaosen-yu 12, and H5 are at the same locus as, and appear to be identical to, *bph 2*.

BREEDING FOR RESISTANCE

Breeding for BPH resistance was initiated at the Chiayi Agricultural Experiment Station in 1968. Because two types of rice are commonly grown in Taiwan, the development of resistant varieties in both indica and japonica rice was a target of the breeding program. In breeding indica rice for BPH resistance, the development of long-grain rice with good grain quality was emphasized. For this reason, IR9-60, Kaosen-yu 12, IR747B2-6, IR1561-228-3, and lR1514-E666 were most commonly used as donor parents in crosses with varieties of improved-plant type and good grain quality such as IR8 and IR22. The pedigree method was used exclusively in handling the segregating populations of the crosses. Screening for BPH resistance started either from F_2 populations or F_3 lines, depending on the availability of insects for infestation. The techniques used for rapid screening of hybrid populations were similar to those used for screening rice varieties. Hybrid seedlings were screened for BPH resistance, and the resistant plants or lines were then transplanted into a paddy field for selection of other agronomic characters. The process was repeated for several generations until the resistant lines with desirable agronomic characters became fixed (Chen et al 1972). Some promising indica selections are presented in Table 8. BPH resistance has been successfully incorporated into an improved-plant type in all selections.

All sources of resistance in Taiwan's breeding program are indica varieties. Thus, some difficulties have been encountered in breeding japonica rice for resistance. Wide segregation and severe sterility usually accompanied indica-japonica crosses, making it difficult to recover lines with desirable plant types from single crosses. For these reasons, backcrossing was used in breeding japonicas for resistance to the BPH. The resistant varieties Mudgo, ASD 7, and IR9-60 were often used as donor parents while the leading ponlai varieties Tainan 5 and Chianan 8 were used as recurrent parents. The backcross procedure varied with the nature of the resistant gene carried by the donor parents. When the gene for resistance was dominant, as in Mudgo, the F_1hybrids were backcrossed to the recurrent parents. The B_1F_1 plants were screened for resistance, and the resistant ones that were phenotypically similar to recurrent parents were selected for the second backcross. If, however, the donor parents carried a recessive gene for resistance, as did ASD 7 and IR9-60, for making backcrosses the resistant plants were selected in F_2 and B_1F_2 instead

Table 8. Agronomic performance of some promising indica and japonica rice selections resistant to the brown planthopper (Chang and Cheng 1973).

Selection code	Parents	Days to heading	Plant ht (cm)	Panicles (no./hill)	Grain yield (kg/ha)
			Japonica type		
C62-2-001	C236//Tainan 5/Mudgo	66	110.2	13.4	1856
C62-2-002	C240//Tainan/ASD 7	63	108.1	15.6	5400
C62-2-005	Nankai-yu 77//Tainan 5/ ASD 7	62	106.3	13.9	5026
C62-2-015	Kaohsiung dwarf// Tainan 5/1R9-60	63	108.8	14.7	4882
C62-2-040	Talnan 5^2/ Mudgo	62	110.3	14.5	4854
C62-2-068	"	65	105.8	10.5	5047
Tainan 5	(Susceptible check)	67	112.7	12.4	4312
			Indica type		
C62-2-092	IR8/IR9-60	73	95.9	18.3	4825
C60-2-103	"	70	85.7	19.4	4585
C61-1-218	IR8/TKN 6//1R9-60	76	94.5	20.2	5645
C61-1-330	Kaosen-yu 12/1R22	69	87.1	15.2	5332
C61-1-337	"	68	91.2	16.0	5538
C61-1-343	"	68	87.5	16.1	5720
C62-1-373	Kaosen-yu 12/1R22	75	100.3	15.9	6039
TN1	(Susceptible check)	67	78.6	17.2	4002

of F_1 and B_1F_1. The number of backcrosses varied with cross-combinations. One or two backcrosses might be enough for a certain cross-combination, while for other crosses more may be needed. In other cases, three-way crosses were made by crossing F_1 or B_1F_1 plants to third parent of improved plant type. The pedigree method was used when the resistant parent was a japonica like KC18-11-8-25-1-17, a selection from the cross of (Hoyoku/Mudgo)// Kochikaze made by Kaneda (1971, 1973). Several promising japonica selections are also shown in Table 8. The BPH resistance of indica rice has been successfully transferred to japonica-type selections.

BIOTYPES

As mentioned earlier, the resistance of rice to the BPH is controlled by a single gene and most resistance sources come from the same area and may possess the same resistance gene. Therefore. it is likely that the insect may develop new biotypes capable of surviving and of damaging resistant varieties as the varieties are planted on large areas. Brown planthoppers were collected from five sites in Taiwan, and their reactions on susceptible varieties were compared with their reactions on resistant varieties. No distinct differences were found in survival rate, host preference, or damage caused (Table 9; Cheng 1973).

Table 9. The reactions of *Nilaparvata lugens* collected from different locations to some selected rice varieties (Cheng, 1973).

Variety	Collection site	Surviving[a] Insects (%)	Insects[b] (no./seedling)		Days to seedling death
			Nymph	Adult	
Mudgo					
Resistant	Hualian	6	3.2	6.0	–
	Taitung	6	5.8	4.2	–
	Pingtun	6	6.4	4.6	–
	Taichung	10	9.6	5.4	–
	Chiayi	6	7.2	4.8	–
IR9-60					
Resistant	Hualian	20	8.8	8.0	–
	Taitung	34	9.6	5.2	–
	Pingtung	38	12.4	8.6	–
	Taichung	34	10.8	5.2	–
	Chiayi	20	21.8	20.0	–
TN1					
Susceptible	Hualian	74	63 4	98.0	19.6
	Taitung	82	72 6	103.6	17.8
	Pingtung	76	55.4	79.8	21.6
	Taichung	70	59.8	82.0	15.6
	Chiayi	78	62.6	89.6	17.8
			LSD (among sites)		
	5%	18.3	10.3	7.6	
	1%	24.6	13.6	10.1	

[a] Surviving to adulthood; introduced to plants as 1st instar [b] Seventy-two hours after infestation.

Table 10. Ability of *N. lugens* biotypes to kill rice varieties having different genes for resistance, 1974.

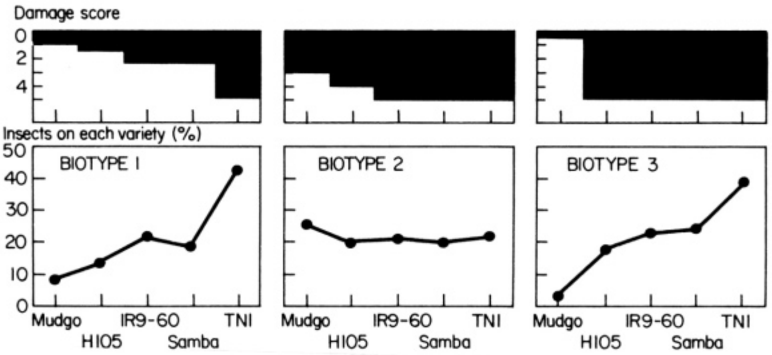
Variety	Seedlings killed (%) by		
	Biotype 1	Biotype 2	Biotype 3
Monogenic recessive (bph 2)			
IR9-60	10	90	100
Kaosen-yu 12	10	100	100
ASD 7	10	100	100
H 5	20	100	100
Samba	30	100	100
Pannetti	30	100	100
H 105	10	100	100
Dikwee	20	100	100
Anbaw C7	50	90	100
Monogenic dominant (Bph 1)			
Pawakhulama	0	100	0
IR747	0	100	0
Murunga 137	10	100	5
EK 1263	0	100	0
Sinnakayan	10	100	10
Sudarvi 306	0	100	0
Mudgo	0	100	10
Heenukhalama	0	100	10
TN1[a]	100	100	100

[a] Susceptible check.

The resistant variety generally caused high mortality among caged BPH; only a very small number of the insects survived to become adults and produce progeny. By rearing BPH on rice varieties with different genes for resistance continuously for 22 generations, we have selected three planthopper biotypes in an insectary at Chiayi Agricultural Experiment Station (Cheng 1975). These biotypes have been designated as biotypes 1, 2, and 3. No distinct differences in morphological characters were observed among them except that biotype 2 was generally the smallest. However, differences in ability to cause plant wilting were observed (Table 10, Fig. 6). The individuals of biotype 1, the predominant biotype in the natural population, can infest only such rice varieties as TN1 that are susceptible to all biotypes so far developed. They can infest neither varieties with a *Bph 1* gene nor those with a *bph 2* gene for resistance. However, all cultivars grown in Taiwan before 1973 were susceptible to biotype 1.

Biotype-2 individuals, in addition to infesting rice susceptible to biotype 1, are able to infest rice with either *Bph 1* or *bph 2* genes for resistance. Biotype 2 is the most destructive so far identified. Biotype 3 was selected by rearing the insects on varieties with bph 2 gene for resistance. It infested, besides rice susceptible to biotype 1, rice with *bph 2* gene, but not rice with a *Bph 1* gene for resistance.

In tests of varietal reactions to biotypes, some varieties such as Balamawee, Muthumanikan, DFl, Ptb 19, Ptb 21, Ptb 33, IET5085, IET5118, IET5199,



6. Host preference of and damage by 3 biotypes of brown planthopper on some selected rice varieties. CAES (Chia-yi Agricultural Experiment Station), 1974. (Damage grading: 0 = no damage, 5 = plants killed.)

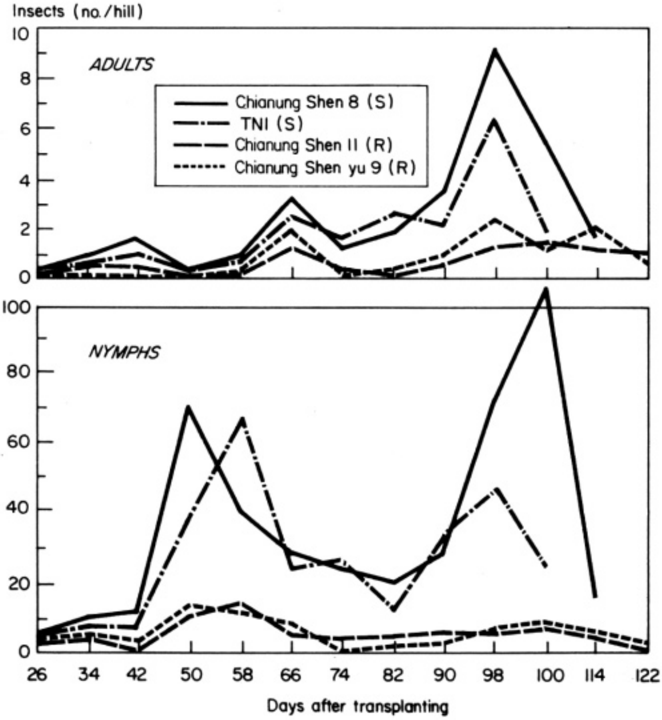
IET5120, IET5122, IET5236, CR94-13, and BR1030-65-1, were resistant to all the biotypes mentioned.

Preliminary investigations into the inheritance of virulence of different biotypes have indicated that F_1 individuals of biotype 1/biotype 2 or of biotype 2/biotype 1 were incapable of wilting Mudgo plants. On the contrary the F_1 individuals of biotype l/biotype 3 or of biotype 3/biotype 1 were capable of infesting plants of H105 as well as those of TN1. These results revealed that the ability of biotype 2 to infest Mudgo was controlled by recessive genes, while the ability of biotype 3 to infest H105 was governed by dominant genes.

ROLE OF NEWLY DEVELOPED RESISTANT VARIETIES IN BROWN PLANTHOPPER CONTROL

Although many studies concerning the interaction between the resistant host plant and the BPH have been made in the laboratory or greenhouse with unimproved resistant varieties, few have been made of the practical significance of resistant varieties in the field. To determine the degree of control obtainable by planting resistant varieties, the performance of some newly developed resistant varieties was observed at the Chiayi station.

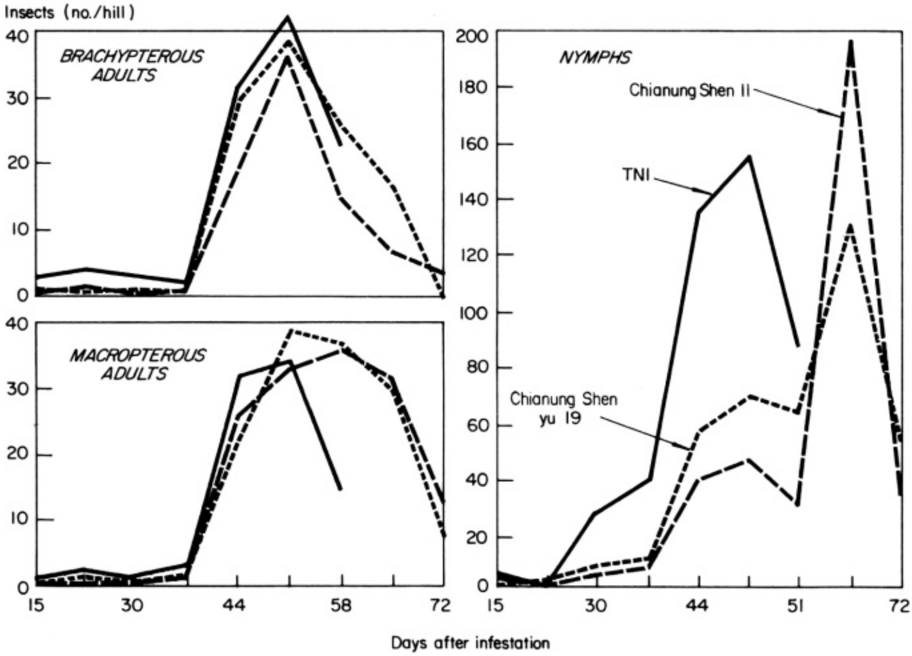
In the second crop of 1973, the development of BPH populations on a resistant variety and a susceptible variety was observed in the screenhouse. Sixteen hills of each variety were planted in a small concrete bed (1 × 1 m), with three replications in a randomized complete block design. One pair of macropterous adults was introduced into each plot 5 days after transplanting. Three major population peaks developed on both varieties (Fig. 7). There was no difference in population densities on the varieties at the first peak. However, the nymphal density on the susceptible variety was greater than that on the resistant variety by about 7 times at the second peak, and by 4 to 10 times at the third peak. The susceptible plants were all killed by the third-generation



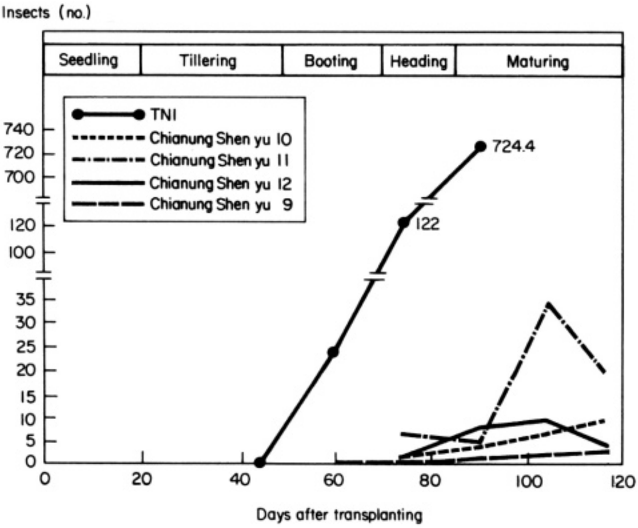
7. Density of brown planthopper on resistant and susceptible varieties in a screenhouse experiment. Single pairs of macropterous adults were introduced to a 16-hill plot 5 days after transplanting.

nymphs. On the other hand the planthopper population on the resistant plants was very low throughout the crop season—less than 10 insects/hil1. The low population on the resistant variety. particularly evident during the adult stage of the second generation, was probably due to the emigration of adult insects.

A similar experiment was conducted during the first crop season of 1976 at the same location. A pair of adults was introduced to each hill of 50-day-old plants. The first population peak of the adults, whether brachypterous or macropterous, appeared at 23 days after the insects were introduced; the second peak, at 51 days (Fig. 8). The differences in the populations of brachypterous adults on the two varieties were greater than those in the populations of the macropterous adults. That caused considerable difference in the development of second-generation nymph populations. As soon as susceptible plants had been damaged severely, most nymphs and adults on those plants migrated to resistant ones. Under the pressure of high colonization, the resistant plants were severely infested. That showed that resistant varieties could suppress the BPH population increase. However, the resistant varieties, particularly those



8. Change in brown planthopper density and age structure on resistant varieties, Chianung Shen 11 and Chianung Shen yu 19, and on a susceptible variety, TN1. One pair of adults was introduced to each hill of SO-day-old plants. Chia-yi Agricultural Experiment Station screenhouse, 1976.



9. Change in density of a field population of brown planthoppers on resistant and susceptible varieties (or selections) in unprotected plots. CAES (Chia-yi Agricultural Experiment Station), 1972.

with moderate levels of resistance, evidently could not deter the abnormal migrant planthopper population before severe plant damage occurred.

Differences in the development of populations on resistant and on susceptible varieties in the field were more distinct than differences in the screenhouse. In one experiment (Fig. 9), it was observed that on susceptible varieties, the planthopper population, in general, increased markedly after the booting stage of the rice (about 50 or 60 days after transplanting—the maximum nymphal stage of the second generation after insect immigration into the field) and rapidly increased from the heading to milky stages (about 70 to 90 days after transplanting — the maximum nymphal stage of the third generation).

Hopperburn usually occurred between the milky and hard-dough stages, depending on the density of the hopper population. In spite of the large populations of BPH on susceptible varieties, in many cases there were fewer

Table 11. Response of certain improved resistant rice hybrids to natural populations of brown planthopper. CAES, second crop, 1973.

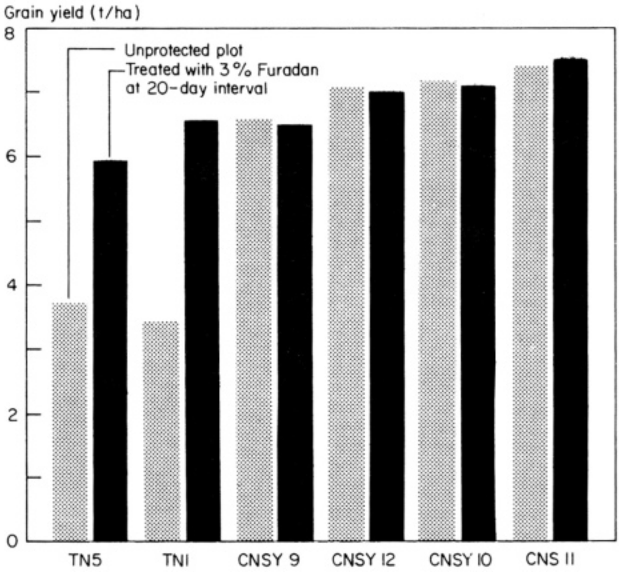
Variety or line	Insects[a] (no./hill)				Grain yield (kg/ha)		Profit from pesticide use[c] (NT$/ha × 1000)
	65 DT	81 DT	95 DT	109 DT	Protected plots[b]	Unprotected plots	
Mudgo	5.8	0.1	0.3	0.1	3565	3157	–3.72
CS 621230	6.9	1.6	2.2	2.4	6243	6524	–1.45
CS 621373	8.4	2.6	6.1	2.4	6040	5533	–2.63
CS 611337	7.4	1.7	6.4	1.4	5538	4143	6.70
CS 611343	4.5	0.7	3.0	1.3	5720	4212	7.90
CN 621032	8.4	1.5	3.1	1.7	5023	3544	7.58
TN1 (S[e])	38.3	28.9	139.4	[d]	5002	2268	20.76
Tainan 5 (S[e])	24.4	17.6	81.9	[d]	4668	2497	1486

[a] DT = Days after transplanting. [b] Using 3% Furadan G, 30 kg/ha, at 30, 60, and 90 days after transplanting to control rice hoppers; 50% Benlate WP, sprayed 80 days after transplanting to control neck blast and sheath blight. [c] Profit from pesticide application is value of rough rice multiplied by amount of increased yield due to pesticide treatment minus cost of pestcide and its application. 38NT$ = US$1. [d] Hopper burned. [e] Susceptible.

Table 12. Responses of certain improved resistant rice varieties to brown planthopper infestation under natural conditions. CAES, second crop, 1975.

Variety	Insects[a] (no./hill)			Grain yield (kg/ha)		Profit from pesticide use (NT$[c]/ha × 1000)
	75 DT	90 DT	105 DT	Protected plots[b]	Unprotected plots	
Chianung shen yu 13 (R)	0.2	2.6	2.3	4754	4327	–1.3
Taichung shen yu 219 (R)	0.6	4.3	6.4	5240	4901	–1.2
TN1 (S)	32.3	134.1	266.7	2653	1505	7.3
Tainan 5 (S)	14.5	42.4	189.3	4065	2237	16.3

[a] DT = Days after transplanting. [b] Rice treated for rice hoppers with 75% Orthene WP at 60, 80, and 100 DT. [c] 38NT$ = US$1.



10. Grain yield of resistant and susceptible varieties (or selections) in protected and unprotected plots. CAES (Chia-yi Agricultural Experiment Station), 1972.

than 10 insects/hill on resistant varieties throughout the crop season. However, the hopper populations increased suddenly because insects immigrated from adjacent plots where susceptible plants were severely infested. But the populations subsequently dropped at the adult stage. Similar results were also observed in 1973 and 1975 experiments (Cheng 1976; Table 11, 12). Resistant rice varieties alone could effectively reduce a population of BPH.

The performance of resistance varieties in BPH control may also be examined by comparing the yield of resistant and susceptible rice varieties that were protected by insecticides and were infested naturally. Yields differed particularly when the BPH was the predominant insect species. In one such experiment (Fig. 10) yield losses of resistant and susceptible varieties or selections that were naturally infested with BPH remarkably differed. Yield losses were about 33% in the susceptible variety TN1 and about 37% in Tainan 5. Under similar conditions, yield reductions in resistant varieties ranged from only 1 to 7.7% (Cheng 1973). Similar experiments at 12 sites scattered throughout Taiwan in the second rice crop of 1973 showed that the yield advantage of resistant selections over the check variety TN1 was about 10 to 15% greater in unprotected treatments than in protected treatments (Chang and Cheng 1974).

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Varietal resistance to the brown planthopper in Thailand

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About 5,000 rice varieties and lines were screened in the greenhouse for their resistance to the brown planthopper (BPH) *Nilaparvata lugens* Stål in Thailand during 1972–1976. The free choice test, in which two-leaf stage seedlings were exposed to a heavy population of first- and second-Instar BPH nymphs, was used. About 100 varieties and lines were selected as resistant and used for hybridization in rice breeding programs in Thailand. Those that showed promise were further studied to confirm their resistance and to investigate the mechanism of resistance.

The main mechanisms of plant resistance to the BPH were identified as nonpreference and antibiosis. The varieties that were less preferred by the nymphs also were not preferred by the adults. More eggs were laid on the preferred varieties.

In addition, nymphs caged on resistant varieties had higher mortality than those caged on a susceptible variety. Significantly fewer adults eventually developed on the resistant varieties than on the susceptible variety Taichung Native 1. Also, the insects took longer to reach the adult stage on the resistant varieties, where the nymphal duration was extended from 4 to 13 days. Adults (male and female) lived longer and produced more progeny when reared on the susceptible variety Taichung Native 1 (TN1) than when reared on resistant varieties. The number of progeny produced on susceptible variety TN1 was 4 to 88 times higher than that produced on the resistant varieties.

The BPH in Thailand was investigated. Insects were collected from five sites in different regions of Thailand and mass reared on TN1 in separate cages in the greenhouse. The biotype of these insects was identified by its ability to infest the seedlings of a set of 10 differential rice varieties. The reactions of the 10 differential varieties to the populations of insects from all sites were mostly the same. That indicated that the insects from all sites tested at this time were of the same biotype.

THE INCIDENCE OF THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens,* formerly not a serious problem in Thailand, began to increase in 1973 with the introduction of double cropping and high yielding varieties. Maximum damage is observed in the dry season (April). Infestation occurs in portions of most

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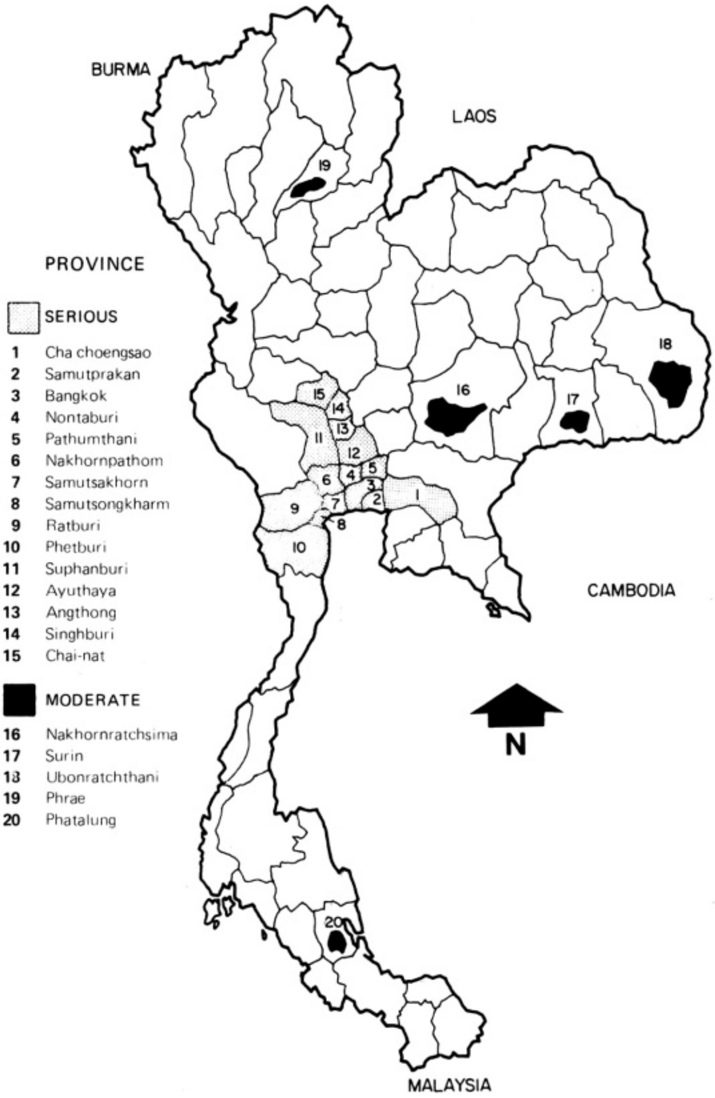

1. Distribution of brown planthoppers in Thailand, 1976 dry season.

provinces of the central plain near Bangkok (Fig. 1). In the 1975 dry season, insect outbreaks occurred in Phrae province in the north, Nakhornratchsima, Surin, and Ubonratchthani provinces in the northeast, and Phatalung province in the south. Outbreaks continue to increase with the expansion of irrigated rice growing areas and the continuous cultivation of high-yielding varieties. In an effort to check the outbreaks in widely grown varieties, a team consisting of a rice breeder and an entomologist monitors insect buildup and suggests control measures. Control measures include insecticides and use of resistant varieties. One resistant variety, RD9, was released in 1975.

SCREENING FOR RESISTANCE

Rice varieties have been screened for resistance to the BPH in Thailand since 1972. The main purpose of screening is to facilitate the quick rejection of most of the BPH-susceptible lines. The screened materials are Thai local varieties and breeding lines, the germplasm bank of the International Rice Research Institute (IRRI), and IRRI's breeding lines. Because BPH are generally easy to mass-rear and because the natural field population is usually low, screening is done in the greenhouse. The methodology used in screening is the same as that described by Choi (this volume).

Retesting of selected varieties

Varieties that show resistance in the preliminary screening are rescreened. Because the purpose of mass screening is to reject the bulk of susceptible lines, the test of each selected variety is replicated two times. Records are made not only of damage, but also of the number of insects present on each variety 24 hours or more after infestation, and of the damage they cause at 5-day intervals. Those varieties showing promise are further studied to confirm their resistance and to investigate the mechanism of resistance. Table 1 shows the varieties and lines selected as resistant to the BPH.

MECHANISMS OF RESISTANCE

Painter (195 1) defined resistance as the "relative amount of heritable qualities possessed by the plant, which influence the ultimate degree of damage done by the insect." He divided plant-resistance mechanisms into three main categories: nonpreference, antibiosis, and tolerance. In our program in Thailand we have studied two mechanisms of resistance: nonpreference and antibiosis.

Nonpreference

Nymphs. Seeds of varieties selected from the general screening were sown in wooden flats. Insects per plant were counted at 2-day intervals for 1 week, starting 24 hours after infestation. Plant damage was recorded 10 days after infestation. Differences in nymphal preference were evident at 3 days after infestation (Table 2). There were more insects on TN1, the susceptible check, than on resistant varieties. Nymphs consistently showed nonpreference for some varieties, such as Ptb 33, Ptb 21, Balamawee, and Mudgo, and were attracted to others like W1263, W1265, and RD9 at 7 days after infestation, when the susceptible check variety had been severely damaged. The resistant varieties were only slightly damaged even when more insects moved to them

Table 1. Rice varieties and lines classified as resistant to the brown planthopper in mass-screening tests. Thailand, 1972-76.

Variety or line	Cross	Origin
RD4	17-7(LT/IR8)W1252//RD2	Thailand
RD9	CNT3176/W1256//RD2	"
BKN6806-46-60	17-1(LT/IR8)/W1259//RD2	"
BKN6953-15-1	IR841/Mudgo/IR8	"
BKN6960-28	RD2/Ptb21	"
CNT7246-11-2-2	RD1/IR532-E-239	"
CNT7255-42-3	BKN6517-11-2-1/CR52-3	"
SPT7202-35	GP15/BKN806-46-62	"
SPT721-40	LY148/RD9	"
SPT7215-20	L152/RD9	"
SPT7329-18-1	KDML105/Sigadis//IR1541	"
SPT7342-20-1	Payah Chom/IR1541	"
BKNBR1008-5	RD3/RJ1//RD9	"
BKNBR 1009-8	DZ192/BKN6517-11-2-1//RD9	"
BKNBR 1030-3-1	BKN6625-109-1/RD9	"
BKNBR 1030-28-1	BKN6625-109-1/RD9	"
BKNBR 1031-15-1-3	BKN6517-63-4-3/RD9	"
BKNBR 1088-81	IR2039-203-3-l/RD1	"
BKNBR 1091-69-1	IR2039-119-3-1/RD1	"
BKNBR 1094-55-2	IR2031-352-3-2/BKN6805-2-7	"
BKNBR 1105-18	IR1529-680-3/RD9	"
Mudgo		India
Ptb 18	–	"
Ptb 19	–	"
Ptb 21	–	"
Ptb 33	–	"
W 1252	–	"
W 1256	–	"
W 1259	–	"
W 1263	–	"
ASD 7	–	"
CO 9	–	"
CO 22	–	"
Dalwa Sanam (MTU 15)	–	"
Hamsa	–	"
TR 26	–	"
Thriveni	–	"
ARC 6650	–	"
ARC 14529	–	"
ARC 14766	–	"
ARC 14771	–	"
CR94-13	–	"
RP9-6	IR8/W1251	"
IET5122(RP825-71-4-11)	–	"
IET5236(RP825-24-7-5)	–	"
IET5085(RP825-70-7-1)	–	"
Andaragahawewa	–	Sri Lanka
Babawee		"
Balamawee		"
Gangala		"
H-5		"
H-105		"
Kuruhondarawala		"
Muthumanikam		"
Murungakayan 3		"
Murungakayan 101b		"
Murungakayan 303b		"
Sudurvi 305		"
Sudurvi Samba		"

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Table 1 continued

Variety or line	Cross	Origin
IR26	IR24/TKM6	Philippines (IRRI)
IR28	IR833-6-2-1-1///IR1561-149-1//IR24^4/*O. nivara*	"
IR29	IR833-6-2-1///IR1561-149-1//IR2^4/*O. nivara*	"
IR30	IR1541-102-6-3//IR20^4/*O. nivara*	"
IR32	IR20^2/*O. nivara*//CR94-13	"
IR34	IR833-6-2-1-l///IRl561-149-1//IR2^4/*O. nivara*	"
IR36	IR1561-228/IR1737/CR94-13	"
IR1154-243-1	IR8^2/Zenith	"
IR1514-A-E597-L	IR20/TKM6	"
IR1539-823-4-1	IR661-1-140-3//Mudgo/IR8	"
IR1628-632-1	IR661-1-140-3-2/IRl154-243	"
IR1632-93-2-2	IR241C013	"
IR2031-352-3-2	IR24^3/*O. nivara*//IR1416-131-1///IR1330-3-2-2	"
IR2034-238-1-2-3	IR1539-60/IR1364-37-3-1//IR24^4/*O. nivara*	"
IR2035-487-3-3	IR1416-128-5/IR1364-37-3-1//IR1539-260//IR24^3/*O. nivara*	"
IR2039-1109-3-1	IR1330-5-3-3//IR24^4/*O. nivara*	"
IR2039-203-3-1	"	"
IR2071-135-3-3	IR1561-228-1-2//IR24^4/*O. nivara*///CR94-13	"
IR2071-251-1-1-3	"	"
IR2153-550-2-6	IR1541-102-6-3//IR20^4/*O. nivara*	"
IR2328-27-3-6	IR1514A-E666/IR1364-37-3-1	"
IR2681-34-5	CR94-13/1/IR20^3/*O. nivara*//IR1541-102-6	"
IR2798-86-6	IR1529-680-3/IR1913-41-2/IR1514A-E666	"
IR2863-38-1	IR1529-680-3/CR94-13//IR480-5-9-3	
TG37	B44/b/pn/83/2/1	Indonesia
Bala	–	"
B441b/190/1/1/3	C4-63gb/5316/TK1391	"
Bogor-1		"
Bogor-6		"
Bogor-20		
Bogor-26		
BR43-11-2	Lakhaya/IR8	Bangladesh
BR51-118-2		"
Chianung-shen-yu 11	IR9-60/IR8	Taiwan
C62-1-230	Kaohsiung-shen-yu12/IR22	
C62-1-373	"	"
HR1231-235-3	WX126-48-12/KR108-2	Korea
HR1231-258-2	"	
WR318-5-4-49-61-1	"	"
Iri 328		"
Dikwee		Nigeria

from the susceptible varieties that had been killed.

Adults. The varieties that were less preferred by the nymphs in the preceding experiment were also evaluated for their attractiveness to adult insects. Individual plants—varieties spotted at random—were grown 10 cm apart in

Table 2. Host preference of brown planthopper nymphs and damage to selected rice varieties.[a] Thailand, 1976.

Variety	Insects[b] (no./plant) at an interval after infestation of				Damage (grade)[c]
	1 day	3 days	5 days	7 days	
Ptb 33	2.8 a	1.0 a	0.9 a	0.8 a	0.1
Ptb 21	3.0 a	2.3 a	1.5 ab	1.3 a	0.1
Balamawee	3.2 a	2.4 a	2.0 bc	1.6 a	0.1
IR32	3.0 a	2.5 ab	2.5 bcd	2.4 bc	0.9
Babawee	4.3 a	3.1 b	2.0 bc	1.8 ab	0.6
ASD 7	4.5 a	3.4 b	3.4 def	3.1 d	0.6
IR34	4.6 a	3.5 b	2.9 cde	2.8 cd	1.2
W1256	4.9 a	3.7 b	3.3 def	3.4 d	1.5
RD9	5.1 a	3.9 h	3.2 f	3.2 e	1.5
W1263	4.8 a	3.8 b	4.1 ef	4.5 e	1.6
RD4	4.3 a	3.8 h	3.8 def	4.0 cd	1.8
Mudgo (resistant)	3.3 a	2.4 a	2.1 bc	2.0 ab	0.2
TN1 (susceptible)	5.8 a	10.0 c	7.5 g	1.0 a	9.0

[a]Mean of 4 replications, 20 seedlings/replication. One week after sowing, each plant was exposed to initial populations of 8 first-instar nymphs. [b]In each column, means followed by the same letter are not significantly different at the 5% level. [c]*Grade* of damage was recorded 10 days after infestation. A higher grade means greater susceptibility

wooden flats (60 × 45 × 10 cm), with five replications. Thirty days after sowing, the plants were pruned to two tillers per plant. The flats were randomly arranged on a galvanized iron tray in the screenhouse, and about 400 freshly emerged adults were released on them. Insects on each plant were counted at 5, 24, and 48 hours after infestation. Seven days after infestation, the plants were dissected under a binocular microscope to determine the number of eggs laid on each variety.

There were distinct differences in the number of adults recorded on different varieties at 6 hours after infestation (Table 3). These differences increased in later observations. The susceptible variety, TN1, had more insects than any resistant variety. The resistant varieties Ptb 33, Ptb 21, Balamawee, Babawee, Mudgo, IR32, ASD 7, and IR34 had fewer insects during every observation period. Significantly fewer insects were on Ptb 33 and Ptb 21 than on other resistant varieties at 2 days after infestation. There were 2 to 4.8 times more insects on TN1 than on resistant varieties. The varieties preferred by the adults were also generally preferred by the nymphs.

The varieties preferred for feeding or for shelter were also generally preferred for oviposition (Table 3). The nonpreferred varieties received fewer eggs per plant than the susceptible varieties. There were 3.7 to 8.8 times more eggs deposited on TN1 than on the resistant varieties.

Antibiosis

Antibiosis is that component of resistance that adversely affects the biology of the insects. It may cause the death of the insects (often as early instars), abnormal length of the life cycle, smaller body size, and decreased fecundity.

Table 3. Oviposition-host preference of brown planthopper adults for selected rice varieties.[a] Thailand, 1976.

Variety	Female insects (no./plant) at an interval after infestation[b] of				Eggs[c] (no./ plant)
	6 hours	1 day	2 days	Mean	
Ptb 33	2.5 a	2.0 a	0.8 a	1.8	56 a
Ptb 21	3.0 ab	2.5 a	1.3 a	2.3	80 a
Balamawee	3.8 abc	3.0 a	2.5 b	3.1	83 a
Babawee	3.5 abc	3.0 a	2.8 h	3.1	84 a
IR32	3.8 abc	3.5 ab	3.0 b	3.4	90 a
ASD 7	4.5 abc	3.7 abc	3.0 b	3.7	100 a
IR34	4.5 abc	5.0 abc	4.8 c	4.8	104 a
W1256	5.0 bc	5.3 cd	5.5 cd	5.0	109 a
RD 9	5.0 bc	5.5 cd	5.5 cd	5.3	115 a
W1263	5.3 bc	5.5 cd	5.8 d	5.5	128 a
RD4	7.0 c	6.3 d	5.5 cd	6.3	134 a
Mudgo (resistant)	4.2 abc	3.5 ab	2.5 b	3.4	78 a
TN1 (susceptible)	9.5 d	13.5 e	14.0 e	12.3	492 b

[a] Average of 5 plants/variety. Thirty-day-old plants were exposed for 7 days in the screenhouse to an initial population of 400 male and female adults. [b] In each column, means followed by the same letter are not significantly different at 5% level. [c] Seven days after infestation

Survival and nymphal development. Resistance of the rice varieties to the first-instar BPH nymphs should reduce insect populations that might otherwise cause damage in later stages. The survival of first-instar nymphs on plants of selected varieties grown individually in pots was studied. At 30 days after seeding, 10 first-instar nymphs were placed with the plants in cylindrical mylar cages. The mortality of the caged nymphs was recorded at regular intervals until they became adults. Survival of nymphs was lower on all varieties tested than on the susceptible check TN1 (Table 4). Between 38%

Table 4. Survival and development of first-instar brown planthopper nymphs on selected rice varieties.[a] Thailand, 1976.

Variety	Survival (%) of nymphs at an interval after infestation[b] of				Nymphs developing into adults (%)	Nymphal stage (days)
	3 days	6 days	9 days	12 days		
Ptb 33	62 a	48 a	44 a	38 a	14 a	26
Ptb21	64 a	52 a	48 a	48 ah	20 ab	25
Balamawee	86 ab	62 ab	62 ab	48 ab	26 abc	24
Babawee	84 ab	74 abc	74 bc	64 abc	34 bcd	23
IR32	82 ab	78 abc	78 bc	72 bcd	40 bcde	22
IR34	90 h	82 bc	74 bc	70 bcd	44 cde	20
W1256	84 ab	74 abc	74 bc	72 bcd	46 cde	19
ASD 7	82 ab	78 abc	78 bc	72 bcd	48 cde	21
RD9	88 b	84 bc	82 bc	72 bcd	48 cde	18
W1263	92 b	84 bc	82 bc	76 bcd	54 de	17
RD4	94 b	86 bc	86 bc	84 cd	54 de	17
Mudgo (resistant)	84 ab	72 ab	64 ab	64 abc	35 bcde	24
TN1 (susceptible)	96 b	96 c	96 c	96 d	96 f	13

[a] Average of 10 replications; in each, 10 freshly hatched nymphs were caged with a 30-day-old seedling.
[b] In each column, means followed by the same letter are not significantly different at the 5% level.

Table 5. Life span and fecundity of brown planthopper on selected rice varieties. Thailand, 1976.

Variety	Life span (days)				Progeny (no./female)	
	Male		Female [b]			
	Range	Mean [c]	Range	Mean [c]	Range	Mean [c]
Ptb 33	1-4	2.8 a	1-7	3.6 a	0-15	3.2 a
Ptb 21	1-5	3.0 a	1-8	3.8 a	0-18	4.0 a
Balamawee	2-7	4.2 a	2-8	4.4 a	0-20	5.0 a
Babawee	2-8	4.6 a	2-10	5.2 a	0-38	7.2 a
IR32	1-11	4.8 a	1-13	5.4 a	0-50	12.2 ab
ASD 7	2-10	5.4 a	2-13	6.2 a	0-68	18.8 ab
IR34	2-13	6.0 a	2-15	7.6 a	0-89	20.6 ab
W1256	2-14	6.0 a	2-18	8.6 a	0-104	22.8 ab
RD9	2-15	6.8 a	2-20	9.0 a	0-139	40.0 ab
W1263	2-16	7.6 a	2-20	9.8 a	0-186	52.8 ab
RD4	2-24	8.2 a	2-25	10.6 a	0-290	78.0 ab
Mudgo (resistant)	1-7	3.6 a	2-7	4.4 a	0-22	4.2 a
TN1 (susceptible)	10-25	17.2 b	11-31	23.0 b	211-331	280.2 c

[a] Average of 10 replications; in each, one pair of newly emerged adults was caged with a 30-day-old Plant. [b] Brachypterous form. [c] Any two means followed by the same letter are not significantly different at the 5% level.

and 84% of the nymphs on resistant varieties survived at 12 days after caging, while nearly 100% of those on TN1 survived. The varieties Ptb 33, Ptb 21, Balamawee, Babawee, and Mudgo caused highest nymphal mortality. At 12 days after infestation, although nymph survival on some of the resistant varieties was not significantly lower than that on TN1, the percentage of nymphs that became adults on them was significantly lower. Also, the insects took longer to reach the adult stage on the resistant varieties. About 14% to 54% of the nymphs became adults on resistant varieties; 96% became adults on TN1. Duration of the nymph stage was extended from 4 to 13 days on resistant varieties.

Longevity and fecundity of adults. Ten plants each of selected resistant and susceptible varieties were grown individually in pots. Thirty-day-old potted plants were caged, each with a pair of newly emerged adult insects in a cylindrical mylar cage. The life span of the insects and the number of progeny they produced were recorded.

The insects lived longer and produced more progeny when reared on susceptible TN1 than when reared on resistant varieties (Table 5). The females generally outlived the males when reared on the same variety. They produced from 4 to 88 times more progeny on susceptible TN1 than on the resistant varieties, where many females died before they could lay eggs.

Rice varieties with sources of resistance to the BPH were identified. The resistance appears to be associated with one or more of the following factors:

1. nonpreference of the insect for the variety as a site for feeding and oviposition,

2. ability to withstand insect damage, and
3. high mortality of first-instar nymphs caged on resistant plants, relatively short adult life, and relatively few progeny.

GENETICS AND BREEDING FOR RESISTANCE

In Thailand, the inheritance of resistance to the BPH in rice was first studied in lines such as W1252, W1259, and W1263, introduced from India by Sristaporn (1976). Because of their high resistance to rice gall midge, these lines, including W 1256, had been used as donor parents in the Thai hybridization program since 1968. Subsequently, promising lines with BPH resistance and gall midge resistance derived from W1252 and W 1256 were released as RD4 and RD9, respectively.

RD4, released in 1973, has waxy grain and is recommended primarily for use in the rice gall midge areas of north and northeast Thailand. Because the gelatinization temperature of its grain starch is high, RD4 has not become popular among the farmers even though its yield is far superior to that of local varieties in areas under heavy gall midge attack. Furthermore, the BPH has thus far not been a serious problem in north and northeast Thailand.

RD9 was released in 1975 for use as a deterrent to the BPH in the Central Plain. Its major weakness is susceptibility to bacterial blight. It is most popular in those areas where the BPH occurs frequently. In such areas. its most noticeable advantage is its freedom from infection by grassy stunt, which badly affects susceptible varieties such as RD7. Work is under way to determine whether mixing RD7 and RD9 can significantly reduce the BPH population and provide more protection against bacterial blight.

To study the inheritance of BPH resistance, seeds of W1252, W1259, and W1263, and F_1 and F_2 of RD/W1252, RD1/1259, and RD1/1263 were germinated in petri dishes and planted in wooden flats. Nymphs of first- and second-instar BPH were then released on the seedlings at the two-leaf stage. Ten days after infestation, the seedlings were classified as resistant or susceptible according to the grading system of International Rice Research Institute (Choi, this volume). W1252, W1259, W1263. and F_1 progeny of the crosses were resistant, but RD1 was susceptible. F_2 segregated in a ratio of 3 resistant to 1 susceptible, suggesting that the BPH resistance in W1252, W 1259, and W 1263 is conditioned by a single dominant gene.

At present, other sources of resistance are being used in the breeding program. Many promising resistant lines have been identified.

INSECT BIOTYPES

Biotypes of the BPH in Thailand were studied in 1975. Until then no rice varieties resistant to BPH had been grown. The resistant variety RD9 was released in 1975 and was commonly grown in farmers' fields in 1976.

In a study to determine whether the BPH that occur in different regions of Thailand belong to the same biotype or of to different biotypes, insects were collected from three sites in the Central Plain (Pathnumthani, Nontaburi, and Chachoengsao provinces), one site in the northeastern region (Ubonratchthani province), and one site in the southern (Phatalung province) region. Insects from each area were mass-reared on TN1 in separate cages in the greenhouse. The biotype of the insects was identified by their ability to infest the seedlings of a differential set of rice varieties: CO9, Gangala, Murungakayan 101b, Chianung-shen-yu 11, Ptb 21, IR34, RD4, RD9, Mudgo (resistant check), and TN1 (susceptible check). The screening method cited earlier in this paper was used. The reactions of the 10 differential rice varieties to the BPH populations from all areas were the same. The resistant check variety Mudgo showed resistance to the insects from all areas. The same was true of the test varieties CO9, Ptb 21, Murungakayan 101b, Gangala, Chianung-shen-yu 11, IR34, and RD9. The susceptible check variety TN1 showed susceptibility to insects from all areas. The moderately resistant variety RD4 showed the same reactions to insects from all areas.

The results indicate that the insects from all areas tested were of the same biotype. However, insects should be collected again from areas where a rice variety resistant to the BPH (RD9) has been intensively grown.

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Appendix 1. Some factors affecting resistance of selected rice varieties to the brown planthopper *N. lugens.*[a] Thailand, 1976

Variety	Preference				Survival (%) of caged nymphs at		Nymphs(%) developed into adults	Nymph stage duration (days)	Longevity (days)		Progeny produced per female
	Plant damage[b]	Nymphs[c] (no./plant)	Adults[d] (no./plant)	Eggs (no./plant)	3 days[e]	12 days[e]			Male	Female	
Ptb 33	0.1	1.0 a	0.8 a	56 a	62 a	38 a	14 a	26	2.8 a	3.6 a	3.2 a
Ptb 21	0.1	2.3 a	1.3 a	80 a	64 a	48 ab	20 ab	25	3.0 a	3.8 a	4.0 a
Balamawee	0.1	2.4 a	2.5 b	83 a	86 ab	48 ab	26 abc	24	4.2 a	4.4 a	5.0 a
Babawee	0.6	3.1 b	2.8 b	84 a	84 ab	64 abc	34 bcd	23	4.6 a	5.2 a	7.2 a
IR32	0.9	2.5 ab	3.0 b	90 a	82 ab	72 bcd	40 bcde	22	4.8 a	5.4 a	12.2 ab
ASD 7	0.6	3.4 b	3.0 b	100 a	82 ab	72 bcd	48 cde	21	5.4 a	6.2 a	18.8 ab
IR34	1.2	3.5 b	4.8 c	104 a	90 b	70 bcd	44 cde	20	6.0 a	7.6 a	20.6 ab
W1256	1.5	3.7 b	5.5 cd	109 a	84 ab	72 bcd	46 cde	19	6.0 a	8.6 a	22.8 ab
RD9	1.5	3.9 b	5.5 cd	115 a	88 b	72 bcd	48 cde	18	6.8 a	9.0 a	40.0 ab
W1263	1.6	3.8 b	5.8 d	128 a	92 b	76 bcd	54 de	17	7.6 a	9.8 a	52.8 ab
RD4	1.8	3.8 b	5.5 cd	134 a	94 b	84 cd	54 de	17	8.2 a	10.6 a	78.8 ab
Mudgo (R)	0.2	2.4 a	2.5 b	78 a	84 ab	64 abc	36 bcde	24	3.6 a	4.4 a	4.2 a
TN1 (S)	9.0	10.0 c	14.0 e	492 b	96 b	96 d	96 f	13	17.2 b	23.0 b	280.2 c

[a] In a single column, any two figures that are followed by a common letter are not significantly different at the 5% level. [b] On a scale of 0–9, recorded 10 days after infestation; larger number indicates greater damage. Average of 4 replications, 20 seedlings per replication. [c] Number of nymphs per plant were recorded at 3 days after infestation. [d] Number of adults per plant was recorded at 2 days after infestation. [e] Afterinfestation

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

M. D. Pathak and G. S. Khush

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 IR747B$_2$–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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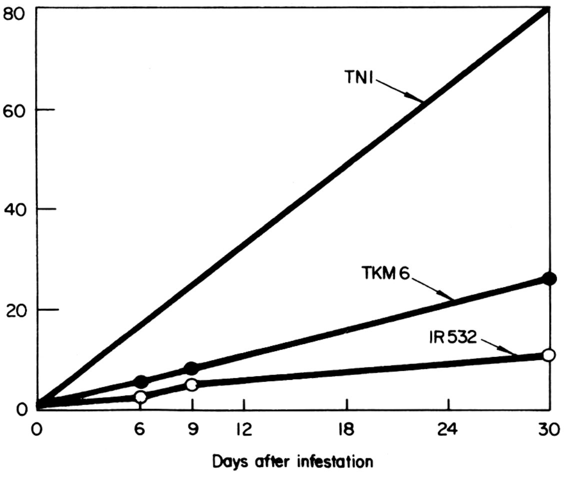
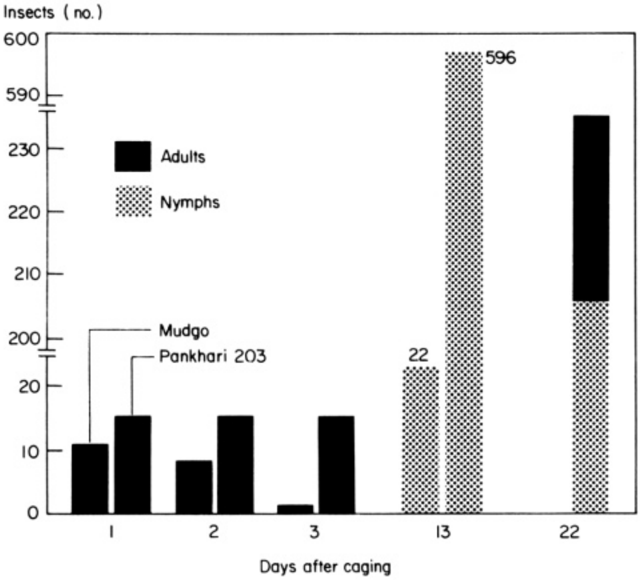
basic insect-host plant interrelationships by determining the preferences of the insects for the cultivars, or the antibiosis effect of the cultivars on the insects, or both. The basic techniques used were adopted from the methodology used in studies of the corn leaf aphid (Pathak and Painter 1958). 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.

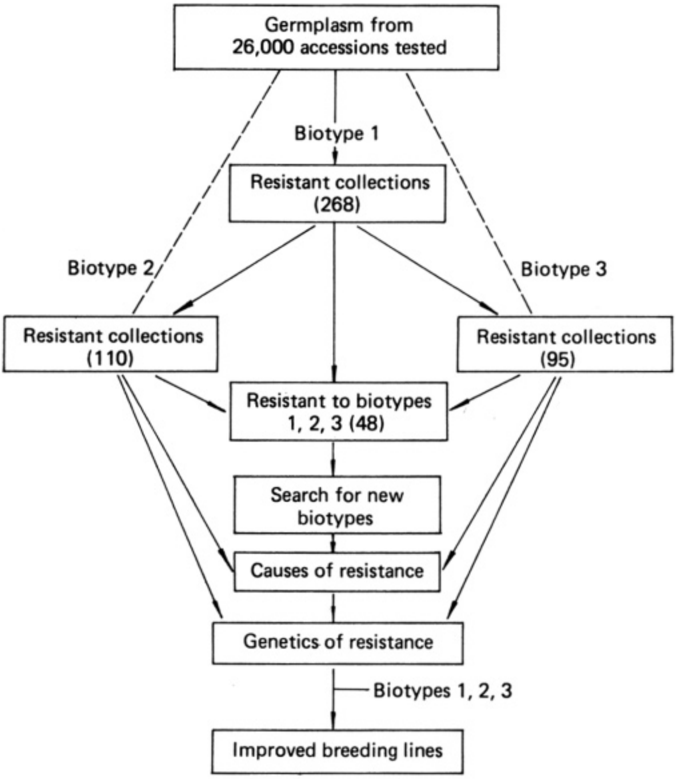
MASS REARING AND SCREENING

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 screenhouse. 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
Ptb 21	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—IR747B$_2$-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 IR747B$_2$-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 IR747B$_2$-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 IR747B$_2$-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*
IR747B$_2$-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/ *O. nivara*	*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 IR747B$_2$-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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Factors governing susceptibility and resistance of certain rice varieties to the brown planthopper

R. C. Saxena and M. D. Pathak

Relative susceptibility or reststance of rice varieties and the nonhost barnyard grass to brown planthopper (BPH) is determined by interactions among different responses of the insect to the plants' physical and chemical stimuli. The insect was attracted to both susceptible (IR20, IR8, TN1) and resistant (Mudgo, ASD 7, IR26) rice varieties and barnyard grass, because of their green color and humidity stimuli. The purplish color of the variety Crava did not attract BPH. The insect's olfactory response to steam distillates of plants showed that odors of all susceptible and several resistant varieties attracted biotype 1; odors of ASD 7 and IR26 were moderately attractive and odors of resistant Babawee and Mudgo varieties, and barnyard grass, repelled the insect. However, the Mudgo odor attracted biotype 2 and the ASD 7 odor attracted biotype 3. Mudgo is susceptible to biotype 2, ASD 7 to biotype 3.

After arriving on a plant, BPH showed equally high proboscis response (application of proboscis and insertion of stylets) on all test plants, which indicated the absence of mechanical barriers. But duration of feeding and quantity of food ingested were markedly less on resistant than on susceptible plants. Food from resistant varieties was also insufficiently utilized by biotype 1. On susceptible varieties, greater ingestion of food and its proper utilization satisfied all metabolic requirements and promoted BPH growth, survival, and egg production On barnyard grass, the insect lost weight and died prematurely. Biotype 2 on Mudgo and biotype 3 on ASD 7 ingested and utilized nearly as much food as both biotypes on susceptible TN1, but biotype 2 did not ingest and utilize food adequately from ASD 7. Biotype 3 insects utilized food from Mudgo but the quantity ingested was small Mudgo is resistant to biotype 3; ASD 7 to biotype 2

All tested rice varieties were equally suitable for BPH oviposition, but hatching of eggs was significantly less on resistant than on susceptible varieties Barnyard grass was less suitable than rice varieties for the insect's oviposition and least suitable for hatching; 82% of eggs laid on it did not hatch. Transplanting BPH eggs from one TN1 plant to another did not hinder hatching, but nearly all eggs transplanted in barnyard grass failed to hatch.

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THE ABILITY OF THE BROWN PLANTHOPPER to establish its population on a variety varies, as indicated by the differences in the degree of infestation among rice varieties. Establishment depends on the insect's responses to the biophysical and biochemical characteristics of the varieties. These responses can be grouped into the following categories:

1. Orientational response, which causes the insects to be attracted to or repelled from a given plant;
2. Feeding response, which determines food intake;
3. Metabolic utilization of ingested food, which determines the insect's nutrition;
4. Growth of the larva to the adult stage, determined by food intake and nutrition;
5. Survival of adults and egg production, also determined by food intake and nutrition;
6. Oviposition (Saxena 1969; Saxena et al 1974); and
7. Hatching of eggs.

Successive generations repeat the pattern. Growth, survival, egg production, oviposition, and hatching of the insect determine its population over a given period. Interruption by unfavorable plant characters of one or more of the cited responses signifies that the plant is resistant to the insect.

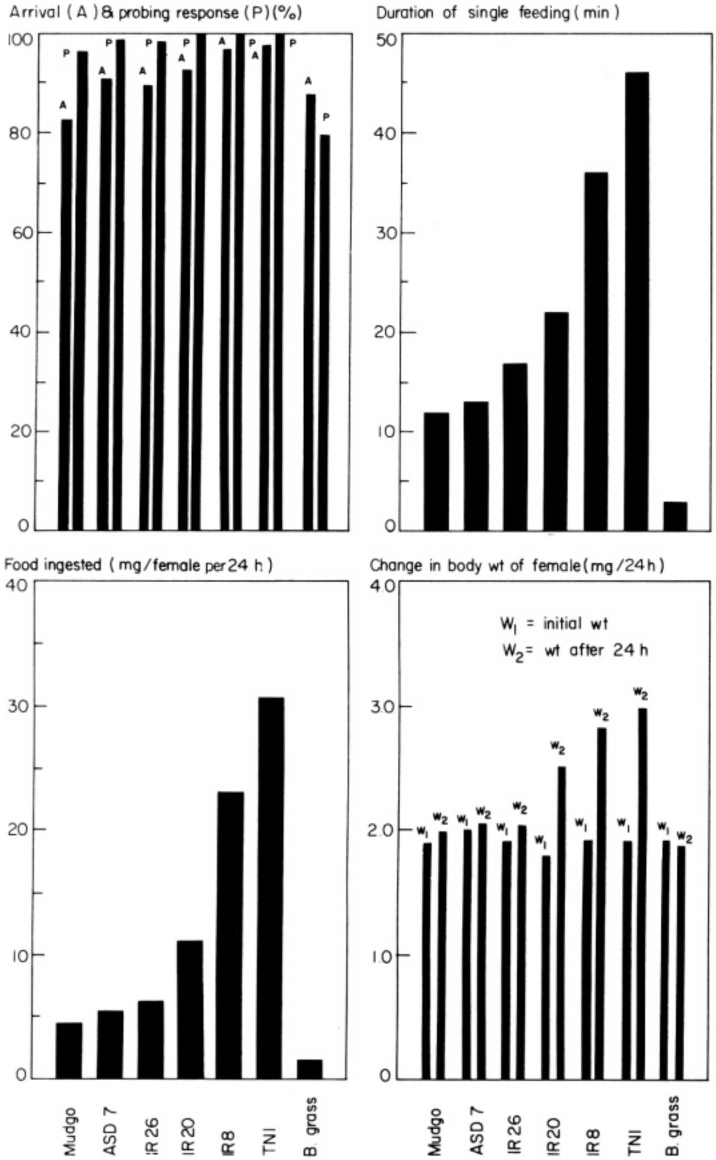
Our study was designed to determine the factors that govern the susceptibility or resistance of rice varieties to the brown planthopper (BPH) and to investigate the possible cause or causes of the breakdown of resistance in certain varieties in the Philippines. We describe our observations of the insect's responses to selected resistant and susceptible rice varieties—Mudgo, ASD 7, IR26, IR20, IR8, and TN1—and to barnyard grass *Echinochloa crus-galli* L., a common weed in the rice field.

OBSERVATIONS

Orientation

The first step in the establishment of BPH is its arrival on a plant. The arrival may be accidental or it may result from insect orientation in response to stimulus of attraction or repulsion (Saxena et al 1974). The arrival of BPH on the wall of a test chamber facing the test plants ranged from 80 to 90%, whether contact with the plants was permitted or not (Fig. 1). The attraction of the BPH to all test plants suggested that the insects' orientation was in response to certain plant stimuli. The role of stimuli perceivable from a distance was therefore investigated.

Visual stimuli. A higher percentage (70–77%) of the insects was attracted toward the nonhost barnyard grass, resistant Mudgo, and susceptible TN1 plants placed out of reach behind glass plates than to the blank wall of the test chamber, which attracted only 23–30% insects. The response was to visual stimuli because other stimuli from the plants, e.g. humidity and odor, could



1. Orientation, feeding, and metabolic utilization of ingested food by *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass. IRRI, 1976.

not cross the glass barrier. Green color was the common visual stimulus among the test plants; it was the attractant. The hoppers were not attracted by purplish-red rice (Crava) plants.

Humidity. More (76%') insects were attracted to the wall of the test chamber facing wet filter paper than to the blank wall, probably because of the high humidity in the vicinity of the paper. The attraction increased to almost 100% if the insects had been desiccated for 1 hour before testing.

Odor. Rice varieties and barnyard grass emit characteristic odors. The odors emanating from steam distillates of most rice varieties — Crava, resistant Gambada Samba, Gangala, Mathumanikam, Ptb 19, Ptb 21, Ptb 33, Sinnanayam 398, Sudu Hathiyal, Sudu Hondarawala, Sulai, Thirissa, and the susceptible IR20, IR8, and TN1 — attracted BPH biotype 1 insects (Table 1). The odors of ASD 7 and IR26 were only moderately attractive, while the odors of the resistant Babawee and Mudgo varieties and of barnyard grass repelled biotype 1 insects. The odor of Mudgo attracted biotype 2 insects and that of ASD 7 attracted biotype 3 (Table 1).

Feeding

The feeding response, which follows the arrival of the BPH on the rice plant, varies from one variety to another and determines food intake. In includes 1) probing response, or the application of proboscis and introduction of stylets into the food source, and 2) duration of feeding. The probing responses to the barnyard grass and all the test rice varieties were equally high (80–l00%),

Table 1. Orientational responses of three biotypes of *Nilaparvata lugens* allowed a choice between a blank and an odor-impregnated surface outside a nylon net wall at two ends of a test chamber. IRRI, 1975–76.

Odor source[a] (steam distillate)	Arrivals (%) on end-wall facing odor source[b]		
	Biotype 1	Biotype 2	Biotype 3
Babawee (IRRI Acc. No 8978)	45		
Crava (10602) Red rice	64		
Gambada Samba (15406)	63		
Gangala (15207)	67		
Gangala (15259)	70		
Mathumanikam (15397)	76		
Ptb 19 (6107)	76		
Ptb 21 (6113)	69		
Ptb 33 (19325)	69		
Sinnanayam 398 (12079)	76		
Sudu Hathiyal (15488)	68		
Sudu Hondarawala (15541)	83		
Sulai (15421)	70		
Thirissa (7734)	66		
Mudgo	44	70	
ASD 7	57		65
IR26	53		
IR20	61		
IR8	75		
TN1	78		
Barnyard grass	45		

[a] A 125-sq-cm muslin disc impregnated with 2 mg of steam distillate. [b] The remaining insects that arrived on the blank end-wall. Each biotype was tested separately.

indicating that none of the test plants presented any mechanical barrier to penetration (Fig. 1). However, duration of a single feeding on the plants differed. TN1, IR8, IR20, IR26, ASD 7, Mudgo, and barnyard grass had, in that order, the longest to shortest single-feeding duration. The differences were reflected in the quantity of food that each female ingested in 24 hours (Fig. 1). Biotype 1 insects ingested the maximum quantity of food from TN1—about 5 to 8 times more than that from resistant IR26, ASD 7, or Mudgo, and about 15 times more than that from barnyard grass (Fig. 1). On the other hand, the amounts of food that biotypes 2 and 3 ingested from Mudgo and ASD 7, respectively, were almost equal to those from TN1 (Fig. 2).

Metabolic utilization of food

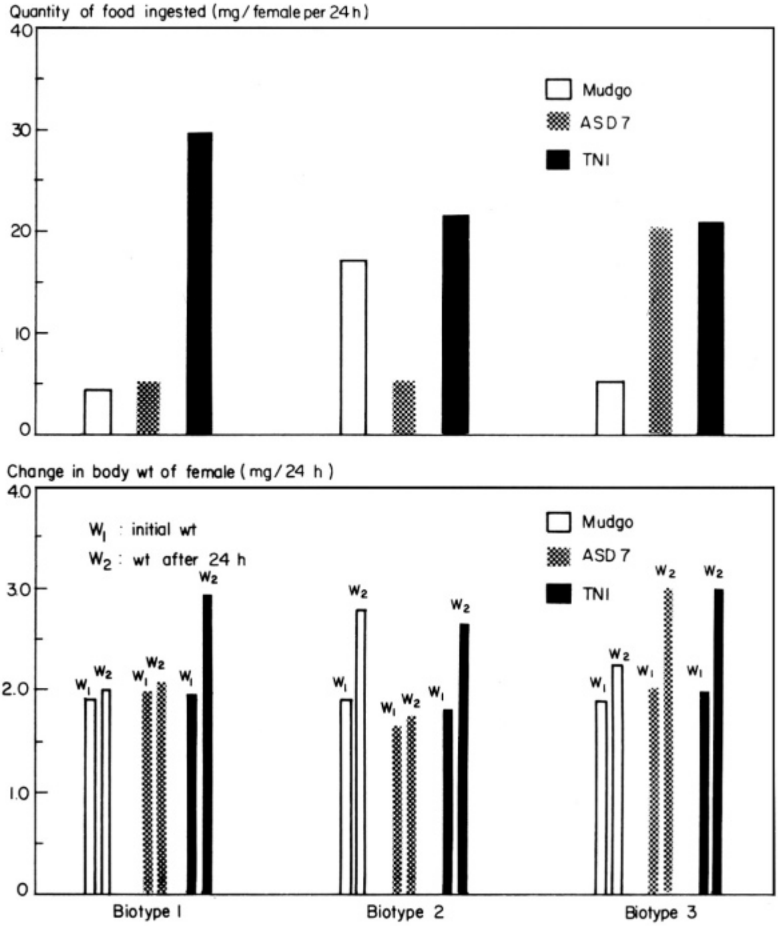
Generally, the greater the proportion of food converted into body tissues, the greater is the nutritive value. Therefore, nutritive value may be expressed as the proportion of the ingested food that is assimilated into tissues and results in weight gain (Saxena 1969; Saxena et al 1974). In 24 hours, the weight of the BPH biotype 1 insects increased a maximum of 56% on susceptible TN1 and 46% on IR8 and IR20. On resistant Mudgo, ASD 7, and IR26, weight gain was slight—from about 4 to 8%. On barnyard grass, the insects lost weight (Fig. 1).

Biotype 2 and 3 insects ingested sufficiently large amounts of food from the biotype 1-resistant Mudgo and ASD 7, respectively, and used it as efficiently as food from susceptible TN1 (Fig. 2). The body weight of biotype 2 insects increased about 50% on susceptible Mudgo and TN1, but only about 10% on biotype 2-resistant ASD 7. The weight of biotype 3 insects increased 45% on susceptible ASD 7 and 53% on TN1, but only 20% on biotype 3-resistant Mudgo.

For biotype 1 insects, the susceptible varieties had higher nutritive value than the resistant varieties. Mudgo and TN1 had higher nutritive value for biotype 2 insects, while all the three varieties Mudgo, ASD 7, and TN1 had higher nutritive value for biotype 3 insects (Table 2). However, biotype 3 insects did not gain as much weight on Mudgo as they did on ASD 7 or TN1 because of reduced food intake from Mudgo (Fig. 2).

Growth

After it emerges from the egg, the BPH increases in size and weight during each instar, molting at the end of each, and becoming an adult after the fifth. Growth was studied in terms of percentage of larvae that became adults, duration of the larval stage, and weight of newly emerged adults. Differences in the percentages of first-instar larvae that reached the adult stage did not correspond with the differences in the period ofdevelopment (Fig. 3). Therefore, the percentage of larvae that completed development over an identical (unit) period, calculated as the ratio of the percentage to the growth period and referred to as *growth index,* was considered a suitable parameter for comparison

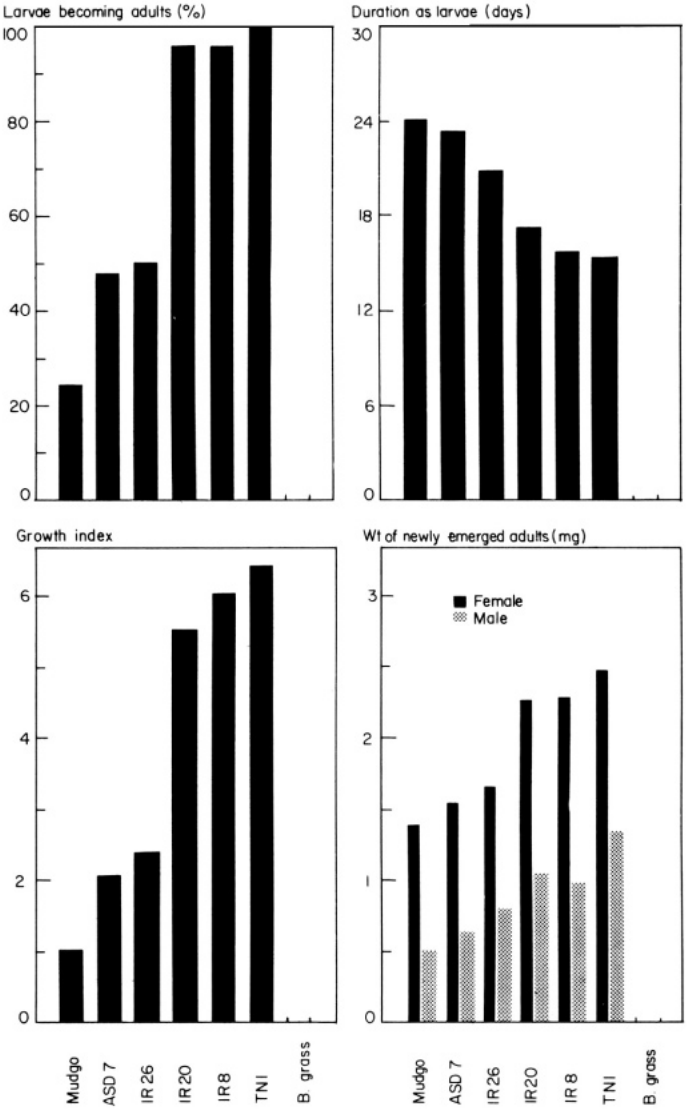


2. Quantity of food ingested and change in body weight of three biotypes of *Nilaparvata lugens* allowed to feed on Mudgo, ASD 7, and TN1 rice varieties. IRRI, 1976.

(Saxena et al 1974). On this basis, growth on the susceptible varieties was significantly greater than that on the resistant varieties or barnyard grass. The largest and heaviest among the newly emerged adults were those produced on the most susceptible variety TN1, followed by those produced on IR8 and IR20. The smallest adults emerged on resistant Mudgo; no adults emerged from larvae kept on barnyard grass.

Survival and egg production in adult stage

After the BPH completes its growth, its level of survival as an adult and its egg production determine the level of population it establishes on a plant.



3. Growth of *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass. IRRI insectary, 1975–76.

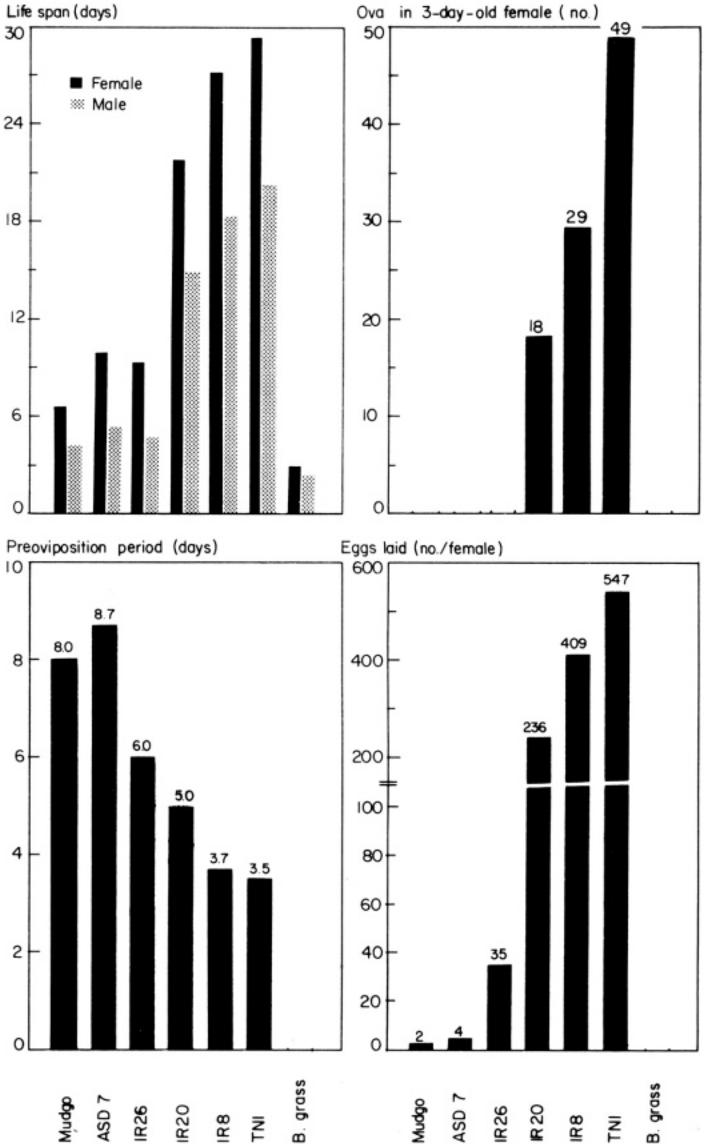
Survival of male and female insects was significantly greater on susceptible than on resistant varieties. Most adults confined on barnyard grass died within 3 days (Fig. 4).

The fecundity of females on various plants may differ. It is reflected in the rate of ovarian maturation, the preoviposition period — the time between adult emergence and the production and laying of fully developed eggs — and the

Table 2. Ingestion and metabolic utilization of food by three biotypes of *Nilaparvata lugens* on resistant and susceptible rice varieties and barnyard grass. IRRI, 1976.

	Quantity ingested daily (mg/female)[a]			Wt of assimilated food (mg)[b]			Nutritive value[c]		
	Biotype 1	Biotype 2	Biotype 3	Biotype 1	Biotype 2	Biotype 3	Biotype 1	Biotype 2	Biotype 3
Mudgo	4.35	17.26	5.55	0.09	0.89	0.40	0.02	0.05	0.07
ASD 7	5.39	5.48	20.39	0.07	0.17	0.93	0.01	0.03	0.05
IR26	6.23	–	–	0.16	–	–	0.03	–	–
IR20	13.91	–	–	0.81	–	–	0.06	–	–
IR8	23.21	–	–	0.91	–	–	0.04	–	–
TN1	30.81	22.81	21.94	1.08	0.89	1.06	0.04	0.04	0.05
Barnyard grass	1.62	–	–	–0.02	–	–	–0.01	–	–

[a] Quantity of food ingested = (wt of assimilated food + wt of excreta + water loss by insect). [b] Wt of assimilated food = (insect wt gain or loss due to feeding + Wt loss due to wear and tear). [c] Nutritive value = (ratio between wt of assimilated food and wt of ingested food).



4. Life span and egg production in *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass. IRRI insectary, 1975-76.

number of eggs produced during the insect's life. The rate of *ovarian maturation,* based on number of ova and eggs in 3-day-old females, was highest in females kept on TN1 and next highest in those kept on IR8 and IR20 (Fig. 4). Females kept on resistant varieties had a much slower ovarian maturation, and those that were less than 5 or 6 days old had neither ova nor eggs. All females kept on barnyard grass died without producing ova (Fig. 4).

The *preoviposition period* was shortest on TN1 and IR8, followed by that on IR20; it was significantly longer on the resistant varieties (Fig. 4).

The *number of eggs* produced on TNl, IR8, and IR20 was higher than that produced on resistant varieties (Fig. 4). The insect produced almost 100 to 200 times more eggs on IR20, IR8, and TN1 than on Mudgo (Fig. 4).

Oviposition

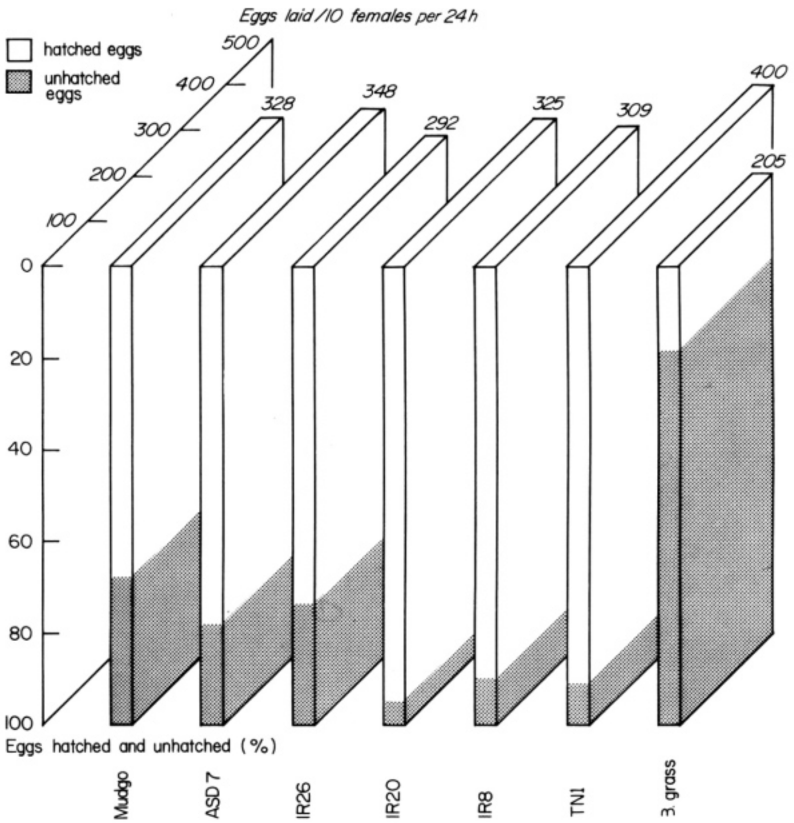
To understand the role of ovipositional response in determining the number of eggs laid on test plants, the differences in egg production caused by differences in food intake and nutrition were eliminated. Females were kept on TN1 plants for 7 days and then their ovipositional responses to the test plants were compared on the basis of the number of eggs laid in a 24-hour period. The resistant and susceptible varieties were equally suitable for BPH oviposition (Fig. 5). The insects laid eggs even on the nonhost barnyard grass, but such eggs were significantly fewer than those laid on rice varieties (Fig. 5).

Hatching

Although the number of eggs laid on resistant and susceptible plants did not differ, the number that hatched on them did (Fig. 5). Significantly more eggs hatched on the susceptible varieties TN1, IR8, and IR20 than on resistant Mudgo, ASD 7, and IR26. On barnyard grass, up to 82% of the eggs remained unhatched. The hatching pattern remained unchanged even when BPH eggs were transplanted to leaf sheaths of TN1 and barnyard grass plants. On TNl almost all the transplanted eggs hatched; on barnyard grass most failed to hatch (Fig. 6).

DISSCUSSION

Our study provides a basis for considering the role of seven types of insect responses to biophysical and biochemical characters of plants in determining differences in the susceptibility and resistance of certain rice varieties and of barnyard grass to BPH. Earlier works (Bae and Pathak 1970; Sogawa and Pathak 1970; Parker et al 1973; Rezaul Karim 1975) have referred to some responses of BPH to certain rice varieties as nonpreference and as antibiosis. However, nonpreference (Painter 1951) may be observed in an insect's orientation, feeding, or oviposition responses to plants. Those responses and their underlying physiological processes are quite unrelated, and occur at different stages of establishment of a pest population (Saxena 1969). Similarly, antibiosis (Painter 1951) refers to the plant characteristics that inhibit insect survival, growth and fecundity, and thereby affect the insect's life history and its population on a plant. Antibiosis as suggested by Painter (1951) may be associated with poor nutritional value of a plant, reduced food intake by insects on the

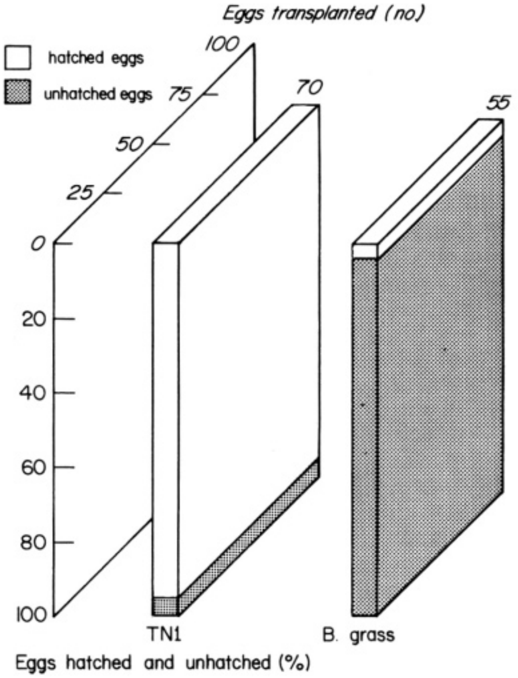


5. Ovipositional response, and comparison of egg-hatch of *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass. IRRI insectary, 1975-76.

plants, or presence of toxic chemicals in the plant. The physiological processes involved in an insect's food intake and nutrition, which result in growth and egg production, are not related and occur in different phases of establishment of insect populations.

This study shows that resistant plants are as likely as susceptible plants to elicit certain responses. The interaction of all the responses determines the overall susceptibility or resistance of plants to the BPH. To understand the role and interaction of the responses, it is helpful to compare their relative intensities, which may be expressed as the ratio between each type of response to the test plant and that to the susceptible check TN1 (Table 3).

The orientational response ("alighting response") (Sogawa and Pathak 1970) was almost uniformly high on all test plants. An analysis of the plant characters affecting orientation showed that the BPH is attracted to the plants by their green color, humidity, and odor. Green color and humidity are probably more important than odor, as indicated by the insects' equal attraction to all



6. Hatching of transplanted *Nilaparvata lugens* (biotype 1) eggs on susceptible rice variety Taichung Native 1 and on nonhost barnyard grass. IRRI, 1977.

plants, resistant or susceptible. The purplish color of Crava rice plant was unattractive to the BPH.

The probing response of the BPH to the rice varieties and barnyard grass was also uniformly high, indicating the absence of mechanical barriers to insertion of stylets (Sogawa and Pathak 1970). But BPH biotype 1 differed in duration of feeding on and in amount of food ingested from barnyard grass and from resistant and susceptible rice varieties. On the other hand, the amounts of food ingested by biotype 2 insects from Mudgo and by biotype 3 insects from ASD 7 were almost equal to that ingested from susceptible TNl.

Differences in the nutritive value of the plants were also observed. Susceptible plants had higher nutritive value than resistant plants. Mudgo and TN1, but not ASD 7, had high nutritive value for biotype 2 insects, but all three varieties had high nutritive value for biotype 3 insects, although the amounts ingested from Mudgo were small. These observations indicate that the susceptible and resistant varieties differ in suitability as BPH food because certain chemicals in the sap of some varieties serve as specific stimulants for the BPH biotypes. For example, the low asparagine content of Mudgo might have reduced sap

Table 3. Relative intensities[a] of different responses of *Nilaparvata lugens* (biotype 1) to resistant and susceptible rice varieties and to barnyard grass. IRRI, 1976.

Plant	Orientation (attraction)	Feeding (quantity ingested)	Food utilization (nutritive value)	Growth index[b]	Survival and egg production		Oviposition (eggs laid)	Hatching (hatchability)
					(Longevity)	(Fecundity)		
Mudgo	0.85	0.14	0.50	0.16	0.22	0.004	0.82	0.74
ASD 7	0.93	0.17	0.25	0.31	0.34	0.007	0.87	0.86
IR26	0.92	0.20	0.75	0.38	0.31	0.06	0.73	0.81
IR20	0.95	0.45	1.50	0.86	0.74	0.43	0.81	1.04
IR8	0.99	0.75	1.00	0.93	0.93	0.75	0.77	0.99
TN1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Barnyard grass	0.89	0.05	0.25	0.00	0.10	0.00	0.51	0.20

[a] Calculated as the ratio between each type of response of female brown planthoppers to a test plant and the susceptible check TN1 [b] Based on larval response.

intake by biotype 1 insects (Sogawa and Pathak 1970), but it did not deter biotype 2 insects from ingesting much greater quantities of sap from Mudgo. Likewise, biotype 1 insects ingested small amounts, and biotype 3 insects large amounts of sap from ASD 7. Reduced feeding (duration and quantity) of BPH on barnyard grass may, however, be due to the absence of phagostimulatory chemicals or to the presence of certain feeding deterrents. Recently, trans-aconitic acid, a BPH antifeedant, has been isolated from the barnyard grass (Kim et al 1975, 1976).

The greater larval growth, better adult survival, and higher egg production of biotype 1 insects on susceptible varieties could, therefore, be explained by the greater quantity of food ingested from, and the higher nutritive value of susceptible varieties.

All the test plants, except barnyard grass, were equally suitable for oviposition by the BPH. Indiscriminate egg laying by gravid brachypterous females implies weakness in the resistance of rice varieties to the insect. Whether macropterous gravid females emigrating from a hopperburned rice field in an area also oviposit indiscriminately on susceptible and resistant rice varieties, until eggs in their ovaries are spent, remains to be investigated.

Significantly fewer eggs hatched on the resistant than on the susceptible varieties. On barnyard grass only 18% eggs hatched, rendering it almost immune even when exposed to heavy brown planthopper infestations. Early embryonic development, indicated by onset of eye pigmentation, proceeds normally, but hatching is affected probably by the failure of developing larvae to split the chorion. Further inquiries in this direction may be useful in BPH control.

CONCLUSION

The factors that determine feeding and metabolic utilization of food, and hatching of eggs of BPH are important in the resistance of rice varieties and of the nonhost barnyard grass to the insect. Reduced quantities of food ingested from resistant varieties and their lower nutritive value lead to poor larval growth and reduced adult longevity and egg production.

Biotype 2 and 3 insects, however, are able to ingest and utilize almost equal amounts of food from varieties that are either resistant or susceptible to biotype 1 insects, and on which they are able to survive and multiply.

Indiscriminate egg-laying by the BPH renders all tested varieties equally suitable for oviposition. But significantly fewer eggs hatch on resistant rice varieties than on susceptible ones. The factors that affect hatching warrant further investigation.

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GENETICS OF RESISTANCE

Genetics of and breeding for resistance to the brown planthopper

G. S. Khush

The development and worldwide distribution of improved rice germplasm with resistance to the brown planthopper (BPH) are a major objective of the International Rice Research Institute's (IRRI) Genetic Evaluation and Utilization (GEU) program. In its varietal resistance research IRRI has emphasized the identification of resistant germplasm, genetic analysis of the resistant varieties to identify diverse genes for resistance, incorporation of those genes into an improved-plant type background, and synthesis of breeding lines with multiple resistance to major diseases and insects. The seeds of the IRRI donor parents, breeding lines, and improved varieties are supplied to rice scientists around the world for use in local hybridization programs and for evaluation as commercial varieties. This paper summarizes the various IRRI breeding strategies and the status of varietal resistance to BPH.

IRRI STUDIES ON THE GENETICS of resistance to BPH started in 1968. Plant breeders investigated the mode of inheritance of resistance in a large number of resistant varieties and determined the allelic relationships of the newly identified genes. The bulk seedling test is used for screening materials for genetic studies, although the tiller test was used to some extent in early work (Athwal et al 1971).

Four resistant varieties—Mudgo, ASD 7, CO22, and MTU 15—were initially analyzed. Mudgo, CO22, and MTU 15, each had a single dominant gene for resistance, which, allele tests revealed, was at the same locus. This locus was designated *Bph 1.* The resistance in ASD 7 was controlled by a single recessive gene, designated *bph 2.* No recombination between *Bph 1* and *bph 2* was observed. It was concluded that these two genes are either allelic or closely linked (Athwal et al 1971). Later studies revealed that varieties with *Bph 1* and *bph 2* react differentially to different biotypes and it was concluded that the two genes are different (Athwal and Pathak 1972). Two more varieties, MGL2 and Ptb 18, were analyzed by Athwal and Pathak (1972). MGL2 had *Bph 1,* and Ptb 18 had *bph 2* for resistance.

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In 1969 a serious outbreak of BPH occurred at IRRI and a yield trial with 55 early maturing entries was hopperburned. Two entries, IR747B_2-6 and IR1154-243, showed resistance (IRRI 1970). None of their parents were resistant to BPH. Martinez and Khush (1974), who investigated the inheritance of resistance in the two selections, found that *Bph 1* governed the resistance of IR747B_2-6, whereas *bph 2* conditioned the resistance in IR1154-243. TKM 6, one of the parents of IR747B_2-6, was susceptible but when crossed with other susceptible varieties such as TN1, IR20, or IR24, a small proportion of the F_2 progeny was resistant. It was hypothesized that TKM 6 is homozygous for *Bph 1* as well as for a dominant inhibitory gene, *I-Bph 1,* which inhibits *Bph 1.* Thus in the segregating progenies of crosses of TKM 6 with other susceptible varieties, those individuals that inherit *Bph 1* but not *I-Bph 1* are resistant to BPH.

A dwarf breeding line, IR4-93, from the cross H105/Dee-geo-woo-gen, was found to have *bph 2* (Martinez and Khush 1974). It was inferred that H105, the resistant parent of IR4-93, had *bph 2* for resistance.

To identify new genes for resistance, Lakshminarayana and Khush (1977) analyzed 28 resistant varieties. Nine of the varieties had *Bph 1* and 16 had *bph 2* for resistance (Table 1). Two new loci for resistance were discovered. A single dominant gene governs resistance in Rathu Heenati. It segregated independently of *Bph 1* and was designated as *Bph 3.* A single recessive gene conveyed resistance in Babawee. It segregated independently of *bph 2* and was designated *bph 4.* Resistance in Ptb 21 is controlled by one dominant and one recessive gene. The allelic relationships of the two genes in Ptb 21 to the other four genes are not known, but further studies are in progress.

The genetic analysis of 20 new varieties has been completed (Sidhu and Khush 1978). Seven of those varieties have *Bph 3* and 10 have *bph 4* for resistance (Table 1). Three varieties Ptb 33, Sudu Hondarawala, and Sinna Sivappu, have two genes for resistance. One gene appears dominant, whereas the second gene appears recessive. The allelic relationships of the genes for resistance in Ptb 33, Sudu Hondarawala, and Sinna Sivappu to other known genes are being investigated.

The inheritance of resistance to BPH is also being studied at several other rice research centers. In Taiwan, Chen and Chang (1971) investigated the inheritance in Mudgo and also found *Bph 1.* Three varieties, IR9-60, Kaosen Yu 12, and H5, had *bph 2* (Chang 1975).

In India, Prasada Rao et a1 (1976) reported that resistance in Leb Mue Nahng is governed by a recessive gene. They are studying inheritance of resistance in several other varieties.

In Japan, Kaneda and Kisimoto, and in Korea, Choi et a1 (see papers by those authors, this volume) studied the linkage relations of *Bph 1* with the representative markers of different linkage groups. *Bph 1* appears to segregate independently of *lg, g, bl,* d_{11}, and *tri.* However, data of Choi et a1 indicate that *Bph 1* may be linked to the *I-Bf—PS* linkage group.

Table 1. Brown planthopper resistant varieties analyzed to date and the resistance genes they possess.

Variety or selection	Resistance gene	Reference
Mudgo	*Bph 1*	Athwal et al (1971)
MTU 15	*Bph 1*	"
CO 22	*Bph 1*	"
ASD 7	*bph 2*	"
MGL 2	*Bph 1*	Athwal and Pathak (1972)
Ptb 18	*bph 2*	"
H 105	*bph 2*	Martinez and Khush (1974)
IR1154-243	*bph 2*	"
IR747B$_2$-6	*Bph 1*	"
Anbaw C7	*bph 2*	Lakshminarayana and Khush (1977)
Tibiriwewa	*Bph 1*	"
Balamawee	*Bph 1*	"
CO 10	*Bph 1*	"
Heenakkulama	*Bph 1*	"
MTU 9	*Bph 1*	"
Sinnakayam	*Bph 1*	"
SLO 12	*Bph 1*	"
Sudhubalawee	*Bph 1*	"
Sudurvi 305	*Bph 1*	"
ASD 9	*bph 2*	"
Dikwee 328	*bph 2*	"
Hathiel	*bph 2*	"
Kosatawee	*bph 2*	"
Madayal	*bph 2*	"
Mahadkikwee	*bph 2*	"
Malkora	*bph 2*	"
M.I. 329	*bph 2*	"
Murungakayan 302	*bph 2*	"
Ovarkaruppan	*bph 2*	"
Palasithari 601	*bph 2*	"
PK-1	*bph 2*	"
Seruvellai	*bph 2*	"
Sinna Karuppan	*bph 2*	"
Vellailangayan	*bph 2*	"
Rathu Heenati	*Bph 3*	"
Babawee	*bph 4*	"
H5	*bph 2*	Chang (1975)
IR9-60	*bph 2*	"
Kaosen-Yu 12	*bph 2*	"
Ptb 19	*Bph 3*	Sidhu and Khush (1978)
Gangala (Acc 7733)	*Bph 3*	"
Gangala (Acc. 15207)	*Bph 3*	"
Horana Mawee	*Bph 3*	"
Kuruhondarawala	*Bph 3*	"
Mudu Kiriyal	*Bph 3*	"
Muthumanikam	*Bph 3*	"
Gambada Samba	*bph 4*	"
Heenhoranamawee	*bph 4*	"
Hotel Samba	*bph 4*	"
Kahata Samba	*bph 4*	"
Kalukuruwee	*bph 4*	"
Lekam Samba	*bph 4*	"
Senawee	*bph 4*	"
Sulai	*bph 4*	"
Thirissa	*bph 4*	"
Vellai Illankali	*bph 4*	"
Ptb 21	[a]	Lakshminarayana and Khush (1977)
Ptb 33	[a]	Sidhu and Khush (unpubl)
Sudu Hondarawala	[a]	"
Sinna Sivappu	[a]	"

[a] These varieties have two genes for resistance but their allelic relationships are not known.

Thus, of 60 varieties analyzed to date (Table 1), 14 have the single dominant genes allelic to *Bph 1,* and 8 have single dominant genes allelic to *Bph 3.* Thirty-four varieties have single recessive genes for resistance. Of those 23 have *bph 2* and 11 have *bph 4.* Four varieties have two genes for resistance.

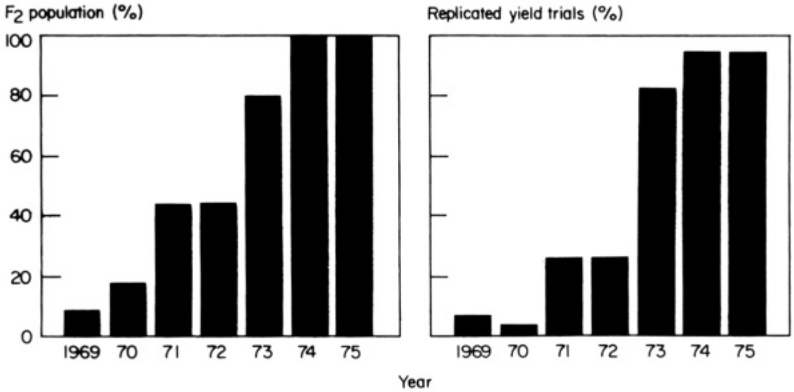
It is noted that varieties with *Bph 1* are resistant to IRRI biotypes 1 and 3, and varieties with *bph 2* are resistant to IRRI biotypes 1 and 2. However, varieties with *Bph 3* or *bph 4* are resistant to all the three IRRI biotypes. Varieties with *Bph 3* and *bph 4* are also resistant in India and Sri Lanka, whereas varieties with *Bph 1* and *bph 2* are susceptible there.

BREEDING FOR RESISTANCE AT IRRI

Breeding for resistance to the BPH at IRRI started as soon as the sources of resistance were identified. A cross between Mudgo and IR8 was made in 1967 and F_3progenies were analyzed for resistance and other traits. Because those lines had poor grain quality, a resistant F_3line was crossed with IR22 and IR24. Promising progenies, such as IR1614-138-3 and IR1614-389-1, were selected from the cross with IR22, and IR1539-260 and IR1539-823-4 were selected from the cross with IR24. Those lines had excellent grain quality, high yield potential, and resistance to the BPH and green leafhopper. They were susceptible to tungro and blast, however. Those selections and several other $F_3$and F_4selections of IR1539 were crossed with tungro- and blast-resistant breeding lines in 1970. Their F_1's were crossed with other F_1's in 1970 and 1971. From those double crosses—includingIR2034, IR2035, 1R2038, and IR2058—several promising breeding lines with multiple resistance were selected and evaluated as varietal possibilities. IR2058-78-1-3 was the most promising line. It inherited its resistance from Mudgo.

Starting in 1969, IR747B$_2$-6 and IR1154-243 were used as sources of resistance to BPH. Promising lines, such as IR1561-149-1, IR1561-228-3, IR1561-243-5, and IR1561-250-2, were selected from the cross IR747B$_2$-6/IR579-48, and IR1628-632-1 from the cross IR24/IR1154-243. In 1970, IR1561-149-1 was crossed with IR1737, a grassy-stunt-resistant line from the fourth backcross of *O. nivara* to IR24. The $F_1$was topcrossed in 1971 with a tungro- and blast-resistant line, IR833-6-2, from the cross Peta^3/TN1//Gam Pai 15. Progenies from that cross were thoroughly evaluated for resistance to all the major diseases and insects, grain quality, and agronomic traits. Two lines, IR2061-214-3-8-2 and IR2061-464-4, were named IR28 and IR29 in 1974, and a third line, IR2061-213-2-17, was named IR34 in 1975.

As noted earlier, when TKM 6 is crossed with other susceptible varieties, a small proportion of the segregating progeny are resistant. Two resistant lines, IR1541-102-7-491 and IR1541-76-3, were selected from the cross IR24/TKM 6 made in 1969. IR1541-102-7-491 was named IR26 in 1973 and became the world's first BPH-resistant variety with improved-plant type. Similarly, two resistant breeding lines, IR1514A-E666 and IR1514A-E597, were selected



1. Changes in the proportion of F_2 populations and entries in the replicated yield trials with resistance to brown planthopper.

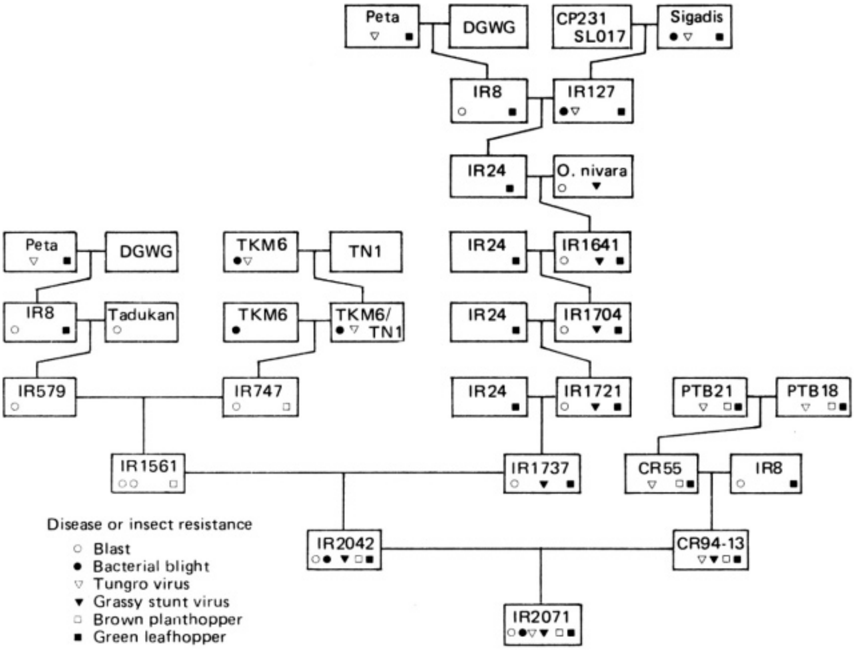
from the cross IR20/TKM6 and used extensively in the hybridization program. In 1971, IR1541-102-6, a close sib of IR26, was crossed with a plant from the fourth backcross of *O. nivara* to IR20, and BPH-resistant IR30 was selected from this cross.

IRRI obtained a gall-midge-resistant breeding line, CR94-13, from the Central Rice Research Institute (CRRI), Cuttack, India. CR94-13 was selected from the cross Ptb 21//IR8/Ptb 18. It inherited *bph 2* from Ptb 18. It was used extensively in IRRI's hybridization program. It is in the ancestry of most IRRI breeding lines and varieties with *bph 2.* Two crosses involving CR94-13, IR2070, and IR2071 have yielded several outstanding progenies. IR2070-747-6-3-2 was named IR32 in 1975.

Special attention was given to incorporating *Bph 1* as well as *bph 2* into IRRI breeding materials. About half of the entries in IRRI replicated yield trials have *Bph 1.* The other half have *bph 2.* IRRI now incorporates *Bph 3* and *bph 4* into improved-plant-type background. Rathu Heenati and Babawee, donors of *Bph 3* and *bph 4,* respectively, were crossed with several other elite breeding lines. Because they have poor plant type, two backcrosses were made with IR3403-267 and IR4432-53 as recurrent parents. Those recurrent parents are improved breeding lines with resistance to all the major diseases and insects except the BPH. Multiple-resistant progenies from these backcrosses are being evaluated.

The progress made in developing germplasm with resistance to BPH is shown in Figure 1. In 1969 less than 10% of the F_2populations segregated for resistance to BPH. That proportion increased to 100% in 1975. Similarly, only 5% of the entries in the 1969 replicated yield trials were resistant to BPH. That proportion rose to 98% in 1975.

Resistance to BPH was combined with resistance to other major diseases and insects. As many as 13 different parents are involved in the ancestry of



2. Pedigree of IR36 and IR42, which were selected from IR2071. Thirteen varieties are involved in the ancestry of these varieties.

IRRI's varieties with multiple resistance. As shown in the pedigree of IR2071 (Fig. 2), which yielded IR36 and IR42, resistance to diseases and insects was contributed by Ptb 18 (BPH, blast, tungro), Peta (green leafhopper), TKM 6 (bacterial blight), and *O. nivara* (grassy stunt).

BPH-resistant varieties released by IRRl

Six BPH-resistant varieties were released by IRRI. Five of them have *Bph 1,* with TKM 6 as donor. One variety, IR32, has *bph 2* from Ptb 18. The selection number, pedigree, year of release, and gene for resistance of these varieties are shown in Table 2.

BPH-resistant IRRI lines named in other countries

IRRI shared the seeds of BPH-resistant materials with scientists in national rice improvement programs. As of mid-1975, seeds of 7,487 BPH-resistant breeding lines had been sent to scientists of 19 countries (Table 3). Since 1975, seeds of breeding lines have been exchanged with scientists in national rice improvement programs through formalized international nurseries. Many of these lines have been extensively used as sources of resistance in the local breeding programs. Some have been named as varieties for commercial production (Table 4).

Table 2. Brown planthopper-resistant varieties released by IRRI.

Variety	Selection number	Cross	Year released	Gene for resistance
IR26	IR1541-102-7-491	IR24/TKM6	1973	*Bph 1*
IR28	IR2061-214-3-8-2	Peta^3/TN1//Gam Pai 15/4/IR8//Tadukan// TKM6^2/TN1///IR24^4/*O. nivara*	1974	*Bph 1*
IR29	IR2061-464-4	Peta^3/TN1//Gam Pai 15/4/IR8/Tadukan// TKM6^2/TN1///IR24^4/*O. nivara*	1974	*Bph 1*
IR30	IR2153-159-1-4	IR24/TKM6//IR20^4/*O. nivara*	1974	*Bph 1*
IR32	IR2070-747-6-3-2	IR20^2/*O. nivara* //CR94-13	1975	*bph 2*
IR34	IR2061-213-2-17	Peta^3/TN1//Gam Pai 15/4/IR8/Tadukan// TKM62/TN1///IR24^4/*O. nivara*	1975	*Bph 1*

Table 3. Number of seed packets of brown planthopper-resistant IRRI lines sent to different countries up to mid-1975.

Country	Seed packets sent (no)
Bangladesh	1,080
British Solomon Islands	19
Burma	123
Cambodia	54
China	39
Fiji	325
India	1,829
Indonesia	1,740
Japan	31
Korea	272
Laos	38
Malaysia	161
Nepal	157
Pakistan	46
Papua New Guinea	39
Sri Lanka	472
Taiwan	139
Thailand	304
Vietnam	619

Table 4. Brown planthopper-resistant IRRI lines named in other countries.

Country where named	Selection	Name
Bangladesh	IR2061-214-3-8-2 (IR28)	BR 6
British Solomon Islands	IR747B$_2$-6-3	GPL1
	IR614-138-3-1	GPL 2
Fiji	IR1539-156	Bilo
Indonesia	IR1541-102-7-491 (IR26)	PB 26
	IR2061-214-3-8-2 (IR28)	PB 28
	IR2153-159-1-4 (IR30)	PB 30
	IR2070-747-6-3-2 (IR32)	PB 32
	IR2061-213-2-17 (IR34)	PB 34
Philippines	IR2071-625-1-252	IR36
	IR2070-423-2-5-6	IR38
	IR2070-414-3-9	IR40
	IR32071-586-5-6-3	IR42
Vietnam	IR1561-228-3	TN73-2
	IR1541-102-7-491	IR26
	IR2153-159-1-4	IR30

ROLE OF RESISTANT VARIETIES IN BROWN PLANTHOPPER CONTROL

Vast areas of rice are now planted to BPH-resistant varieties. In the Philippines, most of about 2.5 million ha grows IR26, IR28, IR30, IR32, IR34, IR36, or IR38. IR40 and IR42 are being multiplied for large-scale distribution to Filipino farmers during the 1977 wet season. Two experimental selections, IR1561-228-3 and IR747B_2-6, are also grown widely in the Philippines.

Indonesia approved IR26 for cultivation in 1975, IR28 and IR30 in 1976, and IR32 and IR34 in 1977. An estimated 2 million ha of Indonesia's rice land is planted to these varieties (pers. comm. with B. H. Siwi). In Vietnam, 1.8 million ha grows TN73-2 (IR1561-228-3), IR26, and IR30 (pers. comm. with V. T. Xuan). In Fiji, Bilo is planted on more than 10,000 ha. Thus, about 6.5 million ha of rice land in Southeast Asia grow BPH-resistant varieties.

Wherever the resistant varieties are grown, the incidence of BPH is drastically reduced. Before the introduction of resistant varieties, hopperburned fields were common in the Philippines, Indonesia, and Vietnam despite the extensive use of insecticides. With the resistant varieties farmers have either stopped using insecticides entirely or drastically reduced the frequency of insecticide application.

STABILITY OF RESISTANCE

IR26 was released for commercial production in the Philippines in November 1973, in Vietnam in 1974, and in Indonesia in 1975. It became one of the most widely grown varieties in those countries within 2 years of its release. It was planted on more than 1 million ha in the Philippines in 1975, and on about the same area in Vietnam in 1976 and in Indonesia in 1977. There were reports of damage to IR26 by the BPH early in 1976 in the Philippines. Insects were collected from the localities reporting damages, multiplied in the laboratory, and tested for virulence on differential varieties. They killed IR26 and other varieties with *Bph 1* and thus were considered biotype 2 insects. Similar reports of sporadic damage to IR26 came from several areas in the Philippines during late 1976 and 1977. In Vietnam, IR26 and TN73-2 were damaged in a few areas during 1977 (pers. comm. with V. T. Xuan). In the northern Sumatra region of Indonesia, where IR26 was first introduced in 1974, biotype 2 damaged fields of IR26 in 1977.

It thus appears that the useful life of varieties with *Bph 1* is about 3 years. In the Philippines, IR32, IR36, and IR38, which have *bph 2,* are fast replacing the varieties with *Bph 1.* Similarly, the Government of Indonesia has released IR32 as a substitute for BPH-resistant varieties with *Bph 1.*

BREEDING STRATEGIES FOR BROWN PLANTHOPPER RESISTANCE

Because the varieties with major genes for resistance have short life spans, IRRI adopted several strategies for utilizing host resistance to BPH.

Sequential release of varieties with major genes

The sequential release strategy involves incorporation of a single major gene into improved varietal backgrounds and making those cultivars available to farmers sequentially. Thus, varieties like IR26, IR28, IR29, and IR30, with *Bph 1* for resistance, were grown in the Philippines during 1973–76. As soon as the biotypes capable of damaging those varieties appeared, IR32, IR36, and IR38, with a different gene for resistance (*bph 2*), were released. These are now widely grown. IRRI has incorporated *Bph 3* and *bph 4* into lines with desirable agronomic background, and varieties with either of these new genes will be released as the presently grown varieties become susceptible due to appearance of new BPH biotypes. As new genes for resistance are identified, they will be incorporated into improved plant types.

Pyramiding the major genes

The strategy of pyramiding major genes aims at combining two or more major genes in the same improved variety. Because *Bph 1* and *bph 2* are closely linked, efforts to develop lines having both genes have been unsuccessful. However, *Bph 3* and *bph 4* segregate independently of *Bph 1* and *bph 2,* and crosses have been made to combine *Bph 1* and *Bph* 3, *bph 2* and *Bph 3, Bph 1* and *bph 4,* and *bph 2* and *bph 4.* Varieties with two genes for resistance are expected to have a longer useful life as they will slow the development of new biotypes.

Multiline varieties

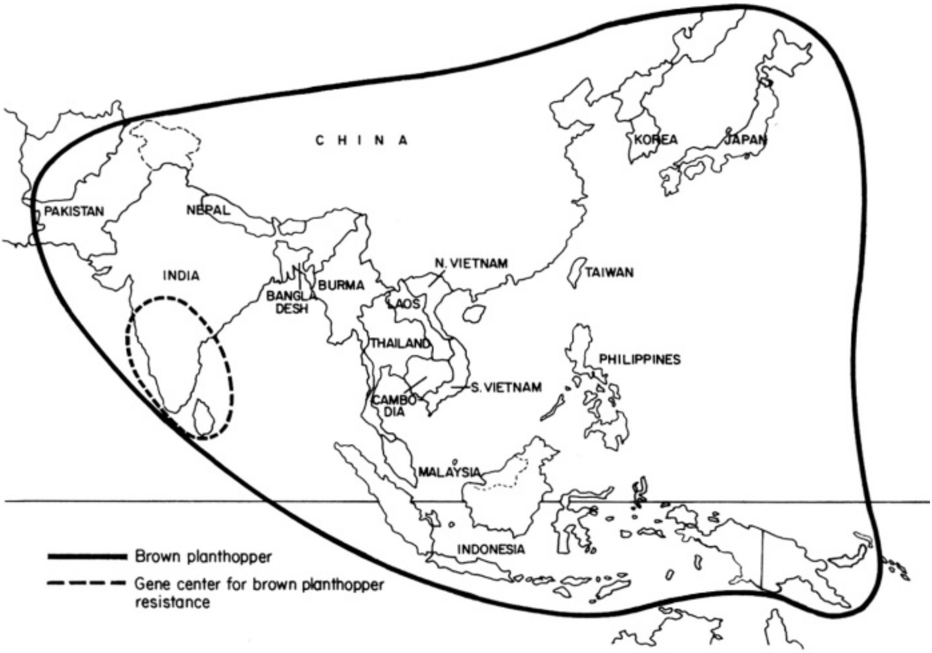
The multiline approach originally proposed by Borlaug (1958) envisages the incorporation of several major genes into an isogenic background and the mixing of these lines to form a multiline variety. This strategy was successfully applied to breeding oats for crown rust resistance in Iowa, USA (Browning and Frey 1969). The effectiveness of the technique for breeding for insect resistance is largely unknown. However, IRRI is transferring the known major genes for BPH resistance into an isogenic background. When appropriate materials become available, the feasibility of this technique will be tested.

Horizontal resistance

IRRI is exploring the possibility of incorporating minor genes for resistance into desirable agronomic background by a process of recurrent selection. Several unimproved varieties and a few improved breeding lines with low levels of resistance have been identified. Crosses between them should yield progenies with higher levels of horizontal resistance. This type of resistance may last longer, but developing improved germplasm with horizontal resistance will take much longer.

BREEDING FOR RESISTANCE IN OTHER COUNTRIES

The distribution of BPH in Asia and the Pacific is shown in Figure 3. Outbreaks of BPH have occurred in most countries where the insect is distributed.



3. Distribution of brown planthoppers in Asia and the gene center for brown planthopper resistance.

Most of the resistant germplasm comes from south India or Sri Lanka. Before resistant varieties were introduced to farmers' fields, the BPH populations consisted of two distinct biotypes. The BPH populations in all the countries of East Asia, Southeast Asia, and the Pacific Islands belong to biotype 1. But populations in the South Asian region belong to a different biotype, which can attack varieties with *Bph 1* and *bph 2.* The exact dividing line between the two biotypes is not clear but the differentiation may occur near the Burma-Bangladesh boundary.

Japan, Taiwan, and Korea have strong programs for developing varieties resistant to BPH. As reported by Kaneda (1971), *Bph 1* from Mudgo was transferred to a japonica background by backcrossing. The lines, called KC lines, had low crossability with other Japanese varieties. Plant height, threshability, and grain quality were not acceptable. Those defects, however, are being corrected by further backcrossing to Japanese varieties. IR1154-243 was used as a source of *bph 2* gene. This line seems to combine well with japonica varieties. *Bph 3* and *bph 4* are also being incorporated into a japonica background by backcrossing.

Resistant materials were first introduced into Korea by a trainee who made crosses and backcrosses between Mudgo and Korean varieties while at IRRI.

Lines derived from those crosses, called KR lines, were distributed to three experiment stations for crossing purposes. KC lines were also introduced into Korea. Many resistant lines from IRRI, particularly IR747B_2-6 and IR946, were extensively used in Korea's hybridization programs. Several BPH-resistant breeding lines are now being evaluated in advanced yield trials and some are likely to be named varieties. Most promising are Suweon 271 and Suweon 272, developed at Suweon, Iri 328 and Iri 329, bred at Honam, and Milyang 30, Milyang 34, and Milyang 36, developed at the Youngnam Crop Experiment Station.

Taiwan's breeding program aims at incorporating resistance into indica as well as japonica backgrounds. IR9-60, IR747B_2-6, IR1561-228-3, and IR1514A-E666 from IRRI, and Kaosen-Yu 12, a local resistant variety, have been used as sources of resistance. One resistant variety, Chianung Sen 11, has been released in Taiwan.

In Southeast Asia, Thailand's breeding program has incorporated *Bph* 1 from W1257 and W1263 into breeding materials. A resistant variety, RD9, was released in 1976. IR32 is being used as source of *bph 2* in the Thai breeding program.

In Indonesia, several resistant lines have been developed. Selections from the crosses of IR2031, IR2070, IR2071, and IR2153 were used as sources of resistance. Several promising breeding lines with BPH resistance, such as B3753-7-Pn-4-1 and B375-8-Pn-2-2, are being evaluated in advanced yield trials.

In India and Sri Lanka, breeding lines and varieties with *Bph 1* and *bph 2* are susceptible. However, donor varieties with *Bph 3* and *bph 4* are resistant. Ptb 33, a variety resistant in both countries, is being extensively used as a donor parent. Early generation, resistant lines are available in both countries. In India, several other resistant donors, such as Ptb 21 and Manoharsali, are also being used in the crossing program.

Work on breeding for resistance to BPH has also started in Bangladesh, Burma, Malaysia, and the People's Republic of China. IRRI materials are used as sources of resistance. Fiji, British Solomon Island, Papua New Guinea, and Vietnam are continuing to grow IRRI-developed, resistant germplasm.

CONCLUSIONS

From the foregoing it is evident that varietal resistance plays an important role in the control of BPH. More than 6.5 million ha of rice land is now planted to BPH-resistant varieties. That area will increase rapidly because many national rice improvement programs have developed germplasm with BPH resistance.

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BIOLOGICAL
AND
CULTURAL CONTROL

Biological control of the brown planthopper

Shui-chen Chiu

Outbreaks of the brown planthopper *Nilaparvata lugens* Stål are often attributed not only to high plant density, heavy nitrogen fertilization, and continuous cropping, but also to the decreasing populations of natural enemies caused by increased use of insecticides. Because those natural enemies are always present in paddy fields, their actions help reduce the brown planthopper population if they are properly managed.

To date, 79 species of natural enemies of the brown planthopper have been recorded, including 42 species of parasites and pathogens (34 insects, 1 nematode, and 7 pathogens) and 37 species of predators (21 insects and 16 spiders) Some of them have shown great potential for controlling pest populations

This paper presents a general review of the natural enemies of the brown planthopper, and the response of natural enemies to insecticides.

OUTBREAKS OF THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* Stål have been reported recently from India, Indonesia, the Solomon Islands, and Sri Lanka. BPH control depends almost solely on the regular application of insecticides. Untreated paddy fields usually suffer heavy hopper infestation and the damage commonly known as hopperburn.

Many natural enemies are almost always present in the paddy fields. Their role in suppressing insect populations has long been considered important. During the last decade, studies of the biological control of the BPH have been conducted in several countries, but they have been generally restricted to the ecology and biology of natural enemies, or to surveys of natural enemies to identify species and estimate the amount of parasitism or predation. However, little practical effectiveness has been demonstrated in the field. Otake (1976b) indicated that the natural enemies of planthoppers on rice have been much less intensively studied than those of the rice stem borer.

Only recently, the effects of insecticides on the natural enemies of insect pests have attracted the attention of entomologists working on control programs.

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The use of selective insecticides and low rates of application to achieve control without destroying natural enemies has been considered. However, no rice insect has ever been consistently controlled solely by natural enemies. Feasibility of using natural enemies as part of integrated control to regulate the BPH must be investigated.

NATURAL ENEMIES

Parasites and pathogens of the BPH have been reported from Taiwan, Japan, Thailand, India, Malaysia, Sri Lanka, Sarawak, Fiji, Philippines, and the Solomon Islands. At least 19 species of hymenopterous insects (Eulophidae, Mymaridae, and Trichogrammatidae) have been identified as egg parasites. Sixteen species belonging to Hymenoptera (Dryinidae), Strepsiptera (Elenchidae), and Diptera (Pipunculidae) were identified as parasites of BPH nymphs and adults. One species of nematode (Mermithidae) and seven species of fungi (Entomophthoraceae and Stilbaceae) were also found in nymphs and adults of BPH (Table 1).

Egg parasites

Mymaridae. Lin (1974) surveyed the BPH parasites obtained from field-collected samples of eggs in Taipei and Pingtung, Taiwan. He found that *Anagrus* sp. was most prevalent among the trichogrammatid and mymarid

Table 1. Egg parasites of *Nilaparvata lugens.*

Parasite	Country of occurrence	Reference
Hymenoptera		
Eulophidae		
Ootetrastichus nr *beatus*	Fiji	Hinckley (1963)
Mymaridae		
Anagrus flaveolus	Japan	Yasumatsu and Watanabe (1965)
A nr flaveolus	Japan	Otake (1970a,b. 1976a,b)
A. optalilis	Thailand	Yasumatsu et al (1975), Nishida et al (1976)
Anagrus sp.	Taiwan, Japan, Malaysia	Lin (1974). Fukuda (1934). Kuno (1973), Heong (pers. comm.)
Anaphes spp.	Solomon island	MacQuillan (1974)
Gonatocerus sp.	Thailand	Yasumatsu et al (1975)
Lymaenon sp.	Taiwan	Lin (1974)
Mymar? indica	Taiwan	Lin (1974), Chiu et al (unpubl.)
M. taprobanicum	Thailand	Yasumatsu et al (1975)
Polynema sp.	Thailand	Yasumatsu et al (1975)
Trichogrammatidae		
Aphelinoidea sp.	Taiwan	Fukuda (1934)
Oligosita sp	Thailand	Yasumatsu et al (1 975)
Oligosita sp. A.	Taiwan	Lin (1974)
Oligosita sp. B.	Taiwan	Lin (1974)
Paracentrobia andoi	Taiwan, Japan	Suenaga (1963), Lin (1974)
P. garuda	Thailand	Yasumatsu et al (1 975)
P. yasumatsui	Thailand	Yasumatsu et al (1975)
Trichogramma sp.	Taiwan	Fukuda (1934)

parasites. It constituted 93% of the egg parasites of the BPH in Taipei paddy fields. Chiu et al (1975) also reported egg parasitism at four sites in northern Taiwan during 1974 and 1975. Most of mymarid parasites appeared in May and June, and from September through November. The parasitism ranged from 11.3 to 29.6% in the first crop and 3.3 to 38.1% in the second crop.

Yasumatsu et al (1975) reported that four mymarid parasites—*Anugrus optubilis, Mymar taprobanicum, Polynema* sp., and *Gonatocerus* sp.—have contributed much to the reduction of the populations of planthoppers and leafhoppers in Thailand. Nishida et al (1976) also indicated that *A. optabilis* was more abundant than *Paracentrobia yasumatsui* (Trichogrammatidae) or a few other unidentified parasites. Parasitism rates ranged from less than 10% to 100%.

Anagrus species had been reported to be a common parasite of delphacid eggs in paddy fields. It was as abundant as *Laodelphax striatellus* and it often attacked eggs of BPH (Otake 1967). Parasitism could be easily detected through the transparent chorion of the host egg when the parasite larva was at least half grown (Otake 1970b). The parasitism of *Anagrus* reported by Kuno and Hokyo (1970) in Fukuoka ranged from 10 to 15% during the various seasons. Otake (1976b) reported that the parasitization of the BPH by *A.* nr *flaveolus* in Zentuz and Kagawa, Japan, was 44.5% and 66.9% respectively. The parasite was said to influence BPH populations during the early growth stages of the pest (Otake 1976b). The seasonal trends in parasitic and dispersal activities of *A.* nr *flaveolus* parasitizing in *L. striatellus* were studied by Otake (1970a).

Trichogrammatidae. Four genera, including at least eight species of Trichogrammatid parasites, have been reported attacking the BPH, but only 3 species of *Paracentrobia* have been identified (Table 1).

Yasumatsu et al (1975) reported that in addition to the mymarid parasites, *Paracentrobia yasumatsui, P. garuda,* and *Oligosita* sp. were abundant and effectively suppressed the population of leafhoppers or planthoppers in Thailand.

Two species of trichogrammatids were found to attack BPH eggs in Sri Lanka. The parasitism rate was about 80%. However, that rate was not consistent, and the parasites did not appear to have much influence on the host population (Fujimura and Somasunderam, unpubl.).

Paracentrobia andoi and *Oligosita* spp. were reared from eggs of the BPH in Taiwan; the parasitism rate was found to be extremely low (Lin 1974). Chiu et al, in a field-sampling and rearing study during 1974 and 1975, found that the trichogrammatid parasitism rates in the first rice crop ranged from 0.6 to 11.7% in Taipei and 7.5 to 19.5% in Hsinchu. They believed that the actual parasitism rate may be higher if sampling and counting methods are improved.

Eulophidae. A eulophid, *Ootetrastichus* sp. nr *beatus* Perk. was observed parasitizing delphacid eggs in Fiji. However, the parasitism appeared to be rare (Hinckley 1963).

Nymph and adult parasites

Dryinidae. Six species of dryinid parasites of the BPH were reported (Table 2). A few unidentified dryinids were recorded in Thailand, Taiwan, India, Sarawak, and Sri Lanka.

A parasitized nymph or adult carries a sac on its abdomen; a mature larva of the parasite emerges from the sac and spins a cocoon and pupates on the surface of a rice leaf or any surface.

Otake (1976b) indicated that the adult dryinids were often caught in paddy fields in Japan, but did not usually parasitize planthoppers to a great extent.

Dryinid larvae sacs carried by rice planthopper nymphs and adults at Ilu, Solomon Islands, have been seen from time to time. The encyrtid parasites *Echthrogonatopus exitiosus* Perk. and *Chrysopophagus australiae* Perk. were reared from the larval sacs on BPH (MacQuillan 1974).

Otake and Hokyo (1976) also reported the low parasitism of BPH by dryinids in Java. The parasites gave little control of pest populations when the BPH was epidemic.

During 1973 and 1974, the parasitism by dryinids of adult BPH and *Sogatella furcifera* in Maha, Sri Lanka, was found to be 5.5% by rearing and 2.3% by dissection (Santa et al. unpubl.).

Elenchidae. Four species of *Elenchus* attacking the nymphs and adults of BPH were recorded (Table 2). Female planthoppers parasitized by elenchids often had degenerate ovipositors (Otake 1976b) and both sexes of the host were inevitably sterile (Kuno 1973). The parasitized hoppers were generally recognized by the extrusion of male parasite puparia or by the opening made by a female adult parasite (Otake 1976b).

Yasumatsu et al (1975) reported that in northern Thailand, the BPH was frequently parasitized by *Elenchus yasumatsui* Kif. & Hir. They believed that the role of the parasite in controlling BPH was significant. The parasitism by *E. yasumatsui* averaged 30% and reached a maximum of 90% in the first rice crop. Parasitized hoppers were also found in the second rice crop in Thailand (FAO 1975).

Hinckley (1963) reported that the BPH was occasionally parasitized by *Elenchus* (*Liburnelanchus*) *koebelei* (Pier.) in Fiji. Another species, *Elenchus japonicus,* also attacks nymphs and adults of planthoppers in Fukuoka, Japan (Kuno 1973). In Sarawak, where a high degree of natural control of the hopper population occurs, rice leafhoppers and planthoppers with protruding Strepsiptera female adults and pupae frequently occur (Munroe 1975). According to his survey in 1974, adult hoppers of the most common species (including the BPH) attacked by Pipunculidae and Strepsiptera had a parasitism rate of 20 to 30% and occasionally one as high as 65%.

The parasitism of BPH caused by Strepsiptera and dryinid Hymenoptera in some locations in Sri Lanka was generally low (Fernando 1975). The combined parasitism by elenchids and dryinids of *S. furcifera* and the BPH occasionally reached 40% (Otake 1976b).

Table 2. Nymph and adult parasites of *Nilaparvata lugens*

Parasite	Country of occurrence	Reference
Hymenoptera		
Dryinidae		
Echthrodelphax bicolor	Japan	Esaki and Hashimoto (1936)
E. fairchildi	India	Rai (pers. comm).
Haplogonatopus japonicus	Japan	Esaki and Hashimoto (1931), Sakai (1932), Esaki and Mochizuki (1941)
Haplogonatopus sp.	India	Rai (pers comm)
	Sri Lanka	Santa et al (unpubl.)
Pseudogonatopus flavifemur	Japan	Esaki and Hashimoto (1933, 1936), Esaki (1932), Sakai (1932)
P. hospes	Thailand	Napompeth (unpubl.)
Encyrtidae (Hyperparasites of Dryinidae)		
Chrysopophagus australiae	Solomon Island	MacQuillan (1974)
Echthrogonatopus exitiosus	Solomon Island	MacQuillan (1974)
Strepsiptera		
Elenchidae		
Elenchus laponicus	Japan	Esaki and Hashimoto (1932), Esaki (1932), Sakai (1932), Mochida and Okada (1973), Kuno (1973)
E. koebelei	Fiji	Hinckley (1963)
E. yasumatsui	Thailand	Kifune and Hirashima (1975), Yasumatsu et al (1975), Otake (1976b)
Elenchus sp.	Sri Lanka	Santa et al (unpubl.)
Diptera		
Pipunculidae		
Dorylas sp.	Sri Lanka	Santa et al (unpubl.)
Pipunculus javanensis	Taiwan	Chiui et al (unpubl.)
Tomosvaryella oryzaetora	Taiwan	Chiui et al (unpubl.)
T. epichalca	Taiwan	Chiui et al (unpubl.)
T. subvirescens	Taiwan, Thailand	Chiui et al (unpubl.), Yasumatsu et al (1975)
Nematoda		
Mermithidae		
Agamermis unka	Japan	Esaki and Hashimoto (1933), Esaki (1932), Imamura (1932), Kaburaki and Imamura (1932), Kuno (1973)
Pathogen		
Entomophthoraceae		
Entomophthora nr *coronata*	Japan	Okada (1971)
E. nr *apiculata* var. *major*	Fiji	Hinckley (1963)
E. coronata	Philippines	IRRI (1973), Gabriel (1968)
E. delphacis	Japan	Esaki and Hashimoto (1936, 1937), Sakai (1932), Shimazu (1976), Aoki (1957)
Stilbaceae		
Isaria farmosa	Japan	Aoki (1957)
Hirsutella sp.	Philippines	IRRI (1973), Gabriel (1968, 1970)
H. citriformis	Solomon Island	MacQuillan (1974)

Pipunculidae. Five species of pipunculid parasites were recorded in BPH nymphs and adults in Sri Lanka, Thailand, Taiwan (Table 2), and Sarawak (unidentified). The degree of parasitism was not high. Yasumatsu et al (1975) reported that *Tomosvaryella subvirescens* Loew was the most important parasite of leafhoppers or planthoppers in Thailand. However, its population was not as high as in temperate countries.

Chiu et al (1974) found four species of pipunculids (Table 2) were also attacking BPH nymphs and adults in Taiwan but with very low parasitism rates.

Nematodes

Nematode parasites of the BPH have been reported from Japan, Sri Lanka, and the Solomon Islands, but only one species, *Agamermis unka* Cobb. (Mermithidae), was identified. Sakai (1932) reported that *Agamermis* usually occurred from June to December, but was most abundant from August through October in Japan. *Agamermis* left its hosts for the soil, where it matured during winter. Mating took place in mid-May. Eggs were laid from late June to early autumn. Larvae appeared in the rice field, swimming until they reached rice plants where the insect hosts were located. After a 2- or 3-week parasitic period, *Agamermis* left its host again. In general, one or two *Agamermis* were found in one host. If parasitism by fungi, bacteria, sporozoa, etc. can be prevented, the nematode is able to breed in the soil under optimum temperature and moisture conditions. Parasitized hoppers had swollen abdomens and were inactive; they could also be distinguished by their dark-brown color (Kaburaki and Imamura 1932). Nematode parasitism of BPH collected from rice fields occasionally reached 38.1% to 41.3% (Sakai 1932; Esaki and Hashimoto 1930). If an artificial rearing technique can be developed *Agamermis* might be able to play an important role in BPH control.

Otake et al (1976) observed in BPH an unidentified nematode parasite whose parasitism rate sometimes reached 20%.

Pathogens

Seven species of entomophagous fungi were found to infect BPH (Table 2), but only a few caused high mortality. *Entomophthora* fungi are considered the most important pathogens for control.

Fungal infestation of *E. delphacis* Hori. was low, but high from August through November in Japan (Sakai 1932). Okada (1971) isolated *E.* nr *coronata* Srin. & Thir. from adult BPH and reported that the infestation of the fungus produced by spraying a conidia suspension was also low. *E.* nr *apiculata* var. *major* was a more important agent for reducing BPH populations in Fiji, especially in densely planted rice. Its infestation rates of adult and nymphal hoppers occasionally exceeded 10% under humid conditions, but never reached an epidemic level (Hinckley 1963). Occasionally *Hirsutella citriformis* Spea. was responsible for some mortality of *S. furcifera* and BPH at Ilu, Solomon Islands (MacQuillan 1974).

The fungi *E. coronata* and *Hirsutella* sp., which usually occurred near the end of a rice crop, periodically killed BPH in paddy fields at the International Rice Research Institute (IRRI). Padua and Gabriel (1975) isolated *E. coronata* and successfully grew it in artificial media. They tested a medium of coconut milk and water for mass production. *Hirsutella* sp. was prevalent from October to November in IRRI experimental fields (Gabriel 1970), but it has not been successfully cultured.

Isaria farinosa also seldom infested BPH in paddy fields (Aoki 1957).

Miridae

Cyrtorhinus lividipennis Reuter is widely distributed in Southeast Asia, Australia, and the Pacific Islands (Table 3). It preys on the eggs, nymphs, and adults of rice leafhoppers and planthoppers and has been considered an effective predator of the BPH and the green leafhopper *Nephotettix virescens* (Hinckley 1963; IRRI 1973; Lim 1974; Stapley 1976; pers. comm. with C.S. Li).

Table 3. Predators of *Nilaparvata lugens.*

Predator	Country of occurrence	Reference
Hemiptera		
Nabidae		
Nabis sp.	Japan	Kuno (1973)
Miridae		
Cyrtorhinus lividipennis	Japan, Sarawak, Solomon Island, Philippines, India, Indonesia, Sri Lanka, Thailand, Malaysia, Taiwan, Australia	Suenaga and Takeuchi (1952), Suenaga (1963), Wan (1972), Bae and Pathak (1966, 1968), MacQuillan (1968), Stapley (1975, 1976), Pawar (1975), Yasumatsu et al (1975), Lim (1974), Chiu and Lung (1975), Li (pers, comm.), Otake et al (1976), Fernando (pers comm.)
C. lividipennis vitiensis	Fiji	Hinckley (1963)
Tytthus chinensis	Fiji, Japan, Solomon Island	Kobayashi (1961), Hinckley (1963). MacQuillan (1968, 1974), Stapley (1976)
T. mundulus	Taiwan, Fiji	Chiu and Lung (1975), Hinckley (1963)
T. parviceps	India	Pathak and Saha (1976)
Hymenoptera		
Formicidae		
Tetramorium guineense	Taiwan	Fukuda (1934)
Coleoptera		
Carabidae		
Acupalpus inornatus	Taiwan	Chiu et al (unpubl.)
Bembidion semilunium	Taiwan	Chiu et al (unpubl.)
Casnoidea cyanocephala	Malaysia	Lim (1974)
C. infersititrialis	Sri Lanka, Malaysia	Lim (1974), Fernando (1975), Otake et al (1976)
Ophionea indica	———	Otake (1976b)

continued on next page

Table 3 continued

Predator	Country of occurrence	Reference
Staphylinidae		
Paederus fuscipes	Japan, Malaysia Taiwan, Thailand	Lim (1974), Otake (1976b), Chiu et al (unpubl.), Yasumatsu et al (1975)
Stenus cicindelloides	Taiwan	Chiu et al (unpubl.)
Coccinellidae		
Coccinella arcuata	Australia India, Fiji, New Guinea, Papua	Israel and Prakasa Rao (1968), Abraham et al (1973), Otake (1976b), Hinckley (1963), Li (pers. comm.)
C. repanda transversalis	Fiji	Hinckley (1963)
Harmonia sp.	Philippines	Dyck and Orlido (unpubl.)
Hippodamia tredacimpunctata	Mainland China	Lei and Wang (1958)
Micrapis discolor	Thailand, Malaysia, Indonesia	Otake (1976b)
M. vincta	Thailand	Otake (1976b)
Verania sp.	Philippines	Dyck and Orlido (unpubl.)
Araneae		
Argiopidae		
Neoscona doenitzi	Japan	Kayashima (1960)
Araneus inustus	Taiwan	Chiu et al (unpubl.)
Lycosidae		
Lycosa pseudoannulata	Japan, Taiwan, Philippines	Kiritani et al (1971, 1972), Chu and Wang (1972, 1973), Sasaba et al (1970, (1973), IRRI (1974), Otake (1976b)
Pardosa T-insignita	Korea	Choi and Lee (unpubl.)
Pirata subpiraticus	Korea	Choi and Lee (unpubl.)
Micryphantidae		
Oedothorax insecticeps	Japan, Taiwan, Korea	Sasaba et al (1970), Kiritani et al (1972), Chiu et al (1974), Otake (1976b), Kobayashi (1961), Paik et al (1974)
Salticidae		
Plexippus paykulli	Japan	Sakai (1932)
Icius magister	Japan	Sakai (1932)
Theridiidae		
Enoploynatha japonica	Japan	Kiritani et al (1972), Kuno (1973), Otake (1976b)
Theridion spp.	Philippines	IRRI (1972)
T. octomaculatum	Taiwan	Chiu et al (unpubl.)
Tetragnathidae		
Tetraynatha spp.	Japan	Kiritani et al (1973), Kuno (1973), Otake (1976b)
T. Japonica	Taiwan	Chiu et al (unpubl.)
T. mandibulata	Taiwan	Chiu et al (unpubl.)
T. nitens	Taiwan	Chiu et al (unpubl.)
Linyphiidae		
Notioscopus pallidulus	Japan	Sakai (1932)

Many workers have observed the predatory activity of *C. lividipennis* against rice hoppers. Bae and Pathak (1966) considered it an active predator against BPH in the greenhouse. IRRI entomologists determined its predation rate at the equivalent of a kill of 0.6 or more planthoppers per day by each predator. It usually killed more nymphs than adults, especially the young nymphs. In the field, the most damaging period probably was when young nymphs were abundant. The predation of *Cyrtorhinus* on BPH was 79% in a 1 : 1 ratio per day while 23% died in a 1 : 20 ratio. Bae and Pathak also showed that the mirid appeared to be an effective predator against both, but more destructive to the green leafhopper than to BPH (IRRI 1973, 1974).

In the Solomon Islands, the maintenance of *C. 1ividipennis* populations on grass appeared to be important in the control of rice planthoppers. Whether the predators entered a rice field depended on the adjacent grass, especially *Digitaria.* A 6-week fallow period for a rice field at the beginning of the year may also help reduce the hopper population. Weeds in the fallow field allow the mirid to multiply. Stapley (1976) suggested that the ratio of prey to predator should be 20: 1.

Hinckly (1963) indicated that mirid bugs preying on eggs were a very important cause of rice hopper mortality in Fiji. *Cyrtorhinus* was the most common, but its populations did not increase rapidly enough to prevent a heavy infestation of BPH in transplanted rice. The mirids were less effective in seedbeds except in grassy areas. It also appeared that *Cyrtorhinus* prevented the increase of pest populations in drilled rice fields, but was less effective in transplanted rice.

Lim (1974) witnessed large numbers of *C. lividipennis* in Malaysian fields and an associated reduction of leafhopper populations. Such observations clearly indicate the significance and potential of the predator.

In Taiwan, two species of mirids, *C. lividipennis* and *Tytthus mundulus,* attacked BPH and green leafhoppers in paddy fields. *T. mundulus* (Bred.) was formerly recognized as an egg predator of the sugarcane leafhopper *Perkinsiella saccharicida.* Its presence was also reported in Australia, Java, Fiji, Philippines, and Hawaii (Chan and Ju 1951). Chiu and Lung in 1975 first observed that it also fed on BPH nymphs. Its appearance, life history, and habitat are similar to those of *C. lividipennis.* It differed in color pattern and a few morphological characteristics. *T. mundulus* was prevalent in May or June while *C. lividipennis* occurred in October and November. There were about 10 generations in a year. Nymph or adult mirids can kill the BPH at every developmental stage. One adult mirid usually preyed on 1 to 20 eggs at one feeding. Nymphal mirids consumed fewer eggs. Mortality rate of the BPH was about 73% when equal numbers of third instar mirids and second instar BPH were caged for 24 hours. It would appear that the mirid plays an important role in BPH control (Chiu and Lung, unpubl.).

Swezey (1936) stated that because it feeds on both parasitized and nonparasitized eggs of leafhoppers, *Cyrtorhinus* reduces the effectiveness of egg parasites.

Other mirid predators preying on the eggs of planthoppers were *T parviceps* (Lin.) and *T. chinensis* (Stål) (Pathak and Saha 1976; Stapley 1976; Kobayashi 1961).

Coccinellidae

Coccinellid beetles are important members of arthropod communities in paddy fields where they play a valuable role in the biological control of insect pests of rice. Sasaji (1968) studied the fauna of oriental coccinellids in paddy fields, and 33 species were recorded, seven of which were recognized as predators of the BPH (Table 3). Yasumatsu et al (1975) reported six species of coccinellids common in the rice fields of Thailand. Among them, *Micrapis discolor* Fabr. and *M. vincta* Gorh. were abundant. *M. discolor* was also dominant in Malaysia (Otake and Hokyo 1976). It is believed that planthoppers are a part of their diet.

Coccinella arcuata has been known as the most common and important coccinellid predators of BPH and *S. furcifera* in India, Fiji, Australia, and Papua, New Guinea (Table 3). In Cuttack, India, the increase of planthopper populations (including the BPH) in rice fields was closely followed by a rapid multiplication of *C. arcuata* from mid-August until late September. Then the hopper population gradually decreased until late October. Because of its feeding habit *C. arcuata* may prove to be an effective predator of rice hoppers (Israel and Prakasa Rao 1968).

IRRI entomologists caged coccinellid predators with BPH preys in a ratio of 1:4 on potted rice plants in a greenhouse. The mortality of BPH caused by *Harmonia* adults was 77% for nymphs and 91% for adults by *Verania* adults was 52% for nymphs and 93% for adults (V. A. Dyck and G. Orlido, unpubl.).

Other common carnivorous beetles found in paddy fields include carabids and staphylinids (Table 3). Staphylinid beetles, particularly *Paederus fuscipes* Curt., are probably significant in the control of insect pests in rice. They usually migrate to the young rice plants shortly after transplanting. In Taiwan, Chiu et a1 (1974) also found that *P. ,fuscipes* and *Stenus cicindlloides* were the most common staphylinid species in paddy fields.

Fukuda (1934) reported that an ant, *Tetranorium guineense* Fabr., preyed on eggs and attacked nymphs and adults of planthoppers during molting or emergence. V. A. Dyck and M. Orlido (unpubl.) also observed that some species of ants attacked the BPH.

Other predators that may be found preying on rice planthoppers in rice fields include Odonata, nabids, anthocorids. reduvids, hebrids, hydrometrids, ochterids, pleids, salids, and veliids; empidids and asilids, sphecids, nyssonids, stizids, and pemphtedonids ; birds ; frogs ; and a giant toad (*Bufo marinus*) (Habu 1958; Kobayashi 1961; Hinckley 1963; Asahina et al 1972; FAO 1975; Yasumatsu et al 1975).

Spiders

The spider fauna in paddy fields in Korea, Japan, Taiwan, and Thailand has been investigated (Table 4). About 16 species of spiders are recorded as preying on BPH (Table 3). *Lycosa pseudoannulata, Pirata subpiraticus, Pardosa T-insignita, Oedothorax insecticeps, Tetragnatha niten, T. japonica, Enoplognatha*

Table 4. Spider-families in paddy fields in Korea, Japan, Taiwan, and Thailand.[a]

Family	Spider species and genera (no.)							
	Korea		Japan		Taiwan		Thailand	
	Genera	Species	Genera	Species	Genera	Species	Genera	Species
Agelenidae	1	1	1	1				
Argiopidae[b]	5	8	8	12	6	12	9	16
Clubionidae	3	5	2	5	2	3	2	3
Ctenidae	2	2	1	1				
Dictynidae					1	1		
Hahniidae	1	1			1	2		
Heteropodidae			2	2	1	1		
Linyphiidae	1	1	2	2	3	3	1	1
Lycosidae	5	8	6	11	3	5	5	5
Micryphantidae	4	8	5	5	4	4	3	3
Oonopidae					1	1		
Oxyopidae	1	1	1	1	1	4	1	2
Pisaundae	1	3	1	3		[c]	2	3
Salticidae	5	6	9	10		(ca.5)		(ca. 10)
Tetragnathidae	3	8	4	11	4	11	4	13
Theridiidae	3	3	5	8	3	5	5	8
Thomisidae	5	9	8	11	7	8	4	4
Uloboridae			2	2			1	1
Total	37	64	57	85	37	62	37	59

[a] Data obtained from Okuma (1968), Okuma and Wongsiri (1973), Chu and Okuma (1970), and pers. comm. with J. S Park, Head, Ent. Dep., Inst. Agric. Sci., Korea. [b] Spiders confirmed to be predators of the brown planthopper, *Nilaparvata lugens.* [c] Including a few very young specimens not determined.

japonica, and *Theridion octomaculatus* were the major species. In India about 20 species of spiders were observed preying on BPH. It was believed these spiders could play an important role in keeping down BPH populations (Samal and Misra 1975).

Lycosa pseudeannulata Boes. et Str. *Lycosa pseudeannulata* a wolf spider, is one of the predominant spiders in paddy fields (Kobayashi 1961 ; Kawahara et al 1969; Sasaba et al 1970; Chu and Okuma 1970; Mochida and Dyck 1976). It has been considered an effective predator of rice hoppers in Taiwan, Japan, and the Philippines. Of the species preyed upon by the spider. 80% were the green leafhopper and BPH (Sasaba et al 1973; Kiritani et al 1972). The mean indices of food preference of adult female spiders assessed in the laboratory were 0.49 and 0.60 for BPH and *Nephotettix cincticeps,* respectively (Sasaba et al 1973). Kiritani et al (1972) also indicated that the ratio of prey taken by the spider was 5 green leafhoppers : 2 BPH in Japan between 1968 and 1970.

Lycosa inhabits the lower part of rice plants in the daytime but moves toward the middle and upper sections at night. The fact that leafhoppers tend to inhabit the middle and upper parts of rice plants while planthoppers inhabit the lower part might explain why *Lycosa* preys on more leafhoppers at night and on more BPH during the day (Sasaba et al 1973).

In the Philippines, *L. pseudeannulata* was common in IRRI rice fields. In spite of its relatively low field density, *Lycosa,* because of its high predation rate, was regarded by IRRI entomologists as the most important predator of BPH. IRRI entomologists caged *Lycosa* with different numbers of BPH adults and nymphs to determine its daily feeding capacity in relation to prey density during 3 consecutive days. Greater prey density occasionally increased the feeding rate of the spider. The spider generally showed no preference for nymphs over adults or vice versa. When 50 or 100 hoppers were available a spider killed an average of at least 14 BPH nymphs or 8 or more adults daily (IRRI 1975).

At IRRI (1976) it was also found that in a 14-day period each spider killed an average of 17 BPH nymphs/day. A similar experiment gave an average of 24 nymphs/day in 9 days. It was found in India that *Lycosa* could kill about 15 to 20 adult BPH/day (Samal and Misra 1975). In another experiment, when green leafhoppers and BPH were caged together with *Lycosa* for over 12 days, the spiders killed three times as many BPH as green leafhoppers. *Lycosa's* apparent preference for BPH over leafhoppers supports the contention that *Lycosa* is a greater predator of BPH than is *C. lividipennis.*

In Taiwan, *L. pseudoannulata* is the dominant spider in rice fields, particularly in the second rice crop. Predation rates observed in the laboratory were 3.08 and 4.28 adult BPH for the second and the fourth instar spider nymphs and 13.32 and 11.48 adult BPH for adult female and adult male spiders, respectively (Chiu et al, unpubl.).

Chu and Wang (1973) studied the feeding habit of the spider and found that leafhoppers and planthoppers were its preferred prey. They found that the daily predation rate of female spiders was apparently greater than that of males. The predation rate for females during their maternal care of their young was low and increased as the young spiders began to disperse. Cannibalism often occurred among the spiders when the food supply was inadequate.

Oedothorax insecticeps Boes. et Str. *Oedothorax insecticeps,* a micryphantid or dwarf spider, was also found to be an effective predator in Taiwan, Japan, and Korea. *Oedothorax,* a small species, prefers to prey on nymphs and adults of hoppers. In the laboratory Chiu et al (1974) observed that the daily predation rates averaged 1.84 and 3.00 adult BPH for second and fourth instar spider nymphs and 3.20 and 2.03 BPH for adult females and adult male spiders, respectively. The spider took prey more often under warmer conditions. The average number of BPH preyed on by each adult female was about 1.5 times that preyed on by a male. Cannibalism occurred when the prey population was low.

Oedothorax had 4 or 5 generations in northern Taiwan. Adults usually situated themselves near the paddy level above the roots, but frequently migrated by skating on the water surface or hanging on a silk that was transported by wind. They could tolerate about 20 days of starvation. The spider spun very thin, irregular webs which were difficult to see and efficient in catching prey. Ensnared victims usually died within 2 days, even if not fed upon.

Other spiders often occurred in paddy fields; *Tertragnathus* was a dominant species in Thailand, Malaysia, and Indonesia (Otake 1976b); *T. nitens* was common in Taiwan. *Gnathonarium dentatum* (Wider) and *Pirata subpiraticus* (Boes. et Str.) were major species in Korea (pers. comm. with J. S. Park,) and *Enoplognatha japonica* (Boes. et Str.) was a major species in Japan (Kiritani et a1 1972). *Theridion octomaculatum* (Boes. et Str.) often occurred in northern Taiwan from May through August; its webs were built on the lower part of rice plants under the rice canopy, situated well for predation on BPH.

RESPONSE OF NATURAL ENEMIES TO INSECTICIDES

Because the mortality of natural enemies was high when insecticides were applied, the response of natural enemies of arthropods to insecticides in rice fields was generally observed qualitatively rather than quantitatively. A number of entomologists have recently suggested that one reason for the presence of many rice hoppers could be the destruction of their natural enemies by intensive application of broad spectrum insecticides (Kobayashi 1961; Miyashita 1963; Kiritani 1972, 1975; Kiritani et a1 1971). The disturbance by insecticides of the balance between pests and natural enemies has contributed to the development and application of the concepts of integrated control and pest management, and has prompted studies of insecticide selectivity in relation to natural enemies (Croft and Brown 1975).

Lycosa and *Oedothorax,* two dominant spider species in Taiwan paddy fields, have been considered effective against rice hoppers. Unfortunately, they are very susceptible to the insecticides commonly used for rice-pest control.

Direct toxicity of insecticides to natural enemies

The reduction in numbers of natural enemies or the degree of parasitism or predation rate after insecticide application has been well documented.

Chu et al (1976b, c) used a dipping method to evaluate the susceptibility of *N. cincticeps, N. lugens,* and *L. pseudoannulata* to various insecticides. They found that the degree of susceptibility of the *Lycosa* spider to different chemical compounds varied greatly. Leptophos, dicrotophos, monocrophos were less toxic to the spiders than were CPMC, bufencad, fenthion, and PM. Fenthion was much more toxic to *Lycosa* than were fenitrothion and methyl parathion, which were commonly used for rice stem borer control.

In a laboratory study of contact toxicity of insecticides currently recommended for rice insect control, Chiu and Cheng (1976) found that *Lycosa* was generally more susceptible to the insecticides than was *Oedothorax* (Table 5). The carbamates tested were as toxic or more toxic than organophosphates. Of all insecticides tested, Hokbal EC., bufencarb, and carbofuran showed highest contact toxicity to the spiders. Compounds with lower toxicity were acephate, monocrotophos, MTMC EC., and sevin WP. All insecticides tested,

Table 5. The contact toxicity of insecticides on predators of the brown planthopper[a] (Chiu and Cheng 1976).

Insecticides	Concn (%)	Corrected mortality (%)		
		Lycosa Pseudoannulata	*Oedothorax insecticeps*	*Cyrtorhinus lividipennis*
		Organophosphates		
50% Fenthion EC	0.05	30	37	100
47% Parathion EC	0.047	30	25	100
40% Vamidothion S	0.05	35	21	85
50% Phosmet WP	0.05	30	20	100
50% Fenthion EC	0.05	15	26	100
75% Acephate SP	0.05	10	15	80
60% Monocrotophos	0.03	5	21	95
5% Disulfoton G	36 kg/ha.	25	8	–
5% Disulfoton G	18 kg/ha.	15	3	–
		Carbamates		
40% Bufencorb EC	0.05	90	21	100
25% Metalvariate 2 EC	0.027	80	25	100
30% MTMC EC	0.038	10	0	100
40% BPMC WP	0.05	35	65	100
50% MPMC WP	0.025	45	15	90
50% MIPC WP	0.025	35	15	100
50% Promecarb WP	0.05	30	5	85
50% Propoxus	0.05	25	20	100
50% CPMC WP	0.025	20	20	85
85% Sevin WP	0.05	15	10	100
50% MTMC WP	0.025	20	0	90
90% Methomy 1 WP	0.05	5	26	80
3% Carbofuran G	60 kg/ha.	95	35	–

[a] Twenty spiders or 40 mirids for each treatment with 2 replications. The spiders were forced to crawl over a chemical-solution film in a large petri dish for 10 minutes then were transferred individually to glass tube and fed with second or third instar nymphs of the brown planthopper. Mortality corrected by Abbott's formula.

except acephate and methomyl, were highly toxic to the mirid hopper predator, *C. lividipennis.*

Cheng et al (1973–75 unpubl.) estimated the rice yield loss caused by insect pests at 12 sites in Taiwan and the effect of frequency of insecticide application on natural enemies. Their results showed more predacious spiders and more egg parasitism in unprotected plots than in plots where insecticides were applied as needed, and fewer spiders and less parasitism in plots where insecticides were applied at 15-day intervals. Frequent insecticide applications apparently reduced the population density of natural enemies of rice crop pests. Similar results were obtained by Chiu et al (Table 6).

Indirect effects of insecticides on predators

Early advocates of integrated control of crop pests stressed the usefulness of compounds that act as systemic insecticides toxic to plant-feeding pests but not appreciably affecting their natural enemies; many experiments have demonstrated the selectivity of systemic toxicants. However, significant mortality of predators, not only from direct toxicity but also from the ingestion of prey

Table 6. Effect of insecticide thru treatments[a] on population densities of brown planthopper and two predacious spiders in paddy fields (1974–1975) (Chiu et al, unpubl.).

Insect	Insects[b] (no /hill)											
	First crop						Second crop					
	1974			1975			1974			1975		
	A	B	C	A	B	C	A	B	C	A	B	C
							Taipei					
BPH	1.0	1.4	2.6	0.3	0.4	1.2	1.7	2.4	11.5	0.8	4.4	3.3
Spider	1.0	1.4	1.7	0.6	0.9	1.1	0.7	0.9	1.5	0.4	0.7	1.2
							Hsinchu					
BPH	0.9	1.0	1.2	1.2	0.4	1.9	0.2	1.1	1.9	0.4	3.5	9.6
Spider	1.1	1.1	1.3	0.6	0.8	1.1	1.1	1.7	2.4	0.3	0.8	1.0

[a] A = insecticides applied on a schedule at 15–20 days intervals, 5-6 applications per crop, B = insecticides were applied as needed, C = no insecticide. [b] Numbers per hill of brown planthopper and predacious spiders, *Lycosa* and *Oedothorax,* shown are averages of 5 samplings at 20-day Intervals.

that had taken up the insecticides in more recent studies, was observed (Kiritani and Kawahara 1973; Chiu and Cheng 1976).

Although predators may be killed by secondary poisoning from contaminated prey, little is known about the fate of some toxicants inside the body of the prey and the factors that determine subsequent toxicity to predators. Kiritani and Kawahara (1973) studied in detail the fate and effect of BHC passing through a food-chain from irrigated soil to rice plants, then to rice hoppers, and finally to *Lycosa* spiders.

Chiu and Cheng (1976) reported the toxicity of insecticides commonly used for rice-insect control to the predators of planthoppers. Their data indicated that carbofuran G and fensulfothion G were more toxic than lindane G to *Lycosa* ; other insecticides—acephate, disulfoton, and fenthion—had low toxicity to spiders through their prey (Table 7). Chu et al (1976a) studied the insecticidal effects of BPMC and propoxur on the predatory ability of *Lycosa.* The results showed that the amount of predation carried out in 6 days by *Lycosa* that survived after feeding on BPMC and propoxur treated hoppers was about 85% of the predation of spiders fed on unpoisoned hoppers. That indicated that BPMC and propoxur had only slight effect on *Lycosa* through its prey.

CONCLUSION

Parasitism has been generally recognized as causing less planthopper mortality than predation. Most parasitism of brown planthopper is low and appears to have limited value for checking hopper populations. However, such a limitation may be overcome by the combined effect of several parasites that attack sequentially during the development of pest insect outbreaks. Various parasites predominate at different times during a crop-growing season, and

Table 7. Effect through the food-chain of granular insecticides on predacious spiders[a] (Chiu and Cheng 1976).

Insecticide	Rate (kg a.i./ha)	Mortality[b] (%)			
		L. pseudoannulata		*O. insecticeps*	
		in 24 h	in 72 h	in 24 h	in 72 h
Acephate G	1.8	0	5	0	15
Disulfuton G	1.8	0	5	5	10
Fenthion G	1.8	5	10	5	15
Propoxar G	1.8	10	20	5	10
Bufencarb G	1.8	25	30	5	10
Lindane G	2.1	20	70	10	35
Fensulfothion G	1.5	40	90	20	25
Carbofuran G	1.8	100	100	25	50

[a] Each treatment consisted of 20 spiders and was replicated twice. The insecticide was applied to irrigation water Twenty second to third instar brown planthopper nymphs and one spider were caged on a potted rice plant 5 days after insecticide application. [b] Corrected by Abbott's formula.

attack the BPH at different developmental stages. Combined egg-parasitism rates exceeded 90% or approached 100% in many localities in Thailand (Nishida et al 1976). The combined egg-parasitism rate of BPH was also recorded as about 80.1% in Taiwan (Lin 1974) and 79.4% in Sri Lanka (Fujimura and Somasunderam, unpubl.). Otake (1976b) also pointed out that natural parasitism may have been underestimated because sampling and calculating techniques were inadequate. It is suggested that even if parasitism is not consistently high throughout a crop season, it may be more important for biological control of brown planthopper than has been thought in the past.

Predation is considered to be more important than parasitism for controlling brown planthopper population; the idea is supported by the abundant fauna of spiders and the existence of other predators. However, a current problem is how to conserve and augment natural enemies. Stapley (1975) indicated that the activity of *C. lividipennis* was increased where the grass *Digitaria* was grown. Fallowed paddy fields were also favorable for the multiplication of the predator. An important recommended practice is the maintenance of the natural population of predators through use of selective insecticides for rice insect pest control.

A better understanding of the responses of natural enemies of BPH to insecticides could eventually lead to better prognosis and better use of natural enemies in management of the insect pest. Experience has indicated that when chemical control is overemphasized, it can disrupt the balance between natural enemies and hoppers, causing heavy losses of the natural enemies and quick resurgence of the pest. When a rice pest management program is established, it would be desirable to apply insecticide less frequently and more critically than usually has been done. The use of selective insecticides and low application rates for brown planthopper control is one way to minimize the detrimental side effects on the environment, including the destruction of natural enemies.

Kiritani (1975) advocated that the effectiveness of insecticide control be assessed, not in terms of percentage killed, but in terms of degree to which the injury or damage caused by insect pests is decreased as measured by yield or crop quality. We must begin applying insecticides on the basis of necessity, and do away with routinary regularly scheduled treatments.

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Cultural control of the brown planthopper

Ida Nyoman Oka

Cultural control methods are needed to help reduce the brown planthopper population because resistant varieties and pesticides alone are inadequate.

Simultaneous rice cropping, if practiced over a wide area and rotated with secondary crops, would break the life cycle of the insect pest. Immediate destruction of rice stubbles and ratoons of a harvested rice crop would help keep down the population of the pest; it would also eliminate the source of Infection by the grassy stunt virus and the ragged stunt virus. Raising a field's water level or draining it for a few days would help destroy the Insect population. Plant spacing should allow some sunlight to reach the basal portion of the plant. Reduced fertilizer use might not be in line with the agronomic requirement of the crop. In certain cases, early planting or simultaneous cropping of early maturing rices would keep the crop well clear of attack. Simultaneous cropping with proper rotation is most promising in the long run, but it needs continuous supervision. Legislation would probably be necessary to make it effective.

AFTER YEARS OF SUCCESSFULLY CONTROLLING the brown planthopper (BPH) *Nilaparvata lugens* (Stål) by using resistant varieties and insecticides, we now find that those methods alone are no longer adequate (pers. comm. with E. A. Heinrichs, The International Rice Research Institute, P.O. Box 933, Manila, Philippines). IR26 and other rice cultivars with the same gene for resistance to the BPH were infested and reported hopperburned in two widely separated small areas in the Philippines (Anonymous 1975). In the Solomon Islands all resistant selections, including IR26, "broke down" (Stapley 1975). New BPH biotypes capable of attacking IR26 have been identified (IRRI 1975).

Indiscriminate and faulty application of insecticides kills effective biological control agents of the pest (Kulshreshtha et al 1974; Nishida 1975; Fernando 1975). Development of resistance to various insecticides has been reported (IRRI 1970; Fernando 1975; Muriya 1976).

Other methods that will help keep down the insect population while reducing the frequency of pesticide applications that may have unwanted side effects

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should be explored (Ripper 1956 ; Akesson and Yates 1964; Newsom 1967; Cope 1971; Pimentel et al 1971; Georghiou 1972).

Cultural control is perhaps as old as agriculture itself. It may be defined as the modification of certain farm operations to make the environment unfavorable for the development and multiplication of insect pests but favorable for crop production. Certain techniques, such as modification of planting, growing, cultivating, or harvesting, aim at preventing insect damage rather than at destroying existing insects (National Academy of Sciences 1971). Plant spacing, the cropping system, and fertilizer management may prevent buildup of certain pest populations. Other methods of cultural control, such as flooding the fields or plowing under the stubble after harvest, aim at destroying certain pest populations. They can reduce the number of larvae and pupae of the rice stem borer *Tryporyza innotata* (Walker) (Coot 1925). Digging of rice stubble to control *T. incertulas* was done in Japan from 1880 until around 1940 (Orita 1935; lshikura and Nakatsuka 1955). On the other hand, keeping plots flooded or saturated favors buildup of the BPH (Dyck 1973). Thus, a thorough knowledge of the ecobiology of the BPH, other pests, and the crop plant is needed before cultural control techniques are introduced. The techniques should be compatible with other control methods and with the needs of the crop. They must be economical to be readily adopted by farmers.

Unlike insecticidal control, cultural control may not give spectacular and immediate results; however, it is the first line of defense against pest attack, and its methods are dependable, economical, ecologically sound, and nonpolluting (NAS 1971; Clark et al 1970). The potential of some cultural control methods already used to combat certain pest complexes should be fully exploited, especially against typical epidemic-type insect pests, such as the BPH, that have high rates of population growth, high tolerance for crowding, high degrees of aggregation, and high dispersal ability (Kuno 1973; Kisimoto 1976).

Experimental data on cultural control of the BPH are relatively scarce in the tropics. One reason might be that the insect was generally a minor pest of rice until recently. In Japan cultural control of the BPH is not practiced (pers. comm. with R. Kisimoto, Central Agricultural Experiment Station, Konosu, Saitama 365, Japan). Epidemics of the insect, which are mainly caused by long-distance migration from mainland China, are effectively prevented by applying insecticides in late July and August (Kisimoto 1971, 1976).

The following cultural control practices are deduced from information on the ecobiology of the insect pest and the suspected causes of recent outbreaks.

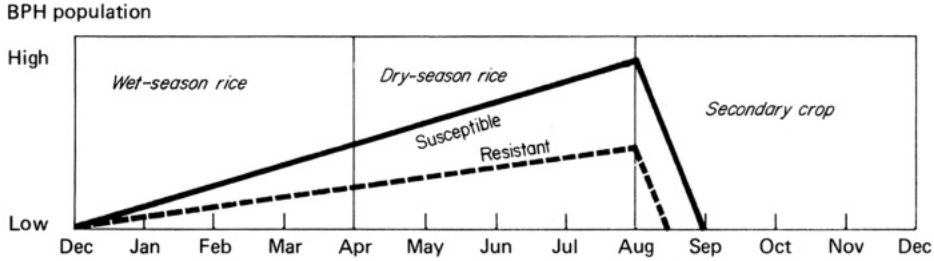
CROP ROTATION

In the humid tropics the BPH is active throughout the year and its population density depends on, among others, the availability of food plants (Pathak 1968, 1969). So far, rice is the only suitable host (Nasu 1964; Kisimoto 1976; Okada 1976). On alternate hosts, the insect can survive but does not multiply well (Mochida and Dyck 1976). Consequently, during a fallow period or one when rice is not grown, the insect population will be much reduced.

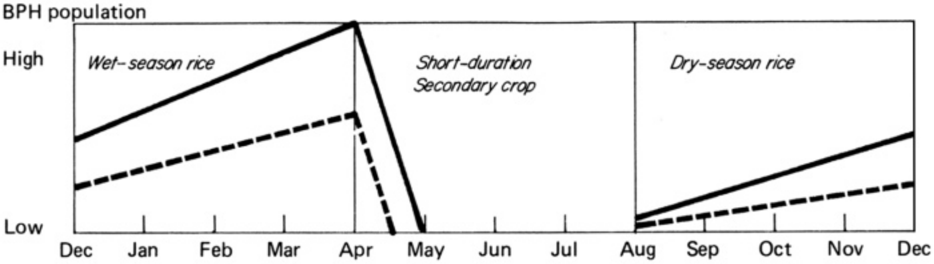
Various cropping systems exist in various rice centers, depending on the availability of water and on custom. In well-irrigated areas, rice is planted twice or even thrice a year and staggered planting with short idle intervals is usual. Such a cropping system appears to stimulate the buildup of the BPH population and to result in serious outbreaks (IRRI 1972; Chatterji 1975; Dyck 1974b; Fernando 1975; Kalode 1974; Kulshreshtha et al 1974: Mochida et al 1975; Mochida 1976; Otake and Hokyo 1976). A recent outbreak of the rice dwarf virus in Japan was also attributed to mixed rice cropping, which increased the abundance and varied the pattern of occurrence of the virus vector, the green leafhopper *Nephotettix cincticeps* (Uhler) (Nakasuji 1974).

Rotating rice with other annual crops or fallowing between two rice seasons will break the life cycle of the pest. The annual crops for rotation should be nonhosts for the insect—soybeans, mung beans. and sweet potatoes. Otherwise they may increase the pest problem. In the Solomon Islands a fallow period appeared to reduce the BPH population to a very low level (Anonymous 1975).

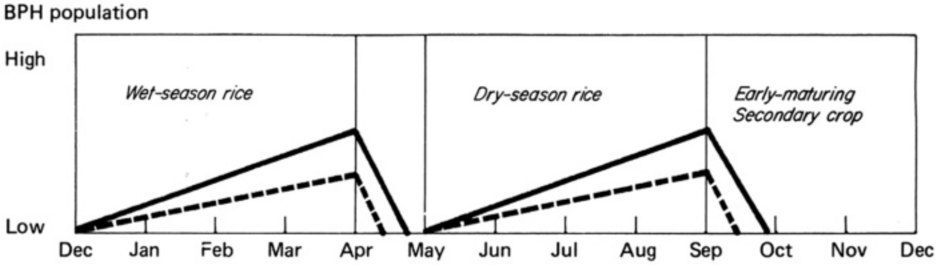
Figures 1 to 4 illustrate cropping systems of well-irrigated areas of parts of West and Central Java and East Java. Rice in the wet season may be immediately followed by rice in the dry season (Fig. 1). Or rice in the dry season may be immediately followed by rice in the wet season (Fig. 2). In this system



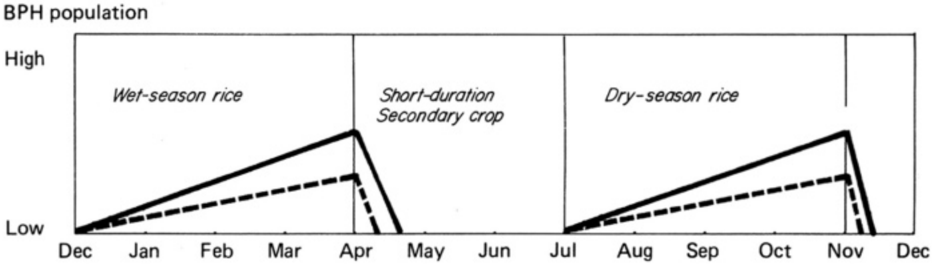
1. Cropping system type 1 for well-irrigated areas (staggered planting).



2. Cropping system type 2 for well-irrigated areas (staggered planting).



3. Cropping system suggested to reduce buildup of the brown planthopper population when wet-season rice is followed by dry-season rice.



4. Cropping system suggested to reduce the buildup of the brown planthopper population when dry-season rice is followed by wet-season rice.

the BPH is able to develop continuously. If a field is fallowed for at least 1 month, e.g. April (Fig. 3) or November (Fig. 4) its following rice crop may have relatively fewer pests.

Integration of this cultural control with resistant varieties (IR26, IR28, IR30) should further reduce pest buildup (Oka 1975; Mochida et al 1976; Samino 1976). A short-duration secondary crop should be chosen to fit the cropping system. To be effective, simultaneous planting should be encouraged and carried out over an entire community (Dyck 1974a; Oka 1976; Mochida et al 1976). But efforts to regulate the planting time in Laguna province, Philippines, were difficult to enforce (Calora 1974).

With simultaneous rice cropping and rotation with other crops in Dolok Masihul, North Sumatra, in the 1975–76 rice season, the average BPH population on the susceptible varieties Pelita and C4-43 was below 20/hill; in Pasar Miring (North Sumatra) it was 77/hill with continuous and staggered rice cropping (Purba 1976). The average BPH population on IR26, however, was low in both places. Similar observations were made in some Java areas by Otake and Hokyo (1976).

Simultaneous cropping with resistant varieties is gradually being introduced to farmers in rice areas of Indonesia (Oka 1976; Soenardi 1976). Simultaneous planting of resistant varieties from different genetic sources would be strategically sound (Otake and Hokyo 1976). It would minimize selection pressure on the BPH and thus reduce the chance for development of new biotypes.

In the Solomon Islands, control of the BPH is attempted through such agronomic practices as fallowing and strip-cropping with grasses, to favor parasites of the egg (MacQuillan 1974; Stapley 1975).

Crop rotation controls certain pests and provides a number of other benefits, but its potential is limited by crop-production economics (Pimentel et a1 1965).

SANITATION

It has been suggested that weedy fields increase the BPH population (Cendaña and Calora 1964: Fernando 1975). Experiments at the International Rice Research Institute (IRRI) show that near rice crop maturity, the planthopper tends to be more abundant in weedy than in weeded plots, probably because the dense vegetation of weedy fields provides an environment suitable for the insect (IRRI 1973). After harvest the insect usually transfers to weeds and grasses but does not hibernate (Alam 1964; Pathak 1969).

Since the survival of the BPH population in the next rice season may depend on alternate host plants, it is important to determine whether certain weeds and grasses serve as alternate hosts on which the insect can breed and feed during both the rice season and the off-season. Definitions of planthopper “host plants” differ. Mochida and Okada (1971) compiled more than 90 plant species other than *Oryza sativa* L. that belong to various families and are believed to serve as host and oviposition plants for the BPH in Japan. They doubt, however, that all are satisfactory host plants for the insect. They consider a real host plant as one on which the insect could develop for at least one generation in the field. Oka (unpubl.) caged 34 species of weeds and grasses individually and infected each with 200 BPH adults. The survival rate on all plants was very low, and by the third week after infestation nearly all the insects were dead. Although they produced a few nymphs on all the test plants, all nymphs were dead 15 days after infestation (Table 1).

Knowing the real alternate hosts for any insect pest is important in sanitation programs. Sanitation aims to remove all breeding or hibernating sites and sources of food of the insect. In Okayama. Japan, epidemics of the rice dwarf virus transmitted by the green leafhopper were almost completely subdued within 2 years by winter plowing to control weeds such as *Alopecurus aequalis* Sobol, an alternate host for the green leafhopper (Nakasuji and Kiritani 1976).

A sanitation program to control the BPH should aim mainly at destroying the stubble and ratoon remaining in a harvested rice field, because the insect can survive in great numbers in the off-season (IRRI 1971) and in fallow period on stubble and ratoon, which may serve as a source of inoculum for the grassy stunt virus and the ragged stunt virus. Stubbles should be plowed under immediately after harvest (Anonymous 1974; Oka 1975) and the field prepared for the next planting. Israel (1969) and Kulshreshtha et al (1974) suggest burning stubble and straw after the punja crop. That practice, carried

Table 1. Survival Of adults Of the brown planthopper and production of nymphs on various weeds.

Weed species[a]	1st wk		2nd wk		3rd wk		Total survival	
	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs
Brachiaria mutica	0	0	0	12	0	0	0	0
Isachne implexicaulis	0	0	0	277	0	7	0	0
Fimbristylis littoralis	5	0	0	99	0	0	0	0
Eragrotis uniloides	0	0	0	20	0	0	0	0
Cyperus cyperoides	1	0	0	56	0	1	0	0
Cyperus difformis	25	0	0	53	0	0	0	0
Cyperus compressus	2	0	0	16	0	0	0	0
Cyperus kyllinga	0	0	0	110	0	0	0	0
Cyperus iria	15	0	0	36	0	0	0	0
Echinochloa crus galli	6	0	0	223	0	1	0	0
Echinochloa colonum	2	0	0	442	0	0	0	0
Scirpus juncoides	5	0	0	171	0	1	0	0
Axonopus compressus	0	0	0	32	0	0	0	0
Eleusine indica	0	0	0	19	0	0	0	0
Fuirena ciliaris	6	0	0	19	0	0	0	0
Leersia hexandra	1	0	0	27	0	0	0	0
Paspalurn vaginatum	0	0	0	48	0	0	0	0
Cynodon dactylon	0	0	0	10	0	0	0	0
Eleocharis pellucida	1	0	0	305	0	0	0	0
Ischaemum rugosum	0	0	0	186	0	0	0	0
Sorghum heolepensis	0	0	0	99	0	0	0	0
Cyperus malacaensis	0	0	0	226	0	0	0	0
Dactyloctenium aegytium	1	0	1	267	0	0	0	0
Bachiaria muticum	0	0	0	21	0	5	0	0
Sphenoclea ap.	0	0	0	61	0	0	0	0
Eclipta alba	0	0	0	0	0	0	0	0
Hyptis capitata	0	0	0	0	0	0	0	0
Panicum distachium	0	0	0	111	0	0	0	0
Ischaemum timorense	1	0	0	227	0	0	0	0
Digitaria sanguinalis	1	0	0	405	0	0	0	0
Rottboelia exaltata	0	0	0	284	0	0	0	0
Cyperus ferax	0	0	0	247	0	0	0	0
Panicum tryphiron	0	0	0	67	0	0	0	0
Brachiaria sp	0	0	0	84	0	0	0	0

[a] Each weed infested with 200 adults.

out in North Sumatra right after harvest (Effendi 1976), helps reduce the pest population. But during wet weather the intensive schedule does not permit drying and, therefore, burning. Burning the stubble may also destroy most of the arthropod populations that play an important role in decomposing plant remains. Burning also eliminates the available nitrogen in the plant remains. Moreover, nutrient loss by leaching is much higher after burning (IRRI 1973).

Weed sanitation in rice fields is, of course, needed, particularly when the rice plant is somewhat older. It makes a microclimate that is less favorable for the insect. However, weeds and grasses from the ditches and fallow fields do not have to be completely removed because they may shelter natural enemies of the BPH. Moreover, weeds are not an ideal habitat of the pest (Otake and Hokyo 1976; I. N. Oka, unpubl.). More research is needed to determine the role of weed grasses in the interaction of the insect pest with its natural enemies.

WATER MANAGEMENT

The BPH prefers lowland (irrigated) to upland rice. It multiplies near the plant base where the microenvironment is humid and shaded (Pathak 1968; Nishida 1975). Rice fields with standing water have been found to encourage the multiplication of the BPH (Pathak and Dyck 1973; Fernando 1975). Experiments at IRRI with continuously flooded plots devloped two large peaks of BPH population. But when the field was kept saturated but not flooded, only one moderate peak developed (IRRI 1972; Dyck 1974a). Stapley (1975) also reported that the BPH problem in the Solomon Islands increased when irrigated rice cultivation replaced dry rice cultivation. In Japan, the insects are numerous in humid lowlands (Suenaga 1963).

Good water management could be a means of controlling the planthopper. Miller and Pagden (1930) reported that several outbreaks of the insect in Malaysia were suppressed by draining the fields for about 2 days. In the Philippines farmers stop irrigating infested fields that are almost mature, and spread the plants apart every few rows to help dry the field (Dyck 1974a). Draining rice fields at the proper time and withholding irrigation water for a while also effectively control the rice water weevil (Pimentel et al 1965).

Excess water also hinders development of the BPH. Esaki and Sameshima (1940) found that the insects eggs perished if kept on leaves at 100% relative humidity. Raising the water level can destroy eggs laid in the leaf sheaths. In Taiwan, Iso (1954) and Grist (1968) reported that the insect was controlled by deep irrigation early in the morning, followed by the addition of a certain amount of kerosene (preferably mixed with pyrethrum) to the water. The plants are shaken to cause the insect to fall into the water. An oil-dropping method with whale oil was used in Japan as early as 1670 to control rice planthoppers (Mine 1910). Raising the water level was a common practice in Indonesia to control the BPH (Tjoa 1952). Sand or sawdust containing 0.25 liter kerosene for every 100 sq m was broadcast on the raised water level and the plants were shaken.

In Fiji raising the water level as the plants grow is also suggested to drown eggs and drive the insect from its favored location on the lower stems (Hinckley 1963).

SPACING

Close spacing of rice plants is believed to contribute to the rapid increase of the BPH population (Kalode 1974; Fernando 1975; Kisimoto 1976a). Experiments at IRRI showed that at times of peak insect populations, both tall and short Peta had significantly more BPH per tiller at 10- × 10-cm spacing than at 50- × 50-cm spacing (IRRI 1972; Dyck 1973). Rectangular plantings (25 × 24 cm) and three-row plantings to facilitate use of the horse-drawn paddy weeder (27-39-27 × 18 cm) tended to have more BPH than row plantings

(60 × 9 cm). If the rows ran east to west, the population also tended to grow (Suenaga 1963). With closely spaced plants microenvironments were slightly cooler and more humid. Mochida (1964) reported that 20 macropterous females laid a total of 2,967 eggs in late August and 2,798 in late September. Temperatures were higher in August than in September.

Cooler temperature in the closely spaced plants may not be the main cause of the BPH populations. More important might be the fact that a shaded and humid microenvironment is unfavorable for the development of the natural enemies of the insect (Nishida 1975).

Close planting, particularly when associated with repeated foliar sprays of parathion enhanced the development of the BPH at IRRI in 1976 (pers. comm. with E. A. Heinrichs). That may be because foliar sprays may not reach insects that are "protected" by the thick canopy of the rice crop, but they destroy natural enemies inhabiting the foliage (Nishida 1975). Aerial spraying of phosphamidon and fenitrothion on the thick canopy of rice failed to check a hopper infestation in Kerala, India (Kulshreshtha 1974).

Little sunshine reaches the bases of closely spaced rice plants. Since the BPH is negatively phototaxic (Pathak 1968), such a dark habitat is an ideal place for it to congregate and multiply. Suenaga (1963) reported that solar and ultraviolet radiation act abiotically against the BPH and restrain its increase. Spacing that allows some sunshine to reach the basal area of the rice plants for some part of the day may thus be another reason for smaller insect populations. The most appropriate spacing would let enough sunshine penetrate to prevent pest increase, but would provide a suitable habitat in which biological control agents could develop. It would allow insecticide sprays, if necessary, to reach the area where the insects congregate. Kulshreshtha et al (1974) suggested planting the crops in rows 15 to 20 cm apart.

More studies are needed to determine how plant spacing influences the complex interrelationships of environmental factors, the BPH, its natural enemies, and rice production.

FERTILIZER MANAGEMENT

While some insect species responded negatively to increased nitrogen fertilization of crops, the populations of many others — certain aphid species and spider mites (Pimentel 1965)—significantly increased with nitrogen level. The rice stem borer *Chilo suppressalis* Walker (Ishii 1964) and gall midge *Orseolia oryzae* (Wood-Mason) (Narayanan et al 1973) were significantly more plentiful in fields receiving high rates of nitrogen.

The BPH population was also largest on plots treated with a combination of 27.3 kg N, and 13.6 and 27.3 kg P_2O_5 (Abraham 1957). Females reared on plants receiving high nitrogen levels showed increased fecundity (Kalode 1971, 1976). IRRI experiments demonstrated that nitrogen fertilizer contributed to the population increase of the pest (Dyck 1973). Evidence from various countries suggests that high rates of nitrogenous fertilizers have caused increased BPH infestations (Dyck and Hsieh 1972; Chatterji 1975; Fernando 1975; Kulshreshtha et a1 1974; Velusamy et a1 1975: Samino 1976). But it is not clear why the high fertilizer levels are associated with greater numbers of planthoppers (Mochida and Dyck 1976). Nishida (1975) suggested that they contribute to the thickness of the canopy.

High rates of nitrogenous fertilizers may result in more protein and amino acid synthesis by the rice plant. The proteins and amino acids are among the essential requirements for growth and development of immature insects and are often needed by adults for the reproductive process (House 1965; Bursell 1970).

Although reducing the amount of applied nitrogen may lower BPH populations, large amounts are essential for high rice yields. It is, therefore, not realistic to recommend less fertilizer use even if pest problems are exaggerated (Pathak 1971; Dyck 1974a).

Integrating the use of fertilizer-responsive BPH-resistant varieties with other control methods should achieve both high rice production and BPH control.

TIME OF PLANTING AND SHORT-DURATION RICE

Manipulation of planting time (early or late) can provide effective control of some pests. For example, epidemics of the Hessian fly *Mayetiola destructor* (Say) on winter wheat are avoided by late fall souwing (Metcalf and Flint 1951). Late planting of rice minimizes infestation by the white rice stem borer *Tryporyza innotata* (Walker) (Goot 1948).

At Cuttack, India, Israel (1969) reported that crops planted by the end of July suffered little from leafhoppers and planthoppers, but crops planted later were severely attacked. Gradual buildup of the BPH population from the beginning of the rice season could cause severe damage to late-planted rice. Early planting also implies simultaneous planting over wide areas, early in the season.

In Sri Lanka the susceptible short-duration (110-day) varieties Bg 34-8 and Bg 94-2, planted in April or up to about 10 May, escaped serious planthopper damage. But 130-day varieties like IR26 were destroyed when planted in the same period. Only two generations of the insect occur on short-duration varieties, while three full generations occur on long-duration cultivars (Fernando 1975). In areas with staggered planting patterns, the short-duration varieties may be damaged because the BPH population is continuously high (Mochida et a1 1976). Therefore, their use should be integrated with such other control measures as simultaneous planting.

CONCLUSION

Little experimental work has been carried out on cultural control of the BPH. In view of the ecobiology of the pest and rice crop, and tentative suggestions of causes for recent outbreaks, the following cultural control methods are suggested :

1. Simultaneous planting and cropping of rice over large areas;
2. Rotating rice with nonhost crops, or fallowing between two rice crops;
3. Selective elimination of suitable hosts and habitats (sanitation);
4. Plant spacing to allow some sunlight to reach the basal portion of the rice plants;
5. Proper water management, i.e. raising the water level, or draining the field for a few days;
6. Early planting of short-season rice; and
7. Integration of methods 1-6 with resistant varieties and the judicious use of pesticides.

The most promising cultural method for planthopper control is synchronized rice cropping and rotation with other crops. Such an approach also makes other pest complexes easier to monitor.

If cultural control of pests is to be more widely accepted, several sociological and political constraints must be overcome.

1. Farmers have to be convinced of the advantages of the method.
2. The regulation of irrigation water may have to be modified so that water becomes available to groups of farmers situated in a large area.
3. Large numbers of farmers have to be organized.
4. There must be close cooperation among researchers, extension people, and local authorities to guide and supervise the program. It may even be necessary to have legislation to enforce the simultaneous planting of rice and proper rotation.

The ideas suggested here should be tested in experiments to allow us to arrive at a sound cultural method or methods that can be recommended as a component of an integrated program to control the BPH.

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