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Management of Resistant Diamondback Moth and Other Crucifer Pests in Taiwan[1]

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Abstract : Resistant diamondback moth (*Plutella xylostella,* DBM) was managed by insecticide alternation of organophosphorus insecticides, *Bacillus thuringiensis* (B.t.) and cartap to avoid cross resistance. The rationale of insecticide selection was discussed in detail. Other pests were also considered in the design of the implementation program. In this implementation program, several counter measures were taken for removing the constraints, including pesticide dependency, misuse of pesticide, marketing competition, etc. After 3-year test (1990—93), the evaluation indicated a 16.7% increase in crop income, 35% saving in insecticide expenditure, lengthening the spray interval by 2.1 days (from 5.7 days to 7.8 days), and 1.6 insecticides reduction (from 4.4 to 2.8 insecticides) per tank mixture.

Key words : Diamondback moth (*Plutella xylostella*), Resistance management program, Insecticide alternation, Nucleus farmers

INTRODUCTION

A serious insecticide resistance in the diamondback moth (*Plutella xylostella,* DBM) occurred in 1970s. It not only resulted in failure of recommended pest control measures but also caused many pesticide related problems such as (1) aimless mixing of pesticides, (2) cost increase in vegetable protection, and (3) residual problem from overuse of pesticides, etc. In order to solve these problems, Taiwan Agricultural Research Institute (TARI) initiated a DBM research program in 1980, which consisted of the following parts :

1. Developing a survey method for detecting resistance.
2. Conducting a general survey of resistance in DBM.
3. Elucidating the characters of insecticide resistance.
4. Examining the cross resistance amongst insecticides.
5. Designing a strategy for managing resistant DBM.
6. Implementing the resistance management program (RMP).

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The first two parts were completed and reported in 1981[3,4], and update reports of resistance survey were followed[8,9,12,23]. The third and fourth parts were completed in 1987, which laid the fundation for the insecticide alternation strategy as proposed in 1987[5]. Later, the Council of Agriculture (COA) assigned TARI to coordinate TACTRI (Taiwan Agricultural Chemical and Toxic-substances Research Institute) and AVRDC (Asian Vegetable Research and Development Center) on three projects below.

1. Biological control of resistant DBM led by Dr. N. S. Talekar of AVRDC.
2. The ecology and population dynamics of DBM by Mr. W. Y. Su of TACTRI.
3. Implementation of insecticide alternation strategy for managing the resistant DBM, conducted by Dr. E. Y. Cheng of TARI.

For the first part of the program, Dr. Talekar of the AVRDC reported that the DBM on highland crucifers had been successfully brought to a level below the economic threshold by an effective natural enemy, *Diadegma semiclausum* with supplementary sprays of microbial insecticide, *Bacillus thuringiensis* (B.t.)[36]. Unfortunately, the same practice was not successful on lowland crucifers, and more complicated pesticide application on lowland was suggested as the reason for failure.

The second part of the program i.e., ecology and cultural control strategy of DBM, was reported[13] in 1993.

In the third part of the program, TARI had invited 6 farmers from two farmer associations to test the insecticide alternation strategy in September of 1990. The preliminary trial received favorable comments[10], and the project was expanded to 68 farmers from 8 farmer associations in the following year. The evaluation of the second year's result prompted COA and PDAF (Department of Agriculture and Forestry, Taiwan Provincial Government) to accept the strategy as a practical way to manage the resistant DBM. In 1993, the program was officially adopted for extension by 29 farmer associations with 192 farmers participated.

After confirming the farmer's acceptance of resistant DBM management strategy, we now report the design, structure and function of this implementation program.

RATIONALES OF DESIGNING THE RESISTANCE MANAGEMENT STRATEGY FOR DBM

We believe that with a clear knowledge of resistance and cross resistance, farmers can be educated to select suitable insecticide to reduce or avoid the resistance, and then a resistance management program based on the alternation of insecticides with minimal cross resistance can be implemented. The following outlines are the characters of DBM resistance (Table 1) which provide rationales for selecting insecticides.

1. Resistance characters of DBM

(1) MFO-involved resistance I : Carbamate insecticides

Table 1. Resistance and cross resistance characters of DBM to different categories of insecticides

Resistance profile	OPs	Carbaryl methomyl and propoxur	Carbofuran	Synthetic pyrethroids	IGRs	Cartap	*Bacillus thuringiensis*
Resistance stability	stable to unstable	stable	unstable	unstable	unstable	stable	unstable
Resistance amplitude	medium	high	high	high	high	medium	medium
Resistance mechanism involved	multifactorial	monofactorial	monofactorial	monofactorial	monofactorial	monofactorial (proposed)	monofactorial (proposed)
Responsible biochemical entities	insensitive AChE GSTase carboxyl esterase esterase	MFOn	MFOc	MFOs	MFOi	broad spectrum esterase (proposed)	change of the receptors in the epithelium of midgut
Practical synergist	TDP	PB	PB	PB	PB	—	—
Genetic expression	intermediate	dominant	intermediate	intermediate	recessive	additive (proposed)	
Comments for field usage	OPs with unstable resistance are useful in the insecticide alternation program	Not recommended	Not recommended for the fast growing crucifer, occasionally use in the early growing stage to avoid residue problem	Strongly recommended for crucifer to control pests other than DBM	Can be used in a mosaic or alternation spraying program	Recommended for the insecticide alternation except in season with heavy precipitation	Recommended for the insecticide alternation, especially in the near-harvest period for safety consideration

AChE : acetylcholinesterase
MFOn : natural inherent MFO
MFOs : synthetic pyrethroid-induced MFO
TDP : 2-(3, 5-dichlorophenyl)-2-(2, 2, 2-trichloroethyl)oxirane
PB : piperonyl butoxide
GSTase : glutathione-S-transferase
MFOc : carbofuran-induced MFO
MFOi : IGR-induced MFO

Mixed function oxidases (MFOs) play a major role in detoxifying carbamates in many insects[1,2], and MFOs are also responsible for the poor performance of carbamates in DBM[14]. Carbamates are not very effective even against susceptible DBM. For instance, carbaryl, propoxur or methomyl were the least toxic material among 15 insecticides tested against a French susceptible strain[26]; and carbaryl and methomyl were also ineffective on Taiwan susceptible IL strain[18]. Despite that, as a member of the carbamate group, carbofuran is exceptionally effective and is not affected by the MFO which detoxify carbaryl and methomyl[14,18]. However, when DBM was subjected to carbofuran selection, a new MFO for resistance to carbofuran developed readily within several generations but with minimal cross effect to other insecticides [18,37].

There is no cross resistance between pyrethroids and carbamates. In other words, the MFOs which oxidize carbamates in DBM are not capable of detoxifying pyrethroids. This is based on the following premises : (1) synthetic pyrethroids provided excellent DBM control when it was first introduced, despite that carbaryl or methomyl had been ineffective for years ; (2) there was no cross resistance to pyrethroids in the carbofuran-selected resistant strain[18] ; (3) in the susceptible IL strain, piperonyl butoxide synergized carbaryl at ca. 47-fold but had no effect on carbofuran or three synthetic pyrethroids tested[14].

In summary, carbamates are not recommended for DBM control because they induce resistance readily, cause resurgence problem[27], and are higly toxic to non-target organisms.

(2) MFO-involved resistance II : Synthetic pyrethroids

Cross resistance within the synthetic pyrethroid (SP) group is commonly occurred in DBM[8] i.e., the resistance induced by one synthetic pyrethroid can extend to other members of the group[18,26].

DBM will lose the SP-resistance upon removal of the selection pressure. The rate of loss varies in different strains[14,35]. However, strong resistance will reappear readily when SP-selection resume. It is assumed that MFOs play a major role in the SP-resistance since most of the resistance is inhibited by the piperonyl butoxide (PB). A residual PB-insensitive resistance still existed and depended on which synthetic pyrethroid was tested[35]. Liu et al.[25,26] reported a 2-fold synergism by esterase inhibitors for permethrin in DBM. In another lepidopterous pest, *Spodoptera littoralis*, the increased esterase activity was strongly linked to the development of SP-resistance[31].

(3) MFO-involved resistance III : Insect growth regulators (IGRs)

In 1987, benzoylphenyl urea (BPU)-type IGRs were introduced for DBM control in Taiwan. Since then, the IGR resistance has been a great concern. The MFO of susceptible DBM possess an inherited metabolic activity toward diflubenzuron and triflumuron[15], and a mild teflubenzuron resistance was induced in DBM by laboratory selection [29]. The MFO degradation was considered as the resistance mechanism for IGRs in houseflies[30] and DBM[29]. In Taiwan, the sensitivities (LD_{50}) of DBM toward chlorfluazuron and teflubenzuron were below 10 mg/l before their registration in 1987[5].

However, the susceptibility (LD_{50}) of DBM to chlorfluazuron in Lu-chu area had increased from 3.8 mg/l in March to 924 mg/l in December, 1988, a 243-fold increase[9] in nine months. By the end of 1989, DBM collected from five different regions showed varied chlorfluazuron resistance as the LD_{50}s were 61.8-1,685.7mg/l, while the LD_{50}s to teflubenzuron ranged from 100.5 to 72,628.6 mg/l[9].

The cross resistance within the BPU-type IGR group is rather obvious. Although hexaflumuron and flufenoxuron have never been registered in Taiwan, resistance to both insecticides had developed in three field DBM strains and two IGR-resistant strains selected by chlorfluazuron and teflubenzuron[6].

The IGR resistance was significantly but not entirely affected by the action of piperonyl butoxide. The synergistic ratios (S.R.) for teflubenzuron were 7.9-10.4 in three DBM populations, while the S.R. for chlorfluazuron in five IGR-resistant DBM strains were in the range of 2.6 to 16.3[9]. Without selection pressure, the IGR-resistance gradually declined in DBM, for example, after 17 selection-free generations the resistance ratios of Lu-chu strain declined from 7,621 and 243 to only 6.5 and 3.1 for teflubenzuron and chlorfluazuron, respectively[9].

By crossing with the susceptible strain, the IGR resistance in DBM reduced drastically. Such a genetic manipulation can result in greater reduction in IGR resistance than the synergistic action of piperonyl butoxide. The IGR resistance almost diminished completely in the offsprings of RxS populations in three generations, as the sensitivities of this F_3 offsprings to both teflubenzuron and chlorfluazuron were almost restored to the level of the susceptible strain[9].

Summary of MFO-involved resistances

With the finding of MFO involvement in IGR resistance, the oxidative detoxication obviously appeared as the most important resistance mechanism in DBM. Chou and Cheng[18] first noticed that DBM can develop a unique carbofuran-resistance, surprisingly, which was different from the resistance to carbaryl and methomyl. Based upon that finding, we had questioned the adequacy of the term "carbamate resistance" [35] in regard to DBM because its obscure definition. Cheng et al.[14] again demonstrated the specificity difference in MFOs to carbamates and synthetic pyrethroids. New lines of MFO for metabolizing IGRs further confirmed the diversity and the importance of MFO in DBM. From the study on carbamates, synthetic pyrethroids, IGRs and an experimental insecticide, SN 72129[11], the characters of MFO-involved resistance in DBM could be outlined as follows :

1. Naturally inherent MFO in DBM was responsible for the tolerance/resistance to certain insecticides such as carbaryl, methomyl and propoxur, and can be further selected to a higher resistance level.
2. MFO-involved resistances to carbofuran, synthetic pyrethroids and IGRs were induced.
3. MFOs were highly diversified for different xenobiotics.
4. MFOs were either specific for a single compound, such as carbofuran, or an entire

chemical group such as synthetic pyrethroids.

5. MFOs involvement was genetically diversed, being recessive for IGRs, intermediate for synthetic pyrethroids, and dominant for carbamates.
6. The MFO-involved resistances responded indefinitely in amplitude and could eventually render the control chemical ineffective at any dosage. Carbaryl, methomyl, carbofuran, synthetic pyrethroids and IGRs have all met the same fate in DBM control.

All these facts indicate that DBM has a very efficient, active, both inherent and inducible MFO complex. Whenever a xenobiotic molecule fits to be the substrate for one of the many "hidden" MFOs, the survived DBM with this subline MFO would multiply under the selection, and a new MFO-involved resistance would appear.

(4) Resistance to organophosphorus insecticides

DBM resistance to organophosphorus insecticides (OPs) is characterized by a series of complicated cross resistance patterns; each covers only a limited number of OPs, and was dependent upon the initial and subsequent selectors. Cheng et al.[8] had characterized the OP-cross resistance by selecting DBM with mevinphos, profenofos and prothiophos. Similar selections have been done for cyanophos, dichlorvos, prothiophos[33], diazinon[17] and phenthoate[28]. Mevinphos induced only slight and unstable resistance (R.R.=8.0 after 20-generation selection) with limited cross resistance to other OPs[7]. According to Sun et al.[35], the resistance declined faster in regard to mevinphos than profenofos and prothiophos. Dichlorvos-selected DBM developed strong resistance to cyanophos, dibrom, salithion, mecarbam and fenitrothion, but showed little or no resistance to other 11 OPs. Sasaki indicated that prothiophos-selected DBM developed strong resistance to 10 out of 17 OPs tested[33], while we observed prothiophos- and profenofos-selected strains only developed resistance to 3 out of 8 OPs [8].

Cheng et al.[5] summarized the OP-resistance in DBM into three groups according to the resistance stability in field :

Group I : The least stable group includes mevinphos, phenthoate, methidathion and pirimiphos-methyl. The developed resistances decayed within 1-3 months.

Group II : The intermediate stable group includes profenofos and prothiophos. The resistances of this group can last for about 3-6 months.

Group III : The most stable group is the resistances to methamidophos, mephosfolan and quinalphos, and the resistances to these insecticides can persist for more than 6 months.

Responses similar to those field observations were confirmed in the laboratory. For instance, DBM with the least resistance to mevinphos, phenthoate and methidathion, turned out to be strongly resistant to methamidophos, mephosfolan and quinalphos [8,14,23]. The stability difference in OP resistance is probably a major reason why certain OPs are still effective for DBM control. Hence they should be considered in the alternate spray schedule.

(5) Resistance to cartap

In Japan[32] and Taiwan[4], DBM developed only weak resistance to cartap after prolonged field usage. However, in the Cameron Highlands of Malaysia, cartap resistance became very strong[34] and the high resistance to cartap can also be induced in the laboratory[18].

The mechanism of resistance to cartap is still unknown. The F_1 offsprings of crossing between resistant and susceptible strains had higher cartap-tolerance than either parent strain. In the isoelectric focusing(IEF) observation, the esterases of F_1 offsprings had higher activities and more isozymes[12], and it was suggested that broad-spectrum esterases in DBM enhance its tolerance to cartap by hydrolysing the thioester bond. The cross resistance to cartap had been reported in a mevinphos-[7], two phenthoate-selected strains[28], and a minor cross resistance occurred in a fenvalerate-resistant strain as well[18]. Surprisingly, mevinphos, phenthoate and fenvalerate all have an ester bond in their structures.

On direct contact, cartap has a good initial action against DBM, but its residual effect is weak[23] because the highly soluble cartap can be washed off by the moisture condensed on leaves in the evening.

(6) Resistance to *Bacillus thuringiensis* (B.t.)

Commercial B.t. products have beeen introduced and widely used in Taiwan for more than 30 years. Field evaluation indicated that new B.t. formulations, viz. SAN415, Florbac-FC, Florbac-XLV and CGA237218 were better than the first generation B.t.[24], and the possibility of B.t. resistance was suspected. However, study in 1992 to 1994 on B.t. efficacy in field DBMs confirmed the existence of B.t. resistance. Thuricide with the longest marketing history in Taiwan, exhibited highest resistance ratio(R.R.) at 118.3. The estimated R.R. of field DBM to *B.t.* subsp. *kurstaki* was 5.4-118.3, and 34.9 to the single CryIA(c) toxin product, MVP. Mild cross resistance of *B.t.* subsp. *kurstaki* to *B. t.* subsp. *aizawai* was also detected[21].

Test of the laboratory-maintained field colonies showed that the B.t. resistance ratios were merely 1.3-7.0, indicating the B.t. resistance will decline in DBM if they are relieved from the selection. Field DBMs collected freshly from different regions showed various insensitivities to B.t. products, reflecting regional difference of B.t. usage in the field[21].

Many efforts have been made to understand the molecular basis of selectivity and insecticidal properties of B.t. toxins. A brief overview of B.t. structures, the interaction of B.t. toxins with insect cell membranes, the histopathology of B.t. action, and a discussion of insect resistance to B.t. was reviewed in 1992[20].

2. Resistance alert for newly introduced insecticides

(1) Diafenthiuron

Diafenthiuron was registered for DBM control in Taiwan since 1993, which has a better and steadier control efficacy on both DBM and *Spodoptera litura* as compared to newly developed B.t. products[24]. Laboratory tests showed diafenthiuron confronts with no cross resistance from other existing insecticides, and PB had no effect on the

efficacy of diafenthiuron[10].

(2) Abamectin

Abamectin was registered in Taiwan for DBM control in 1992-93. Although its control efficacy for resistant DBM is excellent, the acceptancy by farmers is affected by higher cost than other insecticides. Following one year field application, minor abamectin resistance has been detected in two field DBM populations, Lu-chu and Erlung, and the R.R. were 32 and 27, respectively, compared to TARI's susceptible IL strain[22]. The LD_{90} for both field strains was 2.0-3.0 mg/l, which is still lower than the field-recommended spray dosage of 10 mg/l, hence the farmers may not notice the loss in control efficacy. Continuous monitoring of abamectin resistance will be conducted to determine whether this pesticide can be adopted into further insecticide alternation program.

3. Selection of insecticides for alternate spray strategy

For alternate spray, selection of insecticides with independent mode of action is the most important prerequisite because the influence of cross resistance can be minimized. Cartap, B.t. and OPs are the proper candidates, while carbamates, synthetic pyrethroids and IGRs should not be included in the alternate spray program due to the readily induced MFO activities. For OPs, only those confront with inconstant and moderate resistance (e.g., mevinphos, phenthoate, methidathion and pirimiphos-methyl, etc.) should be considered for rotation, and among them mevinphos is the most favorable choice for its short residual span.

We have constructed a list of selected insecticides and their correspondent target pests (Table 2) as the field instruction material for farmers.

Table 2. Insecticides selection for managing resistant DBM and other crucifer pests

Insecticides	Dilution	DBM[z]	CPR	CWW	ICW	CLP	BAW	TCW	FB	APH	LM
Mevinphos	500X	+[y]	+	+	+			+	+		
(or Profenofos)	1000X	+	△	△	△			△	+		
B.t.	2000X	+	+	+	+	+					
Cartap	1000X	+								△	△
Bifenthrin	1000X		△	△	+	+	+	+		+	
Cyromazine	6000X										+

[z] DBM--diamondback moth ; CPR--cabbage pyralia ; CWW--cabbage webworm ; ICW--imported cabbage worm ; CLP--cabbage looper ; BAW--beet armyworm ; TCW--tobacco cutworm ; FB--stripped flea beetle ; APH--aphids ; LM--leaf-miner

[y] + : registered for pest control △ : not registered but effective for control

For other pests, one synthetic pyrethroid is included due to its mammalian safety and broad control spectrum for pests such as *Spodoptera litura, S. exigua, Trichoplusia ni,* etc. The SP-resistance induced in DBM will not interfere with the selected control agents for the sake of no cross resistance.

So far DBM has developed mild resistance to abamectin, and no evidence for resistance to diafenthiuron. This makes them appropriate as the independent DBM control agents. If they meet the requirement of no cross resistance to other insecticides, they will serve as future candidates in the alternate spray program.

4. Other considerations in insecticide selection

In practice, culture-related factors as well as other important crucifer pests should be considered in insecticide selection :

(1) Other important pests include imported cabbage worms (ICW, *Pieris rapae crucivova* and *P. canidia sordida*), tobacco cutworm (TCW, *Spodoptera litura*), beet armyworm (BAW, *Spodoptera exigua*), cabbage webworm (CWW, *Hellulla undalis*), cabbage pyralia (CPR, *Crocidalomia binotalis*), cabbage looper (CLP, *Trichoplusia ni*), stripped flea beetle (FB, *Phyllotreta striolata*), leaf-miner (LM, *Liriomyza trifolii* and *L. bryoniae*), and the aphids (APH, *Aphis gossypii, Lipaphis erysimi* and *Brevicoryne brassicae*).

(2) Profenofos should be used to substitute mevinphos in DBM control when stripped flea beetle is also a concern in the field.

(3) Different B.t. products have to be evaluated against DBM for B.t. resistance, especially for new B.t. product.

(4) For farmers frequently grow other leafy vegetables adjacent to crucifers, precaution should be made to cartap usage as it can cause phytotoxicity in the young seedlings of those vegetables.

(5) Resistant *Liriomyza trifolii* invaded Taiwan in 1988, and we are not able to control it by either biological or other non-chemical agent so far. When the leaf-miner population density is low, cartap and thiocyclam hydrogenoxalate are recommended, and cyromazine should be used only at high leaf-miner density. Besides, leaf-miner can also be controlled by abamectin.

5. Constraints in implementing RMP in Taiwan

In Taiwan, farm unit is small and usually intensively cultivated. Crop varieties are numerous. The hot and humid weather favors the pests and diseases. Agricultural manpower is either aged or in shortage. All these factors make the implementation program significantly different from the resistance management for large acreage crop, e.g. cotton in Australia[19].

Several significant constraints are identified as follows :

(1) Through a 40-year longterm practice, reliance on chemical insecticides is both psychological and operational. Preventive spray has become the best policy adopted by farmers when dealing with the year-round cropping of a great variety of crops. Pest control as a measure of insurance has become routine operation in farming.

(2) In Taiwan, pesticide industry operates in a free market, and the competition of retailers caused a lot of misuses of unfit pesticides in dealing with the resistance problem.

(3) Instead of using insecticides rationally through the recommendation of extension

service, mixing more insecticides in one spray has become a very common solution for relieving the resistance. This ill-fated practice was further encouraged and intensified by pesticide retailers.

(4) All categories of insecticides are used in the same region during the same period, which render the coordination of an area-wide insecticide alternation schedule extremely difficult.

(5) In Taiwan, the warm and humid environment promotes the generation overlapping of pests. Thus any resistance management strategy on seasonal or window-type[19] basis is impractical and destined to failure.

MATERIALS AND TACTICS FOR IMPLEMENTATION

1. Insecticides are supplied to nucleus farmers by "the package consideration"

In order to grow good quality crucifers, vegetable farmers have to control both the resistant DBM and other pests. If only aimed at the resistant DBM, the selected insecticides may not provide satisfactory control for other pests, and farmers will have no choice but add other insecticides. This will cause (1) interference in insecticide alternation, and (2) confusion in interpretating the final implementation results. Therefore, insecticides for controlling other insect pests were also included in implementation.

Based on the rationales of efficacy, resistance and cross resistance, a complete package of 6 insecticides was selected for all major pests in Table 2. The insecticides were supplied to those participated nucleus farmers at a 3-month interval and only at demonstration quantity.

2. Notes for insecticides usage on major crucifer pests :

DBM

(1) For avoiding resistance development, OP, cartap and B.t. should be used alternately.

(2) Bifenthrin is for pests other than DBM, since DBM has already developed SP-resistance.

(3) During high DBM density period, from October to Feburary, spray interval may be shortened to 5 days if necessary.

(4) B.t. spray can also control BAW and CWW.

Other lepidopterous pests

(1) If many species of lepidopterous pests occurred at the same time, do not use many insecticides, try the broad spectrum bifenthrin first.

(2) Bifenthrin is also effective against the eggs of TCW and BAW[16].

(3) Mevinphos and profenofos are effective against DBM, CPR, CWW and TCW, and can reduce the use of bifenthrin.

(4) B.t. is also effective against some lepidopterous pests.

Flea beetle (FB)

(1) The eggs and larvae of FB are in the soil. Larvae feed on roots and adults on leaves.

(2) When there is an outbreak, a 3-5 days spray interval is needed.

(3) Flooding the field before planting is very helpful.

(4) Profenofos is more effective than mevinphos.

Leaf-miner (LM)

(1) When leaf-miner density is low, cartap can provide enough protection.

(2) Cyromazine should be used to suppress the outbreak of leaf-miner.

Aphids

Mevinphos, cartap or bifenthrin can offer proper protection, but they should be used alternately.

3. Examples of insecticides rotation for various pest conditions :

Case 1 : DBM+other lepidopterous pests

Use the following combination alternately :

(1) mevinphos+bifenthrin

(2) cartap+bifenthrin

(3) B.t.+bifenthrin

Case 2 : DBM+FB

Use profenofos or the following combination alternately :

(1) profenofos+B.t.

(2) profenofos+cartap

Case 3 : DBM+LM

Alternately use :

(1) cartap

(2) mevinphos+cyromazine

(3) B.t.+cyromazine

Case 4 : DBM+aphids

Alternately use :

(1) cartap

(2) mevinphos

(3) B.t.+bifenthrin

4. Role of farmer organization : training and on-site education

Farmer association is responsible for coordinating nucleus farmers in the implementation program, and TARI's specialists visit farmer associations once a month on the following occasions :

(1) Supplying selected insecticides.

(2) Holding discussion session with farmers.

(3) Teaching the farmers to identify pests.

(4) Discussing the advantages and disadvantages of suggested control measures on efficacies, residues, safety and cost.

(5) Collecting the implementation working records, and commenting on erroneous usage of insecticides.

5. Report session of participated farmers to their neighboring farmers

At the end of the year, every participated farmer is obligatory by contract to give a talk about his experience to the neighboring farmers in the training sessions.

6. Providing the well-illustrated leaflet of both major crucifer pests and insecticides for rotation application to all vegetable farmers.

We found that vegetable farmers are extremely lacking the knowledge of pest identification and insecticides selection. To solve this problem, a brochure of "Resistant Pests Management on Crucifer Vegetables" was edited and issued in 1993 as a training material to participated farmers.

RESULTS AND DISCUSSION

1. The advantage of supplying a complete insecticide package to participated farmers was manifested in the final evaluation. Participants apparently had a better knowledge about each recommended insecticide and its target pests. A lot of experienced farmers were surprised to find out that the effectiveness of rationally selected insecticide is equivalent to or better than their own choice of mixing four or five insecticides. The most significant improvement is that farmers have learnt to select insecticides on a more informative basis. In the field discussion sessions, nucleus farmers become awakened and realized their 20 to 30 years experience of mixing insecticides is not a correct solution for dealing with pesticide resistance. The fact also revealed that serious DBM resistance problem was probably due to the use of many unfit insecticides.

2. The participated farmers become more confident and enthusiastic as they become volunteer instructors for the implementation program. Neighbors of the nucleus farmer could easily verify his RM practice. Besides, this "honor system" tactics ensured the participated farmer to conduct the experiment truthfully with only minimal manpower for supervising.

3. The brochure of resistant pests management on cruciferous vegetables has gained well acceptance. In view of the response of farmers, the Department of Agriculture and Forest of the Provincial Government immediately adopted the brochure as the official extension material, and 65,000 extra copies were printed for dissemination.

4. An evaluation of this RMP was conducted after implementing the program for two years (1990—1992) on the insecticides mixing, the spray interval, the insecticide expenditure as well as the benefit. In 1991—92, 65 farmers belonging to 8 farmer's associations have gained an average of 20% increase in crop income, 32% saving in insecticide expenditure, 2.3 days' lengthening of the spray interval (from 5.0 days to 7.3 days) and 1.8 insecticides reduction in tank mixture (from 5.1 to 3.3 per tank) (Table 3). The result of 1992—93 was similar, 127 farmers of 21 farmer associations have gained a 15% increase in crop income, 37 % saving in insecticide expenditure, 2 days' lengthening of the spray interval (from 6.0 days to 8.0 days), and 1.5 insecticides reduction in tank mixing (from 4.0 to 2.5 per tank) (Table 3).

5. Newly introduced DBM control agents e.g. diafenthiuron, new types of B.t. and abamectin, will attract the farmer's attention away from the resistance management practice for the reason of convenience rather than the cost. But following the recent finding of DBM resistance to B.t. and abamectin, unavoidable consequence will make the resistance manage-

ment more prevailing in the future.

Table 3. Evaluation of implementation program for the management of pesticide-resistant DBM and other crucifer pests in 1991—93

Evaluation Item	1991—92[z]	1992—93	Mean
Farmer's appraisal (%)			
Good	61.5	56.0	57.8
Fair	37.0	44.0	41.7
Poor	1.5	0	0.5
Insecticide saving (%)	32.0	37.0	35.0
Spraying interval (days)			
Before implementation	5.0	6.0	5.7
After implementation	7.3	8.0	7.8
Insecticides/Tank mixture			
Before implementation	5.1	4.0	4.4
After implementation	3.3	2.5	2.8
Income increase (%)	20.0	15.0	16.7

[z] In 1991-92, there were 65 farmer participants belonging to 8 farmer associations (FA), while in 1992-93, 127 participants from 21 FA.

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REFERENCES

1. Brattsen, L.B. and R.L. Metcalf. 1970. The synergistic ratio of carbaryl with piperonyl butoxide as an indicator of the distribution of multifunction oxidases in the insecta. J. Econ. Entomol. 63 : 101 -104.
2. Brattsen, L.B. and R.L. Metcalf. 1973. Synergism of carbaryl toxicity in natural insect populations. J. Econ. Entomol. 66 : 1347-1348.
3. Cheng. 1981a. Insecticide resistance study in *Plutella xylostella* (L.) I. Developing a sampling method for surveying. J. Agric. Res. China 30 : 277-284.
4. Cheng. 1981b. Insecticide resistance study in *Plutella xylostella* (L.) II. A general survey (1980-81). J. Agric. Res. China 30 : 285-293.
5. Cheng, E.Y. 1988. Problems of control of insecticide-resistant *Plutella xylostella.* Pestic. Sci. 23 : 177-188.
6. Cheng, E.Y. 1993. "Collaboration on the Research of BPU-type IGR-resistance in the Diamondback Moth, *Plutella xylostella*" , presumed working scheme based on IRAC Method No. 7 for the Field Crops and Vegetable Working Group, IRAC. 38 pp. TARI, Wufeng, Taichung, Taiwan.
7. Cheng, E.Y., T.M. Chou and C.H. Kao. 1984. Insecticide resistance study in *Plutella xylostella* (L.) V. The induction, cross resistance and glutathione-S-transferase in relation to mevinphos-resistance. J. Agric. Res. China 33 : 73-80.
8. Cheng, E.Y., T.M. Chou and C.H. Kao. 1985. Insecticide resistance study in *Plutella xylostella* (L.) VI. An experimental analysis of organophosphorus and synthetic pyrethroid resistances. J. Agric.

Res. China 34 : 96-104.

9. Cheng, E.Y., C.H. Kao and C.S. Chiu. 1990. Insecticide resistance study in *Plutella xylostella* (L.) X. The IGR-resistance and the possible management strategy. J. Agric. Res. China 39 : 208-220.
10. Cheng, E.Y., C.H. Kao and C.S. Chiu. 1992. Resistance, cross-resistance and chemical control of diamondback moth in Taiwan : Recent developments. in "Diamondback Moth and Other Crucifer Pests" (N.S. Talekar, ed.) : Proceedings of the Second International Workshop, December 10-14, 1990, Tainan, Taiwan. p. 465-475.
11. Cheng, E.Y., C.H. Kao and D.F. Lin. 1987. The induction and the mechanism of SN72129 resistance in the DBM, *Plutella xylostella* (L.). J. Agric. Res. China 36 : 228—236.
12. Cheng, E.Y., C.H. Kao and D.F. Lin 1988. Insecticide resistance study in *Plutella xylostella* (L.) IX. The selective metabolism of insecticides. J. Agric. Res. China 37 : 328-339.
13. Cheng, E.Y., N.S. Talekar and W.Y. Su. 1993. Integrated control of resistant diamondback moth. Special Publication New No. 1, pp.1-30, The Plant Protection Society of ROC, Taichung, Taiwan (in Chinese with English abstract) .
14. Cheng, E.Y. C.H. Kao, D.F. Lin and T.C. Tsai. 1986. Insecticide resistance study in *Plutella xylostella* (L.) VIII. The specificity of oxidative detoxication mechanism in larval stage. J. Agric. Res. China 35 : 375-386.
15. Cheng, E.Y., D.F. Lin, T.C. Tsai and C.H. Kao. 1988. Insecticide resistance study in *Plutella xylostella* (L.) IX. The selective metabolism of insecticides. J. Agric. Res. China 37 : 328-339.
16. Cheng, E.Y., W.T. Lu, W.G. Lin, D.F. Lin and T.C. Tsai. 1988. Effective control of beet armyworm, *Spodoptera exigua* (Hübner), on green onion by the ovicidal action of bifenthrin. J. Agric. Res. China 37 : 320-327.
17. Chi, H. and C.N. Sun. 1976. A study on the resistance of *Plutella xylostella* (L.) to diazinon in Taiwan. Science Agric. 24 : 403-406 (in Chinese).
18. Chou, T.M. and E.Y. Cheng. 1983. Insecticide resistance study in *Plutella xylostella* (L.) III. The insecticide susceptibilities and resistance response of a native susceptible strain. J. Agric. Res. China 32 : 146-154.
19. Forrester, N. 1990. Designing, implementing and servicing an insecticide resistance management strategy. Pestic. Sci. 28 : 167-179.
20. Gill, S.S., E.A. Cowles and P.V. Pietrantonio. 1992. The mode of action of *Bacillus thuringiensis* endotoxins. Ann. Rev. Entomol. 37 : 615-636.
21. Kao, C.H. and E.Y. Cheng. 1994. The resistance and cross resistance of diamondback moth, *Plutella xylostella* to *Bacillus thuringiensis* in Taiwan. J. Agric. Res. China 43 : 425-432.
22. Kao, C.H. and E.Y. Cheng. Unpublished data.
23. Kao, C.H., E.Y. Cheng and D.F. Lin. 1986. Insecticide resistance study in *Plutella xylostella* (L.) VII. Action patterns of insecticides and the resistance impacts. J. Agric. Res. China 35 : 107-117.
24. Kao, C.H., C.S. Chiu and E.Y. Cheng. 1990. Field evaluation of microbial and chemical insecticides for diamondback moth and other lepidopterous pests control on cabbage. J. Agric. Res. China 39 : 221-227.
25. Liu, M.Y., J.S. Chen and C.N. Sun. 1984. Synergism of pyrethroids by several compounds in larvae of the diamondback moth (Lepidoptera : Plutellidae). J. Econ. Entomol. 77 : 851-856.
26. Liu, M.Y., Y.J. Tzeng and C.N. Sun. 1980. Diamondback moth resistance to several synthetic pyrethroids. Science Agric. 28 : 355-358. (in Chinese) .
27. Nemoto, H. 1987. Factors inducing resurgence in the diamondback moth after application of methomyl. in "Diamondback Moth Management" (N.S. Talekar, Ed.) : Proceedings of the First Interna-

tional Workshop, March 11-15, 1985, Tainan, Taiwan. pp. 387-394.

28. Noppun, V., T. Miyata and T. Saito. 1987. Cross resistance and synergism studies in the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera : Yponomeutidae). J. Appl. Entomol. 22 : 98-104.
29. Perng, F.S., M.C. Yao, C.F. Hung and C.N. Sun. 1988. Teflubenzuron resistance in diamondback moth (Lepidoptera : Plutellidae). J. Econ. Entomol. 81 : 1277-1282.
30. Pimprikar, G.D. and G.P. Georghiou. 1977. Mechanisms of resistance to diflubenzuron in the house fly, *Musca domestica* (L.). Pestic. Biochem. Physiol. 12 : 10-22.
31. Riskallah, M.R. 1983. Esterases and resistance to synthetic pyrethroids in the Egyptian cotton leafworm. Pestic. Biochem. Physiol. 19 : 184-189.
32. Sakai, M. 1987. Chemical control of diamondback moth in Japan with special reference to cartap. in "Proceedings of the First International Workshop" (N.S. Talekar, Ed.), March 11-15, 1985. Tainan, Taiwan. pp. 297-306.
33. Sasaki, Y. 1982. in "Results of Pest Control Studies" -Annual Report for 1982. Japan Plant Protection Association, Tokyo, pp. 92-102 (in Japanese).
34. Sudderuddin, K.I. and P.F. Kok. 1978. Insecticide resistance in *Plutella xylostella* collected from Cameron Highlands of Malaysia. FAO Plant Protection Bulletin 26 : 53-57.
35. Sun, C.N., T.K. Wu, J.S. Chen and W.T. Lee. 1987. Insecticide resistance in diamondback moth. in "Diamondback Moth Management" (N.S. Talekar, Ed.) : Proceedings of the First International Workshop, March 11-15, 1985, Tainan, Taiwan. pp. 359-371.
36. Talekar, N.S., J.C. Yang and S.T. Lee. 1992. Introduction of *Diadegma semiclausum* to control diamondback moth in Taiwan. in "Diamondback Moth and Other Crucifer Pests" (N.S. Talekar, Ed.) : Proceedings of the Second International Workshop, December 10-14, 1990, Tainan, Taiwan. pp. 263-270.
37. Wang, T.C. and H.T. Feng. 1986. Diamondback moth resistance and cross resistance to four commonly used insecticides in Taiwan. Bull. Inst. Zoology, Academia Sinica 25 : 99-104.

抗藥性小菜蛾及其他十字花科蔬菜害蟲之管理[1]

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摘 要

十字花科蔬菜重要害蟲，小菜蛾（*Plutella xylostella* L.），因抗藥性問題而難以防治，經究明其抗藥性及藥劑間之交互抗性關係，確定應該避免使用易爲多功能氧化酵素（MFO）分解之對象藥劑如氨基甲酸鹽、合成除蟲菊精及昆蟲生長調節劑等，而採用培丹、蘇力菌及抗性不穩定之有機磷類，如美文松、亞特松及滅大松，輪流使用，即可達到防治並消除抗性干擾之目的。工作中並將十字花科蔬菜其他重要害蟲，如大型鱗翅目害蟲、黃條葉蚤、潛蠅及蚜蟲等之防治藥劑一併考慮，而提出解決抗藥性小菜蛾及其他害蟲用藥之說明及範例，供農民使用。經過三年田間之示範，並評估29個參加農會之192名參試農民，結果顯示此一綜合防治用藥較農民慣用技術平均可減少35%農藥支出；噴藥間隔可由5.7天延長爲7.8天；藥劑之混合使用由4.4種減至2.8種；而蔬菜農友之收入也增加了16.7%，因而此一防治策略及技術已被納入正規推廣系統，成爲本省十字花科蔬菜害蟲之藥劑防治規範。

關鍵詞：小菜蛾、十字花科蔬菜害蟲、抗藥性管理策略、推廣、核心農民。

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