10. RESISTANCE TO LEAFHOPPERS AND PLANTHOPPERS IN RICE VARIETIES

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Introduction

Several species of leafhoppers and planthoppers are serious pests of rice. They damage the rice plant by feeding on it which results in loss in vigor of the plant, reduction in tiller number, increase in unfilled grains and hopperburn in severe cases, and by transmitting virus diseases. Some of the more common species of these insects with their host plants, distribution and the viruses they transmit are listed in Table 1. The literature on these pests has been reviewed (Everett 1970, Kisimoto 1970, Pathak 1968).

There appears to be a general increase in the populations of various leafhoppers and planthoppers in recent years. The exact cause of this increase is not known but is often attributed to the shift to growing short statured and heavy tillering rice varieties, and the use of greater quantities of nitrogenous fertilizers. Such a change in

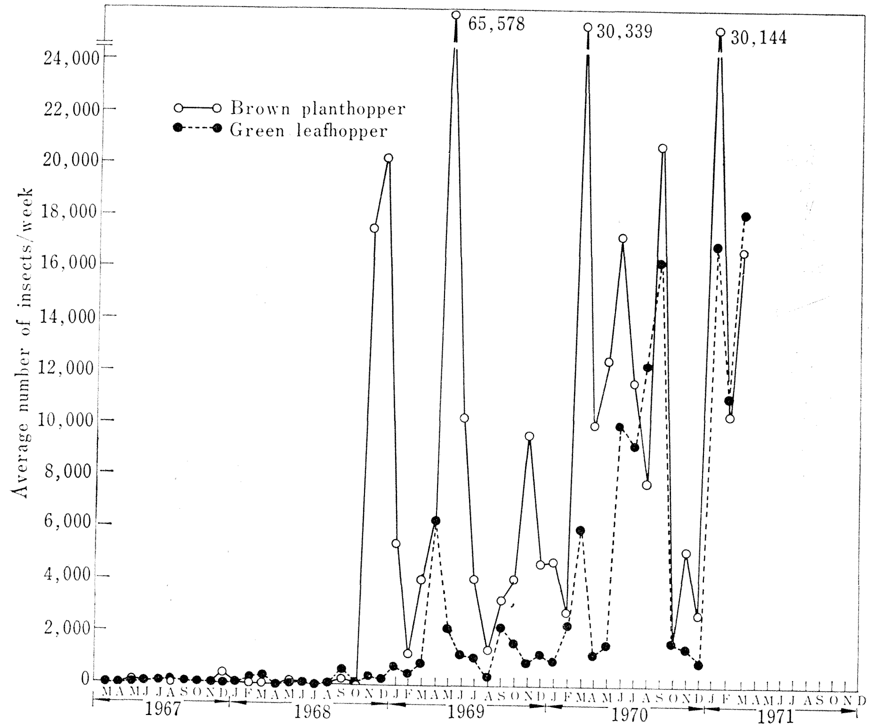

Fig. 1. Change in the abundance of adults of the brown planthopper and green leafhoppers as shown in light trap catches (IRRI, 1967–1971).

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Table 1. Common leafhopper and planthopper pests of rice (Pathak 1968).

Name	Common name	Formally recorded as:	Host	Distribution	Vector of:
Family DELPHACIDAE	Planthoppers				
Sogatella furcifera	white backed planthopper	*Sogata furcifera* *Delphacodes furcifera*	rice, millets, maize, and other grasses	Tropicopolitan Caribbean, Brazil, South and Southeast Asia, Japan, Korea.	
Sogatodes oryzicola	rice delphacid	*Sogata orizicola* *Sogata braziliensis*	rice	Southern United States, Caribbean Islands, Central America	Hoja blanca
Sogatodes cubanus		*Sogata cubana*	Echinochloa and other grasses	Southern United States, Caribbean Islands, Central Ameriac	Hoja blanca
Nilaparvata lugens	brown plant-hopper	*Hikora formosana*	rice and grasses, sugarcane	South and Southeast Asia, China, Japan, Korea, Micronesia	Grassy stunt
Family CICADELLIDAE	Leafhoppers				
Laodelphax striatellus	small brown planthopper	*Delphacodes striatella* *Laodelphax striatella*	rice, wheat, millets, barley	Japan, Formosa, Palearctic regions	Rice stripe disease, rice, black streaked
Nephotettix cincticeps	rice green leafhopper	*Nephotettix bipunctatus* *Nephotettix apicalis cincticeps*	cereals and weeds	Japan, Taiwan, Korea, Manchuria, China	Dwarf, yellow dwarf
Nephotettix impicticeps	rice green leafhopper	*Nephotettix bipunctatus*	rice, wheat, barley, citrus	Japan, Taiwan, Indian subcontinent	Yellow dwarf tungro, penyakit merah, yellow-orange leaf
Nephotettix apicalis	rice green leafhopper	*Nephotettix apicalis* *Nephotettix bipunctatus apicalis* *Nephotettix apicalis apicalis*	rice	South and Southeast Asia, Japan	Dwarf, yellow dwarf, transitory yellowing
Recilia dorsalis	zigzag leafhopper	*Deltocephalus dorsalis*	rice	South and Southeast Asia, Japan, Taiwan	Rice dwarf, orange leaf

populations at the International Rice Research Institute where these practices are intensively followed is shown in Fig. 1. However, the short statured heavy tillering rice varieties and the use of larger quantities of fertilizers are essential for obtaining high yields of rice, and it is not realistic to discourage them even though they may exaggerate pest problems. Therefore, it is important that such methods that help keep the leafhopper and planthopper populations low in spite of the above practices should be thoroughly investigated. The use of insect-resistant rice varieties is one such possibility. This paper reviews progress made along this line at the International Rice Research Institute.

Search for Resistant Varieties

A total of 10,000 different varieties and selections of rice collected from all over the world were evaluated for their resistance to stem borers (Pathak *et al.* 1971). One thousand four hundred varieties selected from these tests were also evaluated for their resistance to the green leafhopper, *Nephotettix impicticeps* Ishihara, the brown planthopper, *Nilaparvata lugens* (Stål) and the white backed planthopper, *Sogatella furcifera* (Horvath). This led to the identification of several varieties that are highly resistant to these pests. Currently, several hundred more varieties are being evaluated to identify additional sources of resistance.

The screening for varietal resistance to these insects is done by growing the test varieties in $60 \times 40 \times 10$ cm seed boxes. Each variety is sown in a 20-cm long row (half the width of the seedbox). Each seedbox contains 10 rows at 10 cm apart. One row is planted to a susceptible check variety and one to a resistant check. At one week after seeding these seedboxes are transferred on to a $5.2 \times 1.3 \times 0.1$ m iron sheet tray inside a large screen cage and several thousand insects of a test species are uniformly scattered on the seedlings. This infestation is sufficient to kill susceptible varieties. Water is maintained at a depth of 10 cm in the tray and serves as irrigation water for these plants, helps maintain high humidity and keeps the ants off the plants.

The number of insects present on each variety and the damage they cause to the plants are recorded at 5-day intervals. The grading for plant damage is done by following the standards described below:

Grade	Description of damage to the plants caused by		
	Green leafhopper	Brown planthopper	White backed planthopper
0	No visible damage.	No visible damage.	No visible damage.
1	Yellowing of the first leaf.	Partial yellowing of the first leaf.	The first leaf yellow-orange in color.
2	1/2–3/4 of the total leaves yellow.	Partial yellowing of the first and second leaves.	About 50% of the leaves, or at least their tips, yellow-orange. Slight stunting of the plants.
3	All leaves yellow. Leaf sheaths and stem green.	Pronounced yellowing and some stunting.	Most of the leaves or their tips yellow-orange. Stunting of the plants.
4	About 50% of the test plants killed.	Wilting and severe stunting	About half of the test plants killd. Signs of wilting and severe stunting.
5	All test plants killed.	All test plants killed.	All test plants killed.

The final grading is made after all susceptible check rows are killed. The varieties falling in the grades of 0–2 are further evaluated for the consistency of their resistance. Others are classified as moderate to highly susceptible and are discarded from

Table 2. List of rice varieties highly resistant to *Nephotettix impicticeps*, *Nilaparvata lugenus* and *Sogatella furcifera*.

Nephotettix impicticeps	*Nilaparvata lugens*	*Sogatella furcifera*
Ginmasari	Ptb 18	Pu San 1
Intan 2400	Ptb 21	Dahanala 2014
Peta 2802	Murungakayan 302	CI 5662–2
CO–9	Kosatawee	JBS 34
Guwen-gu-gi-goo	Sinnakayam	C 5–17
Pankhari 203	Sinnasuappu	Miao-Tien-I-Li-Chan
PTB–21	PK–1	Tien-Lie
ASD–7	ASD 7	Pankhari 203
ASD–8	Babawee	SLO 12
D–204–1	Balamawee	B 76
Su-yai 20	CO 22	Colombo
Tilokachari	Dikwee	Mudgo
Jhingasail	Gangala	3–Month Variety
Godalki	Hathiel	Kaluheenati
DNJ 27	H 105	Sudhubalawe
DNJ 9	Kuruhondarawala	Vellailangayan
DS 1	MTU 15	ARC 5752
DM–77	Mudgo	ARC 6248
DV–29	Murunga 307	ARC 6563
DV–139	PTB 19	ARC 6624
IR–8	Seruvellai	ARC 6634
ARC 5752	SLO 12	ARC 6650
ARC 6006	Sudurvi 305	ARC 7251
ARC 6038	Thirissa	ARC 7331
ARC 6050	T 5	ARC 10214
ARC 6102	Vellailangayan	ARC 10595
ARC 6162	Rather Heenati	ARC 10600
ARC 6180	Sinna Karuppan	ARC 10618
ARC 7059	Periamorungan	MTU 18
ARC 7302	Podikwee	HR 106
ARC 10229	Mahadikwee	SUDURVI 306
ARC 10243	Ovarkaruppan	
ARC 10281	Madayal	
ARC 10656	Palasithari 601	
ARC 10746	Murungakayan 3	
ARC 10804	Murungakayan 101	
ARC 10826	Murungakayan 304	
	Murungakayan 303	
	Hondarawala 502	
	Hondarawala 378	
	Murungakayan 104	
	M. I. 329	
	Pawakkulama	
	Tibiriwewa	
	Heenukkulama	
	Anadaragahawewa	

further tests.

Based on these studies several varieties were identified as highly resistant to these insects (Table 2). The resistance of these varieties could have been due to one or more of the following factors: (1) These varieties were not preferred by the insect (non-preference), (2) They possessed high tolerance to insect damage (tolerance) and (3) The plants contained factors which prevented the insects from feeding on them or were toxic to the insects (antibiosis) (Painter 1958).

Generally, it is this third type of resistance which is most desirable since, in the absence of preferred hosts, the insects may infest those that are non-preferred and heavy populations can damage the tolerant plants. In our tests, therefore, emphasis is being placed on identifying varieties that possess the antibiosis type of resistance. This is done by caging a uniform number of insects (either adults or nymphs) on individual 20-day-old plants of selected varieties. The varieties which bring about the least survival of the insects are classified as truly resistant and are used in future tests. The results of one such experiment using selected rice varieties and the green leafhopper and brown planthopper are presented in Fig. 2. (Pathak *et al.* 1969). The brown planthopper nymphs had very low survival on the variety Mudgo and died within 10 days after caging, but had high survival on the varieties Taichung (Native) 1 and Pankhari 203 on which about 80% of the caged insects survived to become adults. In general a similar reaction was recorded against the green leafhopper except that the variety Pankhari 203 was highly resistant to it while Mudgo was susceptible. This also demonstrated that the resistances to the brown planthopper and the green leafhopper are of a different nature.

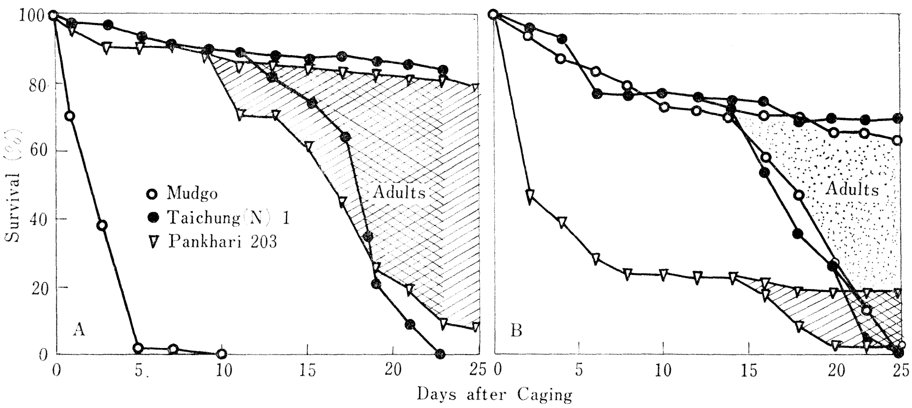

Fig. 2. Survival and development of first instar *Nilaparvata lugens* (A) and *Nephotettix impicticeps* (B) nymphs on 60-day-old plants of resistant and susceptible varieties. (A similar difference in insect survival on these varieties was also recorded in experiments using 15-, 45-, and 90-day-old plants.) (IRRI, 1968)

In another similar experiment the brown planthopper nymphs caged on resistant varieties suffered high mortality and had a slower rate of growth than those caged on susceptible varieties. The varieties Balamawee, Kuruhondarawala and Babawee had even greater resistance than the check variety Mudgo (Fig. 3). Similar tests have been conducted on the green leafhopper and the white backed planthopper to confirm the resistance of the selected varieties.

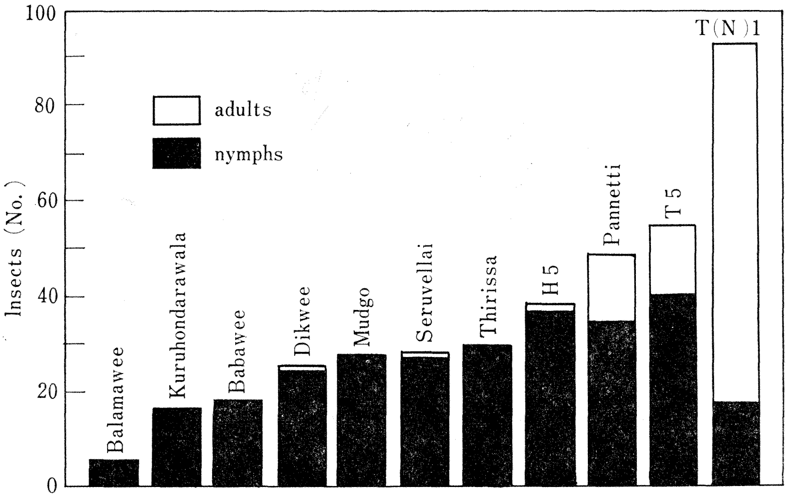

Fig. 3. Survival and growth of first-instar *Nilaparvata lugens* nymphs at 14 days after caging on selected resistant and susceptible rice varieties (IRRI, 1970).

Damage Caused by the Insect to Selected Varieties

Differences in damage to plants by the same number of insects were determined by caging insects on individual potted plants of selected varieties. In one such test 50, 100 and 200 first-instar nymphs were, in separate treatments, caged on individual plants of Mudgo, Taichung (Native) 1 and Pankhari 203. The plants used were at 15 days after transplanting. An infestation of 50 nymphs of the green leafhopper or the brown planthopper caused barely noticeable symptoms of damage on resistant varieties but severely damaged the susceptible check variety Taichung (Native) 1. A population of 100 nymphs per plant caused only yellowing of the lower leaves of resistant varieties at 10–15 days after infestation but all plants of Taichung (Native) 1 were killed (Fig. 4). The comparative damage to resistant and susceptible varieties remained the same when 200 nymphs were caged on each plant.

Thus the insects caged on resistant plants had lower survival and caused less plant damage than those caged on susceptible hosts.

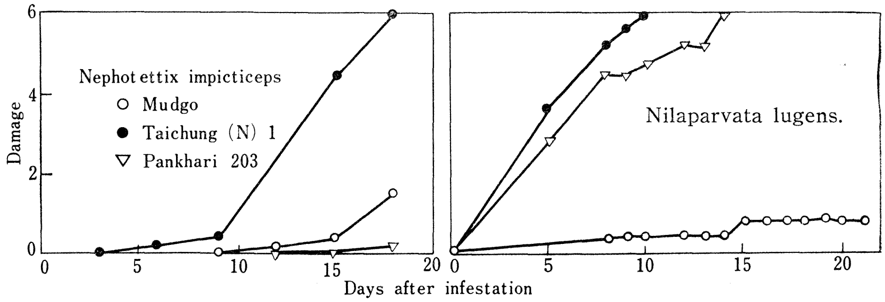

Fig. 4. Damage caused by caging 100 first-instar nymphs on resistant and susceptible varieties (IRRI, 1968).

Causes of Resistance

Non-preference of the insects for resistant varieties:

It was recorded in a series of experiments that the resistant varieties were generally less preferred by the green leafhopper or the brown planthopper than the susceptible varieties. The results of one such experiment on the brown planthopper are presented in Fig. 5. The insects at 1 hour after infestation did not show any

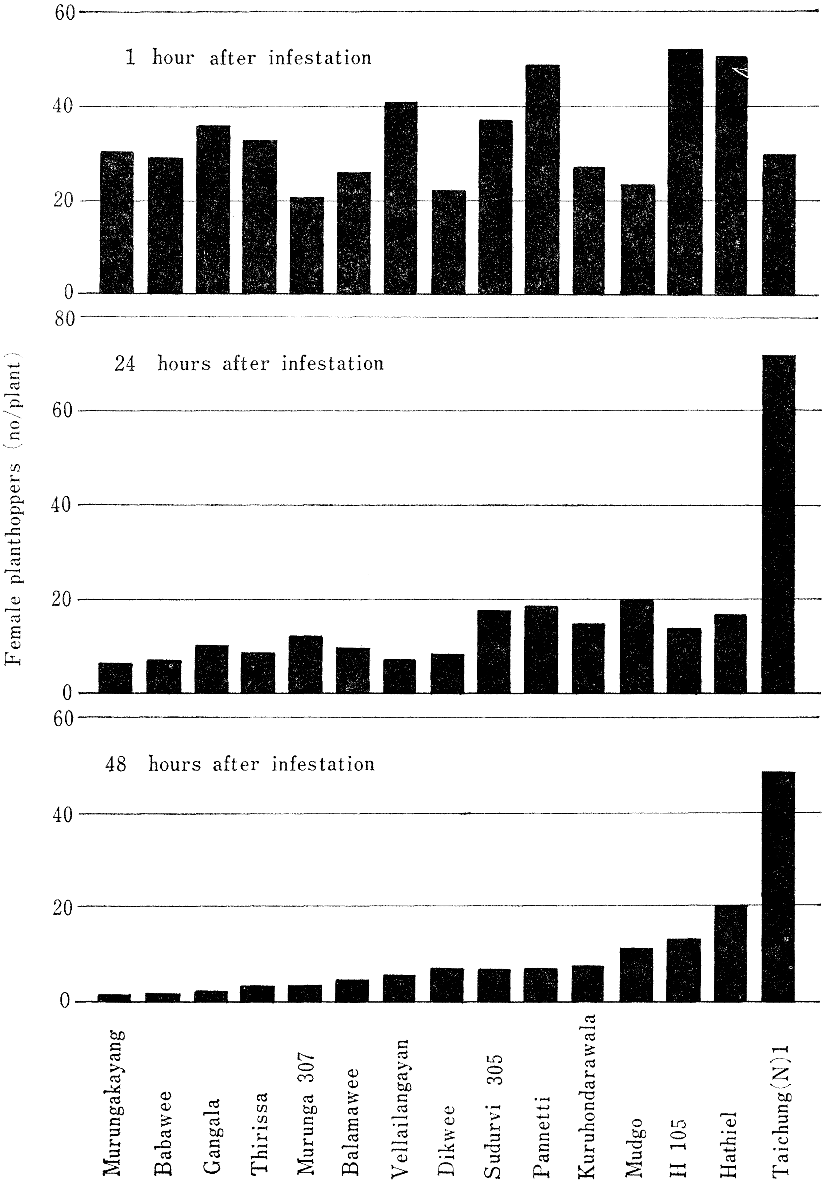

Fig. 5. Preference of the female brown planthopper for selected resistant and susceptible rice varieties (IRRI, 1970).

distinct preference reaction for different varieties, but migrated from resistant to susceptible varieties at 24 hours after infestation and beyond. This showed that the non-preference was more of a gustatory than olfactory or visual nature.

Similar tests conducted in the field showed that the insects did not show distinct differences in their alighting on different varieties, but they did not stay on resistant plants for sustained feeding (Sogawa and Pathak 1970).

The alighting and feeding behavior of the brown planthopper was further investigated by caging the insects separately on the susceptible variety Taichung (Native) 1 and the resistant variety Mudgo. Only a small proportion of them settled on Mudgo even though most of them died in 3–4 days after caging, but most insects moved on to the Taichung (Native) 1 plants within 3–4 hours after caging.

Similar differences in the preference of the green leafhopper for 3 selected rice varies are shown in Fig. 6.

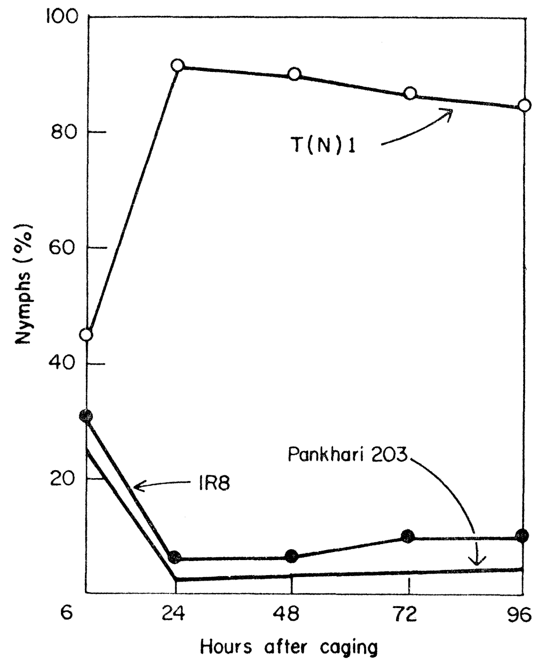

Fig. 6. Preferences of fifth-instar *Nephotettix impicticeps* nymphs for three varieties.

Ability of the insects to feed on resistant plants:

To determine whether or not the insects fed equally well on resistant and susceptible plants, the gain in body weight of the insects and the amount of honeydew excreted by them when caged on these plants were measured. The insects caged on resistant plants lost weight while those on susceptible hosts gained weight (Figs. 7 and 8). This effect was much more pronounced in the case of the brown planthopper than in that of the green leafhopper, and was illustrated more clearly by assessing the amount of honeydew excreted by them on resistant and susceptible plants.

The honeydew was collected on a filter paper at the bottom of a conical plastic cage placed around the base of the test plant. Five adult insects were introduced into

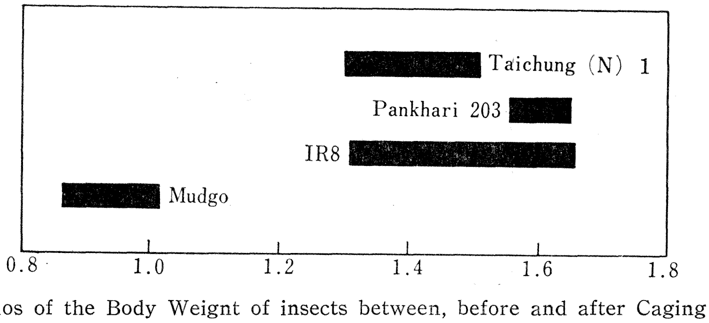

Fig. 7. Rate of change in body weights of female brown planthoppers in 48 hours in different rice varieties. The insects were kept without food for 48 hours before they were caged on these plants (IRRI, 1968).

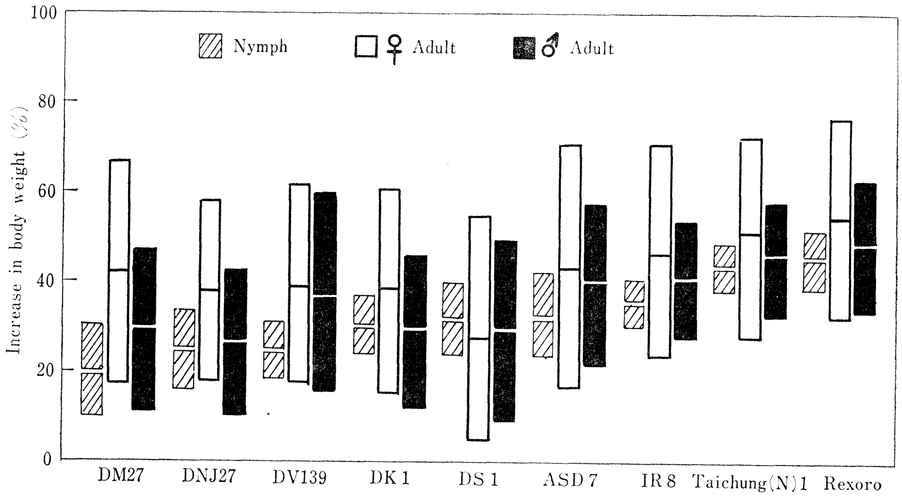

Fig. 8. Range of increase in body weight of *Nephotettix impicticeps* after feeding on different rice varieties (Nymphs fed for 4 hours; adults for 24 hours) (IRRI, 1969).

each cage and were removed 24 or 48 hours later. The dried honeydew on the filter paper was not visible to the naked eye but had a pale blue color under ultraviolet light and stained purplish red on treatment with ninhydrin. Also, a quantitative estimate of the honeydew was made by spectrophotometric assay of the total carbohydrates or sugars present in it.

These results showed that the brown planthopper did much less feeding on the resistant variety Mudgo than on the susceptible varieties IR8, Taichung (Native) 1 and Pankhari 203. Most of the feeding was done by female insects which exhibited a marked difference in feeding on different varieties by excreting 30–50 times more honeydew on the susceptible varieties tested than on the resistant variety Mudgo. The maximum feeding by the insects on Pankhari 203 (Fig. 9) offers an explanation for their greater weight gain on it than on other susceptible varieties (Fig. 7). The brown planthopper males did very little feeding on all varieties.

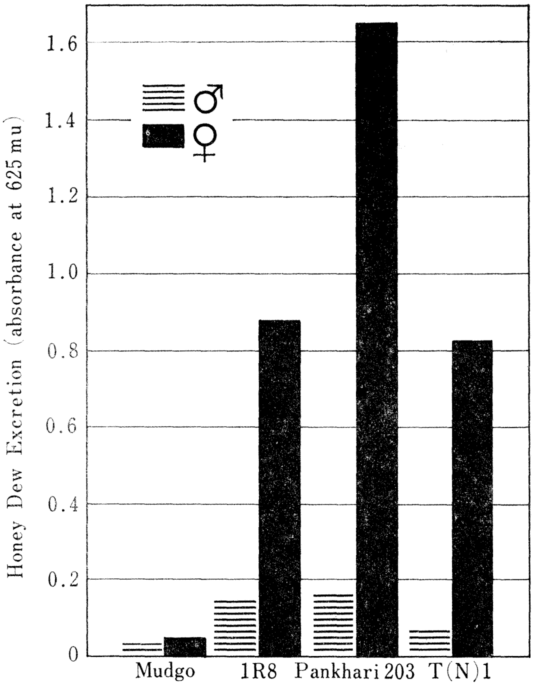

Fig. 9. Quantitative assessment of the *Nilaparvata lugens* honeydew excreted by five adults for 24 hours on different rice varieties by measuring their light interference in a spectrophotometer (IRRI, 1968).

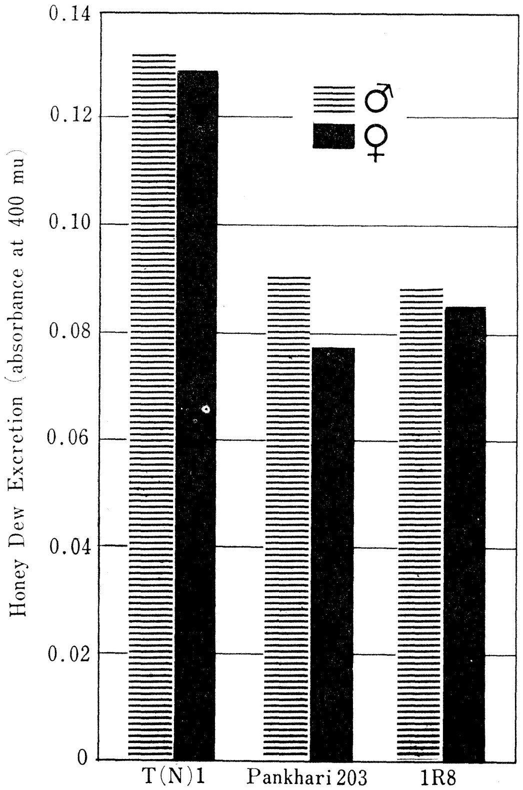

Fig. 10. Quantitative assessments of the honeydew excreted by the five *N. impicticeps* adults feeding for 24 hours on different rice varieties by measuring their light interference in a spectrophotometer (IRRI, 1968).

Although the green leafhopper excreted lesser amounts of honeydew on the resistant varieties Pankhari 203 and IR8 than on the susceptible variety Taichung (Native) 1, the differences were not as distinct as in the case of the brown planthopper (Fig. 10). Furthermore, unlike the brown planthopper both male and female green leafhoppers excreted identical amounts of honeydew, suggesting similar feeding quantities.

Accessibility of insects' stylet sheaths to feeding sites:

These results thus established that the insects did less feeding on resistant than on susceptible varieties. An investigation was carried out to determine whether or not this was due to any mechanical barrier that prevented their stylets from reaching the proper feeding sites. Microtome sections of the insect's stylet sheaths were made in different varieties (Sogawa and Pathak 1970; Cheng and Pathak, in preparation). It was found that the brown planthopper males or females caged on susceptible varieties IR8 and Taichung (Native) 1 produced an average of 15 feeding marks in 24 hours, while on Mudgo plants the male or female insects produced 31 and 50 feeding marks respectively (Table 3). Furthermore, stylet punctures through the fiber tissues (which are harder than the parenchyma cells) were more numerous in Mudgo than in IR8 and Taichung (Native) 1 plants. This indicated that the hardness of the tissues of the varieties tested was not a factor of planthopper resistance. Also a higher percent of salivary sheaths terminated in the vascular bundles of Mudgo than in the bundles of IR8 or Taichung (Native) 1 plants. Similar results were obtained for the green leafhopper caged on resistant and susceptible plants. Thus no mechanical barrier to the insects feeding was apparent in any of the resistant varieties tested. Furthermore, the insects made more feeding punctures on resistant than on susceptible hosts. These facts suggest that the variety Mudgo either lacked a feeding stimulus or possessed feeding repellents for the brown planthopper. However, the resistance to the green leafhopper, which did some feeding on resistant varieties, appears to be due to either a toxic factor for the leafhopper in the plants or the plants lacked nutrients vital to the insect.

Table 3. Comparison of the feeding behavior of brown planthopper adults on different rice varieties (IRRI, 1968).

Observation	Mudgo	IR 8	T(N)1
Average feeding marks per insect per day			
Female	50.8	15.8	15.4
Male	31.0	15.6	17.2
Sites of stylets penetration* (%)			
Fiber layer	45	22	10
Parenchyma	55	78	90
Termination of salivary sheaths* (%)			
Vascular bundles**	79	47	60
Non-vascular tissues	21	53	40

* Numbers of the salivary sheaths studied in Mudgo, IR8, and T(N)1 were 457, 153, and 425 respectively.

** Based on at least one branch of the salivary sheath entering the vascular bundles.

Further studies on the biochemical basis of resistance suggested that the brown planthopper resistance in Mudgo was attributable to the lower asparagine amino acid content of this variety (Sogawa and Pathak 1970). The details of these and other biochemical factors of resistance will be presented in another paper by Mr. Sogawa during this conference.

The asparagine content of the rice plant is believed to be greatly influenced by the amount of nitrogenous fertilizers applied to it. However, tests using various rates of nitrogenous fertilizers showed that the varieties Mudgo and Taichung (Native) 1 retained their comparative resistance to the brown planthopper at all fertility levels (Table 4).

Table 4. Effect of different levels of nitrogenous fertilizers on the reaction of Mudgo and Taichung (Native) 1 to the brown planthopper (IRRI, 1971).

Rate of nitrogen kg/ha	% Survival*		Male/Female ratio**		Total number of progenies produced***	
	T(N)1	Mudgo	T(N)1	Mudgo	T(N)1	Mudgo
0	30	2	1 : 2.3	1.5 : 1	4,775	11
50	38	0	1 : 1.4	1.4 : 1	5,139	0
100	44	10	1 : 1.2	2 : 1	6,835	19
150	54	22	1 : 1.4	1 : 1	8,875	85
200	57	18	1 : 1.6	1 : 1.1	9,363	70

* At 22 days after infestation with first-instar nymphs.
** At 17 days after infestation with first-instar nymphs.
*** At 37 days after infestation with first-instar nymphs.

Build Up of the Insect Population on Resistant and Susceptible Varieties

The insects caged on resistant varieties suffered higher mortality, had slower rates of growth, smaller body size, underdeveloped ovaries and laid fewer eggs than those caged on susceptible varieties. All these effects should bring about a cumulative reduction in pest populations on resistant varieties. In greenhouse experiments insects caged on resistant varieties generally died out or reached very low population levels within 2–3 generations while those caged on susceptible varieties increased several fold in each generation. Similarly in field plots only a small number of insects was recorded on resistant varieties while the susceptible varieties planted in adjacent plots were heavily infested (Fig. 11).

Genetics of Resistance

The genetics of resistance of several rice varieties to the brown planthopper and to the green leafhopper was studied in the greenhouse (Athwal *et al.*, in press). Two testing techniques were employed. In one, 7-day-old seedlings were infested with insects and then classified on the basis of insect injury. In the other, a known number of insects were caged on tillers of 6-week-old plants and insect survival was used as the criterion for classification. The resistance of Mudgo, Manavari CO22, and Dalwa Sannam MTU15 to the brown planthopper was controlled by single dominant genes which appeared to be allelomorphic. Another cultivar, Karsamba Red ASD7, possessed a single recessive gene for brown planthopper resistance which was either allelic or closely linked to the locus that conditions resistance in the other three varieties. The field reaction of F_3 lines of a cross between Mudgo and a susceptible cultivar was strongly correlated

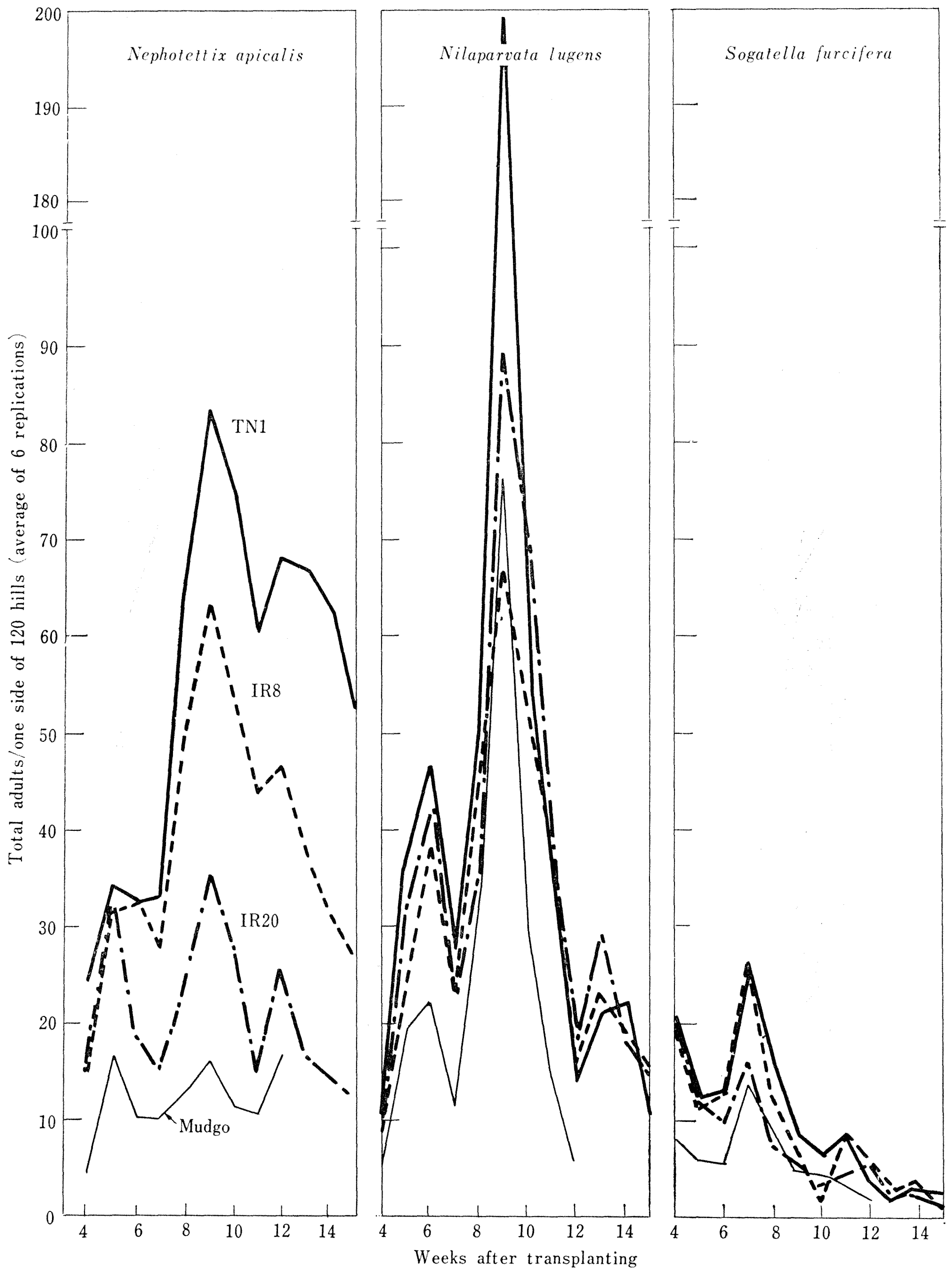

Fig. 11. Populations (average of 3 separate experiments) of different leafhopper and planthopper species on selected rice varieties (IRRI, 1969–970).

with the greenhouse reaction and apparently the same gene controlled planthopper resistance of different stages of growth. Resistance to the green leafhopper in the varieties Pankhari 203, ASD7, and IR8 was also controlled by single genes which were non-allelic and dominant. The planthopper resistance of Mudgo, the leafhopper resistance of Pankhari 203, and the resistance of ASD 7 to the two insects were independently inherited.

Breeding for Green Leafhopper and Brown Planthopper Resistance

Breeding for leafhopper and planthopper resistance has gained wide popularity in recent years. At IRRI, it has become one of the main objectives of the breeding program and a large number of crosses have been made to this effect. (IRRI 1970, 1971). More emphasis is being laid on developing lines that possess resistance to several pests and diseases.

Mudgo × IR8 hybridization has produced progenies that are highly resistant to the green leafhopper and the brown planthopper and possess the plant type of IR8. Mudgo itself is a typically tall and lodging susceptible variety with poor agronomic characters. The progenies of (Mudgo × IR8) × [(Peta/3 × Taichung (Native) 1) × Khao Dawk Mali] have in addition excellent grain type. IR20 × (Mudgo × IR8) progenies appear to have resistance for stem borers, the green leafhopper and the brown planthopper plus the other desirable qualities of IR20.

So far no *jajonica* rice has been identified as resistant to the brown planthopper, but the brown planthopper is a serious problem in many areas where *japonica* rice is grown. Kaneda (1971) has investigated the feasibility of transfering the Mudgo resistance to the brown planthopper to *japonica* rice. Several selections, now in F_6, from the Hoyoku × Mudgo cross are highly resistant to the brown planthopper and are of the *japonica* plant type with low amylose content grains. These selections have been further used in well over 100 crosses to further improve their plant type and to also incorporate resistance to the green leafhopper.

Summary

High levels of natural resistance in rice varieties to the green leafhopper, the brown planthopper and the white backed planthopper have been recorded. The insects generally do not prefer the resistant varieties. Those caged on resistant varieties lost body weight, had a slower rate of growth, had underdeveloped ovaries, and laid a smaller number of eggs in contrast to those caged on susceptible varieties. For both the green leafhopper and the brown planthopper, resistance appeared to be of a biochemical nature, and no mechanical barrier to the insect's feeding on resistant varieties was apparent. A lower concentration of the amino acid asparagine in variety Mudgo as compared to other varieties appeared to be a major factor of the resistance of this variety to the brown planthopper. Even when caged with a large number of insects the resistant varieties suffered little plant damage while similar infestations killed the susceptible varieties. Also, on resistant varieties the population of the insect declined to low levels, but on susceptible varieties it increased several fold in each generation.

Thus the resistance in rice varieties to various leafhopper and planthopper species can be used as a practical method for minimizing pest populations and their damage. The resistance is monogenic and has been transferred to improved plant types.

Discussion

C. Kaneda, Japan (Comment): In addition to the information presented to your desks, I would like to introduce some points observed from the plant-breeder's standpoint. In F_2 and F_3 lines of (Hoyoku × Mudgo) × Kochikaze, the resistance seemed to be associated to some extent with *indica* plant characteristics, easier shattering, and higher sterility percentage originating from japonica × indica cross.

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