Insecticide Resistance in the Brown Planthopper

Toru Nagata

Hokuriku National Agricultural Experiment Station

ABSTRACT

Of the rice insect pests in Japan, the brown planthopper, *Nilaparvata lugens* Stål has been rather slow in developing insecticide resistance, which is supposed to be attributable to its characteristic biology, long-distance migration and incapability of overwinter in our country. However, apparent resistance development for the organophosphates and carbamates has been observed since the 1970's, which is presumably caused by some selection pressure in migration origins. Comparisons of various immigrant populations revealed variations in insecticide resistance and, especially in the relation between nymph density and proportion of brachypterous form appearing under laboratory rearing conditions. Applicability of these inherent variations for characterization of geographical populations in this species was discussed with the objective to determine corresponding migration sources of respective immigrant populations for predicting future trend of insecticide resistance in the areas of immgrant's destination.

I. Migration and Insecticide Resistance in BPH

Being favored with relatively cheap market price of our agricultural chemicals, insecticides have been the sole control measures of the brown planthopper, *Nilaparvata lugens* Stål, (BPH), which is the rice pest of primary importance in southern half of Japan. BHC was the first insecticide used for BPH control in Japan and after ca. 20 years of use it was generally banned in 1971 for the reason of environmental contamination and replaced by the carbamates. It was a surprizing fact that only one insecticide had been used for so long period as 20 years without any serious problem of insecticide resistance in rice paddy while other rice insects developed resistance within ca.10 years after use.

Various organophosphorus insecticides such as malathion, parathion, diazinon, etc. which were used primarily against the rice stemborer, *Chilo suppressalis* and the green rice leafhopper, *Nephotettix cincticeps* (GLH), exherted concurrent effects for BPH control. But a series of carbamate insecticides which appeared after the 1960's to overcome organophosphorus resistant GLH took place of the organophosphates and BHC as BPH control agents. Again, these carbamates were replaced by the synergistic mixtures such as organophosphates + carbamate which were devised to overcome the carbamate resistant GLH. Thus insecticides have undergone so much change not for BPH's own reason but for that of resistance development in other rice insects, especially in GLH. Presently, no small portion of our insecticide production is being consumed for BPH control. Dust is most commonly used formulation in our country and our dusts are mostly formulated with more than two kind of active ingredients for the purpose of: (1) Saving labor by controlling several pest species at one time. (2) Utilizing joint action by mixing two pesticides against resistant insects (Table 1).

The reason for relatively slow rate of resistance development in BPH can be elucidated with its characteristic biology, which was clarified in recent two decades; Though BPH are exposed to intensive insecticide application in our paddy, they eventually die out in winter for the lack of food plant and low temperature and susceptible populations are supplied by long-distance migration year by year from outside Japan as immigrant.

Table 1. Production of Insecticide Dust Used for BPH Control in Japan (1982)

Formulations	Production (ton)
Insecticides	
BPMC	6,149
Malathion: BPMC	5,903
Cartap: BPMC	3,856
Fenthion: BPMC	2,666
Diazinon: carbaryl	2,645
MTMC	2,644
Mixtures of insecticides and fungicides	
Fenthion: BPMC: ediphenphos	5,833
Fenthion: XMC: ediphenphos	5,633
Fenitrothion: BPMC: rabcide: kasugamycin	2,577
BPMC: ediphenphos	2,115

Source: Japan Plant Protection Association "Noyaku-Yoran-1982"

Particular seasonal fluctuation of BHC-resistance related with this biology was detected while inter-generation variations of BHC susceptibilities were traced from 1968 to 1970 in Kyushu areas, that is, gradual increase of BHC-resistance in autumn generations and its recovery in the immigrant generation of the following year, which was observed repeatedly during the period (Nagata and Moriya, 1979).

However, long-term comparison of insecticide susceptibility in immigrant BPH revealed apparently increasing trend of resistance in Kyushu areas. A significant increase of topical LD_{50} values for the organophosphates, malathion and fenitrothion, was observed in 1976's survey (Nagata *et al.* 1979) and carbamate resistance was confirmed in 1979 (Kilin *et al.* 1981) (Fig. 1). Other worker's data also support resistance development in the 1970's (Ozaki and Kassai, 1982; Hosoda, 1983). Hosoda (1983) concluded resistance development based on the yearly survey since 1970 in Hiroshima Pref. His data did not show constant increasing trend of resistance and considerable yearly fluctuation was involved. However, abrupt increase of carbamate resistance was also observed in 1979 coincident with the results in Kyushu areas (Fig. 2).

Naturally, resistance development in the immigrant BPH arose in migration origins. Origin of our immigrant BPH is presumed to be southern part of China mainland (Kisimoto, 1976). Recent studies on migration of BPH clarified that the insect can breed all the year round in a limited part of southern China, southern half of Hainan island, and extend its distribution by five times of northward migration reaching 35°N in the autumn and return migration occurs as three times of southward migration (Cheng *et al.*, 1979). Some portion of the northward migration is considered to be conveyed to Japan by wind stream in the rainy season.

Occurrence of BPH in China mainland was reported to have increased in the 1970's as a result of the increase in double cropping areas of rice and changes in rice varieties. They have largely depended on insecticides, especially parathion and BHC, for BPH control as they have no effective resistant variety against BPH. Hence recent increase in insecticide use in China is presumably responsible for the resistance development observed with the immigrant. In fact, BPH collected on the East China Sea in 1980 summer showed resistance levels almost equal to the Japanese immigrant of the year for

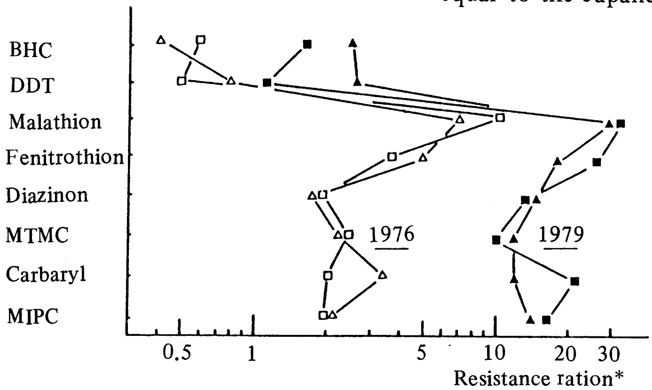
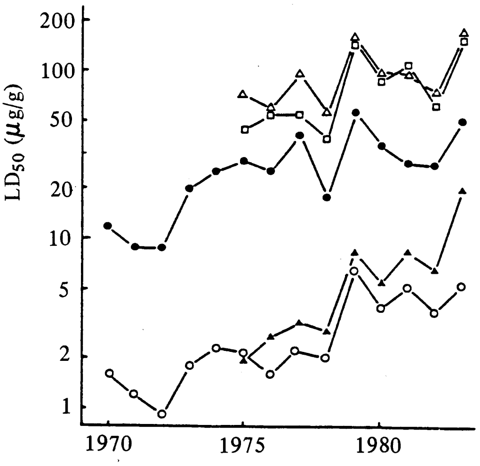


Fig. 1. Development of insecticide resistance in immigrant BPH monitored at two different sites in Kyushu. △:Kogoshima. 1976, □: Nagasaki. 1976, ▲:Kagoshima. 1979. ■:Nagasaki. 1979, *: Resistance ratios were calculated on the basis of 1967 topical LD_{50} values (Fukuda and Nagata, 1969).



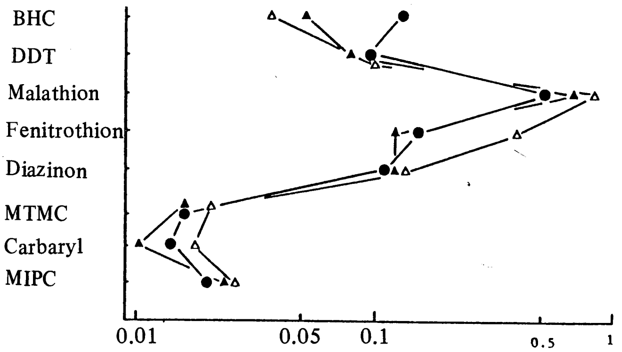


Fig. 2. Insecticide-resistance patterns of immigrant and East China Sea population of BPH (1980). △: 1st migration wave, ▲: 2nd migraion wave, ●: East China Sea population.

Fig. 3. Resistance development in BPH observed in Hiroshima Pref, central Japan (Hosoda, 1983; Data after 1982 were obtained by pers. com.). △: Fenitrothion, □: Malathion, ●: Diazinon, ▲: BPMC, ○: Carbaryl.

the eight insecticides tested (Fig. 3). Three local populations of BPH collected 1981-1982 were offered from the Government of China for the first time in 1982. Comparison with the Japanese immigrant showed that the three populations from Shanghai, Hangchow and Kwangchow showed almost similar response to the 11 insecticides including pyrethroids (Fig. 4).

Selection pressure of some insecticides, when given continuously in laboratory, cause resistance development in BPH. For instance, when BPH is selected with malathion for 9 generations in laboratory, ca. 19-fold increase of LC$_{50}$ occurred (Chung *et al.* 1982) and 25 generations of diazinon selection caused ca. 5-fold increase of LD$_{50}$ (Hosoda, 1983). However,

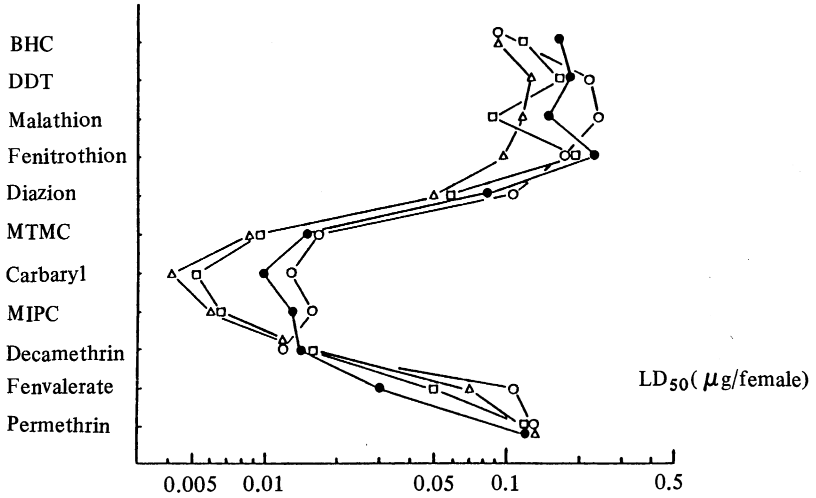


Fig. 4. Insecticide-resistance patterns of BPH collected in Chia mainland. ○: Shanghai (1981), △: Hangchow (1982), □: Kwangchow (1982), ●: Immigrant population collected at Chikugo in Kyushu (1982)

carbamate selection appears not so efficient in causing resistance in BPH according to Japanese worker's data. BPMC or carbaryl selection for successive 52 generations caused only 3.7- and 1.7-fold increase of topical LD_{50}, respectively (Hosoda, 1983). Also, 15 generations of carbaryl selection by Korean scientists caused only 1.5-fold increase of topical LD_{50} (Chung and Choi, 1981). However, results of laboratory selection with carbamates are rather different in Taiwan. Lin *et al.* (1979) reported that MIPC or MTMC selection for 6 or 7 generations caused 6.1- and 8.0-fold increase of resistance for respective insecticides and also 34-fold increase of LC_{50} for MIPC occurred after 16 generations of continuous selection with MIPC (Chung *et al.* 1982). These results are inconsistent with those obtained in Japan and the reason is not understood.

Thus, selection experiments in laboratory suggested possibility of resistance development in general when BPH is exposed to insecticides, therefore presumable increase in insecticide use in China mainland caused by continuous outbreaks of BPH in the 1970's are likely to be associated with the resistance development in the immigrant BPH invading our country in these ten years. Similarly in China, decrease in efficiency of malathion has been reported and they add IBP to make up for the effect of malathion (IRRI, 1978). However, BPH immigrants show no significant increase of BHC resistance for these 15 years. LD_{50} for BHC remain unchanged around 0.05μg/female since 1967 survey, which is very strange to consider that BHC has been used long in China and it was banned only recently in 1982.

Secondly, migration of BPH from tropical areas to China should be considered. It is highly probable that BPH migrate into China mainland from some neighboring tropical areas such as Vietnam or Philippines as suggested by Chinese report (Guangdong Academy of Agriculture, 1979).

In the tropics, resistant varieties of rice are being used predominantly and selection pressure by insecticides is relatively lower than those in Japan or China. Therefore, resistance levels of tropical populations are considered to be lower than those in the temperate areas. Actually, a few available data in the tropics show that their topical LD_{50} values are generally smaller than those of the Japanese immigrant obtained in the same year. BPH collected from Thailand and the Philippines showed considerably higher insecticide susceptibility, especially to DDT, compared with the Japanese immigrants (Nagata and Masuda, 1980).

In addition, population size of BPH resident in China mainland is presumably changeable. It fluctuates remarkably according to the minimum temperature in winter year by year. In fact, overwintering areas of BPH was confined to relatively small areas in 1976 with its northern margin at 21°N due to cold winter. However, in 1977, warm winter expanded its margin to 25°N and Kwantung Province, Kwangsi Province and most part of Fukien Province entered within the limit of overwintering areas (Cheng *et al.* 1979).

Hence a hypothesis will be proposed that; Resistance levels of our immigrant BPH are determined by the three complex factors on the assumption that direct migration origin of our BPH is China mainland and some inflow is occurring from the tropics into China mainland and some resident populations are present in China mainland: (1) Resistance level of China resident populations; (2) Resistance level of tropical populations migrating to China mainland; (3) Mixing ratios of the both populations in the Japanese immigrants.

The fact is more complicated and there remain many problems to be considered. Conflicting results have been obtained about local difference of insecticide resistance in Japan. For instance, no significant difference was detected in Hiroshima Pref. for the 11 insecticides tested between 7 local BPH populations collected in 1979 and 5 populations in 1980. The maximum difference being less than 2-fold though they were derived from autumn generations (Hosoda, 1983). On the other hand, there are reports on the presence of local difference in autumn generations (Ozaki and Kassai, 1982; Kilin *et al.* 1981). Differences detected in autumn generations, however, are not of substantial significance, might be caused by the difference of selection pressure by insecticides in respective areas after the insects settled there and eventually these differences disappear in winter.

More important are variations in insecticide resistance in immigrant populations. In Kyushu, immigrant populations collected from 8 different sites during the same migration period in 1979 showed completely equal levels of resistance for the 8 insecticides tested (Kilin *et al.* 1981). Migration period of our immigrants is rather long in rainy reason extending over one month as several migration waves and it is probable that BPH of each migration waves starts from different migration sources and have different properties with regard to insecticide resistance and so for th.

Although we have found no significant difference in resistance levels between the two major migration waves in 1980 and 1981, remarkable variation was found in 1981 between the two waves in wing-form density response as shown in later section of this article. Similarly, a considerable variation in resistance for malathion (9.1-fold) and propoxur (4.8-fold) were detected between two migration waves in Kagoshima Pref, southern extremity of Kyushu isl. in 1981 (Hama, pers. comm.).

Thus it appears appropriate to consider that the immigrant invading Japan is not always homogeneous regarding insecticide resistance and some other properties. Therefore, long-range comparison of mean annual levels of resistance in immigrant BPH gives most clear-cut indications for resistance monitoring in this country. Fortunately, further increase of insecticide resistance in immigrant BPH has not been observed after 1979 so far (Nagata, in prep.; Hosoda, pers. comm. in Fig. 2) but it appears probable because the maximum resistance levels attained by laboratory selection are still higher than presently occurring populations.

In case of GLH, development of carbamate resistance led to use of mixtures of organophosphate + carbamate, or organophosphorus fungicide (IBP) + organophosphate to overcome them and any of carbamates is not used solely for the control of GLH presently. However, synergistic effects of these mixtures are not so conspicuous in BPH as observed with carbamate resistant GLH in general, though IBP exhibits highly synergistic activity with malathion and fenitrothion in BPH, especially for organophosphorus resistant BPH (Hama and Hosoda, 1983).

The promising substitute chemicals for future BPH control are; (1) Pyrethroids: Though most of existing pyrethroids have drawback to be used in rice paddy as they have high fish toxicity, but recently several advanced pyrethroids with low fish toxicity have been developed in our country. The second point at issue is its cross resistance with conventional insecticides. Kassai and Ozaki (1984) produced fenvalerate-resistant BPH by 19 generations of laboratory selection. LD_{50} for fenvalerate increased 11 times while malathion resistance decreased 1/4 of the parental population used for selection, that is, negatively correlated resistance was observed for the two insecticides, (2) Insect growth regulator (IGR): A promising chemical has been commercialized recently as buprofezine in our country, which has outstandingly long persistent period over 20-30 days to suppress population growth of BPH and no cross resistance with conventional insecticides. Considerable portion of presently used chemicals will be replaced with this compound.

II. Biochemical Aspects of Insecticide Resistance in BPH

Biochemical analysis on mechanism of insecticide resistance in BPH started only recently. The reason for the delay seems to be due to lack of suitable material strains of BPH which have high resistance ratios, especially for the carbamates.

Hama and Hosoda (1983) studied biochemical features of resistance in BPH and found significant positive relationship between aliesterase activity and resistance levels for malathion and fenitrothion by comparing 6 strains which have 86- and 53-fold differences of LD_{50} for malathion and fenitrothion respectively. Chung and Sun (1983) also found independently that esterase hydrolysis are contributing malathion- and MIPC resistance. However, mechanism of carbamate resistance in BPH has not been manifested definitely at present.

Miyata *et al.* (1983) studied in vitro degradation of ^{14}C-methyl malathion with laboratory-selected malathion-and fenitrothion-resistant strains of BPH and found enhanced activity of carboxyesterase in the both strains. Degradation of malathion was remarkable in the esterase bands with the highest activity to hydrolyze β-naphthyl acetate. Hasui and Ozaki (1984) compared electrophoresis zymograms of BPH with varied resistance levels on proteins, aliesterase and acetylcholinesterase by polyacrylamide gel disk electrophoresis and discussed their relation with resistance mechanism.

III. Geographical Variations of BPH and Their Relation with Insecticide Resistance

In Japan, trend of insecticide resistance in BPH is exclusively dependent on the situation in migration origins. There is possibility that BPH which have very broad geographical distribution have varied levels of insecticide resistance in nature or as a result of insecticide use and migrate to Japan by occasional conditions of air mass movement in migration season. Though direct origins of our BPH are presumed to be southern part of China mainland (Kisimoto, 1976), exact features are not known fully yet. Therefore, if any trait of geographical population of BPH are present, it could be of great practical as well as basic significance and used as a means to determine their exact origins.

Presently we are not sure if immigrants originate from single source. In our attempt to compare insecticide susceptibilities of BPH obtained from various locations of Asia, we expected to find definite difference between geographical populations and succeeded to some extent by finding generally higher insecticide susceptibility in BPH and the white backed planthopper, *Sogatella furcifera* of the tropics. But insecticide susceptibility is not an appropriate trait of geographical variation because it is not constant, being affected readily by insecticide use. However, we came across another more interesting findings in these researches, that is, remarkable inherent geographical variations in proportion of brachypterous form appearing under laboratory rearing conditions.

BPH and the white backed planthopper collected from the tropics (Thailand and Philippines) gave outstandingly higher proportion of brachypters when reared on rice seedlings compared with those collected in Japan while two different BPH populations occurred in Taiwan in closely located two sites, Touliu and Chiayi (Nagata and Masuda, 1980). Recently Indonesian populations of BPH also proved to give extremely high proportion of brachypters (Nagata unpublished; Tojo in prep.). Hence, we postulated some geographical clines in wing-form density response of these species, that is, presence of "tropical type" and "temperate type".

Besides this, a considerable other diversities in various characters of BPH have been reported; Distribution of BPH populations with geographical variations have been found with regard to the vilurence to resistant varieties of rice (Seshu and Kauffman, 1980; Verma et al, 1979). Results of hybridization experiments and comparisons of acoustic signals revealed that BPH populations obtained from Australia and Solomon island differed definitely from all other local populations (Claridge, 1980). Also, phenotypes of esterase electrophoresis showed inter-population variations (Claridge, 1980; Chu *et al.* 1982).

We examined feasibility of immuno-electrophoresis using antiserum prepared from normal Japanese immigrant BPH as standard. Although it is still on preliminary step, fairly marked differences have been obtained in numbers and density of specific bands detected. (Nagata in prep.).

However, in 1978, an autumn population of BPH collected in central Japan (Hiroshima Pref.) attracted our attention by producing unusually high proportion of brachypters on laboratory rearing and majority of nymphs developed into brachypters as was observed with the Philippine population. This character was apparently inherent. The Hiroshima strain was used to determine inheritance of wing morphs by crossing experiments and it was demonstrated to be sex-conditioned inheritance because brachypterous form was controlled by single dominant allele in the females but segregation in the male did not show expected goodness of fit (Iwanaga *et al.* in prep.).

There have been no clear explanation on inheritance of BPH's wing morphs except some scattered ones which suggest vaguely genetic determination of wing forms in this species. Mochida (1975) reported a brachypter-abundant strain of BPH derived from a stock culture of a recessive mutant with red eyes which had been maintained for ca.10 generations, during which it was likely to have been selected unintentionally toward brachypterism because adults appearing earlier was used as parents to prevent the valu-

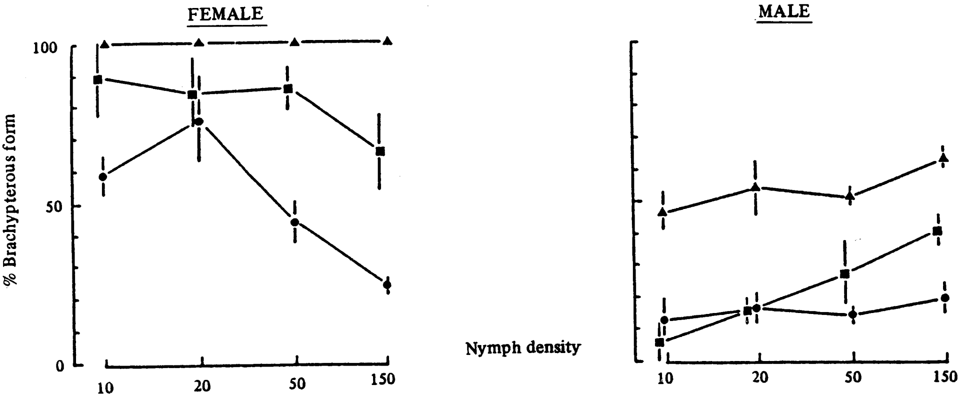


Fig. 5. Variations in the relation between proportion of brachypterous form and nymph density. ▲: Hiroshima (1978), ●: Nagasaki (1981, 1st migration wave), ■: Nagasaki (1981, 2nd migration wave) (Iwanaga *et al.*, in prep.).

able strain from extinction. Saxena *et al.* (1981) also suggested inheritance of wing forms from the results of experiments on biotypes of BPH conducted at IRRI, in which parental wing form influenced that of the progeny.

Later on, extended surveylance on wing-form density response of various immigrant populations was conducted in 1981-1983 and a considerable variations were found. For instance, significant difference was found in 1981 between the two populations derived from different swarms of immigrant BPH captured at the same sites in Kyushu (Nagasaki Pref.) with interval of about one week (Fig. 5). In 1983 attempts were made to collect as many possible immigrant populations in Japan in June and July and remarkable variations were again confirmed between the 11 immigrant populations including so extremely brachypterous population almost equal to the tropical BPH reported before. Hence it appeared probable that our immigrants are composed of populations with varied biological properties as represented in wing morphs.

The relation between insecticide susceptibilities and variations in wing morphs of BPH, however, has not been established yet, but generally brachypterous populations appear slightly more sensitive to insecticides as indicated by the tropical populations and the 1978 Hiroshima strain which gave somewhat higher susceptibility compared with the other 8 populations collected in the same year (Kilin *et al.*, 1981).

Though we have no clear interpretation of these variation of wing morphs of BPH and the white backed planthopper, this inherent variations in naturally occuring populations appear to be result of selection in annual breeding areas caused by removal of macropters by emigration leaving brachypters behind because selection experiments in laboratory transformed a normal population into a strain which give significantly higher proportion of brachypters or mavcropters after they were subjected to continuous selection of same wing form for ca. 10 generations. Therefore macropterous immigrant population is assumed to have migrated from the fringe of this species' distribution.

Neither insecticide susceptibility nor wing-form density response is not necessarily appropriate property alone to be used for characterization of a hopper population. Many recognizable characters have to be combined to detect spacial isolation of geographical populations of BPH.

IV. Conclusion

For the resistance development in migratory insects like BPH, we have no measures to prevent it in advance before the problems arose such as rotating or sparing use of insecticides which is usually believed to prevent or delay resistance development in overwintering resident insects. Therefore, what is of vital importance is to determine exact distribution of source areas from which our immigrant BPH arrive and where the insects are affected by the influences causing resistance development. Secondly, it is also necessary to monitor resistance levels of immigrant populations closely and regularly. The informations about insecticide-resistance levels, cropping system, insecticide use and yearly occurrence of this insect in these source areas should be constantly secured to predict future trend of resistance development in the immigrant's destination areas such as Japan and Korea.

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