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29ème

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DECLINE OF CABBAGE PRODUCTION IN BARBADOS: CAUSES AND SOLUTIONS

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ABSTRACT

Since 1980 there have been marked declines in cabbage production in the area planted under cabbage in Barbados. It is likely that these were in response to the development of insecticide resistance in the major pest of *Brassica* in the island, the diamondback moth (*Plutella xylostella*). Data are presented on levels of insecticide resistance in *P. xylostella* and minimal insecticide resistance in its parasitoid *Cotesia plutella.* Strategies for managing insecticide resistance are discussed and results from trials conducted with new and novel insecticides are presented.

INTRODUCTION

The production of cabbage in Barbados showed a severe decline after 1980 (Figure 1). A notable feature of the decline was the 1982 experience when, although there was a slight increase in the area planted over 1981, there was a 60% decline in the amount of cabbage harvested. It is believed that this was largely a result of crop loss due to the diamondback moth, *Plutella xylostella* (L.) which is a serious pest of brassicaceous crops wherever they are grown. Insecticides have been widely used in its control but the chemical schedules require frequent applications, often twice or three times per week. The combination of these high rates of application, subjection of all life stages to the insecticides and the high reproductive rate of the insect, has lead to the development of resistance in *P. xylostella* to a wide range of insecticides. In other parts of the world, the moth has developed resistance to practically all classes of chemical insecticides. Resistance has been reported to carbamates, DDT, organophosphorus compounds and pyrethroids (Sun *et al.*, 1986). Of particular note are (i) the report from Taiwan that the greatest resistance, in that country, is to synthetic pyrethroids (Cheng, 1986), (ii) reports of resistance to formulations of *Bacillus thuringiensis* (Berl.) (e.g. Kirsch and Schmutterer, 1988; Tabashnik *et al.*, 1990) and (iii) the reported resistance to insect growth regulators in Thailand (Cheng, 1988; Perng *et al.*, 1988).

It has been estimated that, in developing countries, insecticides account for approximately 30% of production costs (Brader, 1986). This figure is higher than that for temperate agriculture and results from higher pest incidence, generally higher pesticide costs and a low level of crop productivity. Chinnery and Gibbs (1990) presented data which suggest that the insecticide proportion of production costs of cabbage in Barbados is probably much higher. It is likely that the large amount of insecticides used and the increased severity of the *P. xylostella* damage may well have been due to development of resistance by the local population.

If insecticide resistance and the associated increases in the cost of production are the reasons for the dramatic decline in production, solutions need to be found. This paper reviews the evidence supporting the development of resistance and suggests some potential solutions to the problem.

INSECTICIDE USE

Chinnery and Gibbs (1990) reported the results of a survey of 60 cabbage farmers in Barbados carried out between September 1988 and June 1990. They found that, at that time, farmers were using large quantities of insecticides to control *P. xylostella* and that these were often applied as elaborate "cocktails" of chemicals. This is not only a major cost of production but has lead to concerns about residues remaining on the crop, especially in relation to praedial larceny, and the possibility of the ground water becoming contaminated. Despite the heavy application of insecticides, many farmers surveyed reported heavy losses of their cabbage crops with almost half reporting losses in excess of 50%.

From the survey it was found that a wide range of insecticides, a total of 18 different products, were being used in attempts to control diamondback moth. Pyrethroids and organophosphates were the most frequently used types and the most common product was Tambo$^{(R)}$, a combination of the pyrethroid Sherpa$^{(R)}$ and the organophosphate Selecron$^{(R)}$.

In the late 1980's there was an upsurge in populations of aphids, *Brevicoryne brassicae* (L.), and whiteflies, *Bemisia tabaci* (Gennadius), causing further problems to cabbage farmers. This may have been a result of the heavy use of pyrethroids since there are reports from other countries, e.g. in Honduras (Andrews *et al.*, 1990), of this phenomenon.

Chinnery and Gibbs (1990) found that many farmers were using insecticides at rates above and below that recommended by the manufacturers. When used above the recommended rate, the selection for those insects that are resistant is much more intense and only those with well developed resistance will survive. On the other hand, if the insecticide is used below the recommended rate selection is for tolerance which is the basis of future resistance development. Therefore, both practices will have contributed to the evolution of insecticide resistant populations.

According to Hill (1983) development of resistance to insecticides by pests may be rapid in the tropics because of greater biological productivity. It is generally recognised that 10-15 generations are required in most insect species for resistance to manifest itself (Hill, *ibid.*). 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 the same chemical control agent for four to six months would exhibit reduced susceptibility due to developing resistance.

LEVELS OF INSECTICIDE RESISTANCE IN DIAMONDBACK MOTH

In 1938, seven insect species were already resistant to insecticides. Fifty years later, close to 500 species were resistant (Brattsen, 1989). In the view of Brattsen (*ibid.*) of greater significance than the increase in number of resistant species is the increasing number that have multiple resistance or cross-resistance. Multiple resistance results from multiple co-occurring resistance mechanisms, such as insensitive acetlycholinesterase combined with enhanced detoxification by several enzymes, as in resistance to organophosphates. It differs from cross-resistance which is where different groups of insecticides interfere with a common target that has changed, e.g. cross-resistance to pyrethroids and DDT is most often attributed to an insensitive sodium channel (Brattsen, *ibid.*). Cross-resistance also occurs when a single enzyme detoxifies more than one class of insecticides.

An indication of the presence of insecticide resistance within *P. xylostella* populations in Barbados was given by Gibbs *et al.* (1989). In an initial screening for resistance to eight insecticides, a substantial proportion of the insects survived. The doses used were the recommended rates and the insecticides tested were those used on the farms from which the insects were collected. LC_{90} bioassays have been conducted on adults from three widely separated populations (Gibbs and Chinnery, 1990). The LC_{90} values were greater; sometimes as much as four orders of magnitude greater, than the manufacturer's recommanded rate. The insecticides tested were : - Ambush (R), Diazinon (R) 60EC, Padran (R) 50SP, Selecron (R) 500EC, Sherpa (R), and Marshal (R) 25EC. In subsequent bioassays performed two years later, adults and larvae from one plantation were tested.

The results were alarming with at least one population having a LC_{90} more than one hundred times the recommended rate for five of the six insecticides tested. The exception was Marshall(R), a carbamate introduced to the Barbados market in late 1989. The level of resistance detected in the fourth population was higher than in the first three suggesting continued development of resistance. The data also provide evidence of multiple resistance to pyrethroids and cross-resistance to pyrethroids and organophosphates. This is probably the result of the heavy reliance on the pyrethroid Ambush(R) and the pyrethroid/organophosphate mixture Tambo[(R)] as well as the use of "cocktails".

ALTERNATIVE CONTROL METHODS

The potential of sex pheromones for field trapping and control of *P. xylostella* (Koshirara and Yamada, 1980; Chisholm *et al.*, 1983) and the use of chemosterilization (Cook and Hooper, 1974) have been demonstrated. Other control measures tried include the use of insect growth regulators and juvenile hormones (Rejesus and Flabellar, 1979: Hong, 1981) and companionate planting (Buranday and Raros, 1975; Latheef and Irwin, 1979). In the Philippines, Buranday and Raros (1975) found significantly lowered populations in companionate plantings of cabbage (*B. oleracea* var. *capitata* L.) with tomato (*Lycopersicon esculentum* Mill.) but, in Barbados, Cadogan (Unpubl. report, Ministry of Agriculture, Food and Consumer Affairs, Barbados, 1978) found no significant difference in population levels, or damage, using the same crop pair.

In Barbados, attempts at biological control of *P. xylostella* have involved the introduction of *Oomyzus* (=*Tetrastichus*) *sokolowskii* (Kurdj.), a larval-pupal parasitoid, the larval parasitoids *Cotesia plutellae* (Kurdj.) and *Diadegma* spp., and *Thyraellia collaris* (Grav.), a pupal parasitoid. Of these, only *C. plutellae*, a braconid wasp introduced from India in 1976, has become established and caused significant mortality (Jones, 1985).

The brassicaceous crops, cabbage, cauliflower, broccoli, etc., on which these species interact are relatively short-term, and *P. xylostella*, for its reproductive success, must necessarily respond as a r-strategist. The accepted dogma of population biologists is that population stability in an interacting system is the result of some degree of permanence of the interacting species, a situation that would enhance the probability of successful biological control. Therefore, it is not surprising to find that most of the examples of successful biological control are on perennial crops and those on short-term crops are dependent on repetitive inundative releases.

There is little doubt that natural enemies of pests are adaptive to their hosts' seasonal abundance, and are themselves r-strategists. Thus, they should contribute to the stability of pest populations even if the equilibrium population is above an economically acceptable level.

Nine contiguous plots of cabbage were established by Jones (1985). These were staggered in time so that each subsequent plot was planted half way through the growing period of the previous one, thus some stability was added to the system. The mean percentage parasitism of *P. xylostella* by *C. plutellae* was maintained at about 90% from crop five, coinciding with the period of host decline, and it is reasonable to infer that in a permanent continuous habitat, *C. plutellae* is capable of reducing the pest population significantly, and may lead to quite stable oscillations about some reduced equilibrium level. However, the success of any pest management programme can only be measured in terms of crop loss and, in this case, crop loss was severe in all nine plots. *P. xylostella* larvae were found feeding several layers deep in the cabbage heads, rendering a large portion of the head unfit for sale. The outer head leaves suffered sustained pest attack during head formation, and the number of damaged leaves that had to be removed resulted in substantial losses. The harvested heads were hardly marketable by virtue of their small size and local consumer preference at the time of this experiment; therefore actual crop loss was close to 100%. Thus, the high rates of parasitism experienced in each crop had no significant effect on yield. Parasitized larvae continue to feed until parasitoid emergence and cause at least as much damage as unparasitized larvae (Jones, 1985). Thus, this delayed mortality inhibits a direct positive relationship between parasitism and crop yield.

In specific reference to crop loss, the pressure of biological control must be exerted early enough to limit larval feeding. Therefore, *C. plutellae*, at least in the short term, cannot effect the necessary control and, despite resistance problems, chemical control appears to be the only practical choice for the farmer.

Two possible considerations before abandoning biological control of *P. xylostella* are (a) the possibility of obtaining additional species of parasitoids to complement *C. plutellae* through parasitisation of another stage in the life cyle, and (b) developing insecticide resistant strains of *C. plutellae* that could be used in conjunction with less frequent insecticide spraying. The first is currently being considered seriously with the egg parasitoid *Trichogrammatoidea bactrae* Nagaraja being a prime candidate. Studies at the Asian Vegetable

Research and Development Centre, Taiwan have indicated that, since the importation and field release of this insect, the need for chemical control of *P. xylostella* has been significantly reduced in certain areas of that country.

The idea of combining insecticide resistant natural enemies with insecticides in an integrated pest management programme is very attractive. Predators and parasitoids are exposed to the selective pressures of pesticides in the field situation and may be expected to develop resistance. Croft and Brown (1979) reported that Pielou and his co-workers were the first to study the possibilities of selecting a resistant natural enemy, when in 1949 they started submitting *Macrocentrus ancylivorus* Rohwer, a braconid parasitoid of the oriental fruit moth *Cydia molesta* (Busck) to laboratory selection with DDT. After eight months' selection a 4-fold increase in DDT resistance was obtained. Croft and Brown (*ibid.*) suggested that systematic testing of samples of natural enemies in heavily treated ecosystems should detect cases of resistance, provided that susceptible strains can be obtained for comparison from untreated areas. We have screened eight Barbadian populations of *Cotesia plutellae* and found limited resistance to the insecticides tested. Whether this means that the development of a strain, or strains, with enough resistance to allow *C. plutellae* to coexist with the current insecticide regimes is a question still to be answered.

SOLUTIONS

Over the last two years, farmers have been urged to use Jupiter(R), an insect growth regulator (IGR) that works by inhibiting chitin synthesase and Dipel(R), a formulation of *Bacillus thuringiensis*, the _-endotoxins of which are digested to become a poison in the insect's gut. Thus farmers have been asked to use chemicals that are very different from those traditionally used to control *P. xylostella*. These two chemicals have other advantages in terms of their specificity and environmental friendliness. However, despite their obvious success in increasing farmers' cabbage yields there are some problems. Firstly, the spraying schedules are very different thus farmers need to be educated carefully. Secondly, the safe period for Jupiter(R) is much longer than that of other insecticides that the farmers may be using. Thirdly, resistance to IGRs and *B. thuringiensis* has developed in *P.*

xylostella populations in other countries.

In the light of the inevitable development of insecticide resistance in *Plutella xylostella* to Dipel(R) and Jupiter(R), two trials of new insecticides have been conducted in 1993. These trials included Jupiter(R) and Dipel(R) as well as four insecticides new to Barbados (see Table 1). The Dipel(R) treatment was in conjunction with Bioshield(R) a product designed to reduce the rate at which Dipel(R) is degraded by ultra-violet light. The first trial was subject to severe praedial larceny therefore data are only presented for the second trial conducted at Hopewell Plantation, St. Thomas.

Seedlings were transplanted on 93-04-19 and treatments were assigned to 18 plants in each of two rows. A row of tomatoes separated each of the four replicate blocks. For assessment of pest populations, 10 randomly selected plants were sampled. The plants were only sprayed three times during cultivation, on the days after assessment of pest populations. The data from these assessments are presented in Table 2. Although there are clear trends in the data, the only statistically significant differences are for white flies at the last sample date (93-06-03) where the Applaud(R) treated plots had a significantly lower population than the control and Dipel(R) treated plots.

One reason for the absence of other significant differences after insecticicde treatment is the design of the experiment. There were large differences between replicates which may have resulted from the fact that it was easier for pests to spread from one treatment block within a replicate than between replicates separated by the rows of tomatoes.

Although there were no significant differences in the percentage of harvestable heads (Table 3), heads from the Jupiter(R) treated plots were significantly heavier than those from the Dipel(R)/ Bioshield(R) treated plots.

Three interesting features of these results are:- (a) that acceptable yields were obtained with only three sprayings whereas many farmers will spray 10-15 times per crop, (b) that the most important pest was not *P. xylostella*, and (c) that there were no major differences in the performance of the insecticides. The last is probably the most important in that the development of an insecticide resistance management programme (IRM) requires a pool of efficaceous products that can be rotated.

ACKNOWLEDGEMENTS

The following contributions are gratefully acknowledged : - the Government of Barbados' sponsorship of IHG's postgraduate studies; CARDI's provision of equipment for insecticide resistance testing; Mr. F.B. Lauckner's assistance with probit analysis; and the field and laboratory assistance of Mr. L. Boyce and Mrs. G. Skeete.

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Table 1: Insecticides used in recent trials on cabbages in Barbados.

Commercial Name	Active Ingredient	Manufacturer
Applaud(R) WP	buprofezin	Nihon Nohyaku, Japan
Azatin(R) EC	azadirachtin	Agridyne Technologies Inc., U.S.A.
Cascade(R) 100 GL	flufenoxuron	Shell, U.K.
Dipel(R)	*Bacillus thuringiensis*	Abbot Laboratories, U.S.A.
+Bioshield(R)		Agro-K, U.S.A.
Jupiter(R) 120 EC	chlorfluazuron	Ciba-Geigy, Switzerland
Trebon(R) 20 EC	etofenprox	Mitsui Toatsu Chemicals Inc., Japan

Table 2: Mean pest populations plant^{-1} on cabbage in the insecticide trial at Hopewell, St. Thomas.

Sampling Date	Insecticide treatment	DBM larvae	Aphids	White flies	Thrips	*Ascia* larvae
93-05-04	Applaud	0.18	1.25	22.63	1.55	0.15
	Azatin	0.23	1.40	27.75	1.70	0.23
	Cascade	0.53	0.60	26.10	2.25	0.35
	Dipel + Bioshield	0.25	0.53	26.43	2.58	0.30
	Jupiter	0.35	1.53	23.38	1.58	0.10
	Trebon	0.18	0.25	29.53	1.30	0.08
	None	0.78	0.15	33.88	1.60	0.13
93-05-21	Applaud	0.10	12.25	55.20	0.00	0.00
	Azatin	0.00	0.00	90.85	0.00	0.00
	Cascade	0.00	4.58	52.83	0.10	0.00
	Dipel + Bioshield	0.00	0.63	68.23	1.00	0.10
	Jupiter	0.00	9.38	79.18	0.00	0.00
	Trebon	0.00	1.75	77.85	0.00	0.00
	None	0.00	5.13	83.00	0.20	0.00
93-06-03	Applaud	0.08	23.05	14.98	0.00	0.10
	Azatin	0.03	7.25	76.55	0.00	0.00
	Cascade	0.00	26.13	66.63	0.00	0.00
	Dipel + Bioshield	0.03	25.88	140.38	0.00	0.00
	Jupiter	0.00	78.00	79.18	0.00	0.55
	Trebon	0.03	14.80	56.85	0.00	0.03
	None	0.03	55.58	121.75	0.00	1.35

Table 3: Yield data for the insecticide trial at Hopewell Plantation.

Insecticide	Avge. Weight of Marketable Heads (kg)	% Marketable Heads
Applaud	0.64	80.5
Azatin	0.54	87.5
Cascade	0.54	86.1
Dipel	0.45	69.4
Jupiter	0.70	80.5
Trebon	0.58	84.7
Control	0.48	74.3