

Factors governing susceptibility and resistance of certain rice varieties to the brown planthopper

R. C. Saxena and M. D. Pathak

Relative susceptibility or resistance 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.

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.

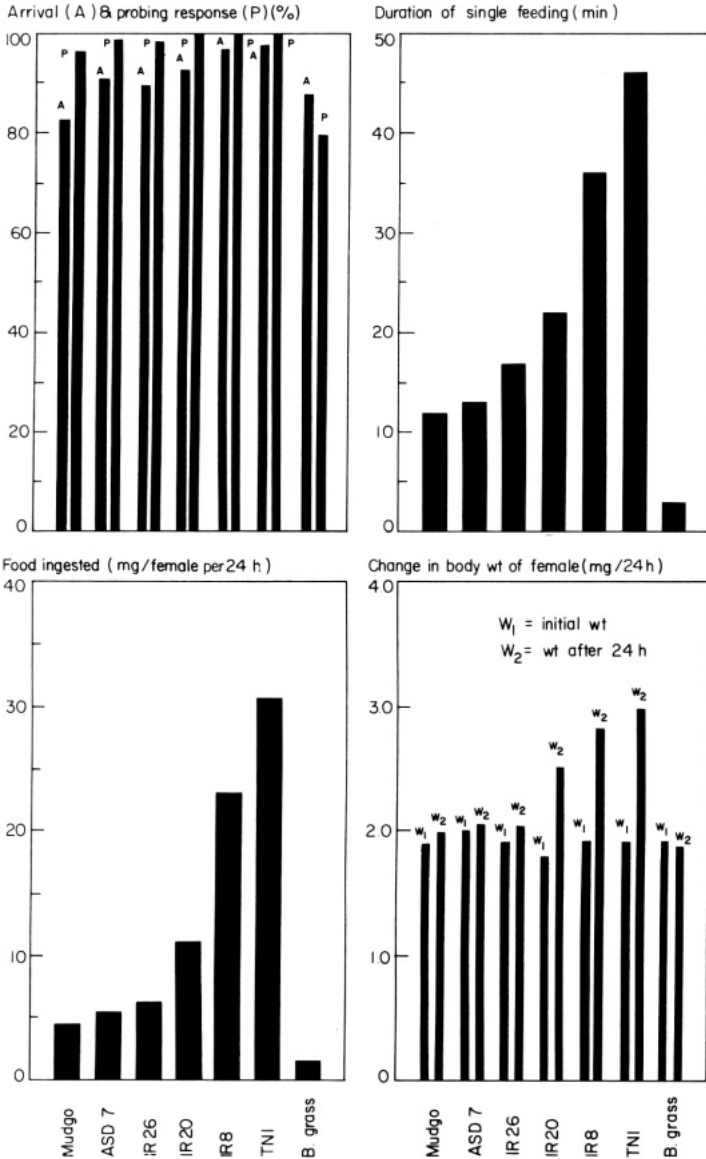
Our study was designed to determine the factors that govern the susceptibility or resistance of rice varieties to the brown planthopper (BPH) and to investigate the possible cause or causes of the breakdown of resistance in certain varieties in the Philippines. We describe our observations of the insect's 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* (bio-type 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. It 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 (80–100%),

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

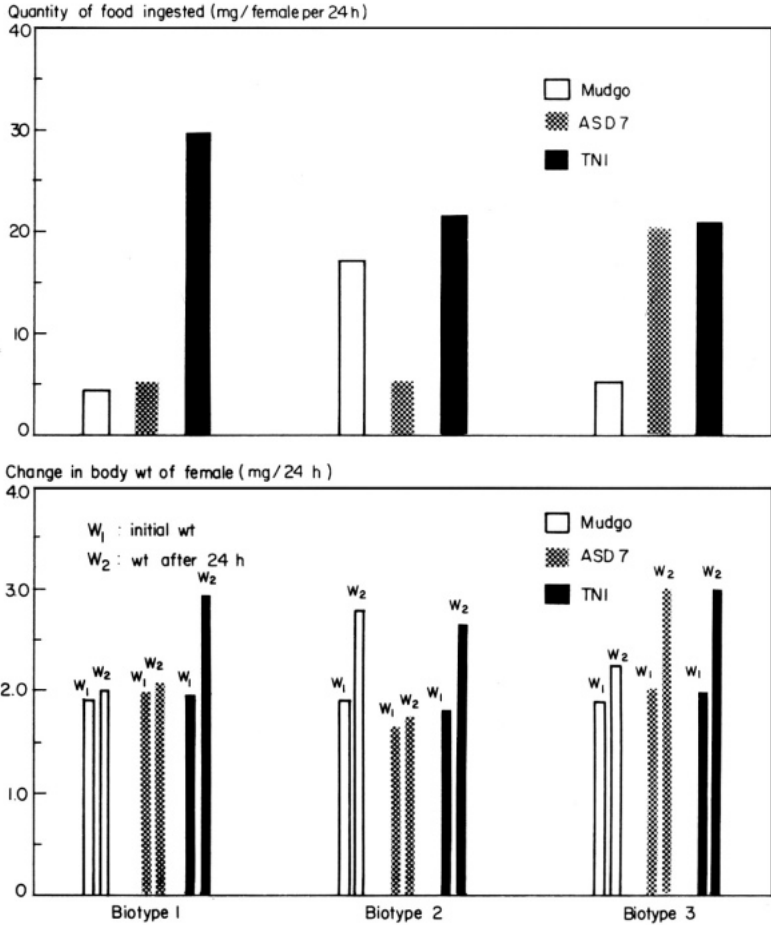
Generally, the greater the proportion of food converted into body tissues, the greater is the nutritive value. Therefore, nutritive value may be expressed as the proportion of the ingested food that is assimilated into tissues and results in weight gain (Saxena 1969; Saxena et al 1974). In 24 hours, 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 of development (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

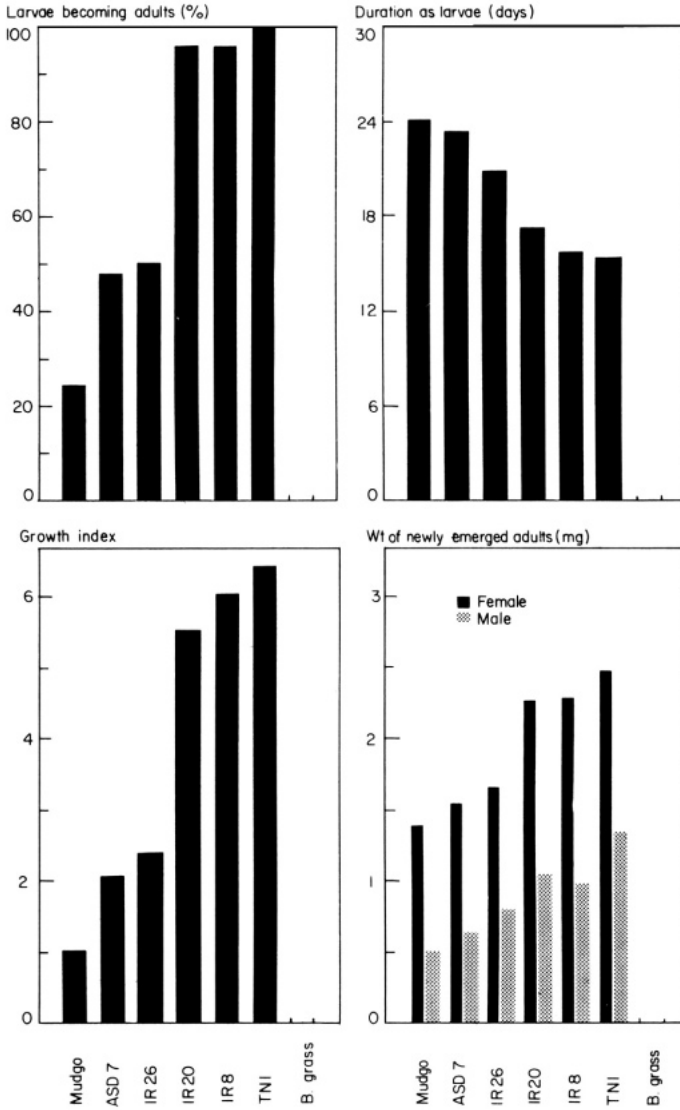


2. Quantity of food ingested and change in body weight of three biotypes of *Nilaparvata lugens* allowed to feed on Mudgo, ASD 7, and TNI rice varieties. IRRI, 1976.

(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 TNI, 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. IIRI insectary, 1975-76.

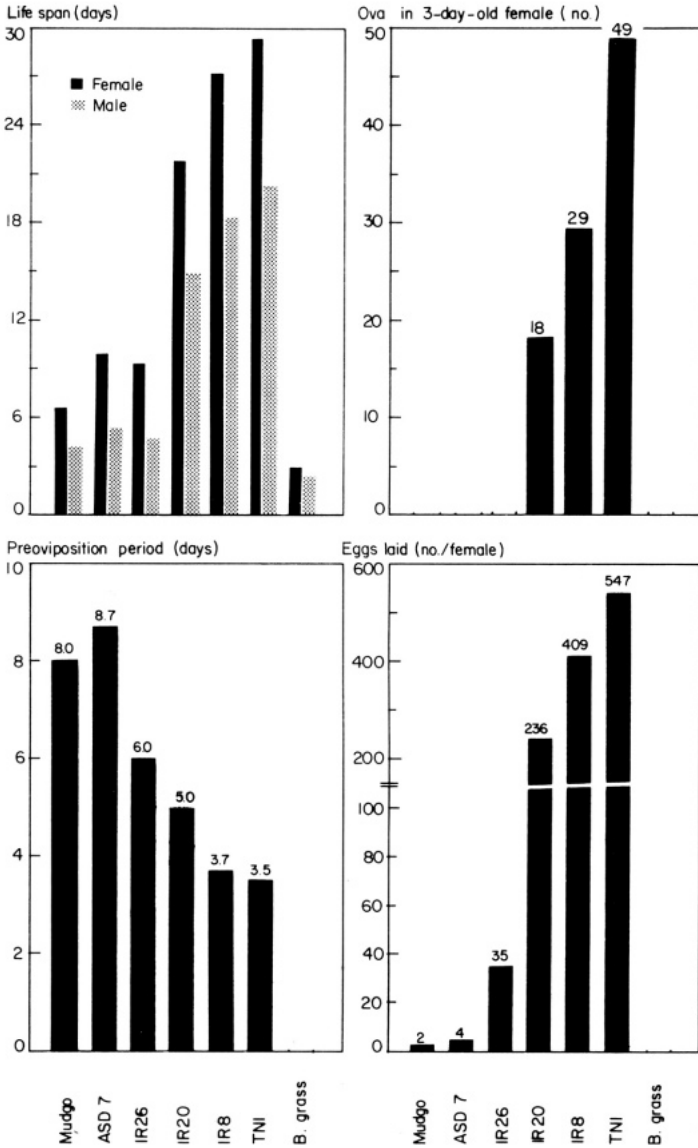
Survival of male and female insects was significantly greater on susceptible than on resistant varieties. Most adults confined on barnyard grass died within 3 days (Fig. 4).

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. IRR1, 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
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	—	—

^aQuantity of food ingested = (wt of assimilated food + wt of excreta + water loss by insect). ^bWt 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 TNI 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 TN1, 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

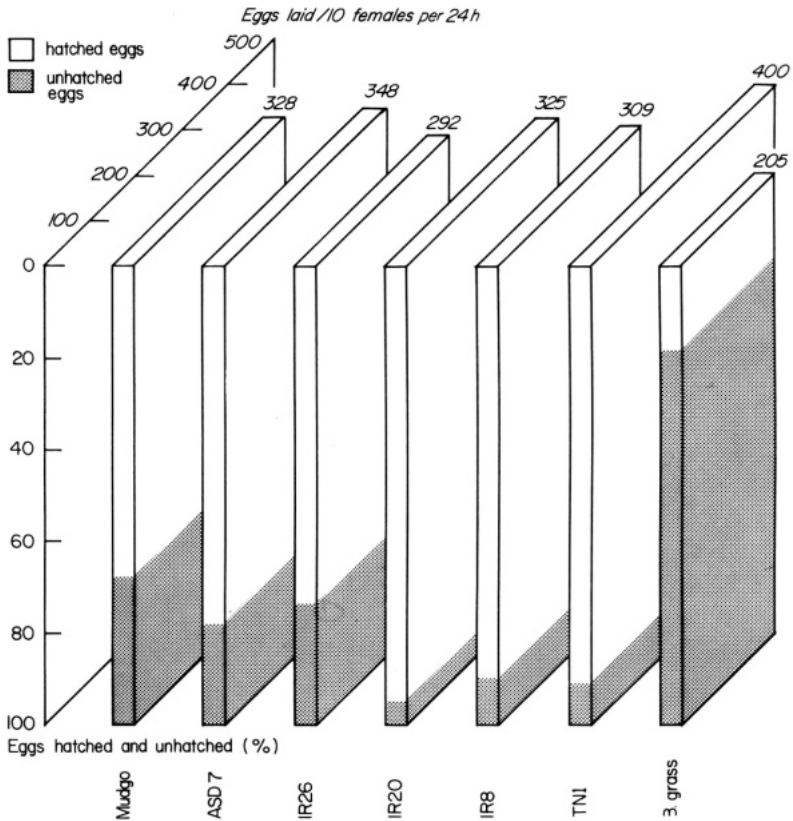
To understand the role of ovipositional response in determining the number of eggs laid on test plants, the differences in egg production caused by differences in food intake and nutrition were eliminated. Females were kept on TN1 plants for 7 days and then their ovipositional responses to the test plants 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 TN1 almost all the transplanted eggs hatched; on barnyard grass most failed to hatch (Fig. 6).

DISCUSSION

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

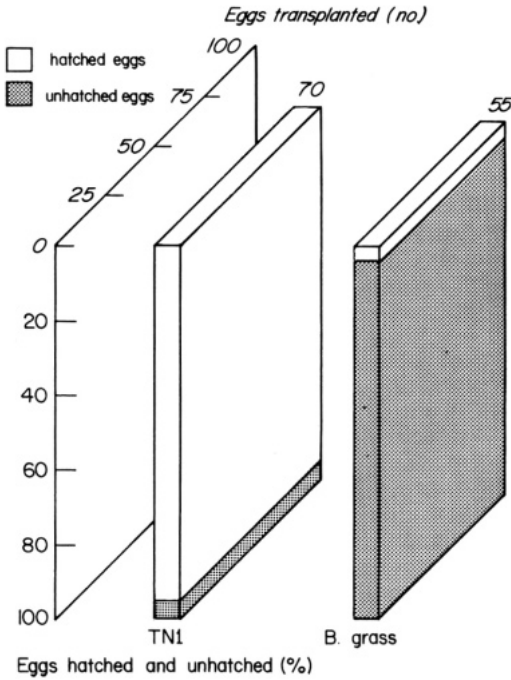


5. Ovipositional response, and comparison of egg-hatch of *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass. IRR1 insectary, 1975-76.

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 TN1.

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.

REFERENCES CITED

- BAE, S. H., and M. D. PATHAK. 1970. Life history of *Nilaparvata lugens* (Homoptera: Delphacidae) and susceptibility of rice varieties to its attacks. *Ann. Entomol. Soc. Am.* 63:149-153.
- KIM, M., H. KOH, T. ICHIKAWA, H. FUKAMI, and S. ISHII. 1975. Antifeedant of barnyard grass against the brown planthopper *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Appl. Entomol. Zool.* 10:116-122.
- KIM, M., H. KOH, T. OBATA, H. FUKAMI, and S. ISHII. 1976. Isolation and Identification of trans-aconitic acid as the antifeedant in barnyard grass against the brown planthopper *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Appl. Entomol. Zool.* 11:53-57.
- PAINTER, R. H. 1951. *Insect resistance in crop plants*. The MacMillan Company, New York. 520 p.
- PARKER, B. I., G. SINGH, and L. Y. NAM. 1973. The resistance of fifteen rice varieties to *Nilaparvata lugens* (Stål) in Malaysia. *Malays. Agric. Res.* 2:1-7.
- REZAUL KARIM, A. N. M. 1975. Resistance to the brown planthopper *Nilaparvata lugens* (Stål) in rice varieties. M. S. thesis, University of the Philippines at Los Baños. 131 p. (unpubl.)
- SAXENA, K. N. 1969. Patterns of insect-plant relationships determining susceptibility or resistance of different plants to an insect. *Entomol. Exp. Appl.* 12:751-766.
- SAXENA, K. N., J. R. GANDHI, and R. C. SAXENA. 1974. Patterns of relationships between certain leafhoppers and plants. I. Responses to plants. *Entomol. Exp. Appl.* 17:303-313.
- SOGAWA, K., and M. D. PATHAK. 1970. Mechanisms of brown planthopper resistance to Mudgo variety of rice (Hemiptera: Delphacidae). *Appl. Entomol. Zool.* 5:145-158.