The historical failure of insecticide resistance management of the diamondback moth and the way forward

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Abstract
Resistance of diamondback moth (DBM) to insecticides in Southeast Asia remains notorious despite repeated efforts by the chemical industry and academia to manage it. New insecticides continue to lose their efficacy a few seasons after their introduction for use. Scientific knowledge on the DBM resistance profile and resistance mechanisms in the literature is voluminous. However, there is still a large gap between knowledge and practical implementation to avoid or delay resistance at the farm level. Farmers lack practical technical guidance on methods of pest control in crucifers. They often follow their innovative instinct by searching for new products from retailers for quick and effective solutions. Farmers may use an effective product continuously until it can no longer control the pests. In addition, the practice by farmers to ensure efficacy by mixing a cocktail of different products, often without a technical foundation for the mix, probably contributes further to aggravating the resistance problem. The risk of resistance to the mixture as well as to the new products may be accelerated.

At first sight, it is an almost insurmountable task to manage the resistance of DBM in Southeast Asia. The way forward in insecticide resistance management is a bottom-up approach, hand-in-hand with the farmers and retailers who are the starting point from where all concepts and techniques of Integrated Pest Management (IPM) and Insecticide Resistance Management (IRM) will be implemented. A commitment from the chemical industry, academia, governments, international organisations (financial donors, researchers, trainers, advisers) to work together, is essential in devising a common practical IRM strategy that will be favourably perceived and accepted by farmers and pesticide retailers. The chemical industry is ready for partnership with all concerned parties to arrive at a workable solution for the benefit of all.

Key words: Diamondback moth, insecticide resistance, IRM/IPM holism, implementation, partnership

Introduction
The notoriety of diamondback moth resistance to insecticides in the Far East and Southeast Asia needs little elaboration. All crucifer growers and vegetable entomologists are well aware of the destructive potential of this tiny lepidopterous pest when control measures fail. Talekar (1993) estimated an annual cost of US $1 billion world-wide to manage DBM on crucifers. DBM resistance was observed in Southeast Asia in the 1950’s and gradually increased in seriousness as more and more insecticides lost their efficacy (e.g. Syed and Loke, 1995). In the last 15 years no new products have remained effective longer than 2–3 years after market introduction (Murai et al., 1992; Adachi and Futai, 1992, etc.). Even complex molecules such as avermectin or Bt endotoxins (macromolecules) could not escape the resistance ability of DBM (Abro et al., 1988; Shelton et al., 1993; Martinez-Ramirez et al., 1995; Tabashnik, 1994; Tang et al., 1995a and 1995b).

Research knowledge on the extent of DBM resistance, the mechanisms of resistance and the scientific potential of resistance is sufficient to implement a set of practical recommendations at the farmer level. However, despite numerous scientific publications, local and international workshops and conferences, the practical reality in the field leaves much room for improvement. Implementation of IRM cannot be mere writings of procedures; one must go to the field and convince growers and pesticide retailers to adopt the recommendations. Thus, the recommended IRM tactics must be simple, convenient, relevant, and in the interest of retailers and farmers.

This paper hopes to reinforce the need to go beyond mere discussion and publications of recommendations.

Root of the DBM resistance problem
Farmer’s attitude
Farmers, like anyone else, have a flair for trying innovative ways to solve problems. Innovation takes different forms under different circumstances – in the case of vegetable growers in the Far East and/or Southeast Asia, innovation often means searching for newly introduced products for pest control and using them until the arrival of other new compounds. This practice is inadvertently encouraged by pesticide retailers who are also proud to promote their new merchandises. Pesticide retailers and farmers tend to think that there will always be new products on the
market to replace those that have lost their efficacy. Superficially, they have been right so far. The last ten years saw the regular introduction of new insecticides for use on crucifers just as the existing products began to lose their effectiveness (real or perceived) on DBM. Examples of recently introduced compounds are diafenthiuron, avermectin, new Bt’s (Centari®, Agree/Turex, etc.), tebufenozide, fipronil and chlorfenapyr. The truth is that these new products are results of at least 10 years or more of expensive research and development work. New products with different modes of action are valuable tools that would help the implementation of IRM recommendations. On the other hand, these new products may lead retailers and farmers to a false sense of security. They may disregard recommendations (or plea) from academic, governmental or industrial researchers to use insecticides judiciously. Persuading farmers to believe and accept insecticide resistance management (IRM) is a challenge that governments, academia and industry must take up and pursue with patience and with a united front.

**Technical constraints**

Two main aspects inherent to the crucifer crops in tropical Asia make the implementation of IRM for DBM a very difficult task. As Prof. Sun pointed out at the Second International DBM Workshop (Sun, 1992):

1. Crucifers are grown year-round, thus providing an uninterrupted food supply for DBM to develop many overlapping generations per year (> 20 generations).
2. Different crucifer cultivars are attractive to many species of phytophagous insects; several of them may infest the crop from the beginning of the growing period. Depending on the pest species, the crop may require the use of an insecticide that contradicts insecticide resistance management for DBM. The implication of this is that separate, fragmented recommendation for each pest is doomed to failure; the entire pest complex must be studied and understood before devising a pest management model for the crop.

**Market perception**

The practice of grading harvested crucifers into different marketable categories does not help the implementation of IPM and IRM. The price differences that farmers receive from vegetable-wholesale dealers for their crops may encourage the farmer to use only a single most effective insecticide than is necessary in the hope of obtaining all Grade-A crops. Informal interviews have often brought to light that farmers spray their cabbage or Chinese kale every 3 to 5 days. The direct money or credit received from the buyers remains the strongest incentive for the small vegetable growers in Southeast Asia. One obstacle to IPM implementation caused by “cosmetic quality standard of produce” has been outlined in a review by Wearing (1988). Wearing assumed the cosmetic factor to be of low importance, even in fruit crops where unblemished fruit appearance is essential. The situation is reversed in the crucifers, whereby cabbages or Chinese kale with perforated leaves will fetch only a fraction of the price of their larger, attractively perfect counterparts. The attitude of merchants and consumers has to change from favouring good physical appearance in order for IPM/IRM to be practised universally with greater success.

**Classical IRM process**

IRM has no general recipe and each resistance case needs its own local solution (Uk et al., 1995). IRM tactics must be based on local knowledge of the pest susceptibility status and crop management habit of farmers. However, all cases of IRM development will have in common the following steps:

- General survey and monitoring of pest susceptibility and resistance. This needs the development of suitable monitoring technique. Initial baseline data on susceptibility and resistance are the basis to further investigations.
- Determination of major resistance mechanisms.
- Investigation of cross resistance pattern amongst insecticides in use.
- Development of relevant IRM tactics that are simple and practical to local growers.
- Periodic updating of tactics as experience and new tools are available.

Research data from the above steps, although never all conclusive, should be sufficient to formulate and recommend IRM techniques for DBM (e.g. Zhu et al., 1991; Cheng et al., 1992; Saito et al., 1992; Sun, 1992; Verkerk and Wright, 1996). Despite the diversity of crop management practices in different regions requiring different IRM tactics, research results have highlighted some common features in DBM resistance in Southeast Asia:

- DBM can develop high field resistance to new insecticides quickly (average of two years after market introduction).
- Resistance is unstable in most cases; reversion can be as rapid as development when insecticide selection pressure is relaxed (Noppun et al., 1984; Sinchaisri et al., 1989; Fahmy and Miyata, 1992; Hama et al., 1992; Kuwahara et al., 1995).

A first step to IRM is to exploit the unstable character of DBM resistance by avoiding the continuous selection pressure with one compound. Alternation of products of different modes of action is one classical IRM recommendation, which may be followed by or used in conjunction with other well-known methods of IRM.

**IRM-IPM holism**

Although farmers have traditionally controlled pests by judicious use of direct or indirect methods, the concept of integrated pest management was scientifically formalised and promoted in the 1950’s and 60’s as a result of problems caused in part by
excessive use of synthetic pesticides. We evoke the original definition of IPM by R.F. Smith and Reynolds (1966) – “IPM is a pest management system that utilises all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury”. One simplistic but basic rule of IPM is that *suitable pesticide types should be used correctly and only when necessary*. This prevents unnecessary pest selection pressure. Considering IRM, the basic principle is ‘the preservation of pest susceptibility’, implying that pesticides should be used only when needed. As a consequence, natural enemies of pests are spared. IRM and IPM are mutually complementary and justify the definition that IRM is an integral part of IPM as has also been mentioned by others (Phillips et al., 1989; Denholm and Rowland 1992). A true IPM must integrate IRM in a holistic outlook. Unfortunately, to this date many researchers, regulators and advisers still inadvertently or intentionally overlook IRM in favour of purist IPM in their general thinking. The interpretation of IPM philosophy has been distorted by many to think of pesticide-free practice rather than the rational integration of all methods of pest management. Researchers in IPM have an obligation to take an holistic approach in every step of investigations (Lim, 1992) in order to formulate advice that has a high chance of being accepted by farmers. A holistic approach to pest management is of prime importance and encompasses more than one pest or one crop in space and time. IPM for crucifers cannot progress without IRM and vice versa. By the same token, DBM should not be considered in isolation whereas crucifers are highly attractive to a number of pest species that may occur simultaneously. Field success on a practical scale of IRM/IPM for crucifers depends on well thought out methods and implementation process.

**IRM implementation**

The chemical industry’s contributions to IPM/IRM include basic research into finding compounds with new modes of action to avoid cross resistance, are specific to target pests, and have minimal undesirable side effects on beneficial arthropods and the environment to suit IPM requirements. However, new compounds that fulfil these requirements are difficult to find, take many years to develop and cost hundreds of millions of dollars. Beside this long term approach, industry works to promote a rational use of existing products for the sake of IRM.

The Insecticide Resistance Action Committee (IRAC) was created in 1984 under the patronage of the International Group of National Associations of Manufacturers of Agrochemical Products (GIFAP). The aim was to co-ordinate, encourage and support financial, insecticide resistance monitoring and management world-wide (Voss, 1988). One of the many IRAC grants to finance resistance research in major pests is the collaborative project conducted by Dr. E. Y. Cheng of Taiwan Agricultural Research Institute (TARI) on the pattern of DBM resistance to benzoylureas (Cheng, 1993 and 1996). Based on Dr. Cheng’s findings and on literature the IRAC Field Crops and Vegetables Working Group has published a one-page IRM strategy for DBM (Appendix 1, Harris, 1995). Verkerk (1995) has proposed similar IRM for DBM in Cameron Highlands giving details of a specific product alternation programme. All countries in the Pacific Rim have ongoing IPM/IRM programmes for crucifers including DBM. For example, Indonesia (National IPM program, BALISTA), Malaysia (MARDI), Philippines (National Crop Protection Center, University of the Philippines, PhilRice, CABI, funded by FAO, IRRI, ADB, USAID, etc.), Taiwan (TARI, AVRDC), Thailand (co-operation between the Department of Agriculture, Kasetsart University, Nagoya University and Japan Society for the Promotion of Science), and others. Agrochemical companies as well as the NGOs have been testing their individual IPM/IRM programmes wherever conditions allow. Additionally, there is the Asian Vegetables Network (AVNET) sponsored by AVRDC.

As one example of an IRM programme, in the TARI project Cheng (personal communication) used farmers themselves as experimental parameters as well as method promoter. His success relies on background knowledge of resistance and cross-resistance pattern, and on the subtle surveillance of farmers’ action during the growing season. Participating farmers were given a complete package of chemicals required to protect their cabbages from all pests. Clear recommendations for product usage (including components of mixtures if essentially needed) on different pests were also given. Co-ordination, on-site training and discussion and record keeping were done by farmer associations. At season’s end all participating farmers gave oral reports in organised public meetings. Fellow farmers were thus referees, forcing everyone to report the real truth of his season’s achievements. Discrete monitoring of insecticide usage was done by periodic residue analyses. Non compliance of recommended guidelines was penalised by exclusion from the programme the following year.

Considering the resources that are being invested on DBM management, one would expect that farmers would have no problem with the pest. Yet we still hear rumours from Thailand and Malaysia that some products introduced recently have already lost some of their initial efficacy. Whether rumours are the result of real resistance development or not, they are early warning signs of the well-known recurring problem.

The IPM/IRM programmes mentioned above are in the experimental stage and sometimes methods are complicated for farmers to follow. More often than not, the real interest and habits of farmers and pesticide retailers are not foremost in the minds of researchers, politicians and international financial donor organisations. Shortcomings of human nature in research and implementation of IPM have been discussed by Lim (1990). Literature on IPM tends to blame the pesticide industry (for paying lip-service)
and insecticides (for killing natural enemies) for failures of IPM. Such an attitude is consistent with Lim’s remark – the authors’ motivation is driven by self-interest. To paraphrase Lim – unless we all can awaken to this sub-conscious weakness and are willing to turn around – we will not see crucifer growers practising IPM/IRM in the not too distant future; DBM will then be the sure winner. Current scientific and technical knowledge is sufficient to go beyond publishing scientific papers and reach the farmers at all levels and all time.

On behalf of IRAC we challenge the academia, governments, international aid organisations and NGOs to join forces in bringing together farmers and pesticide dealers for discussions, education and implementation of IPM/IRM methods that are relevant to the farmers’ needs. Discussions on IPM/IRM recommendations, scientific or political, should include the pesticide industry; this has rarely been the case to date. There have been bilateral co-operations at scientist level such as the IRAC-TARI project or individual company-research institute collaborations, but industry is still regarded with suspicion by some individuals in various organisations and NGOs. Whether we like it or not, in rational agricultural management pesticides will always be available to farmers when needed. Industry offers itself as a competent partner for dialogue and co-operation with all bodies concerned with agricultural production and pest management, be it in research or in training of farmers and pesticide retailers. Mutual suspicion and indirect squabble are sterile and only cause wastage of resources and valuable time for managing DBM resistance. Reputable pesticide manufacturers are strictly controlled by their own internal scientific and ethical standards as well as by governments, closely refereed by international organisations (e.g. FAO, WHO) and the media. They have a vested interest in maintaining their reputation, the quality standard of their products and the desire for their products to be used properly and intelligently. The obvious reasons are that pesticides are valuable tools that help protect crop losses from pest damages, but require huge resources for their discovery and development. Prolonging the effective life of products through appropriate IRM will benefit all (producers, users and consumers alike). IRM will make a major contribution to sustainability in agriculture.

Concluding remarks

Insecticide resistance in DBM remains the most difficult, but not intractable, problem to manage in cruciferous crops. The recurring problem of DBM resistance to new insecticides is caused by the insect’s ability to use more than one mechanism of resistance. The problem is further aggravated by the farmer’s habit of using a single product continuously until it becomes ineffective.

Significant knowledge has been accumulated by researchers during the past decade, but IPM/IRM implementation at farmer’s level is still at embryonic stage. Close multilateral co-operation, especially between the public and private sectors must be strengthened further if there is genuine will to help farmers and pesticide retailers.

IRAC offers itself as a competent partner in implementing IRM and is challenging the public sector (international organisations, governments and NGOs) to candid dialogues and closer co-operation as a way forward to rational pest management for the real benefit of all.

Farmers and pesticide retailers must be closely involved in the development and training of IRM/IRM methods.

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References


— (1994). Personal communication. Pesticide Research Laboratory, TARI, Taiwan, ROC.


Appendix 1

Insecticide Resistance Management Strategy for *Plutella xylostella* L. (Diamondback moth)
(Prepared by IRAC Field Crops & Vegetables Working Group)¹

Benzoylurea compounds have been used widely on cabbages because of their efficacy on lepidopterous pests and their low mammalian toxicity. The diamondback moth (DBM) in Southeast and Northeast Asia has developed widespread resistance to organochlorines, organophosphates and pyrethroids in the 1960’s and 1970’s and to the early benzoylureas introduced into the region in the 1980’s. The risk of cross-resistance to new benzoylureas is high.

The pesticide industry, through IRAC, wishes to implement an insecticide resistance management (IRM) for the DBM.

IRM aims at preserving the pest susceptibility to insecticides by minimising the continuous selection pressure that a given product or class of compounds may exert on it. Regular monitoring of susceptibility/resistance levels is the basis for managing resistance or introducing new products.

Since there are more benzoylureas recently introduced as new products for DBM control, the IRM recommendations should address two areas:

- Countries (and/or areas) where benzoylureas are still effective,
- Countries (and/or areas) where benzoylureas are no longer effective.

Although it refers mainly to benzoylureas, this strategy should also apply to all classes of products.

1. Benzoylurea effective areas

- Do not use products of the same chemical class more than once per DBM generation.
- Limit the benzoylurea applications to two per crop cycle at maximum (never use it alone continuously).
- Always alternate a benzoylurea with other effective products of different modes of action, e.g., Bt., thiourea, avermectin, pyrrole, and/or effective organophosphate.
- Use the most effective products or mixture of products during the early crop growth stage.
- Use three or more different product groups if several sprays are needed, particularly when aimed at different pests that may occur concurrently with DBM.
- If resistance to a class of products has been confirmed locally, do not include that class in the spray programme.
- Promote IRAC strategy through group companies, local research institutes, government extension, farmer co-operatives, and farmer meetings or trainings.

2. Benzoylureas ineffective areas

- Use non-benzoylurea classes of chemicals that are effective and alternate between them. In case of control failure, change class of insecticides.
- Check possible cross-resistance to any new benzoylurea.
- Refrain from introducing a new benzoylurea into the area where cross-resistance is confirmed.
- Wait until reversion to susceptibility before attempting to introduce a benzoylurea.
- Follow the steps recommended for benzoylurea-effective areas above when introducing a new benzoylurea.
- Involve farmers, distributors, research institutes, government extension, and local co-operatives in participatory trials or demonstrations.

Notes:

- The strategy of product rotations exploits the low biotic fitness of resistant individuals in a population, so that their frequency would decline when a different insecticide is used.
- The DBM could eventually develop resistance to an insecticide mixture if used long enough. Therefore, a mixture of products if judged necessary, should also be alternated with other effective products of different modes of action. In other words, appropriate product alternation is a better option than just mixture.

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