# DEVELOPMENT OF INSECTICIDE RESISTANCE AND TACTICS FOR PREVENTION

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Five species of rice insect pests have been reported resistant to insecticides in Japan. They are green Ieafhopper, striped stem borer, small brown planthopper, brown planthopper, and rice leaf beetle. The first four species are discussed in detail, based on data from Japan; Taiwan, China; and Korea.

Japan was the first Asian country to introduce synthetic organic insecticides to control rice insect pests, and has used insecticides extensively. This has encouraged insecticide resistance and destroyed various nontarget insect species.

Insecticide resistance in other rice growing countries is still rare. A few recent reports of mild resistance have concentrated on rice leafhoppers and planthoppers. Green leafhopper (GLH) *Nephotettix cincticeps* (Ku and Wang 1975, Ku et a1 1976) and brown planthopper (BPH) *Nilaparvata lugens* (Lin et a1 1979) have been reported resistant in Taiwan, as have small brown planthopper (SBPH) *Laodelphax striatellus* and GLH in Korea (Choi et a1 1975, Song et a1 1976), GLH *Nephotettix virescens* in Indonesia (Merthakota and Sutrisno 1982), BPH and whitebacked planthopper (WBPH) *Sogatella furcifera* in Sri Lanka (Wickremasinghe and Elikawela 1982), and BPH in the Philippines (Mochida and Basilio 1983). Most of these reports lack sufficient laboratory data, but there is strong evidence that the rice water weevil *Lissorhoptrus oryzophilus* developed high levels of resistance to aldrin in early 1960s in the USA (Rolston et a1 1965), and the paddy bug *Leptocorisa varicornis* has been reported to have BHC resistance in Sri Lanka (Wickremasinghe and Elikawela 1982).

In this article we discuss some typical cases of insecticide resistance in Japan and briefly refer to problems in other Asian countries.

## STATUS OF INSECTICIDE RESISTANCE IN RICE INSECT PESTS

### Green leafhopper (GLH) *Nephotettix cincticeps*

*Resistance in foliar application.* GLH insecticide resistance is the most serious among rice insect pests. The most detailed knowledge about GLH resistance has been compiled in Japan.

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Malathion and parathion were the first insecticides extensively used against GLH. Malathion use began in 1953 and resistance was first reported in 1960-61 at Kochi prefecture, where double-cropped rice received frequent insecticide applications. Methyl parathion applications to control SB and GLH began in 1951. Resistance developed in 1962. Resistance to these insecticides spread rapidly throughout southern Japan. Distribution of resistant GLH populations was carefully mapped at the village level using standard bioassay techniques.

Malathion and parathion (both organophosphates) were replaced by carbamate insecticides because GLH showed cross resistance to other organophosphates too. Carbaryl, the first carbamate, was commercialized in 1959 and many other carbamates were developed in the 1960s: CPMC and propoxur in 1964; MPMC, MIPC, MTMC in 1967; and BPMC and XMC in 1969.

In 1969 carbamate-resistant GLH was found in Ehime prefecture in central Japan, where farmers had used carbaryl and phenylcarbamates for 7 years. By 1975 resistant GLH populations occupied most of western Japan. They had nearly 100-fold resistance to propoxur and BPMC and a high level of resistance to malathion (Table 1).

Diazinon, pyridaphenthion, propaphos, or a mixture of these with carbamates were used against carbamate-resistant GLH. Combinations of IBP + malathion, IBP + phenthoate, phenthoate + propoxur, and a mixture of N-propylcarbamate with N-methylcarbamate have also been found effective (Yamamoto et al 1978).

Insecticide-resistant GLH have been reported in Taiwan, China (Ku et al 1976), Korea (Song et al 1976), and China (Chen et al 1978), but resistance is generally low, except in Taiwan, where GLH-resistance almost equals that in Japan.

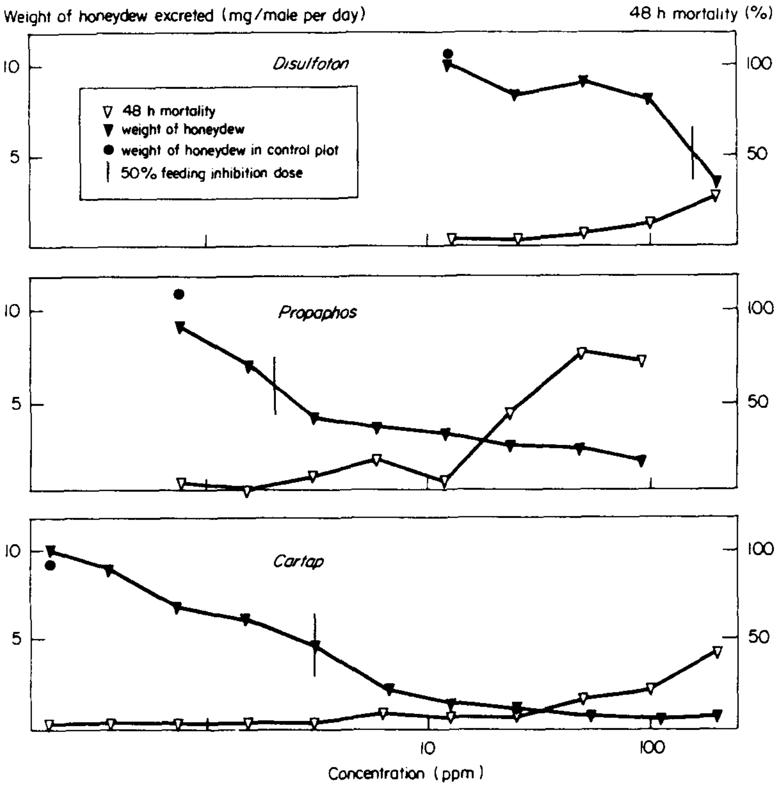
*Resistance to granular treatments in nursery boxes.* Mechanized transplanting, which allows more efficient insecticide applications for GLH control, has been used in Japan since 1969. Disulfoton, cartap, or propaphos granules are applied to nursery boxes immediately prior to transplanting to control GLH and SBPH. Cartap, propaphos, or propoxur are applied to control the rice leaf beetle *Oulema oryzae.*

Control is good because granules dissolve and release active ingredients slowly. Other advantages are labor savings because application coincides with transplanting, lower application rates, long period of persistence, and reduced effect on natural

**Table 1. Development of insecticide resistance in rice green leafhopper *N. cincticeps* in Shikoku, Japan.**

| Insecticide | $LD_{50}$ (µg/g) | | | |
|---|---|---|---|---|
| | Ehime prefecture [a] 1963 | Ehime prefecture [a] 1970 | Ehime prefecture [b] 1981 | Koti prefecture [b] 1981 |
| Malathion | 12.41 | 330 | 143-570 [c] | 292 |
| Diazinon | 8.99 | 11 | 44-53 | 37.2 |
| Carbaryl | 1.64 | 71 | 33-48 | 68.8 |
| Propoxur | 3.23 | 440 | – | 1396.8 |

[a] Iwata and Hama (1971). [b] Shikoku Experiment Station (1982). [c] $LD_{50}$ range Of 2 local Populations.




**1.** Feeding inhibition by three systemic insecticides administered to green rice leafhopper *N. cincticeps* (resistant strain) through parafilm membrane (Nagata and Masuda 1981).

enemies. Disulfoton granules were widely used, beginning in 1973. After 1978 reduced field efficacy prompted replacement by propaphos or cartap granules.

Resistance to granular insecticides often is evaluated using topical application data that measure contact toxicity. Other bioassay methods should be used to evaluate oral intake of systemic insecticides by sapfeeding insects, especially as Nakasuji et al (1975) showed that rice dwarf is more effectively controlled by reducing insect transmitting ability than by population reduction. Sublethal doses of cartap have also been shown to be important to rice dwarf control (Kono et al 1975). Using a combination of these techniques will allow a more thorough evaluation of the nature of resistance relative to the control of insect-transmitted virus by systemic insecticides (Fig. 1).

**Striped rice stem borer (SB) *Chilo suppressalis***

SB was the most destructive rice pest in Japan until 1952, when parathion became widely used. The first parathion resistance was reported at Kagawa prefecture in 1960. BHC 3% dust was used for SB control beginning in 1954. BHC broadcast granule use began in 1960. BHC resistance was reported in western Japan in the late 1960s.

BHC and parathion were replaced with diazinon, trichlorfon, fenthion, fenitrothion, or chlordimeform in 1966 and cartap in 1967. Parathion production was stopped because of human toxicity in 1969 and BHC was banned in 1971 because of environmental contamination. During the late 1960s and 1970s SB resistance build-up was limited by a decrease in pest occurrence, and most farmers considered pest control unnecessary.

Since 1978, however, SB incidence has increased in several areas in southern Japan, and most new populations have high-level resistance to organophosphates (Table 2), which may have developed as a side effect of insecticides applied to control leafhoppers, planthoppers, and leaffolder *Cnaphalocrocis medinalis.* SB incidence is expanding.

## Small brown planthopper (SBPH) *Laodelphax striatellus*

SBPH transmits rice striped virus and black-striped dwarf and occurs throughout Japan, even in snowy areas. They hibernate as 4th-instar nymphs in diapause. Sporadic severe occurrence was observed in the 1960s, when aerial application of malathion was the predominant control.

SBPH malathion resistance appeared in 1964, as did BHC resistance. Malathion and BHC were replaced by fenthion, fenitrothion, disulfoton, and carbamates.

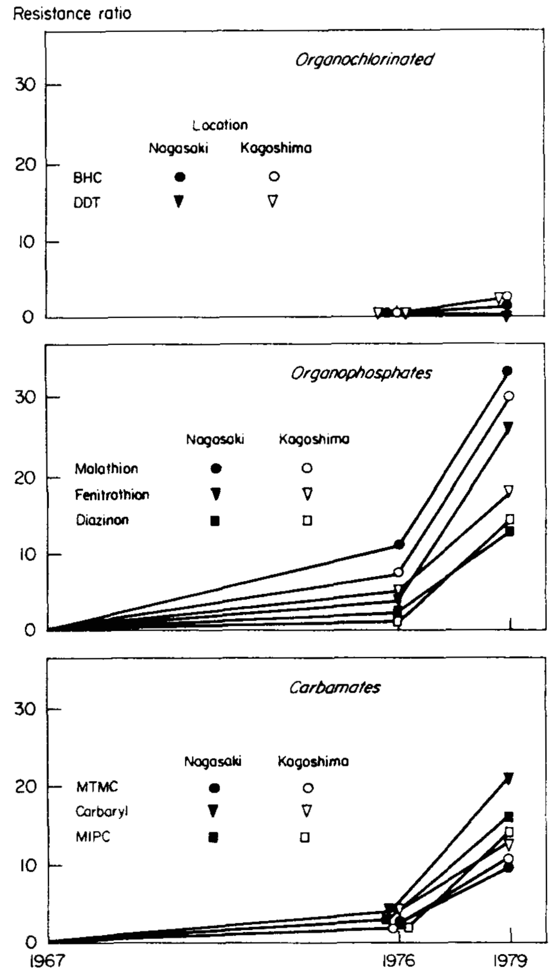
Large decreases in area planted to wheat, an alternate SBPH host, took place after 1969. Pest incidence was substantially reduced and the diseases it transmits are no longer of economic importance. However, since 1974, when the Japanese Government began to enlarge the area planted to wheat, SBPH has increased substantially in central and northern Japan.

Comparative data on 1967 topical applications show that SBPH is developing resistance to organophosphates (malathion, fenitrothion, and diazinon). A 1976 survey shows a 10– to 20-fold increase of $LD_{50}$ and slightly increased carbamate resistance (Fig. 2). Data from several populations collected at Kyusyu in 1980 showed further increases in organophosphate resistance: 92- to 287-fold in malathion, 31 -to 46-fold in fenitrothion, and 30- to 40-fold in diazinon. Carbamate

**Table 2. Development of organophosphate resistance in the striped stem borer *C. suppressalis* in Japan.**

| Insecticide | 1960[a] Kagawa prefecture | $LD_{50}$ (µg/g) in 1981[b] Tokusima prefecture (2-5)[c] | Okayama prefecture (6-7)[d] |
|---|---|---|---|
| Diazinon | 3.59 | 12.3-21.0 | 8.9-79.2 |
| Fenitrothion | 2.16 | 45.3-58.1 | 4.7-99.3 |
| Fenthion | 2.08 | 67.2-91.2 | 5.0-79.5 |
| Trichlorfon | 7.93 | 113.4-262.1 | – |
| Cartap | – | 3.4-4.1 | – |
| Dimethylvinphos | – | 1.1-1.7 | 0.6-1.1 |

[a]Ozaki et al (1971). [b]Figures in parentheses indicate the number of collecting sites compared. [c]Noguchi (1982). [d]Tanaka et al (1982).




**2.** Development of insecticide resistance in immigrant SBPH as expressed by resistance ratio on the basis of 1967 data in Japan (Fukuda and Nagata 1969).

resistance had increased by 9- to 21-fold in MTMC, 36- to 76-fold in carbaryl, and 23- to 26-fold in MIPC (Nagata et al 1982).

In a 1980 survey, comparative data from 7 populations collected around Kyusyu showed no significant difference in susceptibility to 8 insecticides. Levels of susceptibility were similar to those of a SBPH population collected on a ship at 31° N, 126° E 400 km from Shanghai, China, on the East China Sea. Further resistance data should be collected from sea-captured migrating SBPH populations and compared with land-captured populations.

SBPH is also an important pest in Korea, where insecticide resistance was first checked in 1973 (Choi et al 1975) and in 1974 (Song et al 1976). Rates of resistance were similar to those in Japan except for carbaryl, to which Japanese populations had developed less resistance. Substantial local differences in resistance, especially for malathion, were observed, however. Choi et al (1975) reported 8.4-fold differences among 5 locations and Song et al (1976) reported 26.1-fold differences.

**Brown planthopper (BPH)** ***Nilaparvata lugens***

BPH infestation in Japan once fluctuated substantially, but has stabilized to become most serious in southern Japan. Insecticides are the sole control measures because commercial resistant cultivars have not been developed.

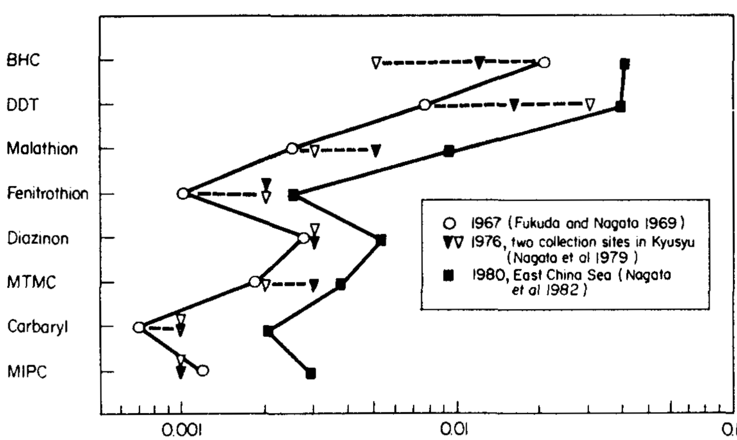
BHC and DDT were the first insecticides used to control BPH. BHC dominated because it also controlled SB, WBPH, and SBPH. Although other insects developed resistance to BHC, BPH did not show substantial resistance after 20 years (1949-71). BHC was banned and replaced with carbamates in 1971.

Studies of BHC resistance in BPH have suggested several interesting aspects of BPH insecticide resistance. Perhaps one of the reasons BPH did not develop BHC resistance is because the insect has high migrating ability. Long distance BPH and WBPH migration from outside Japan was first observed in 1967.

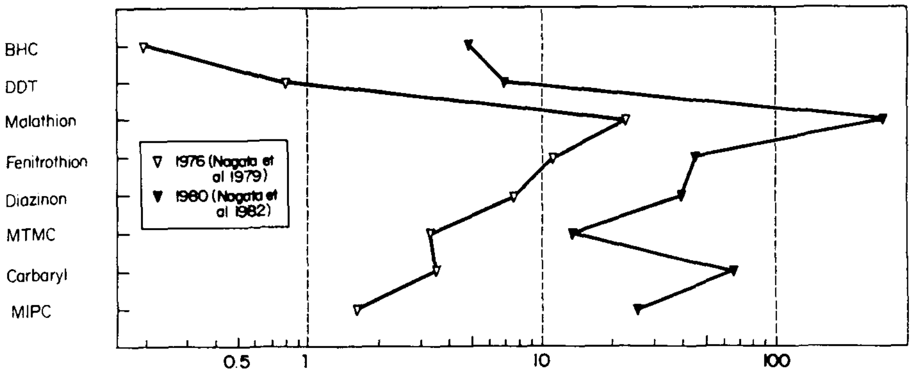
Restoration of BHC susceptibility has been observed in BPH field populations after an influx of susceptible insects. Research shows that fields treated with BHC have a zigzag-shaped resistance fluctuation. BHC-resistant populations increase rapidly with frequent insecticide applications, then die during winter. Susceptibility is restored by the migration of susceptible populations from less-treated areas during the next summer (Nagata and Moriya 1974).

BPH insecticide resistance in Japan depends primarily on the resistance level of immigrants. Immigrant BPH is developing resistance to some insecticides. Data collected at two monitoring sites on Kyusyu Island showed that $LD_{50}$ of malathion and fenitrothion had increased significantly from 1967 to 1976. No significant increase was observed for carbamates (Nagata et al 1979, Fig. 3). By 1979 $LD_{50}$ to organophosphates had increased further, and a 10-fold increase in carbamate resistance was recorded (Djatnika Kilin et al 1981).

That WBPH, which migrates to Japan in greater numbers than BPH, is more susceptible to insecticides shows BPH has not developed significant resistance levels. In 1980 a slight increase in $LD_{50}$ was recorded, but it was less than 5-fold (Fig. 4).




**3.** Development of insecticide resistance in BPH.




**4.** Development of insecticide resistance in WBPH, as expressed by resistance ratio on the basis of 1967 data at Kyusyu National Agricultural Experiment Station, Japan (Fukuda and Nagata 1969).

Malathion and diazinon were recommended to control BPH until their effectiveness declined in the early 1970s. The control value of all organophosphates had declined by 1972 (Tsurumachi 1978). Carbamate effectiveness has also decreased. In 1973-74 carbamate dust gave satisfactory control in 80.7% of 60 official field tests conducted by the Japan Plant Protection Association. Control decreased to 51.6% in 93 tests in 1979-80 even though the portion of high content carbamate formulation (2%) increased from 53 to 82% (H.Yamashina, pers.comm.).

Despite gradual BPH insecticide resistance buildup, there still is a substantial stockpile of promising chemicals for BPH control, including the growth regulator buprofezin and synthetic pyrethroids. Until now new insecticide development has kept up with resistance buildup, but the situation may change in the future.

BPH insecticide resistance in Japan probably originates on the Chinese mainland, where most BPH migration to Japan originates. BPH breeds on the southern half of Hainan Island (21° N) and overwinters between 21 and 25° N, depending on annual temperature range. Northern migration begins in March and continues through August. There are five migration waves that reach 35° N, then a three-wave southern migration begins (Cheng et al 1979).

Outbreaks of BPH in China became a more serious problem during the 1970s; the increased insecticide selection pressure in that country may have developed resistance, as BPH-resistant rice varieties are not widely planted. Although a few data are available on BPH migration from tropical regions to China, some toxicological data available from Thailand (Nagata and Masuda 1979), the Philippines (IRRI 1979, Nagata and Masuda 1979), and Indonesia (Djatnika Kilin et a1 1979) indicate BPH resistance in those areas may be less than in Japan.

Hama (1982) studied homogeneity of insecticide resistance in migrating BPH populations and found that toxicological properties of insects from different migration waves varied conspicuously. Although insects were collected from the same site in southern Kyusyu in 1981, their different resistance levels may indicate that they migrated from different areas.

Characteristics of geographical BPH variation may help determine migration range and route. Nagata and Masuda (1979) showed that BPH populations collected in Thailand and the Philippines are more susceptible to some insecticides, particularly DDT, than Japanese populations. However, BPH insecticide susceptibility is not a stable sign of geographical variation.

Koike (1982) compared chromatograms of BPH protein content using an autoanalyzer, and found two different chromatograms, Philippine-type and Taiwan-type. BPH collected from eight Japanese sites had Taiwan-type chromatograms.

Insecticide resistance buildup of BPH, particularly carbamate resistance, is a matter of great importance to the Japanese pesticide industry and scientists concerned with pest control. Several researchers are conducting laboratory experiments to predict future resistance levels and develop an understanding of the cross-resistance relationship between current insecticides and candidate insecticides.

BPH resistance usually develops rapidly under laboratory selection with organophosphates (malathion, fenitrothion). Carbamate resistance develops slowly. Fifty generations of continuous BPMC selection increased topical $LD_{50}$ only 3-5 times (A. Hosoda, pers. comm.). In Korea, Chung and Choi (1981) selected BPH for carbaryl resistance for 15 generations and observed a 2.5-fold $LD_{50}$ increase. However, MIPC $LD_{50}$ increased 34-fold during 16 generations of testing in Taiwan, China (Chung et al 1982). Lin et al (1979) observed 6.9-fold differences in MTMC $LD_{50}$ in a 1979 survey of 12 Taiwan sites. Results correlated with insecticide use at the sites.

Other information on development of insecticide resistant populations is shown in Table 3, although most data are not substantiated by precise studies.

## TACTICS TO PREVENT INSECTICIDE RESISTANCE

Development of insecticide resistance can be prevented by planning to prevent or delay resistance before an insecticide is released or by developing new control methods after a population has become resistant. The latter is the most practical tactic.

Resistance can be prevented by limiting the frequency and amount of insecticide application, which reduces selection pressure. However, this method is not usually practical and even uneconomical.

Ozaki et al (1973) found that rotating application of several conventional insecticides and applying a mixture of insecticides effectively prevented SBPH from developing resistance in laboratory experiments. However, recent experiments with GLH did not always limit resistance buildup (Hiramatsu et al 1976). Prevention of resistance using this technique may depend on the combination of insecticides used and genetic traits of the target insect. Further research is needed in this area.

The most popular method of controlling resistant insect populations is to use new insecticides with no cross resistance to the old pesticide. Malathion and parathion were first used for GLH control, then replaced with carbamates. Carbamates were again replaced with organophosphates such as diazinon and propaphos to which malathion- or parathion-resistant GLH showed no cross resistance. Mixed

**Table 3. Rice insect pests (excluding storage pests) resistant to insecticides, in addition to those described in text.**

| Species | Insecticide | Region | Country | Year | | References |
|---|---|---|---|---|---|---|
| | | | | First appeared | Started using insecticides | |
| *Chilo suppressalis* | parathion | Kagawa | Japan | 1960 | 1952 | Yamashina (1974) |
| | BHC | Kagawa | Japan | 1964 | 1949 | Yamashina (1974) |
| | fenitrothion | | South Korea | 1964 | ? | Choi (1965) |
| | fenthion | | South Korea | 1964 | ? | Choi (1965) |
| *Laodelphax striatellus* | malathion and OPs | Hiroshima, etc. | Japan | 1964-65 | 1953 | Yamashina (1974) |
| *Leptocorisa varicornis* | BHC | | Sri Lanka | ? | ? | Wickremasinghe and Elikawela (1982) |
| *Lissorhoptrus oryzophilus* | aldrin | Texas | USA | 1956 | ? | Bowling (1972) |
| | aldrin | Arkansas | USA | 1963 | ? | Rolston et al (1965) |
| *Nephotettix cincticeps* | malathion | Koti | Japan | 1961 | 1953 | Yamashina (1974) |
| | malathion | Ehime | Japan | 1962 | 1953 | Yamashina (1974) |
| | methyl parathion | Okayama, Ehime, Kagawa | Japan | 1963 | 1952 | Yamashina (1974) |
| | malathion | Okayama, Sizuoka, Totigi | Japan | 1964 | 1953 | Yamashina (1974) |
| | carbaryl | Hukuoka, etc. | Japan | 1965 | 1959 | Yamashina (1974) |
| *Nilaparvata lugens* | EPN | Okayama | Japan | 1966 | 1955 | Tsuboi et al (1973) |
| | malathion | Okayama | Japan | 1966 | 1953 | Tsuboi et al (1973) |
| | methyl parathion | Okayama | Japan | 1966 | 1952 | Tsuboi et al (1973) |
| | diazinon | IRRI farm, Los Baños | Philippines | 1969 | ? | IRRI (1970) |
| | carbofuran | Taiwan | China | 1976 | ? | Ku et al (1977) |
| | carbofuran | IRRI farm, Los Baños | Philippines | 1977 | ? | IRRI (1978) |
| | BPMC, acephate, chlorpyrifos + BPMC | IRRI farm, Los Baños | Philippines | 1982 | ? | Mochida and Basilio (1983) |
| | BHC, diazinon, endrin | | Sri Lanka | ? | ? | Wickremasinghe and Elikawela (1982) |
| *Oulema oryzae* | BHC | Hokkaido | Japan | 1966 | 1949 | Yamashina (1974) |
| | BHC | Sadogasima, etc. | Japan | 1967-70 | 1949 | Yamashina (1974) |
| *Sogatella furcifera* | carbaryl | | Sri Lanka | ? | ? | Wickremasinghe and Elikawela (1982) |

formulations of organophosphates and carbamates also have been used to overcome carbamate resistance (Hama and Iwata 1973, Yoshioka et al 1975).

All of these insecticides are gradually losing effect because GLH is developing multiple resistance. Few promising chemicals are now available to destroy resistant GLH populations except some pyrethroids.

Laboratory use of synergists that inhibit specific detoxification enzymes in resistant insects has been documented but is not yet a practical resistance control technology. Negatively correlated resistance between propaphos and propoxur was observed for GLH (Iwata and Hama 1981). Kassai and Ozaki (1978) showed that laboratory-developed malathion resistance of BPH and SBPH was negatively correlated with resistance to fenvalerate. These facts should be considered in developing effective countermeasures to resistance buildup.

## CONCLUSION

When general economic and climatic conditions in Asian rice growing countries are evaluated, varietal resistance is probably the most desirable method of controlling rice insect pests. If varietal resistance is the only measure, however, there is always the danger that new insect biotypes will develop and destroy large crop areas. Insecticide use will continue to increase gradually, even in areas where insect-resistant varieties are planted and integrated pest management techniques are used.

Japan, as an early user of extensive insecticide control measures, has been troubled by the buildup of insecticide resistance, which should be a warning to countries that are trying to expand insecticide use. Reckless choice or supply of insecticides for economic or political reasons often encourages resistance buildup. We must always hold ourselves ready to answer the question “How can we use an insecticide effectively and safely for the longest period?”

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## DISCUSSION

MAGALLONA: Is insecticide resistance really inevitable even if pesticide use is managed as suggested, e.g. use in IPM/IPC, spot treatments, etc. In other words, do we know enough to prevent resistance from developing?

*NAGATA:* Theoretically. we can delay resistance development by careful insecticide use as suggested in the IPM concept. However, resistance will eventually develop as long as we use insecticides. In a sense, it is also a socioeconomic problem. Most of the methods suggested for preventing resistance development are labor consuming. For example, spot treatments. are economically practical only when labor is cheap.

SADJI: One of the tactics for preventing insecticide resistance is rotating applications of several conventional insecticides. How would you practice that in the field?

*NAGATA:* This recommendation is not very useful because the supply of insecticides by pesticide industries and choice of insecticides by farmers are done for diverse, mainly economic reasons. Farmers are reluctant to bother with future problems when they still have good control of impeding pests. Therefore, the supply of insecticides must be planned by some centralized agency according to the rotational-use schedule.

HEINRICHS: You indicated that there is an increase in the level of insecticide resistance in the BPH migrating from the tropics, possibly Southern China. Do Japanese scientists have any linkage with China to enable them to study the insecticides China is using and is the Japanese BPH resistant to those insecticides?

*NAGATA:* We concluded a cooperation treaty on agricultural technology last year and sent missions to China to conduct research on natural enemies of citrus, insect migration, and the pesticide industry. BHC and methyl parathion are mainly used against BPH in China. Direct corresponding relations can not always be expected between the kinds of insecticides used there and the resistance development in the immigrant BPH observed in Japan because cross resistance disturbs such correspondence.

KENMORE: Have the mixtures of malathion and propoxur developed in Japan over 10 years ago to retard the development of insecticide resistance in the green leafhopper been successful?

*NAGATA:* Yes, resistance has developed only gradually.

BATEMAN: We hear conflicting reports on the relationship between the use of mixtures and the development of insecticide resistance. You said that malathion and propoxur retard the development of resistance, and others say that mixtures should be avoided. For example, IRRI has recommended the mixture of chlorpyrifos and BPMC (Brodan).

*NAGATA:* As a general principle, mixtures should be avoided as they lead to a more rapid development of resistance in a population. However, once a pest such as the green leafhopper has become resistant to most insecticide groups, mixtures can be attempted as a last resort.

HEINRICHS (comment): IRRI, as an international organization is in no position to make recommendations to farmers.

HEINRICHS: Because you have detected the development of higher levels of insecticide resistance in BPH over the years, and given that this pest does not overwinter in Japan but migrates each year from China, have you attempted to gather information on insecticide usage from China?

*MOCHIDA:* Yes, research institutes of the Ministry of Agriculture are involved in this now.

KENMORE: Do insect populations become resistant to synergistic combinations more quickly than they become resistant to single compounds?

*NAGATA:* It depends on the kind of insecticides to be combined, pest species, and genetic composition of insect population. Some reports indicate that specified mixtures of insecticides delayed resistance development in *L. striatellus,* but recent experiments on *N. cincticeps* did not always give such favorable results. So, general conclusions can not be drawn.

MOCHIDA: In tropical rice-growing countries, we are considering the acceptance of mixture formulations and tank mixtures. Are mixtures always dangerous in developing insecticide resistance?

*NAGATA:* Some combinations give favorable results, delaying development of resistance, as shown in laboratory experiments on *L. striatellus* conducted in Japan. However, some workers have observed adverse results. Therefore, general conclusions can not be drawn at present. We have to check the combinations of pesticides and the genetic components of target pest populations through preliminary experiments.

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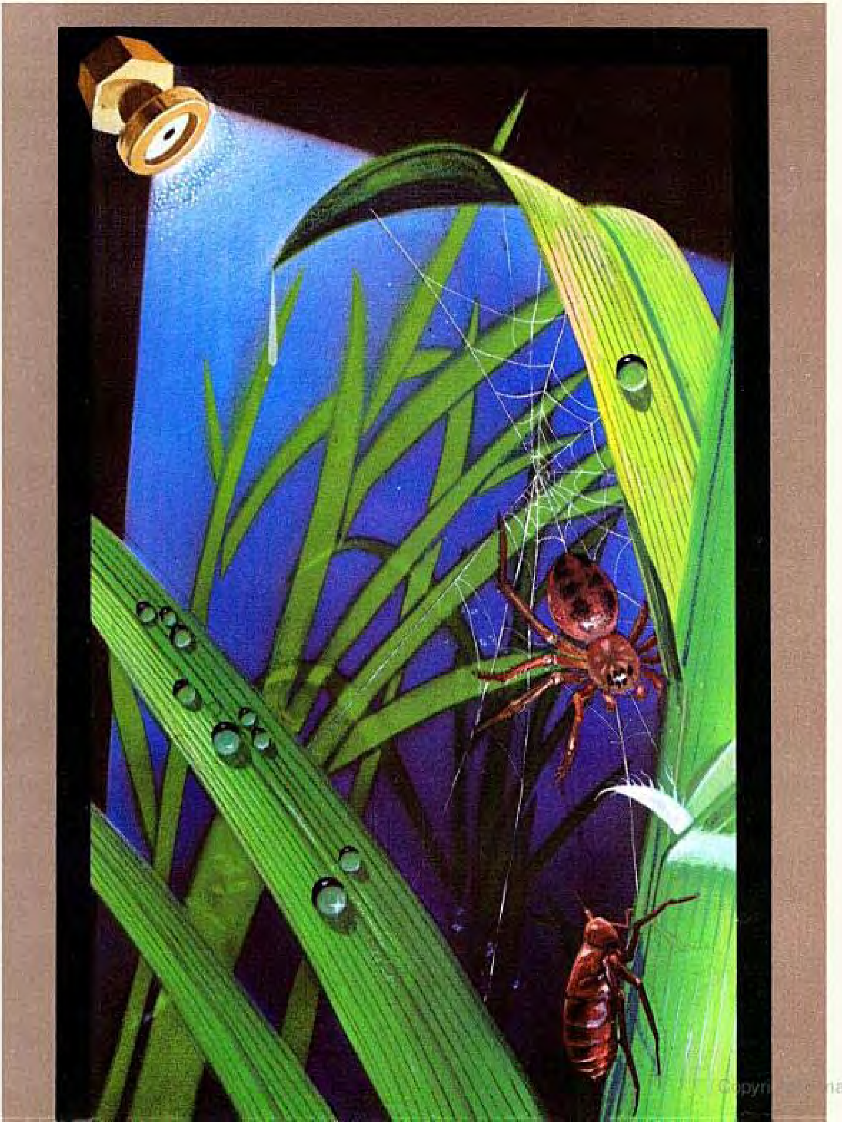
International Rice Research Institute



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