Pesticide Resistance of Agricultural Pests in Japan

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A quarter century has passed since DDT was firstly applied to control agricultural insect pests. The amount of synthesized organic insecticides applied in fields increased rapidly since 1952 and the rate of increase was about 10 per cent a year. In 1960 an evident report was made on insecticide resistance of insects, so 10 years have passed following the first appearance of insecticide-resistant insects. Today, pest species developed or suspected of resistance totals 11 species of insects and 6 species of mites as shown in Table 1. The author reviews the circumstances of occurrence and some results of studies on major instances of resistant pests.

Rice stem borer, *Chilo suppressalis* Walker

The rice stem borer is one of the most important pests of rice plants in Japan. Parathion has been used extensively to control them since 1953. In 1960, it was reported that the control of the rice stem borer by parathion had failed in some parts of Kagawa Prefecture, Shikoku districts. This was the first important problem of pesticide resistance of agricultural pest insects in Japan, and its remarkable phenomenon was attributed to the fact that this was the first example of resistance to organophosphorus insecticides in Lepidopterous insects in the world. Studies clarified the point that parathion-resistant larvae had high activity of parathion degradation and did not have cross resistance to the other organophosphorus chemicals such as methyl paration. As the result the parathion-resistant borer was prevented from spreading by changing insecticide to be applied for the control.

Control of the rice stem borer by BHC dust was established in about 1950, and application of fine dust or granular formulation of BHC to paddy fields became very popular in 1961 or 1962. In 1964, declination of susceptibility of the borers to BHC was found in Kagawa Prefecture. After that, similar phenomena were reported in some other prefectures. The amount of BHC applied to paddy fields has been decreased for its residue in rice plants. Consequently, BHC resistance of rice stem borer may not become a serious problem in future.

Recently, declination of susceptibility of the borer to fenitrothion is suspected in a few parts of Japan. A more detailed survey is needed to clarify the resistance of fenitrothion.

Green rice leafhopper, *Nephotettix cincticeps* Uhler

In 1954 and '55, malathion was found to be an excellent chemical to control the green rice leafhopper. Since then, this chemical has been applied extensively in most areas where this insect is prevalent. In Kôchi Prefecture, Shikoku districts, malathion has been used to control this pest from 1955, and 1.5% malathion dust was applied to paddy fields under

Table 1. A list of agricultural pests developed (or suspected to be developed) resistance to pesticide in Japan

Pest species	Host plant or crop	Pesticide developed resistance
Insect in paddy field		
Rice stem borer, *Chilo suppressalis*	Rice	parathion, BHC, fenitrothion*
Green rice leafhopper, *Nephotettix cincticeps*	〃	malathion, other OP**, carbamates
Smaller brown planthopper, *Laodelphax striatellus*	〃	BHC, malathion
Rice leaf beetle, *Oulema oryzae*	〃	BHC
Smaller rice leaf miner, *Hydrellia griseola*	〃	BHC*
Insect in vegetable field		
Common cabbage worm, *Pieris rapea crucivora*	Cruciferous vegetable	DDT
Onion maggot, *Hylemya antique*	Onion	aldrin*, heptachlor*
Seed-corn maggot, *Hylemya platura*	Bean and other crops	aldrin, heptachlor
Diamondback moth, *Plutella xylostella*	Cruciferous vegetable	DDVP*
Striped flea beetle, *Phyllotreta strioleta*	〃	aldrin*, heptachlor*
Green peach aphid, *Myzus persicae*	〃	some kinds of OP
Mite		
European red mite, *Panonychus ulmi*	Apple tree	phenkapton, Tedion, Sappiran, vamidothion, Imidan, Kelthane, Morestan
Citrus red mite, *Panonychus citri*	Citrus	phenkapton, Tedion, dimethoate, Kelthane, binapacryl, Morestan
Two-spotted spider mite, *Tetranychus ulticae*	Apple, peach, pear plant	phenkapton, methyl demeton, vamidothion, Kelthane
Sweet cherry spider mite *Tetranychus viennensis*	Peach tree	methyl demeton
Kanzawa spider mite, *Tetranychus kanzawai*	Tea plant	phenkapton, Tedion, Estox, Kelthane
Carmine mite, *Tetranychus telarius*	Flowering and pear plants	methyl demeton, Estox, Kelthane

*: suspected or farmer's report
**: abbreviation of organophosphorus chemical

the cooperative control program from 1958. In the spring of 1960, the effect of malathion dust was low and satisfactory results of control could not be obtained even by application of 3% dust.

In Ehime Prefecture, Shikoku districts, malathion was used in 1959 to control the green rice leafhopper, but at that time, methyl parathion had been already used in a large amount to control the rice stem borer from several years ago. In 1962, methyl parathion was applied for control of both the stem borer and the leafhopper, but it was discovered that only poor results were obtained to control the leafhopper. In the following year, insecticide-susceptibility was tested in the leafhopper populations from many parts of the prefecture and it was found that some populations had inferior susceptibility to methyl parathion and malathion. In 1965, effect of fenthion was also found to be low against this leafhopper.

These are two remarkable examples of resistant leafhopper which were reported early, but afterwards, reports of similar evidences in many prefectures were received in succession.

Due to the fact that green rice leafhoppers inhabit paddy fields throughout the rice cultivating period and pass three or four generations there, they are frequently exposed to various organophosphorus insecticides which are applied to the other insect pests. For this reason, some other organophosphorus insecticides as well as malathion are considered affecting the green rice leafhoppers as selecting pressure. Therefore, the leafhopper resistance to organophosphorus insecticides is likely to occur as multiple resistance as well as cross of malathion. This possibility is fully observed in Table 2; that is, there is a close relationship existing between LD_{50} values of insecticides and their amounts applied previously in paddy fields.

In contrast with parathion resistance of rice stem borer, there is practically no alternative organophosphorus insecticide for the resistant green rice leafhopper, and the only effective insecticides may be carbamates. As there seems to be a possibility that the green rice leafhopper will develop resistance to carbamate insecticides in future, insecticide resistance of this leafhopper is now a serious problem confronting Japan.

Rice leaf beetle, *Oulema oryzae* Kuwayama

In Hokkaidō, BHC has been applied to control the rice leaf beetle which is one of the major pest insects of rice plants in the north-

Table 2. LD_{50} values of insecticides to the green rice leafhoppers collected in five places and amount of insecticides previously applied there

Insecticides	LD_{50} ($\mu g/g$ of body weight) of populations collected in				
	Kōnosu	Sojima	Fujita	Ōsone	Nakagawara
Malathion	0.65	8.51	3.51	4.63	12.41
PAPTHION	0.75	5.45	4.43	6.58	9.46
Dimethoate	2.53	46.99	14.39	7.45	43.83
Parathion	3.06	19.54	32.60	4.09	125.26
Methyl parathion	6.84	40.65	141.98	16.08	319.76
Fenitrothion	14.62	37.67	390.16	19.92	1090.94
Diazinon	1.85	5.36	2.77	1.44	8.99
Fenthion	9.91	56.63	32.83	14.46	39.43
EPN	4.91	15.98	18.25	5.32	63.65
Carbaryl	1.14	3.07	1.04	1.39	1.64
Hoppcide	3.30	4.76	4.08	2.99	4.18
Propoxur	4.33	4.43	3.75	3.60	3.23
		Amount of insecticides (g of ingredient per hectare applied in each place for period of)			
		1960–1963	1958–1963	1957–1963	1957–1963
Malathion		2860	2131	4232	101
Parathion		—	669	—	5953
Methyl parathion		2243	2690	637	7304
Fenitrothion		—	887	—	—
Fenthion		—	29	5	—
EPN		151	725	2720	3892
Carbaryl		—	—	—	87

ern part of Japan. This chemical has been used once or twice in a nursery bed for control of the rice leaf beetle since 1954 when the smaller rice leaf miner, *Hydrellia griseola* Fallén, occurred severely. BHC was also applied customarily to control the rice stem borer in the periods when the rice leaf beetle was in the larva or new adult stage. For these reasons, damage to rice plants by rice leaf beetles was slight, but it increased in 1963 and some areas where BHC dust showed only poor effect to this beetle were found in 1964. At that time, even 3% dust of BHC was not sufficient, although in early time, good control results were achieved by BHC dusts of 0.5 to 1.0%. Areas where the resistant populations occurred were surveyed and detecting methods of resistance were studied from 1965. Those were clarified that there were some populations which were about ten times more resistant than susceptible population and that the resistance was maintained in all stages of this insect.

In Hokkaido, DDT, EPN or PAPTHION are now used for alternative insecticides against the rice leaf beetle resistant to BHC. Recently, similar phenomena were reported in Sado Island and some other places.

Seed-corn maggot, *Hylemya platura* Meigen

The seed-corn maggot is one of the most important pests of bean seedlings in Hokkaido, and soil application of aldrin or heptachlor has been recommended for control of this pest since 1958. But a few years later, some places where the control effect was not always satisfactory were reported frequently and it was suspected that the seed-corn maggots had developed resistance to insecticides.

Studies on insecticide resistance were started in 1962. By these studies it was clarified that susceptibility to heptachlor and aldrin was very different among localities. When the susceptibility of adults to heptachlor was assayed by topical application, the highest LD_{50} value among surveyed populations was 487 times higher than the most susceptible population.

Now, VC-13 is recommended as an alternative insecticide to control the seedcorn maggots resistant to organochlorinated hydrocarbons.

There are similar other cases that the seedcorn maggots are suspected to have developed resistance to aldrin or heptachlor, but no trouble occurs by using that alternative insecticide.

Mites

Resistance to pesticides is a very serious problem in mites. Not only fruit and tea culturists but also chemical manufactures are now distressed by the fact that several kinds of mites damaging fruit trees and tea plants develop resistance to various acaricides one after another.

European red mite, *Panonychus ulmi* Koch, in Aomori Prefecture, for example, lowered its susceptibility to phenkapton in 1959 and to Sappiran in 1960, then to Tedion, Miteran, Milvex, vamidothion, one by one, and even any good acaricide became ineffective after some years of recommendation.

In citrus red mite, *Panonychus citri* McGregor, Tedion resistance reported in Saga Prefecture in 1960 was the first citrus example in Japan. Since 1963, resistance to phenkapton, dimethoate and the other organophosphorus acaricides occurred in many places. Now, most of the organophosphorus acaricides are not used practically for control of the citrus red mite. Although it had been said that the resistance to Kelthane was hard to be developed, declination of susceptibility to Kelthane was also found gradually in both the European red mite and the citrus red mite about three or four years ago.

As to Kanzawa spider mite, *Tetranychus kanzawai* Kishida, of tea plants, instances of resistance to phenkapton were gradually spread since 1962 or so. Following this, the control effect of Estox also declined which was recommended as alternating acaricide of phenkapton. Decreasing in susceptibility to

Kelthane was also found in 1966.

Studies on acaricide resistance of mites were promoted extensively since 1963 and many results have been obtained on surveying of resistance, detecting methods of resistance, cross and multiple resistance, alternating acaricides, recovery of susceptibility after stoppage of the acaricide application, genetics of resistance and other investigations. As mites collected in fields are generally considered to have been exposed by selecting pressure of various acaricides, discriminating cross resistance from multiple one is very difficult.

Generally, cross-resistance pattern to chemicals in mites is considered to be more complex than in insects. For instance, study is under way in which the two-spotted spider mite, *Tetranychus urticae* Koch, continuously selected by Kelthane is developed to have more resistance to phenkapton than to Kelthane. Tedion-resistant citrus red mite found in Saga Prefecture ten years ago has been reared isolatedly not exposed with any acaricide. At first the resistance level was lowered but afterwards it was not so lowered as first and at present that strain of mite still maintains a fair degree of resistance.