Studies on varietal resistance to the brown planthopper in Taiwan

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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	Srl 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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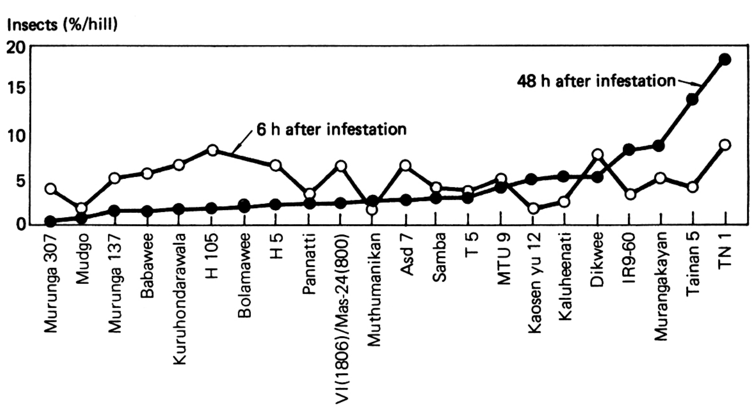
varieties less than they did the susceptible varieties (Fig. 1). In general, the variety preferred by the adult insect was also preferred by the nymphal insect (Table 2), and the variety that the insect preferred for feeding or for shelter was the one it also preferred for depositing eggs (Fig. 2). During 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).

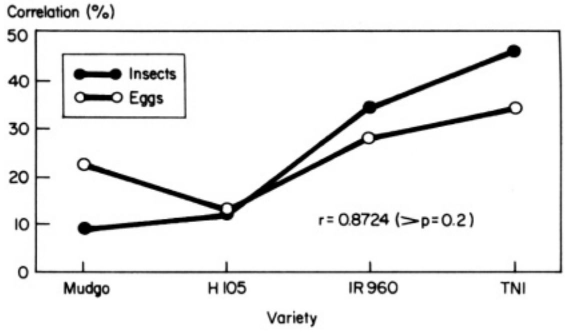
Variety	Insects[a] (%) on plant at				
	Instar			Adult stage	
	1st	2nd-3rd	4th-5th	Female	Male
Mudgo (R)	12.7	11.7	5.3	10.2	14.2
H 105 (R)	19.9	11.1	14.9	9.6	13.4
Samba (R)	20.2	12.5	20.8	13.9	12.7
TN1 (S)	47.3	64.7	59.7	66.3	59.7
LSD 5%	7.44	15.13	5.81	14.04	6.8
LSD 1%	10.69	21.21	8.35	21.27	10.31

[a] Differences among insect stages within a variety were not significant.

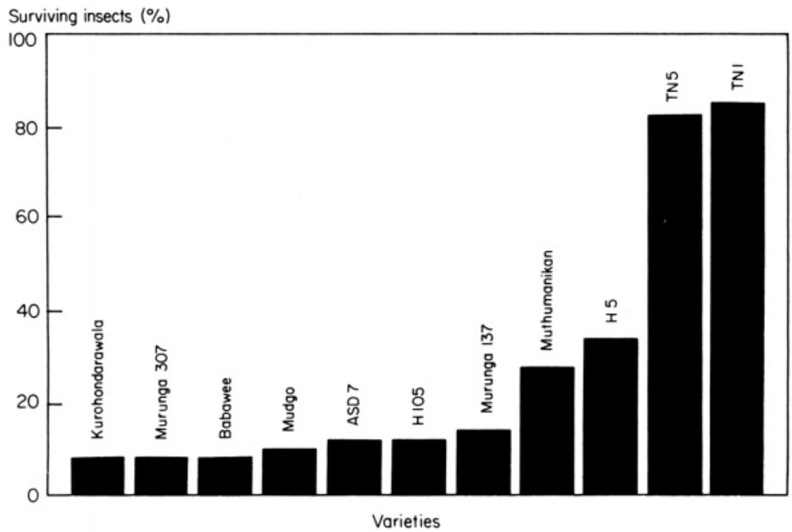
In greenhouse and field trials, the BPH exhibited strong nonpreference for the following varieties: Mudgo, Murunga 137, Murunga 307, Sudarvi 305, Sudarvi 306, Balamawee, Rathu Heenati, Heenukhulama, Babawee, Kuro-hondarawald, Ptb 18, Pawakhulama, SLO 12, Sinnakayam, Tibiriwewa, EK 1263, and Andaragawewa. 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).

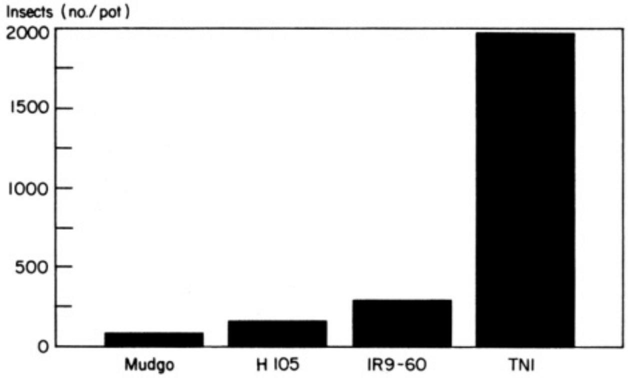
rate of nymphs caged with resistant varieties ranged from 8 to 38%, while that of nymphs caged with susceptible varieties ranged from 82 to 85%. Furthermore, the nymphs on resistant varieties generally took longer to become adults than those on susceptible plants. Varieties that exerted high mortality 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.

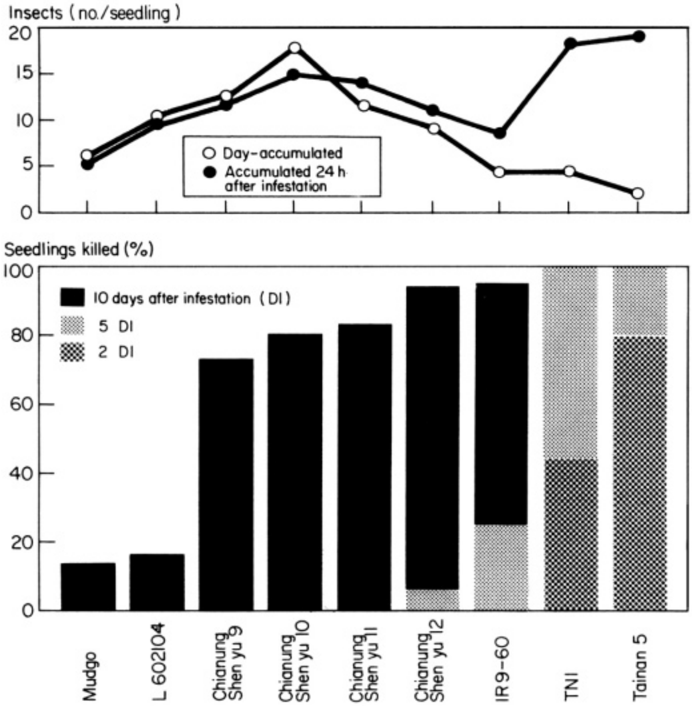
increased more than 200 times on a susceptible variety 50 days after caging, but only 6 to 30 times on resistant varieties (Fig. 4). The lower rate of population increase on resistant varieties seemed to have been caused by the high mortality of adults and nymphs, or by reduced fecundity.

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.

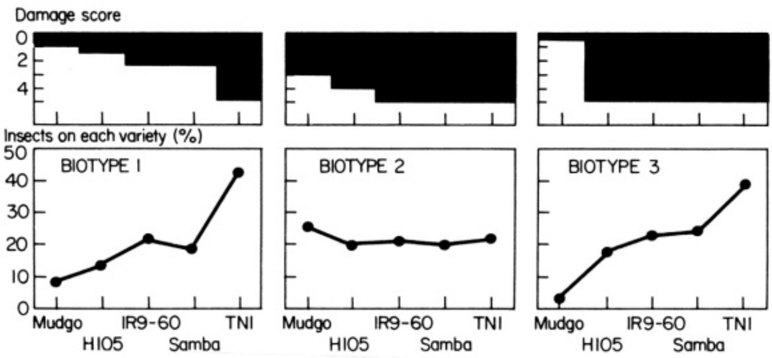
Variety	Seedlings killed (%) by		
	Biotype 1	Biotype 2	Biotype 3
Monogenic recessive (bph 2)			
IR9-60	10	90	100
Kaosen-yu 12	10	100	100
ASD 7	10	100	100
H 5	20	100	100
Samba	30	100	100
Pannetti	30	100	100
H 105	10	100	100
Dikwee	20	100	100
Anbaw C7	50	90	100
Monogenic dominant (Bph 1)			
Pawakhulama	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.)

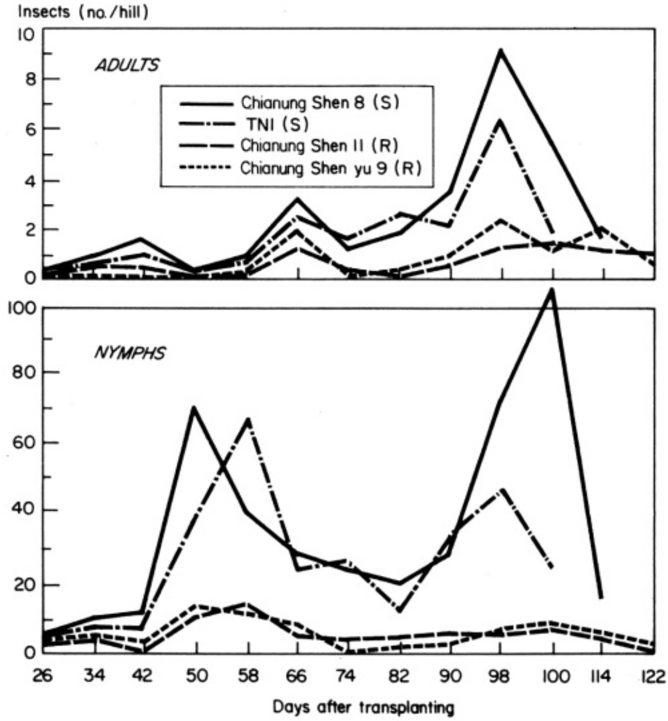
IET5120, IET5122, IET5236, CR94-13, and BR1030-65-1, were resistant to all the biotypes mentioned.

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.

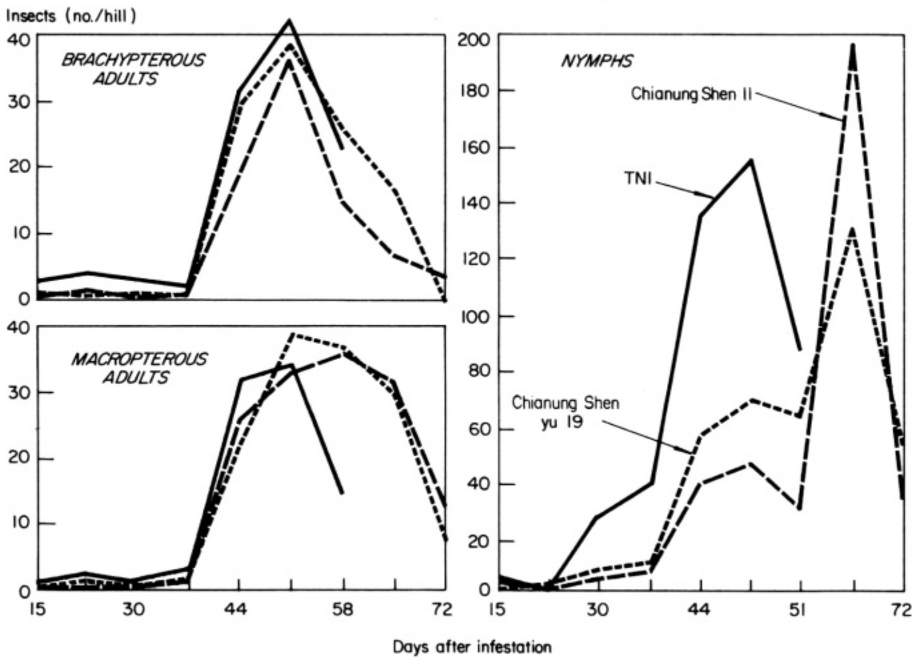
In the second crop of 1973, the development of BPH populations on a resistant variety and a susceptible variety was observed in the screenhouse. Sixteen hills of each variety were planted in a small concrete bed (1 × 1 m), with three replications in a randomized complete block design. One pair of macropterous 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



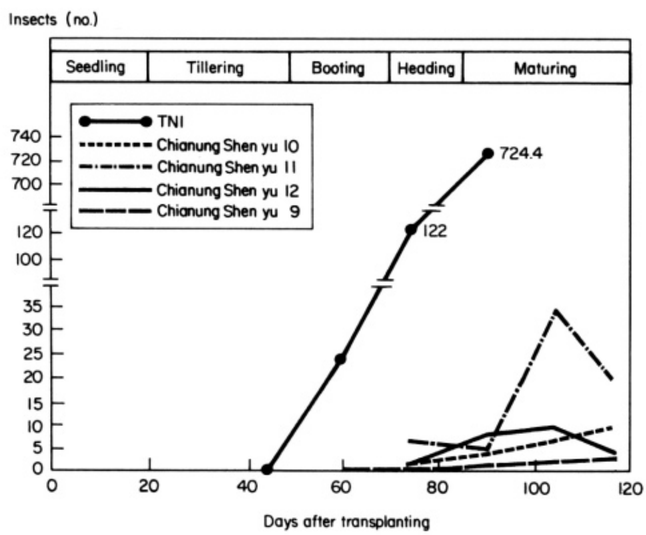
7. Density of brown planthopper on resistant and susceptible varieties in a screenhouse experiment. Single pairs of macropterous adults were introduced to a 16-hill plot 5 days after transplanting.

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 screen-house, 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.

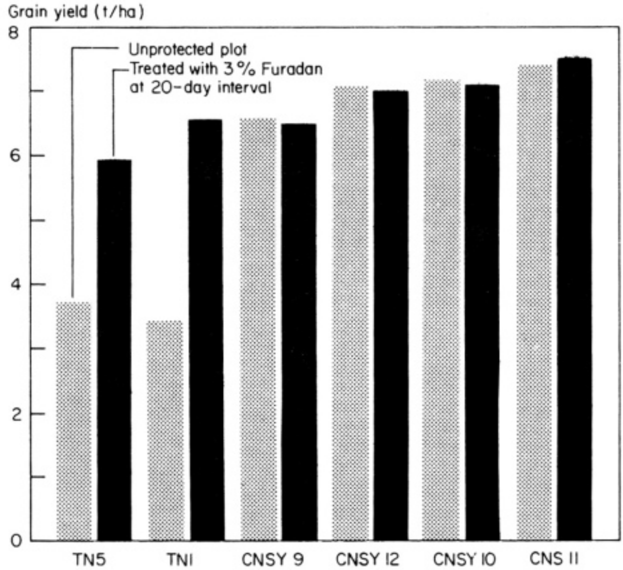
Variety or line	Insects[a] (no./hill)				Grain yield (kg/ha)		Profit from pesticide use[c] (NT$/ha × 1000)
	65 DT	81 DT	95 DT	109 DT	Protected plots[b]	Unprotected plots	
Mudgo	5.8	0.1	0.3	0.1	3565	3157	–3.72
CS 621230	6.9	1.6	2.2	2.4	6243	6524	–1.45
CS 621373	8.4	2.6	6.1	2.4	6040	5533	–2.63
CS 611337	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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