Monitoring on Insecticide Resistance of the Brown Planthopper and the White Backed Planthopper in Asia

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Abstract Annual change in insecticide susceptibility of the long-range migrating rice insects, the brown planthopper (BPH) and the white backed planthopper (WBPH), monitored by topical application was reviewed covering temperate and tropical Asia. Monitoring in Japan revealed consistent increase in topical LD_{50} of BPH for various insecticides during the period between 1967 and 1983 with small peak in 1979 and abrupt increase occurred in 1984 and 1985 with the highest peak ever observed, and then recovered to the 1979 level and remain unchanged to the present. The WBPH showed no obvious change until 1984 when marked increase in LD_{50}, especially for the organoosphates occurred and gradual increase still continues. In the tropics, recent data on BPH obtained from Vietnam, Thailand and Malaysia shows apparent development of insecticide resistance with remarkable increase in LD_{50} as compared to the late 1970's data. Present level of insecticide susceptibility is close to those in temperate Asia. WBPH from those tropical zone also showed remarkable increase in LD_{50} during the last two decades.

Key words insecticide resistance, topical application, brown planthopper, white backed planthopper

Introduction

The brown planthopper (BPH), *Nilaparvata lugens* Stål and the white backed planthopper (WBPH), *Sogatella furcifera* Horvath have been always devastating rice pest in Japan as described in the old historic records. Control measures had been almost powerless except the whale oil used since the 16 century. Introduction of new synthetic insecticides represented by BHC threw brilliant light upon control strategy of this nuisance pests since the 1940's.

Initially, BHC was used widely and then replaced by

oraganophophates and carbamates and so on. Transition in the group of insecticide occurred by varying reason, not only for these two rice planthoppers but for resistance development in other pests and environmental hazard and human safety.

Meanwhile long-term monitoring in Japan confirmed and attracted attention that those long-range migrating hoppers developed insecticide resistance as well as the resident insects. However, fortunately in Japan, resistance issues of BPH and WBPH looks evaded at present so far thanks to exploitation of new control agents such as buprofezin and various group of persistent systemic insecticides which are being used extensively for nursery-box application in Japan.

In the tropics, use of insecticide in rice paddy has been blamed for inducing BPH resurgence (Reissig *et al.*, 1982). It is agreed non-discriminate use of insecticides often induced latent pests to become major insect pest as encountered with BPH and the green rice leafhopper (GLH), *Nephotettix cincticeps* Uhler. We also have learned much from collapse of resistant rice varieties which enjoyed blessed success at one time and broke down by appearance of biotypes soon after their extensive cultivation. Therefore, we have no single ultimate countermeasure for pest control on which we can rely. So far as insecticide remains as essential component of IPM, more rational and judicious use of insecticides should be pursued with as much effort as has been extended until now. Monitoring of insecticide resistance for efficient pest management will be of more vital importance and it is always necessary to judge weather a control failure is due to deteriorated quality of an insecticide, improper application or development of insecticide resistance.

Recently, some rice farmers in Asia are going back again to local and insect-susceptible varieties of high quality protecting hoppers with insecticide for making more economic benefit. Then, it is highly plausible that the amount of insecticide used for rice will increase again.

Materials and Methods

Initially, insecticide susceptibility of rice planthoppers had been determined by various methods such as dry-film method or systemic test using rice seedlings etc, which were not satisfactory in reproducibility of tests and lacks preciseness and topical application had never been applied to rice planthoppers. The reason was their small body size to be treated by this method.

Topical application for the rice planthopper was established in 1967 for the first time by Fukuda and Nagata (1969) improving the preceding device designed with complicated and laborious apparatus by Miyahara and Fukuda (1964). In this method, topical application was simplified by adopting a small microsyringe for gaschromatography and improvement in handling of the insects to be treated. Until that time topical application had been used only for GLH. GLH is large enough in body size to be treated with usual apparatus of topical application. This improved device enabled quick and repeated application of droplets as small as $0.05 \mu l$ of solution of insecticide dissolved in acetone to the thoracic region of individual hoppers.

Fukuda and Nagata (1969) determined LD_{50} of BPH, WBPH and the small brown planthopper (SBPH), Laodelphax striatellus Fallen, collected in 1966 in Kyushu for the 18 insecticides which were being used conventionally in rice paddies. These data became of enormous importance as base-line data being quoted for monitoring of resistance in rice planthoppers because this simplified topical application method was followed by many workers as standardized testing method making all the data comparable each other.

In this article topical LD_{50} data of BPH and WBPH were compiled from various countries for the attempt to overview development of insecticide resistance in those long-range migrating rice planthoppers.

Results and Discussion

Monitoring on insecticide resistance of brown planthopper in Japan

Nagata and Moriya (1974) investigated BHC resistance of BPH by this method firstly and revealed peculiar seasonal variation of BHC susceptibility at the same monitoring site in Kyushu and proposed that this fluctuation was reflecting development of BHC resistance in paddies of Japan and recovery of susceptibility took place by migration of susceptible population from abroad. This was in good agreement with the migration theory of BPH and WBPH which was be-coming predominant at that time being fortified by the accidental finding of hopper swarm migrating on the Pacific ocean (Asahina and Tsuruoka, 1968).

From this finding Nagata put emphasis on monitoring of insecticide susceptibility with migrant generation because comparison of later generations might involve effects of selection pressure in respective paddies where the migrant settled and of less significance for annual comparison of the change in insecticide susceptibility extending long term.

Results of the 1976 monitoring on migrant BPH in Kyushu areas revealed apparent development of resistance for the organophosphates with significant increase in LD_{50} for malathion, fenitrothion and diazinon (Nagata and Masuda, 1979). Further, 3 years later, the 1979 monitoring revealed evident sign of resistance development for the carbamates as well (Kilin et al., 1981). With the passage of time, many topical LD_{50} for BPH and WBPH were produced at various institutes and all of these data also supported gradual increase in the LD_{50} for organophosphates and carbamates on the basis of the 1967 base-line data.

Long-term monitoring was also performed by Hosoda (1983), who started regular annual monitoring on insecticide resistance of BPH in Hirosima Prefecture located ca 300 km north of Kyushu where receives migration of BPH and WBPH though less in number of migrant compared to Kyushu areas (Fig. 1).
His monitoring was started in 1970 for the two insect-icides, diazinon and carbaryl and later other three insecticides, malathion, fenitrothion and BPMC, were added after 1975 and the monitoring was continued patiently until 1991 on these 5 insecticides without interruption. These data also clearly showed marked increase in LD_{50} for the 5 insecticides in 1979 supporting Nagata's data in Kyushu. Population density of migrant generation is much lower in Hirosima Prefecture compared to Kyushu and collecting sufficient number of migrant was impossible. Accordingly, insect collection was conducted during August and October and insect-icides were applied 3-5 times per crop season at that time. No significant local difference in insecticide susceptibility was detected at the 7 sites in the Hirosima Prefecture for 11 insecticides with maximum difference of LD_{50} being only 1.6 fold in 1979.

Ozaki and Kassai (1982) also adopted topical application after 1976 for monitoring LD_{50} in Sikoku areas. When compared their 1979 data with their initial data obtained in 1976, remarkable increase in LD_{50} was observed for malathion (ca 24 folds), fenthion (ca 14 fold) and slight increase in all other 6 organophosphates and carbamates. They managed to calculate resistance ratio based on LD_{50} of their own artificially produced laboratory strain (Low-esterase strain), which was produced by segregation of progeny derived from parents giving low aliesterase activity
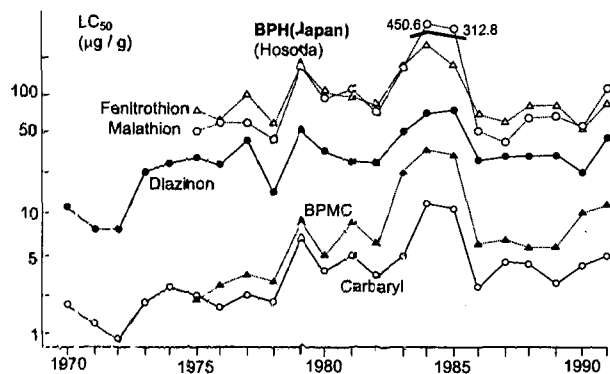
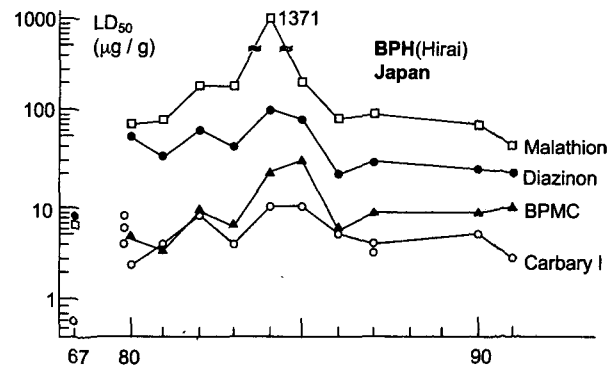**Fig. 1.** Annual Change in Topical LD50 of BPH (Japan, Hirosima Pref.) (Hosoda, 1991).

Fig. 2. Annual Change in Topical LD50 of BPH (Japan, Hyogo Pref.) (Hirai, 1993).

on agar gel electrophoresis. Therefore, it is not comparable with usual resistance ratios obtained by annual comparison of LD50 based on field populations actually existed in the past.

However, LD50 did not continue to rise after 1979 and remained constant for a while as described by Hosoda (1983) and then increased sharply again after 1983 reaching the highest peak ever obtained in 1984 and 1985. The highest peaks of topical LD50 for various insecticides appeared in 1984 and 1985 was also confirmed by the regular annual monitoring on the 4 insecticides conducted by Hirai (1993) in Hyogo prefecture located ca 100 km north of Hosoda's Prefecture who continued annual monitoring between 1980-1991 (Fig. 2). After 1986 it declined again to the 1979 level and remained at almost same level until present time.

The change in insecticide susceptibility of BPH observed in Japan during these 30 years can be categorized into 4 phases as below:

(1) Gradual and consistent increase in LD50 during the period of 1967-1979.

(2) Stabilized phase during the period of 1980-1983.

(3) Sharp increase and the highest peak of LD50 in 1984 and 1985.

(4) Stabilized phase around the (2) level during the period of 1986-1999.

The cause of these changes can be attributed to the change of insecticide use in origin areas. Migration of BPH and WBPH from abroad has been confirmed in Japan since the accidental finding of migrating hoppers on the ocean (Asahina and Turuoka, 1968).

These hoppers cannot overwinter in Japan and all of population exposed to selection pressure of insecticide application in Japan extinguish during winter and replaced with new migrant in the following summer. The origin of migration is now presumed to be southern China and northern Vietnam from coincidence of the period when the shift from biotype 1 to biotype 2 occurred between 1987 and 1991

(Sogawa, 1992). Therefore, the change in insecticide susceptibility of BPH and WBPH is presumed to be associated closely with some drastic change in insecticide use and cultural practice, and indirectly with the change in rice variety in those migration origins. Insect-resistant varieties have been extensively used in those areas being supplied from IRRI as consecutive introduction of various resistant gene sources.

The pronounced and sudden increase in LD50 is considered to be attributable to the change in insecticide use in the origin areas, China mainland. It is widely known that hybrid rice cultivation expanded in China in the 1970's. These varieties stimulated outbreak of WBPH and rice leafrollers. Consequently, the farmers were obliged to increase insecticide application for their control. This period coincide with the remarkable increase in LD50 for BPH and WBPH observed in Japan after the end of the1970's.

Cultivation of hybrid varieties was initiated in China in 1976 and total area planted to this improved varieties expanded quite rapidly and amounted to 5 million ha in 1979. However, planthoppers, stem borer and leafroller became prolific on the hybrid varieties compared to the native varieties used so far, which pushed up insecticide use causing gradual development of insecticide resistance as observed with the Japanese monitoring during the period between 1967 and 1979.

The increase in acreage of hybrid rice halted expansion after 1979 for some while, but, it again resumed increase being accelerated by adoption of the improved hybrid varieties and total area of hybrid rice finally amounted to 10 million ha (60% of total rice areas in China) in 1983 and 1984. These new hybrid varieties, though some of them were carrying BPH-resistant gene derived from IR-26, stimulated occurrence of WBPH and rice leafroller requiring still more frequent insecticide application. This period coincide with the highest peak of insecticide resistance of BPH in 1984 and 1985 and sudden increase in LD50 for the organophosphates in WBPH which occurred between 1980

and 1984.

Another important factor related with insecticide resistance of BPH is the shift in the kind of insecticides used in China occurring in this period. BHC had been used in great amount in China dominating as major insecticide with proportion of 50% of total insecticide consumption (0.2 million tons as active ingredients), but it was totally banned in 1983 and replaced with imported organophophates, mainly methamidofos. Import of insecticides was 16,000 tons in 1983, but it jumped up 4 times amounting to 60,000 tons in 1984 and 1985.

In short, the first peak of insecticide resistance for BPH appeared to be caused by increased insecticide use to suppress WBPH and leaf folder which were particularly prolific on the hybrid rice introduced into China after 1976 and which had covered up to 5 million ha by 1979. The second peak in 1984 and 1985 coincide with a further increase in hybrid rice over an area exceeding 10 million ha by 1983 which accelerated still more serious outbreak of WBPH which consequently lead to a further increase in insecticide application. Prohibition of BHC production in China in 1983 caused its replacement with alternative chemicals, mainly organophosphates, which lead to rapid development of insecticide resistance in those two planthoppers.

Thus, the two sharp increase in resistance level observed with BPH in 1979 and in 1984, 1985 at various monitoring sites in Japan reflects precisely the corresponding changes in the use of insecticides in the assumed origin of migratory planthoppers, mainland China.

Reduction in LD_{50} observed after the late 1980's is presumed to be associated with increase of paddies in China planted to BPH-resistant varieties on a much larger scale than ever before as reflected in the record of biotype 2 occurrence in southern China between 1989 and 1990 (Yu et al., 1991). Also in Vietnam, biotype 1 shifted to biotype 2 between 1987 and 1988 (Ich, 1991).

Thus, the changes observed in insecticide resistance in Japan for the two migratory rice planthoppers on the long-term monitoring verified that resistance actually develops rapidly even with the migratory rice insects when insecticides are used intensively and extensively at the migratory origin.

It is highly plausible that the peculiar peaks of insecticide resistance observed with the 1984 and 1985 migrant of BPH on the Japanese monitoring was caused by those specified change of situation regarding rice variety and insecticide use in China.

Monitoring on insecticide resistance of white backed planthopper in Japan

White backed planthopper had been neglected in Japan in terms of control efficacy on chemical control. Major stress had been placed on BPH and SBPH. WBPH was lumped together with BPH as target of chemical control. WBPH was the easiest target for chemical control among the rice plant- and leafhopper in terms of insecticide resistance. SBPH had provoked attention to insecticide resistance since the 1950's and BPH also in the late 1960's WBPH had never posed any problem with regards to insecticide resistance.

As shown in the report of Fukuda and Nagata (1969), WBPH was generally most susceptible to insecticides compared to other planthoppers, not to say about GLH, with the smallest topical LD_{50} among the 3 planthopper species. Any sign of resistance development was found on the 1976 monitoring for the 8 insecticides tested (Nagata, 1982). Furthermore, topical LD_{50} on the 1980 monitoring remained on almost same level of resistance and no significant increase in LD_{50} was observed with the 8 insecticide compared with the base-line data determined in 1967. The difference of LD_{50} (1980/1967) ranged 1.9~5.4 (Endo et al., 1988).

However, remarkable resistance development for the organophosphates was clearly detected on the 1987 monitoring in Kyushu (Endo et al., 1988). The resistance ratios (1987/1967) were so large for the organophosphates tested as 69 fold for fenitrothion and 50 fold for malathion, respectively and 5.8~9.9 fold for the 3 carbamates tested compared to the 1967 data by Fukuda and Nagata (1969). Hosoda (1989) insisted that the marked increase of LD_{50} had already occurred in 1985, earlier than Endo's finding. According to his annual monitoring extending between 1985 and 1987, he found the 1985 population collected in Hirosima Prefecture gave LD_{50} for the organophosphates by far much larger LD_{50} than those reported earlier by Fukuda and Nagata (1969). The resistance ratios (1985 /1967) were generally large with organophosphates, 73 fold for malathion, 51-fold for fenthion, 39-fold for phenthoate, 30 fold for malathion and 7 fold for diazinon. The resistance ratios for the 4 carbamates tested ranged 5~8 fold. However, later, Hirai (1994) addressed that marked increase in LD_{50} for WBPH had already been detected in 1984 from his regular monitoring conducted between 1984-1990.

Hosoda (1989) also compared $LD_{50}s$ between the migrant populations collected on the East China Sea and those collected inland on his 1986 survey and concluded that those resistance development was actually occurring with the migrant on the ocean as well because no significant difference was found between the two populations. Similar comparison had
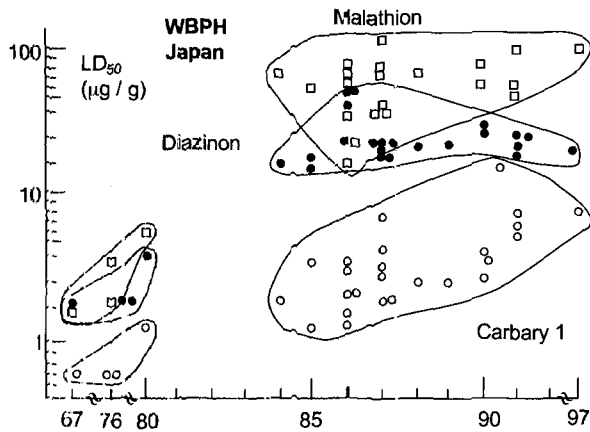
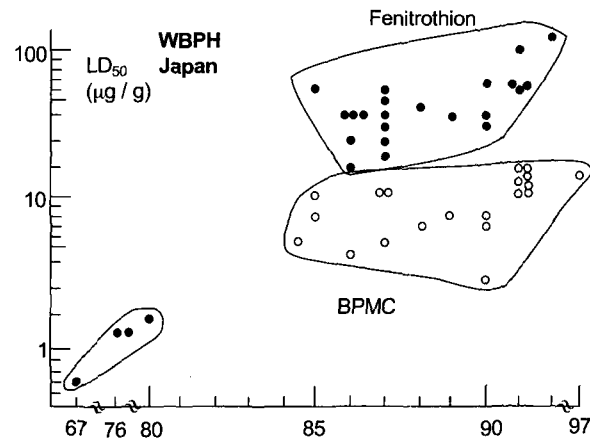Fig. 3. Topical LD50 values of WBPH compiled from Japan during 1984-1997.

Fig. 4. Topical LD50 values of WBPH compiled from Japan during 1984-1997.

been done in 1980 with BPH reaching similar conclusion (Endo et al., 1988).

After the sharp increase in 1984, LD50 for organophosphates remained on almost same levels until present time. Carbamates look to have slight tendency to increase its LD50. It is a great regret that the 1981 ~ 1983 data for WBPH are missing in Japan. It could be of great value to compare those annual change in the LD50 of WBPH with those of BPH which gave characteristic jump of resistance level during corresponding period (Figs. 3 and 4).

Strangely, no apparent reduction of LD50 occurred with WBPH while LD50 of BPH have declined distinctly after 1986. Reversely, slight increasing tendency of LD50 of WBPH is visible when the data until 1998 was outlooked.

Detailed research is required to clarify these difference in resistance development between those closely-related two species of rice planthoppers living under similar cultural conditions and presumably subject to equal selection pressure of insecticides.

Monitoring on insecticide resistance of brown planthopper and white backed planthopper in Asian countries

For international cooperation on monitoring insecticide resistance in Asian countries, following workshop was noteworthy: FAO/IRRI workshop on Monitoring Susceptibility Levels of Rice Pests to Insecticides was held in 1984. This workshop was follow-up of preceding FAO/IRRI workshop on Judicious and Effective Use of Insecticides on Rice held in 1983 at IRRI, Los Banos, Philippines. This timely program was worked out by Dr. Mochida of IRRI and 9 countries joined to establish a network for monitoring insecticide susceptibility in Asian rice growing countries.

Initial aim of this workshop was standardization of testing method, determination of base-line data and establishment of a network for compilation and exchange of information on insecticide resistance of rice insects. Priority of target pests was placed on the 5 species, BPH, WBPH, striped stem borer, GLH and leaf folder. Top priority was placed on BPH and topical LD50 for the 8 insecticides, malathion, diazinon, carbaryl, carbofuran, delthamethrin and permethrin, were requested to be contributed to the data center. As for the documentation of data, data analysis was to be done at IRRI and MARDI and the data were to be compiled at IRRI or FAO and should be circulated to member countries. Data sheet and testing kit were distributed, but, follow-up activity of this program was not necessarily so active due to shortage of budget.

(1) Korea

An early stage research on insecticide resistance of rice insects was initiated on the small brown planthopper and the rice stem borer and topical application was adopted for these insects(Choi et al., 1975; Song et al., 1976). Later, Yoo et al. (1997) determined topical LD50 of BPH for the first time in Korea and conducted continuous monitoring on 3 insecticides, diazinon, fenobucarb and carbofuran for the 25 local populations collected in 1982, 1983, 1985, 1986 and 1987 and recognized gradual decrease in the LD50 for diazinon during the period with no significant change in carbofuran, and vague peak of LD50 was perceived for fenobucarb in 1985 which correspond to the characteristic peak of LD50 commonly observed by several workers in Japan in 1984 and 1985. Regrettably the remarkable peak of topical LD50 observed in Japan for malathion and fenitrothion was not detected in this survey because these insecticides were not tested. If these organophosphates were checked, we could

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have comparable data for analyzing migration route of BPH in those years. Thus 1984 and 1985 was valuable and rare chance to trace migration range of BPH in terms of insecticide susceptibility.

(2) China

China has been producing great amount of topical LD_{50} data since the 1980's using their own domestic device for topical application, steel micro capillary for thin-layer chromatography. Gao et al. (1987a) was the first in China to start monitoring of insecticide susceptibility of BPH by topical application who surveyed the four locations in central and southern China for 18 insecticides extending 1985-1986 and reported significant increase in LD_{50} for the organophosphates comparing their data with those obtained in Japan (Fukuda and Nagata, 1969).

Gao et al. (1987b) also monitored insecticide susceptibility in 1987 on WBPH and BPH collected in Henam Province and observed a significant increase in LD_{50} for WBPH, but not so much for BPH as compared with the 1967 Japanese data.

Monitoring was succeeded by the Nanjing Agricultural University which played an important role as the National Training Center of Resistance Monitoring in China and worked out a national project on resistance monitoring since 1988. In this project Wang et al. (1996a) conducted continuous regular monitoring on topical LD_{50} of BPH during 1988-1995 on the 13 insecticides at Anhui Province and reported recent tendency decreasing insecticide susceptibility, but resistance for the organophosphates developed markedly. It is a great regret that monitoring started too late to seize the peculiar increase in topical LD_{50} observed in Japan in 1984 and 1985. Wang et al. (1996b) compared local difference of insecticide susceptibility of BPH between northern China and southern China at the 3 fixed monitoring sites.

Wang et al. (1996c) also determined topical LD_{50} for WBPH collected from the 3 locations for the 12 insecticides in 1987, 1988, 1989, 1992 and 1994 and also for BPH in 1992, 1994 and 1995 for the 9 insecticides collecting insects from the 4 locations (Fig. 5, Fig. 6). The results with WBPH were highly interesting for the variation detected. Resistance levels were generally similar with those obtained in Japan in 1989 (Endo, unpublished) as shown in Fig. 6. However, it is noticeable the difference of LD_{50} for monocrotophos and carbaryl was so large when short time interval of 7 years was considered. The LD_{50} ranged 4.8~111.2 μg/g for BHC, 0.7~54.8 μg/g for monocrotophos, 48.4~147.7 μg/g for malathion, 2.4~31.1 μg/g for methamidophos, 10.0~77.8 μg/g for fenitrothion, 1.0~38.5 μg/g for carbaryl, 1.2~40.8 μg/g for isoprocarb and 4.9~73.4 μg/g for delthamethrin,

respectively. Those difference seems too large as change occurred during the 7 years interval, especially, the difference was large with BHC (22-fold), monocrotophos (78-fold), methamidophos (13-fold), carbaryl (39-fold), isoprocarb (34-fold) and delthamethrin (15-fold). There found no apparent constant tendency in change of LD_{50} with years.

Monitoring was conducted also at the China National Rice Research Institute (CNRRI) in Hangzhou where Mao and Liang (1992) adopted the FAO/IRRI standardized testing method of topical application faithfully and determined topical LD_{50} for BPH collected in Zhejian Province with 13 insecticides in 1987-1991 and also LD_{50} for WBPH for 11 insecticides in 1987-1990. All of the data both for BPH and WBPH were almost equal to the 1989 Japanese data (Fig. 5, Fig. 6).

In 1992-1995, Wang et al. (1996d) determined LC_{50} by vial test for buprofezin, the insect growth regulator, for BPH and WBPH which will be referred as baseline data for future monitoring.

(3) Taiwan

Monitoring on insecticide susceptibility of BPH was initiated in earlier period in Taiwan. The first monitoring was conducted by Ku (1979) who surveyed resistance level by dry film method for the 7 commonly used insecticides during 1975 and 1976. This work was followed by Ku et al. (1977) who compared LC_{50} levels for the 14 insecticides (6 organophosphates and 8 carbamates) by the same testing method for 9 years extending from 1976 to 1984 and found apparent gradually increasing tendency in LC_{50} for several organphosphates.

Another work was conducted by Lin et al. (1979) who adopted spray method in which acetone solution of insecticides was sprayed to old nymph of BPH with Shandon spray. 12 locations in Taiwan was surveyed in 1977-1978 for MIPC and MTMC, the most widely used insecticide for BPH control in Taiwan. They were much more interested in detection of local variation of LC_{50} than annual change of resistance levels.

(4) Vietnam

Vietnam directed their attention to insecticide resistance of BPH when they were working on the FAO project to strengthen plant protection which started in 1981. The author supported to establish a new laboratory for the purpose and gave technical training based on the standardized method of FAO/IRRI extending 1986-1987. This laboratory conducted surveillance of BPH extending 1987-1990 as given in Fig. 5. Topical LD_{50} of the Vietnam population for the organophosphates looked slightly smaller than the 1989 Japanese values.

BPH(Asia)

Malathion, Fenitrothion, Diazinon, Carbaryl, MTMC, MIPC, BPMC, Carbofuran, Carbosulfan, Ethofenprox, Deltamethrin, Fenvalerate

Thailand77

Legend:
■ Vietnam 87-90
□ " 92
△ Thailand 92
▲ Malaysia 89-90
⌐ China 88-95
● Japan 89
○ " 92

$LD_{50}(\mu g / g)$
1   10   100   1000

● : Thailand (1977), ■ : Vietnam (1987-1990), □ : Vietnam (1992),
△ : Thailand (1992), ▲ : Malaysia ("1989-1990) ⌐: China (1988-1995) given
as range, ● : japan (1989), C : Japan (1992)

Fig. 5. Topical LD$_{50}$ values of BPH compiled from Asia.

WBPH(Asia)

Malathion, Fenitrothion, Diazinon, Manocrotophos, Carbaryl, MTMC, MIPC, BPMC, XMC, PHC, Carbofuran, Carbosulfan, Ethofenprox, Deltamethrin, Fenvalerate

Thailand77

Legend:
▲ Malaysia 89-90
○ China 87-94
● Japan 89

$LD_{50}(\mu g / g)$
1   10   100

● : Thailand (1977), ▲ : Malaysia (1989-1990), ○ :China (1987-1994),
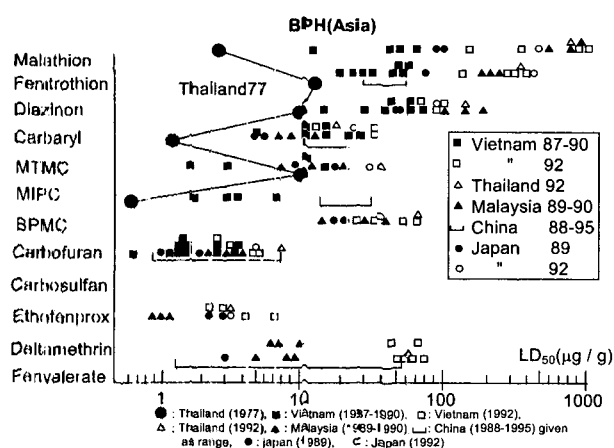● : Japan (1989)

Fig. 6. Topical LD$_{50}$ values of WBPH compiled from Asia.

Generally, the 1992 values were slightly larger than those obtained between 1987 and 1990 indicating gradual development of resistance in those origin areas. Of interest is relatively larger LD$_{50}$ for the pyrethroids, delthamethrin and fenvalerate.

The 1992 data were determined in Japan on the transported samples from the 4 locations in Vietnam (Hanoi, Haihung, Tiengiang, Haujiang) (Endo, unpublished).

(5) Thailand

The first data was obtained by Nagata and Masuda (1980) who determined topical LD$_{50}$ for BPH and WBPH collected from Nakhonpathom Prefecture in central Thailand in 1977. These field-collected populations of the two planthopper were generally more susceptible to the 8 insecticides tested than the Japanese populations with the largest difference in DDT as well as the Philippines populations of BPH and WBPH. Thailand joined the FAO/IRRI workshop on monitoring susceptibility levels of rice insects, but, they have produced not many data since then.

In 1992, topical LD$_{50}$ was determined for the Suphan buri population of BPH for 11 insecticides and remarkable increase in LD$_{50}$ ranging 10~40-fold was found compared to the 1977 data (Nagata and Masuda, 1980) indicating apparent development of insecticide resistance in the tropics (Endo, unpublished).

(6) Philippines

The first survey was conducted in 1977 on the field population of BPH and WBPH collected from IRRI field, Los Banos, Philippines and topical LD$_{50}$ were determined for the 8 insecticides on macropter and brachypter of BPH and macropter of WBPH (Nagata and Masuda, 1980). The Philippines population was
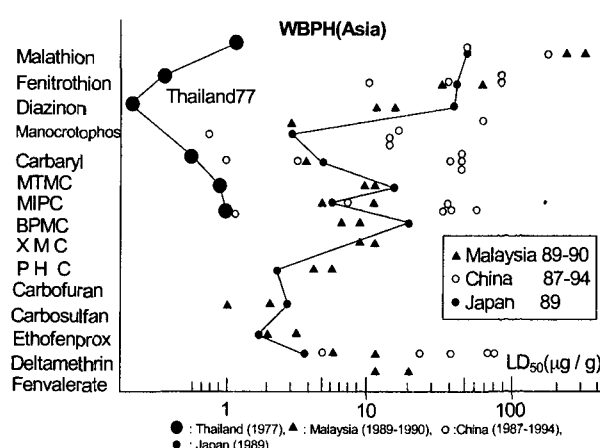
generally more susceptible compared to those collected in Japan during corresponding period. In particular, both BPH and WBPH showed specifically higher susceptibility to DDT compared to the Japanese populations.

At IRRI attention was directed to organizing international network for information exchange of resistance levels and they themselves conducted some experiment on resistance of BPH for diazinon and carbofuran and recognized development of resistance in the fields (Heinrichs et al., 1979).

(7) Malaysia

Topical LD$_{50}$ was determined for the 3 local populations of BPH for 12 insecticides in 1989 and 1990 (Endo unpublished). No significant local difference was found and they were generally less susceptible to organophophates compared with the Japanese population of corresponding years (Fig. 5), inversely to the earlier data of 1977 which indicated all of the BPH and WBPH population collected from the tropics were generally more susceptible than the Japanese populations.

WBPH were collected from 2 locations in Malaysia and tested for the 14 insecticides in 1989 and 1990 (Fig. 6). When compared with the Japanese populations of the year, LD$_{50}$ were almost same level except malathion which gave 4~7 fold larger LD$_{50}$ than the Japanese population (Endo, unpublished).

(8) Indonesia

Only few data were produced in Indonesia by entomologists who visited Japan and mastered bioassay technique for monitoring insecticide resistance of rice insects. LD$_{50}$ obtained in 1977 for carbaryl and diazinon were at almost similar levels with those of Japan in that period (Kilin, unpublished). Their interest was

more focused on Nephotettix virescens and Plutella xylostella in the early 1980's.

Conclusion

According to monitoring on insecticide susceptibility of BPH and WBPH by topical application which started in 1967 in Japan, LD$_{50}$ of BPH increased gradually for the organophosphates and carbamates during the period of 1967-1983 with small peak in 1979 and then sharp increase occurred in 1984 and 1985 with the highest peaks ever observed and it turned to decline and recovered to the 1970's level and remains unchanged until now. However, LD$_{50}$ for WBPH did not change until the early 1980s and then started to increase abruptly after 1984 and continues to increase slightly until now.

Now it has been confirmed that resistance development actually occurs even with the long-range migrating rice planthoppers. Eventually, the peaks of LD$_{50}$ observed for BPH in 1984 and 1985 coincided with the drastic change in insecticide use in the presumed migration origin, China mainland.

In the tropics, insecticide susceptibility of BPH and WBPH was generally higher compared to those in temperate regions on the 1970's monitoring. But, this situation seems to have changed presently with finding of highly resistant populations of BPH and WBPH even in the tropics. As the case in Malaysia suggests, it is striking that the tropical populations of the two planthoppers are not necessarily more susceptible than the temperate populations as reported in the 1970's. Situation seems to have changed greatly with regard to insecticide use in the tropics. It should be taken into consideration that some degree of correlation may exist between change in biotypes of BPH and change in insecticide susceptibility.

Non-chemical means of pest control are being pursued enthusiastically as major component of IPM scheme at present so far. But, sufficient supply of major food crop such as rice to meet increasing demand in Asia can not be achieved without insecticides. Therefore, more rational use of insecticide with prolonged lifetime will be needed in future. On this viewpoint, management of insecticide resistance in the key pests on rice production has to be conducted with more precaution. The factors associated with resistance development should be analyzed as a whole, insecticide usage, varieties, cultural conditions etc. Global warming may influence survival of those planthoppers in temperate regions increasing area where hopper can overwinter. Overwintering of selected population may result in quick establishment of insecticide-resistant populations of BPH and WBPH.

Climatic change may also affect migration range of these planthoppers.

Presently we need more continuous, coordinated surveillance on insecticide susceptibility of long-range migrating rice insects. The data have to be produced by standardized testing method including sample collection, rearing, handling and standardized sample set of insecticides and be compiled quickly at a centralized data center if possible. Otherwise, it sometimes takes a couple of years until they are published or kept aside as fragmentary data without publication.

Compiled data will facilitate making reference from all the countries concerned with this problem, especially between the origin countries and the destination countries in terms of migration. More important is continuity of surveillance at fixed monitoring sites and on the same set of insecticides. Fragmentary and scrappy data will greatly reduce their values.

What needed for international cooperation of monitoring on insecticide resistance of those long-range migratory insects can be summarized as follows. It is in a sense wasteful to make surveillance of insecticide susceptibility using different method and under different test conditions making incomparable data, especially in the case of wide-range migrating insects. Data produced separately or without coordination cannot be compared.

Following points are of primary importance for future cooperation. We propose following requirements:
(1) Standardization of testing method.
(2) Continuous supply and renewal of qualified insecticide samples.
(3) Systematic survey considering migration range of planthoppers.
(4) Not fragmented, simultaneous and continuous survey to trace migration range.
(5) Compilation of data by a core laboratory authorized as data center.
(6) Core laboratory to check suspected population when a specific population is found.
(7) Establishment of standardized testing method for IGR.
(8) Establishment of testing method for systemic insecticide used for nursery-box application.

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