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TOWARDS AN INTEGRATED PEST MANAGEMENT PROGRAM FOR DIAMONDBACK MOTH IN BARBADOS

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ABSTRACT

On the basis of a survey of cabbage farmers' practices and studies of the level of insecticide resistance in diamondback moth in Barbados, a provisional integrated pest management program for diamondback moth has been devised. Those components that have been implemented are reviewed. Components that need to be added are discussed. Research needs, and research realities, are discussed in relation to keeping the program current.

INTRODUCTION

Diamondback moth [*Plutella xylostella*] is a major pest of brassicaceous crops, especially cabbage (*Brassica oleracea* var. *capitata*), wherever they are grown. In Barbados, the development of insecticide resistance in diamondback moth (Gibbs *et al.*, 1989; Gibbs and Chinnery, 1993; Chinnery *et al.*, 1993 and Gibbs, 1993), led to a decline in cabbage production (Fig. 1).

In addition to the environmental and human health consequences of the resultant excessive use of insecticides (Chinnery and Gibbs, 1990), reduced cabbage production led to the importation of diamondback moth infested cabbage from a country using outdated (banned/ineffective) insecticides, compounding the problem.

The results of a survey of the practices of 60 Barbadian cabbage farmers, carried out between September 1988 and June 1990 (Gibbs, 1993), were used to develop a provisional Integrated Pest Management (IPM) program for diamondback moth in Barbados.

THEORY

IPM involves all aspects of the crop cycle from site selection and land preparation to harvest.

Flint and van den Bosch (1983) listed three key aspects of the philosophy behind IPM systems:

(1) a conception of the managed resource as a component of a functioning ecosystem,
(2) an understanding that the presence of an organism of pestiferous capacity does not necessarily constitute a pest problem, and
(3) an automatic consideration of all possible pest control options before any action is taken.

They added that IPM systems consider the whole ecosystem when making pest management decisions and not just the pest organism. Each managed system is unique, with a different biotic composition and subject to varying abiotic stresses (Flint and van den Bosch, *ibid.*).

Flint and van den Bosch (*ibid.*) listed 10 major points as a guide to setting up an IPM program. These are:

(a) understanding the biology of the crop, especially in the context of how it is influenced by the surrounding ecosystem;

(b) identification of the key pests; knowledge of their biology; recognition of the damage they inflict; and initiation of studies on their economic status;

(c) consider and identify, as quickly as possible, the key environmental factors that impinge upon pest and potential pest species in the ecosystem;

(d) consider concepts, methods and materials that individually and in combination will help to suppress permanently or restrain pest and potential pest species;

(e) structure the program so that it will have the flexibility required to adjust to change;

(f) anticipate unforeseen developments and be constantly aware of the complexity of the ecosystem and the changes that can occur within it;

(g) seek the weak links in the life cycle of the key pest species and direct deliberate control practices as narrowly as possible at these weak links;

(h) whenever possible, consider and develop methods that preserve, complement and augment the biotic and physical mortality factors that characterise the ecosystem;

(i) whenever feasible, attempt to diversify the ecosystem; and

(j) assume and even insist that technical surveillance for programs be available, e.g. monitoring

The development of an IPM program for *P. xylostella* in Barbados must take Insecticide Resistance Management (IRM) into account. According to Croft (1990), the primary goals of such a subcomponent of IPM are:

(a) avoiding resistance development in pest populations,

(b) slowing the rate of resistance development,

(c) causing resistant populations to "revert" to more susceptible levels and, thereafter,

(d) keeping resistance below some threshold.

Selection of arthropod natural enemies in the laboratory or the field by artificial means to develop resistant strains is another aspect of IRM (Croft, *ibid.*). Phillips *et al.* (1989) noted that, by adhering to the principles of IRM and using other IPM components such as biological control and cultural control, IPM has the potential of conserving the susceptibility of pests to insecticides. Croft (1990), citing a 1986 report by the United States National Academy of Sciences, listed various operational tactics for pests under an IRM program. They include varying dose or frequency of pesticide application; applying treatments only when economic levels of pests are present; using less persistent pesticides; treating only certain life stages of pests; using pesticide mixtures; using alterations, rotations, or sequences (of pesticides); using improved pesticide formulations; using synergists; exploiting unstable resistance; and identifying new toxicants with alternate sites of activity. It must be stressed, however, that IRM and even IPM programmes developed in one country or even one ecological zone cannot be readily transferred to another to obtain similar results, as many factors including weather, topography, pest biology, natural enemies, pesticide usage and socioeconomic constraints may be different. Thus, the design of an IRM implementation system is usually specific to a particular species and an ecological/management environment.

Forrester (1990) stated that once laboratory evidence confirms resistance to be the problem, then there are a series of questions that need to be answered before a resistance-countering strategy is designed. These are:

(a) What are the resistance mechanisms and cross-resistance patterns? A knowledge of these will enable the planning of sequential use patterns for the available chemical groups. It is also important to test for any possible regional differences in resistance mechanisms and cross-resistance patterns.

(b) What is the resistance status of alternate compounds? The design of a strategy must consider the resistance status of all compounds used, present and past.

(c) Are there any concurrent pests and are they resistant? Resistance management can become quite complicated in crops with multiple pests, like cabbage in Barbados. Some pests may be resistant, others not, and the resistance patterns of multiple pests may overlap. Sometimes overriding IPM considerations preclude the use of certain insecticides at specific times to preserve natural enemies and/or to prevent resurgence of other pests. Quite often, other key pests may dictate insecticide usage patterns and any strategy must be designed for the whole pest complex.

(d) What is the ecology of the key resistant pest? Information on the biology and ecology of a pest is essential in designing a resistance management strategy. It is necessary to have information on the pest's host plants, its seasonal abundance, number of generations per year and to what extent does the population mix. The latter is dependent on the pest's dispersal capacity. Once this information has been gathered, it should be possible to devise a preliminary working strategy that can be later refined by further research (Forrester, *ibid.*). Phillips *et al.* (1989) noted, however, that before the full benefits from IRM, or more importantly those from IPM, can be realized, sampling technology needs to be improved as the entire system revolves around a knowledge of the population densities of the pest and the natural enemies that exert a regulatory effect.

IPM OF *P. XYLOSTELLA*

Several attempts to develop an IPM program for *P. xylostella* have been made in several countries (Lim, 1990). Lim (*ibid.*) listed eight important common features of these IPM programs:

(a) Only a few of the potential elements have so far been practically incorporated.

(b) The most common components used are biological control agents (particularly parasitoids), action thresholds and monitoring, and judicious use of chemical insecticides when the economic threshold of the pest is exceeded. In a few cases additional elements such as crop rotation, proper time of planting, light trapping and use of a physical barrier have been incorporated.

(c) In general, none of the IPM programs are inferior to the existing prophylactic control measures presently practiced by farmers. Although crop yields may not always improve substantially, they generally are not reduced.

(d) In cases where the thresholds are exceeded and insecticidal applications are necessary, both the frequency and amount of insecticides used are substantially reduced.

(e) For most of the IPM programs, *Bacillus thuringiensis* based products have been incorporated, serving as a replacement to many broad-spectrum insecticides and providing the needed selectivity when quick action by chemical intervention is necessary.

(f) There is usually a substantial increase in terms of profit, mainly due to savings from the enormous reductions in chemical inputs.

(g) Most of the IPM programs are presently still at the experimental stage. Although there has been field adoption, this is only on a limited scale.

(h) The IPM programs are still largely executed and confined within the domain of researchers. There is presently inadequate involvement of both extension personnel and farmers.

Lim (*ibid.*) added that most research programs on *P. xylostella* management have been centered only on the biological aspects, but IPM technology adoption extends well beyond this and includes the many social and marketing factors that can influence pest control decisions.

With reference to (b) and (d) on Lim's (1990) list, Binns and Nyrop (1992) stated that decision making is a key aspect of current IPM programs and relies on protocols for deciding on the need for some management action based on the assessment of the state of a pest population and ideally its natural enemies. These protocols, which they call control decision rules, consist of at least two components and may include a third. These are:

(a) a procedure for assessing the density of the pest population,
(b) an economic threshold level for the pest, and
(c) a phenological forecast, which is often necessary to determine the appropriate time to assess population densities.

According to Binns and Nyrop (*ibid.*), sampling is important, as assessment of pest density usually requires obtaining actual counts of the pests. They added that decision making in IPM is important for two reasons. First, decision-making protocols can be used to reduce pesticide use, particularly in crop production systems where biological control is prominent. Secondly, should biological and cultural practices fail, pest control can still be accomplished through the effective use of pesticides, and decision-making protocols must be available to determine when to intervene.

Holl *et al.* (1990) stressed that there is no one practice or combination of practices that works to control pests in all situations: each IPM system must be tailored to the specific agro-ecosystem involved. Factors to be considered when deciding which pest control techniques are most feasible for a particular agro-ecosystem include climate, crop(s), pests, soils, hydrological cycles and local natural ecosystems as well as farmers' perceptions of pest problems.

The problem of insecticide resistance in *P. xylostella* in Barbados and its effect on cabbage production is quite complex and there are many interrelating factors involved (reviewed by Gibbs, 1993). Denholm and Rowland (1992) stated that in some populations of *P. xylostella*, resistance to most available insecticides has evolved, and poses a formidable challenge in view of present difficulties in discovering and, in particular developing new chemicals with novel modes of action. They added that *P. xylostella* resistance in some countries is so intractable, extending now to the benzophenyl ureas (insect growth regulators) and even *B. thuringiensis* based products, that only cohesive IPM approaches incorporating more emphasis on non-chemical methods offer a realistic prospect of long-term control.

In tropical countries, insects like *P. xylostella* usually have rapid reproductive rates, short generation times, and generally there are overlapping generations at any given time (Jones, 1985; Sagenmueller and Rose, 1986). In Barbados, the problem with *P. xylostella* and its resistance to insecticides is aggravated by the year round cultivation of cabbage and other brassicaceous crops. In addition, the overuse of insecticides in tropical regions like the Caribbean (Gooding, 1980; Pollard, 1980) only enhances the conditions necessary for the selection of resistant strains. Pesticide misuse can also cause the destruction of non-target organisms such as the beneficial parasitoids and predators, the contamination of precious water reserves, and unnecessarily high residue levels in crop produce.

Jones (1985) stated that chemical control of *P. xylostella* remained the overwhelming practical choice of the Barbadian cabbage farmer. He added that a shift in control strategy would most likely follow an integrated approach. In such an approach, emphasis should be placed on the diversification of selection pressures on *P. xylostella* to reduce the rate at which resistance is selected. If an IPM programme for *P. xylostella* is to be devised, the development of insecticide resistance should be controlled, or delayed, when possible. Broadley (1985) suggested that this might be achieved by doing the following:

(a) Avoid the use of insecticides with high residual times.
(b) Apply insecticides at the most vulnerable stage of the insect's life cycle. Since first instar *P. xylostella* larvae mine cabbage leaves, application of contact insecticides at this stage is not very effective.
(c) Use insecticides at the recommended rates only. Sub-lethal doses and rates higher than the recommended ones, not only select for resistance, but waste money.
(d) Control drift of insecticides when applying them to the crop. This is important when

insecticides are used in mixed cropping areas, as is the situation on most small farmer holdings in Barbados.

Hama (1990) recommended a rotational application of various kinds of insecticides in order to delay or suppress the rapid development of insecticide resistance in *P. xylostella* in Japan. They should be different in terms of their modes of action or resistance mechanisms. Hama (*ibid.*) further suggested that an IPM program needs to be developed to reduce the number of insecticidal applications and to incorporate rotational applications with other techniques such as avoidance of continuous growing of brassicas, introduction of plant races resistant to *P. xylostella* and the use of sex pheromones, pathogens, parasites and predators

In Barbados, more emphasis should be placed on the selection of insecticides that have least affect on the survival of natural enemies like *Cotesia plutellae* and *Oomyzus sokolowskii*. Although there have been some additional reports on the development of resistance in *P. xylostella* to *B. thuringiensis* based products (J. Waage, CABI-IBC, Pers. comm.), these insecticides should, for some time in the future, continue to play a significant role in the control of *P. xylostella* in Barbados.

There is also a need for the introduction of additional exotic parasitoids to control *P. xylostella*, and a prime candidate could be the egg parasitoid. *Trichogrammatoidea bactrae* Nagaraja. A successful IPM technology package developed by the Asian Vegetable Research and Development Centre to control *P. xylostella* utilises this parasitoid in combination with *C. plutellae*, *Diadegma semiclausen* and *B. thuringiensis* subsp. *kurstaki* (PCCARD, 1991). *T. bactrae* might also play a vital role in Barbados, particularly in an IPM program for *P. xylostella*. The effects of the currently used insecticides on *T. bactrae* would also have to be investigated.

PROVISIONAL IPM PROGRAM FOR *P. XYLOSTELLA* IN BARBADOS

Based on the survey data (Gibbs, 1993), other factors affecting farmers decisions (weather, market price, etc.) and the results of insecticide bioassays on *C. plutellae* (Gibbs, *Ibid.*), an IPM program for *P. xylostella* on cabbage in Barbados should be structured along the following lines. Firstly, farmers should be encouraged to:

(a) Grow dark leaf (and if possible also glossy leaf) cabbage varieties. These tend to be more resistant to *P. xylostella* (Gibbs, *Ibid.*).

(b) Where irrigation is available, use overhead sprinkler systems and irrigate from dusk onwards. This practice interrupts flying-mating activities in *P. xylostella* moths and would lead to decreased oviposition.

(c) Plant cabbage during the wetter months of the year. *P. xylostella* larvae can be washed away or drowned by rain.

(d) Restrict fertilizer use to recommended rates. Overuse not only leads to increased production costs but adds to the cabbage plants' "attractiveness" to *P. xylostella* and other pests.

(e) Replace use of conventional type insecticides, particularly those to which *P. xylostella* has shown resistance, by *Bacillus thuringiensis* (Bt) based products and, preferably, insect growth regulators (benzophenyl ureas and similar compounds). These products have different modes of action to those of the conventional insecticide types (organophosphates, pyrethroids, carbamates) and have been shown to be relatively non-toxic to beneficial organisms like *C. plutellae*. Bt has also been shown to significantly reduce the feeding rate of *P. xylostella* (Hoy and Hall, 1993), an added advantage.

(f) Farmers should always use the manufacturers' recommended rates and frequencies of insecticide application.

(g) Conserve populations of natural enemies like *C. plutellae* and *O. sokolowskii* by employing component (e) above and by providing some refugia including nectar producing plants. Extensive use of herbicides to destroy all surrounding wild vegetation should be avoided as this would destroy possible refugia sites for natural enemies and might also kill some of their populations by direct contact with herbicide.

In addition, research should be conducted to provide information to farmers on which chemicals have the least mortality impact on natural enemy populations in the field. Seminars/field days should be organized to show to farmers the correct usage of insecticides, i.e. what are the various types of insecticides available in Barbados, how they work and how to correctly apply them, stressing that they should be used only at their recommended rates and frequencies. A farmer training program on the safe use and proper handling of pesticides like that outlined by Sjerven (1991) for farmers in Indonesia, would be very appropriate and timely for cabbage farmers in Barbados.

ADOPTION, CONSTRAINTS AND FUTURE RESEARCH

With respect to the use of dark leaf (glossy) cabbage varieties, this aspect of the IPM program may be best achieved by convincing the seed retailers in Barbados of the resistance qualities exhibited by these varieties. Resist Crown, a dark leaf hybrid, is already available in Barbados and has shown lower levels of crop loss due to *P. xylostella*.

One constraint to the use of overhead sprinkler irrigation to suppress *P. xylostella* activity is that most of the cabbage farmers in Barbados who use supplemental irrigation, have drip irrigation systems. This latter type of irrigation is encouraged as it costs less, both in terms of equipment and water usage. It uses much less water than the overhead sprinkler system and puts the water where it is most needed and utilized. However, there are some farmers who still use the overhead sprinkler system and it is to these farmers that efforts would have to be made to convince them of its effectiveness in suppressing *P. xylostella* populations. The survey revealed that most of the cabbage farmers in Barbados grow cabbage as a rain-fed crop, and thus will be utilizing the possible effects of the rain in washing away and drowning some *P. xylostella* larvae on their cabbage crops.

To some extent, parts of the proposed IPM program above have already taken place. The insect growth regulator Jupiter(R) 120EC, 12% chlorfluazuron (CIBA-GEIGY, Switzerland) became commercially available to farmers in Barbados in 1991, after one author (I.H. Gibbs) had discussed the *P. xylostella* problem of conventional insecticide resistance with one of the island's agrochemical retailing companies. Cabbage farmers were also advised not to use Jupiter(R) exclusively, but to rotate its use with Dipel(R) (*B. thuringiensis* subsp. *kurstaki*). Since then, many farmers have adopted this advice, resulting in considerable reductions in *P. xylostella* populations on their cabbage crops and substantial increases in the availability of the produce in the markets (Fig. 2). However, it is inevitable that *P. xylostella* will, at some time in the future, develop resistance to Jupiter(R). Based on this inevitability, a series of insecticide trials against *P. xylostella* on cabbage have been recently initiated (Chinnery *et al.*, 1993), in which other insecticide growth regulators such as teflubenzuron, flufenoxuron and azadirachtin are being investigated as possible replacements for Jupiter(R). Ultraviolet light protectants are also being evaluated to prolong the effectiveness of *B. thuringiensis* products in the field.

P. xylostella resistance to products based on the ä-endotoxin of *B. thuringiensis* (Bt) has already developed in many countries (e.g. Kirsch and Schmutterer, 1988; Tabashnik *et al.*, 1990) and is inevitable in Barbados. The high hopes for genetically engineered *Brassica* plants, in which the Bt gene is expressed, prominent in temperate countries (e.g. Bai *et al.*, 1994) would most certainly not be fulfilled for cabbage in the tropics.

Hill (1983) reported that 10-15 generations are required in most insect species for resistance to manifest itself. Thus, with continuous breeding of pest species with overlapping generations, insecticide resistance can rapidly develop in the tropics. For diamondback moth, which produces as many as 30 overlapping generations per year in Barbados (Jones, 1985), it would be expected that any population exposed to these genetically engineered plants for four to six months would develop resistance. Not only making the transgenic plants useless to the farmer, but also eliminating the analogous Bt insecticide from the IPM package.

The use of entomopathogenic fungi against *P. xylostella* is another area for future research. Field experiments in Malaysia have shown the efficacy of two species, *Beauveria bassiana* and *Paecilomyces fumosoroseus* (Ibrahim and Low, 1993), with the entomopathogens leading to significantly more marketable heads than plots alternately sprayed with cypermethrin (Cymbush(R)) and phenthoate (Elsan(R)). Plants sprayed with *B. bassiana* and permethrin (Ambush(R)) were equally likely to reach a marketable size as plants treated with this fungus alone.

At this time, dead and dying insects found in the field, that appear to be infected with pathogens, are brought to the plant pathology laboratory at the University of the West Indies. Fungi, and bacteria, cultured from the pest are identified and cultures of potential entomopathogens are placed in storage for future evaluation.

Spiders are voracious feeders and, depending upon the species, can consume 11 to 221 larvae of diamondback moth per day (Mansingh, 1994). Research is needed to determine the species present and ways to augment the populations of those feeding on *P. xylostella*. Since spiders are highly susceptible to insecticides, the current program using less, and more specific, insecticides may already be benefitting from increased spider predation.

A simple, practical, "farmer-friendly" sampling method, based on a realistic economic threshold limit for *P. xylostella*, needs to be developed. This would, hopefully, persuade farmers to apply insecticides only when required by the results of the above-mentioned sampling method, and not as many do now on a calendar basis. Smith (1970) stated that fixed treatment schedules, such as treatments by the calendar, are almost certain to result in many unnecessary pesticide applications thus intensifying the problem of resistance. He added that such rigid treatment schedules not only give natural enemies no refuge or chance for recovery, but have also caused severe resurgence of target pests and the rise of secondary pests, both conditions requiring still additional treatments and intensification of resistance selection.

Although, a few of the components of the suggested IPM program for *P. xylostella* in Barbados are already being used by cabbage farmers, convincing them to adopt the others will be the next challenge, as cabbage is a high value cash crop and Barbadian consumers now require produce that is mostly, if not entirely, blemish free.

The IPM program for *P. xylostella* on cabbage in Barbados was also prepared, considering the fact that this is not the only pest of cabbage in the island (Chinnery *et al.*, 1993). The judicious use of newer insecticides with modes of action different from the conventional insecticides previously used on the crop was strongly suggested together with their rotation with *B. thuringiensis* based products. This strategy should delay the development of resistance in *P. xylostella* to these insecticides besides conserving field populations of important parasitoids like *C. plutellae* and *O. sokolowskii*.

Furthermore, the adoption of this program should enable farmers to produce quality cabbages and reduce the levels of toxic insecticide residues and the risk of human and environmental pesticide contamination.

Since effective IPM requires continuous field research and farmer education, it has caused a change in the role of extension entomology (Allen and Rajotte, 1990). In most Caribbean countries, there are very few professional entomologists, and other pest management professionals. The development of IPM programs for all our crop/pest combinations will require a serious reallocation of financial resources and expansion of manpower. This will only occur if the crop scientists of the region effectively educate the public of the general benefits of IPM.

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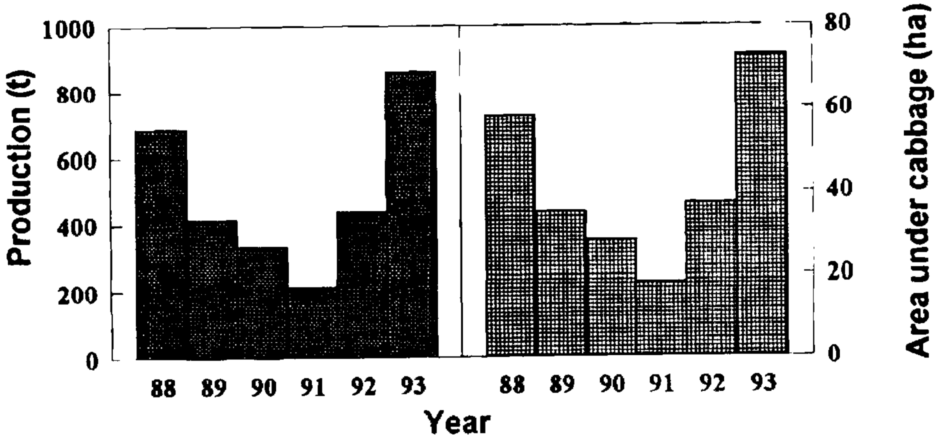

Fig. 1. Cabbage production in Barbados 1980-1991 (After Chinnery *et al.*, 1993).

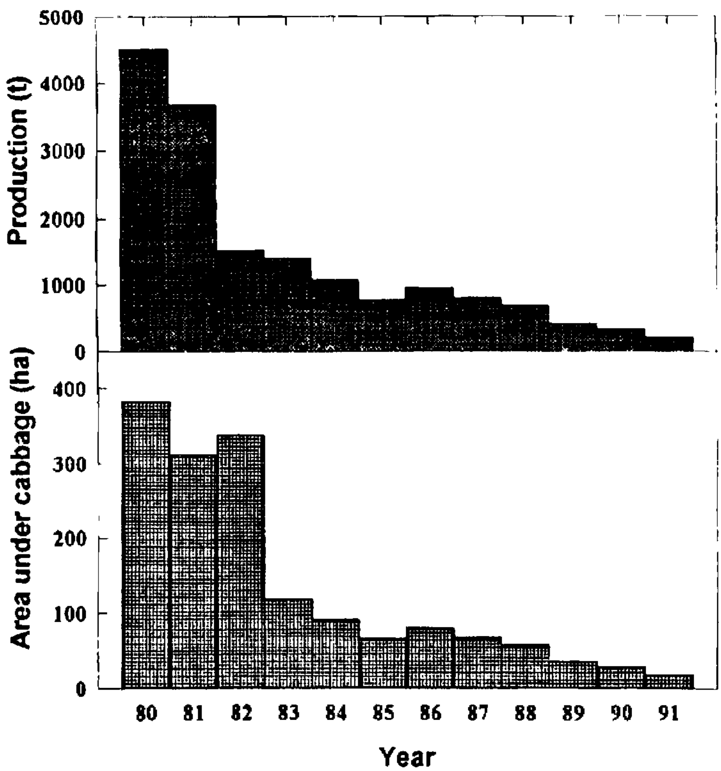

Fig. 2. Recent changes in cabbage production in Barbados.