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Project Leader:	Mr R J Jacobson Horticulture Research International Stockbridge House
Principle Workers:	Dr P Croft and Ms C Sampson Horticulture Research International Stockbridge House
Project Co-ordinators:	Mr D Hargreaves, Horticultural Consultant, 111 Copandale Road, Beverley, East Yorkshire, HU17 7BN Dr N Dungey, Hazlewood VHB, Toddington Lane, Littlehampton, West Sussex, BN17 7PP
Location:	Horticulture Research International Stockbridge House Cawood Selby North Yorkshire Y08 3TZ Tel: 01757 268 275 Fax: 01757 268996
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The results and conclusions in this report are based on a literature and information search. The report draws on the results and experience of other research workers and technicians from around the world. Because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with the interpretation of the results especially if they are used as the basis for commercial product recommendations.

CONTENTS

PRACTICAL SECTION FOR GROWERS

BACKGROUND

The pesticide, Dynamec (abamectin) has recently received approval for control of *Tetranychus urticae* (two-spotted spider mites) and *Liriomyza* spp. (leaf miners) on protected tomato crops (except cherry tomatoes), and *T. urticae* and *Frankliniella occidentalis* (western flower thrips or WFT) on protected cucumber crops. However, growers are unsure how to use the product within IPM programmes because there is insufficient information available regarding compatibility with beneficial invertebrates. Furthermore, there are reports of resistance to abamectin in *T. urticae* and *F. occidentalis* populations in other countries and a reliable resistance management strategy is required to avoid such problems developing in the UK. The Cucumber Technology Group and the Tomato Growers Association requested that these subjects be reviewed and guidelines produced for the most effective use of Dynamec in UK cucumber and tomato crops.

SUMMARY OF RESULTS

Important properties of abamectin

- A natural product derived from the soil fungus, *Streptomyces avermitilis*.
- Broad spectrum of activity against invertebrates.
- Stomach and contact activity but most effective when ingested.
- Pests are immobilised rapidly but death may not occur for three to five days.
- Effective against all motile stages of *T. urticae* and larvae of *Liriomyza* spp., and reasonably effective against nymphal stages of *F. occidentalis*.
- Exhibits strong translaminar movement but little further systemic activity.
- There is no protection to plant growth that occurs after treatment.
- Chemical degradation is reported to be dependent on environmental conditions, in particular light levels; leaf surface residues may persist for three weeks during the winter but decline within hours in good summer light conditions.

Compatibility of abamectin with natural enemies

There are four important factors to take into consideration when assessing the effects of pesticides on natural enemies that are used as biocontrol agents:

- Mortality of all life cycle stages following direct exposure to the recommended dose of the pesticide.
- Sub-lethal effects (*eg*. reduced egg laying, reduced feeding) on all life cycle stages following exposure to low doses or partially degraded residues of the pesticide.
- Indirect effects on all life cycle stages through feeding on intoxicated pests.
- Indirect effect of starvation due to reduced numbers of prey.

The various effects of abamectin on the natural enemies most commonly used against the six principal pests of UK cucumbers and tomatoes are summarised in the full HDC report. Ideally, all that information would be derived from properly designed experiments that are fully documented in the scientific literature. However, such data is quite limited and sometimes contradictory. The report therefore draws on unpublished records and field observations that have been interpreted with caution.

The reported harmful effects of abamectin on natural enemies are further summarised in Table 1. Direct exposure to the recommended dose of abamectin is known to kill some life cycle stages of some natural enemies but there are many gaps in the information. Sub-lethal effects resulting from exposure to low doses of the pesticide, and the indirect effects of feeding on intoxicated prey, are largely unknown.

Table 1. A summary of the reported harmful effects on natural enemies following direct exposure to recommended doses and sub-lethal doses of abamectin, and indirect exposure through feeding on intoxicated prey.

	Reported harmful effect on life cycle stages:		
Biocontrol agent	**lethal to:**	**sub-lethal effect on:**	**acquired via feeding**
Diglyphus isaea	adult, #	*	*
Dacnusa sibirica	adult, #	*	*
Trichogramma spp..	adult, egg, #	Egg, #	*
Aphidius colemani	adult, larva, #	*	*
Aphidoletes aphidimyza	adult, larva, #	*	*
Encarsia formosa	adult, larva, #	*	Adult, #
Macrolophus caliginosus	adult, larva, egg	*	*
Phytoseiulus persimilis	egg, #	adult, egg, #	adult, #
Feltiella acarisuga	adult, #	*	*
Amblyseius cucumeris	adult, larva, egg,	*	*
Orius spp..	adult, larva, #	*	*

insufficient information on other life cycle stages * no information found

Development of resistance to abamectin

Insects and mites are able to develop resistance to abamectin through a number of different mechanisms, which are sometimes cross-linked to pyrethroids. However, resistance often confers other disadvantages and these individuals may not compete well with susceptible members of the population. As a consequence, the population often reverts to susceptible status when the selection pressure of the chemical is removed. The reported instances of resistance include:

***Tetranychus urticae*:**

- Resistance has been recorded in both outdoor and protected crops.
- Resistance was recorded in Californian ornamental crops, though not where abamectin was used less than six times per year or less than 30 times over six-years.
- In contrast, resistance has developed in Dutch nurseries where the chemical was only used twice per year with a total of 12 applications.
- These examples suggest that the mechanism of resistance development may differ between mite populations.

***Frankliniella occidentalis*:**

- The first record of abamectin resistance in a population of *F. occidentalis* was in a Californian glasshouse, even though the chemical was not yet registered for the control of the pest in that country.
- Resistance has also been recorded in *F. occidentalis* on greenhouse flower crops in Israel.

***Liriomyza* spp.:**

- No published records of abamectin resistance have been found.
- However, resistance has been implicated where control of *Liriomyza huidobrensis* (South American leaf miner) has failed following repeated use of abamectin in Dutch and USA flower crops.

ACTION POINTS FOR GROWERS

Dynamec (abamectin) is approved for use in the UK on protected tomato (except cherry tomato) and cucumber crops as a horticultural acaricide/insecticide. Various statutory restrictions apply on the maximum individual dose and on the numbers and timing of treatments on tomato and cucumber crops. ALWAYS READ THE LABEL. USE PESTICIDES SAFELY

Possible opportunities to incorporate Dynamec in IPM programmes

Despite the lack of a complete data package for safety to biocontrol agents, it is possible to suggest the following opportunities to incorporate Dynamec in IPM programmes in cucumber and tomato crops. However, it is impossible to anticipate all the implications to IPM at this stage and each suggestion must be executed with care and the results monitored carefully.

Against spider mites on recently re-planted mid-season cucumber crops:

- Due to the rapid "turn-round" of cucumber crops in mid-season, it can be difficult to prevent the "carry-over" of spider mites from the old to the new crop.
- Abamectin is extremely effective against motile stages of spider mites and it could be used soon after planting to kill invading mites and thereby reduce the pressure on the subsequent biocontrol programme.
- The main reservation concerning this strategy is the possibility of residues of the product harming biocontrol agents that are subsequently released in the crop. However, this is unlikely to happen during mid-season because:
  - The pesticide degrades quickly at this time of the year.
  - The plants grow away from the abamectin treatment very quickly.

Against spider mites on cucumbers and tomatoes during cropping:

- There are often occasions when spider mites "out-strip" the predatory mite, *Phytoseiulus persimilis*, during cropping. This most commonly occurs during hot weather when the pests congregate at the tops of plants while the predators prefer the cooler environment in the middle of the crop canopy. In most cases, the first response would be to apply the spider mite specific chemical, Torq, but control may be inadequate if there have recently been several applications of the product.
- Where Torq fails, an application of Dynamec to the tops of the plants may redress the predator-prey balance.

- The main reservation concerning this strategy is the possibility of harming biocontrol agents already operating in the crop. This may not be ruled out entirely. However, the risks should be minimal because:
    - The pesticide degrades quickly under such conditions.
    - The principal biocontrol agents are active lower down the plant.

Against WFT on cucumbers during cropping:

- In most situations, the predatory mite, *Amblyseius cucumeris,* should suppress the development of WFT populations for the duration of the cucumber crop. However, there are occasions when the pest "out-strips" the predator and remedial action is required. When this happens, action must be taken quickly to contain the pest in localised areas of the crop.
- Two or three Dynamec treatments in the "hot spot" will help to contain the infestation.
- The main reservation concerning this strategy is the possibility of harming biocontrol agents that are already operating in the crop. This may not be ruled out entirely. However, the risks should be minimal because:
    - Such problems usually occur mid-season when the pesticide degrades quickly.
    - Biocontrol agents can be re-released locally soon after treatment.
    - Biocontrol agents move into the area from surrounding untreated plants.

End of season "clean-up" treatments in cucumber and tomato crops:

- Pest numbers sometimes increase towards the end of cucumber and tomato crops because the efficiency of biocontrol agents decreases during the shortening days. It is important to restrict the carry-over of these pests to the next crop because this will reduce the pressure on the new IPM programme.
- If spider mite numbers are still large at the end of the season, a single application of Dynamec within a few days of the last harvest should reduce numbers significantly. However, as many areas should be left unsprayed as possible.
- If leaf miner numbers are too large at the end of the season, two applications of Dynamec at a three-week interval just before the end of cropping should reduce numbers significantly. Again, leave as many areas unsprayed as possible.
- Co-ordinate treatments against the various pests to avoid unnecessary repetition.
- The main reservation concerning this strategy is the possibility of harming biocontrol agents that are controlling other pests, resulting in an alternative pest problem. This may not be ruled out entirely. However, the risks can be minimised if the treatments are delayed as late in the cropping cycle as possible.

How not to use Dynamec in the IPM programme

- As an entire crop treatment; particularly if plants are growing slowly in early/mid-season. Some areas of the crop or parts of the plants should always remain untreated.
- Do not use Dynamec at key times of *Diglyphus isaea*, *Encarsia formosa* or *Amblyseius cucumeris* establishment. This is particularly important early in the year when the chemical could persist on plants for over three weeks.

How to avoid the development of resistance

- Where possible use non-chemical control methods.
- Do not use the chemical unnecessarily.
- Do not use rates below those recommended on the product label.
- Rotate Dynamec with Torq for *T. urticae* control to help prevent resistance developing to both products.
- Rotate Dynamec with Dichlorvos for *F. occidentalis* control on cucumbers to help prevent resistance developing to both products.
- Do not spray entire crops. By treating only part of the crop, the pest population will maintain a wider genetic base and will be more likely to revert to susceptible status when the chemical selection pressures are removed. Hence:
  - Restrict treatments to "hot spots" of pest activity.
  - If more general treatments are required, identify the least infested areas and leave these unsprayed.
  - Only spray the parts of the plant that are most heavily infested (*eg.* tops of plants infested with spider mites in mid-summer).

RECOMMENDATIONS FOR FURTHER RESEARCH

The following topics have been identified as high priority for future research:

- **Direct mortality:** It is important that indisputable data is produced for mortality of all life cycle stages of natural enemies used in cucumbers and tomatoes following exposure to recommended doses of abamectin.
- **Sub-lethal effects:** This has serious implications for the establishment of natural enemies and must be a high priority for future research.
- **Feeding on intoxicated prey:** The indirect effects of natural enemies feeding on intoxicated prey are not immediately obvious but could have a serious impact on the success of IPM programmes and should be a high priority for future research.
- **Indirect effect through starvation:** The indirect effect of natural enemy starvation due to reduced numbers of prey could seriously affect the continuity of IPM programmes and should be better understood.
- **Degradation and residual activity:** To make informed decisions about the compatibility of abamectin with natural enemies, the rate of degradation and the residual effect of abamectin should be determined on tomato and cucumber plants during winter, spring and summer conditions.
- **Adjuvants:** The effect on natural enemies must be determined before UK growers consider using Codacide oil as an adjuvant with Dynamec.
- **Resistance tests:** The efficacy of abamectin should be regularly monitored in pest populations on cucumber and tomato crops to aid resistance management strategies.

PRACTICAL AND FINANCIAL BENEFITS TO THE INDUSTRY

The Cucumber Technology Group (CTG) and the Tomato Growers Association (TGA) Technical Committee requested guidance on the most effective use of Dynamec within IPM. The acquisition of this knowledge will also be beneficial to growers of ornamental crops who are moving towards IPM.

The use of Dynamec in cucumber and tomato IPM programmes could:

- Reduce direct economic loss resulting from damage by spider mites and WFT.
- Reduce the risk of indirect economic loss resulting from the breakdown of biological control of other pests following inappropriate use of Dynamec.
- Prolong the effective life of Dynamec through the adoption of a sensible resistance management strategy and prolong the effective life of Torq and Dichlorvos by reducing the dependence on these chemicals.

SCIENCE SECTION

1. INTRODUCTION

Growers of cucumber and tomato crops urgently require additional control measures to reduce infestations of *Frankliniella occidentalis* (WFT) and *Tetranychus urticae* (spider mites). The pesticide Dynamec (abamectin), which has activity against *T. urticae*, *F. occidentalis* and *Liriomyza* spp (leaf miners), has recently received approval for use on cucumber and tomato crops in the UK. However, growers are unsure how to use Dynamec within IPM programmes because there is insufficient information available regarding the product's compatibility with biological control agents (Dynamec product label). Furthermore, there are reports of resistance to abamectin in *T. urticae* and *F. occidentalis* populations in other countries and a reliable resistance management strategy is required to avoid such problems developing in the UK.

The Cucumber Technology Group and the Tomato Grower's Association requested that these subjects be reviewed and guidelines produced for the most effective use of Dynamec in UK cucumber and tomato crops.

2. OBJECTIVES

The specific objectives of the project were:

2.1. To compile all available information regarding the compatibility of abamectin with biological control agents commonly used in cucumber and tomato IPM programmes.

2.2. To identify gaps in the knowledge of the compatibility of abamectin with biological control agents commonly used in cucumber and tomato IPM programmes.

2.3. To compile all available information regarding the development of resistance to abamectin in spider mite, WFT and leaf miner populations in other countries.

2.4. To produce recommendations for the most appropriate and effective use of abamectin within IPM programmes in cucumber and tomato crops in the UK.

2.5. To produce an HDC Information Sheet to guide growers in the most appropriate and effective use of abamectin in IPM programmes in cucumber and tomato crops.

3 ABAMECTIN

3.1 An introduction to abamectin

Avermectins are a group of macrocyclic lactone compounds that have a wide spectrum of activity against insects, mites, molluscs, roundworms, tapeworms and nematodes (Clark *et al.*, 1994). They are natural products, which are isolated and fermented from the soil actinomycete, *Streptomyces avermitilis* (Lasota & Dybas, 1991). The group was discovered in 1976 and released onto the world market in 1982.

Avermectins act by stimulating the release of aminobutyric acid, an inhibitory neuro-transmitter that causes paralysis (Turner & Schaeffer, 1989). The novel chemistry and mode of action means that they are an important resource for pest control and resistance management. Although the chemicals are contact and stomach acting poisons, they are most effective when ingested. Avermectins exhibit strong translaminar movement but little further systemic activity.

Abamectin is the common name assigned to avermectin B_1 and it was first made commercially available in South Africa in 1984. In horticulture and agriculture, abamectin is used to control the motile stages of mites, leaf miners, suckers, beetles and others on a range of crops including ornamentals, cotton, citrus fruit, pome fruit, nut crops, vegetables and potatoes. It is a slow acting chemical and although pests become immobilised soon after treatment, they may take three to five days to die. Application rates range from 5.6 to 28g active ingredient (a.i.)/ha for mite control and 11 to 22g a.i./ha for leaf miner control. Higher concentrations of a.i. are required to kill phloem feeders, such as aphids, than leaf feeders because the feeding mechanism results in the insect having less contact with the chemical. The most widespread commercial use of abamectin has been as an acaricide. It has been shown to be effective against immature and adult mites on a variety of crops at lower concentrations of a.i. than 'conventional' acaricides. It is also toxic to some beneficial invertebrates (see section 4). Although harmful to humans when swallowed (acceptable daily intake 0.0001 mg/kg body weight), abamectin breaks down relatively rapidly is in the environment and has been placed in the low toxicity category, Class IV (Lankas & Gordon, 1989).

Abamectin is sold in various countries under the trade names Affirm, Abacide, Avid, Agrimec, Agri-mek, Dynamec, Vertimec and Zephyr. Dynamec was approved for use on UK protected tomato and cucumber crops in February 1998 (see Section 7.1 for summary of label recommendations). Dynamec is an emulsifiable concentrate containing 18g a.i./litre.

3.2 Efficacy of abamectin against pests on UK cucumber and tomato crops

Abamectin is extremely effective against motile stages of spider mites on cucumbers and tomatoes. Trials have demonstrated at least 80% control of *T. urticae* on tomatoes with a single application of abamectin applied at 11.2 to 22.4g a.i./ha (Dybas, 1989). However, there is little ovicidal activity, so applications must be repeated to achieve complete control. The recommended application rate of Dynamec against spider mites is 25ml product per 100 litres water applied to maximum leaf retention (*i.e.* approximately equivalent to 11.25 and 18g a.i./ha on tomatoes and cucumbers respectively, depending on the density of foliage).

Abamectin has been used successfully for the control of *Liriomyza* spp. larvae with up to 100% reduction in numbers (Calbretta *et al.*, 1987). However, a higher application rate is recommended than against *T. urticae*; 50ml Dynamec per 100 litres of water (equivalent to approximately 23g a.i./ha on tomatoes). Adult survival of *Liriomyza trifolii* (American serpentine leaf miner) on tomatoes was only reduced for one day after treatment with abamectin but the effect on reduced adult feeding and oviposition continued for a week (Schuster & Taylor, 1987).

Abamectin is less effective against *F. occidentalis* but a programme of two to three treatments reduced populations by over 80% (Oetting, 1988; Kontsedalov *et al.*, 1998). The application rate is the same as that recommended against leaf miners (*i.e.* equivalent to 36g a.i./ha on cucumbers). Helyer & Ledieu (1986) found abamectin ineffective against *Thrips tabaci*.

3.3 Factors affecting the efficacy of abamectin

Age of pest:
The youngest motile stages of pests tend to be the most susceptible to abamectin. For example, under laboratory conditions, first instar *Bemisia tabaci* (tobacco whitefly) were more susceptible to abamectin than third instars or adults; the lethal concentration to kill 50% of the population (LC_{50}) being 0.015, 0.14 and 1.83 mg a.i./litre respectively (Horowitz *et al.*, 1997).

Degradation of abamectin:
The rate of abamectin degradation is dependent on environmental conditions and is particularly enhanced by sunlight. Leaf surface residues decline within hours in good summer light conditions but may persist for three weeks during the winter (GreatRex, Novartis, pers. comm.,1999). When tested against *B. tabaci* on cotton under laboratory conditions without exposure to sunlight, an application of 1 mg a.i./litre resulted in adult mortalities that declined from 86 to 39% over 28 days. However, when the treated seedlings were placed outdoors daily for three hours, adult mortality declined to 20% mortality over two days (Horowitz *et al.*, 1997). Abamectin degrades rapidly in soil with a half-life of between eight hours (aerobic conditions) to two months (anaerobic conditions).

Residual activity of the chemical:
The residual effect of abamectin varies considerably between crops and invertebrate species. For example, residual effects have been reported for two to six weeks against *Panonychus citri* (citrus red mite), 21days against *Polyphagotarsonemus latus* (broad mite) and 46 days against *T. urticae* (Dybas, 1989). Residual effects also vary between life cycle stages; *eg.* mortality of *L. trifolii* larvae has been observed for up to 20 days (Calbretta *et al.*, 1987) but adult survival was only reduced for one day (Schuster & Taylor, 1987). However, there may continue to be sub-lethal effects; Schuster & Taylor (1987) reported that adult feeding and oviposition was reduced for a further week.

Effect of plant growth on residual activity:
Although abamectin shows translaminar movement, it is not systemic. Therefore, after treatment, new growth will be unprotected and will provide a safe refuge for invertebrates (Walsh *et al.*, 1996). This is particularly relevant in cucumber crops because the plants can grow over one metre in a week.

Adjuvants:
The Novartis product label specifically states that Dynamec should not be mixed with oils prior to application. However, mixing with oils has been shown to improve the efficacy of abamectin in both laboratory and field trials. For example, a mixture of 18g a.i./ha and 1% mineral (paraffin) oil decreased *B. tabaci* numbers on cotton to 2.9 larvae per leaf at day 27, compared to 9.6 and 14.6 larvae per leaf in plots treated with abamectin or mineral oil respectively (Horowitz *et al.*, 1997). The addition of oil enhances the compound's translaminar activity, resulting in reduced LC_{50} values for species such as *T. urticae* and *Aphis fabae* (black bean aphid) (Lasota & Dybas, 1991). The use of oils can also increase the residual effect of abamectin; for example, from six to 16 weeks against *Panonychus citri* (Lasota & Dybas, 1991). The use of oils would also affect the residual effect against natural enemies (Hoy & Cave, 1985) and the impact of this on biological control programmes should be determined.

4. COMPATIBILITY OF ABAMECTIN WITH NATURAL ENEMIES

There are four important factors to consider when assessing the effects of pesticides on natural enemies:

1. Mortality of all life cycle stages following direct exposure to the recommended dose of the pesticide.
2. Sub-lethal effects (*eg*. reduced fecundity, feeding inhibition) on all life cycle stages following exposure to low doses or partially degraded residues of the pesticide.
3. Indirect effects on all life cycle stages through feeding on intoxicated prey.
4. Indirect effect of starvation due to reduced numbers of prey.

This section summarises the available information regarding the various effects of abamectin on the 12 natural enemies most commonly used against the six principal pests of cucumbers and tomatoes in the UK. Ideally, all this information would be based on data that had been produced in properly designed experiments that were fully documented in the scientific literature. However, irrefutable information of this type is currently quite limited.

The biological control companies, Koppert Biological Systems, Biobest Biological Systems and Novartis BCM, provide guidance to their customers by issuing lists that summarise the effects of pesticides on beneficial species. They attempt to base this information on data from the scientific literature but where none exists they use unpublished records and field observations from a variety of sources. The companies try to ensure that such records are accurate; for example Koppert's information is verified by a panel of eight field technicians in Holland and by technical colleagues from their subsidiaries in France, Spain and Canada (Bolckmans, Koppert bv, pers. comm., 1999). However, it is possible that some of the unpublished records and field observations may not be completely robust.

Where the information presented here has been sourced from the scientific literature, the appropriate reference is cited in the text. Where the information has come from another source, it is cited as a personal communication or more generally attributed to the "biocontrol companies" lists.

4.1. Leaf miner parasitoids

***Diglyphus isaea*:**

- There are conflicting reports of the direct effect of abamectin on *D. isaea*. Helyer *et al*. (1992) found adults to be very susceptible (80-99% mortality) when exposed to chrysanthemum leaf discs immediately after they had been sprayed. In contrast, Ochoa-Chavarria & Carballo-Vargas (1993) measured the effects of abamectin on pupae and adult stages in laboratory bioassays and found there to be zero mortality. This variation may be due to differing experimental methods and in particular the time between application of the chemical and the assessment of mortality. For example, in a separate study using a semi-synthetic derivative of abamectin but with similar residual activity, Chukwudebe *et al*. (1997) showed that *D. isaea* mortality decreased from 75% at 0.5h post-application to 15 % (similar to control) at 60h post-application.

- Abamectin can control leaf miner larvae for up to three weeks (Calbretta *et al.* 1987) and this may have an indirect effect on the parasitoid population by removing the food source upon which adult *D. isaea* depend for survival.
- The biocontrol companies' lists show abamectin to be very harmful to adults (>75% mortality).
- The sub-lethal effects of abamectin on the parasitoids are unknown.
- The effects of parasitoids feeding on intoxicated leaf miner are unknown.

***Dacnusa sibirica*:**
- Helyer *et al.* (1992) demonstrated 30-79% mortality of adults placed on chrysanthemum leaf discs during the 48h following application of abamectin.
- The biocontrol companies' lists show abamectin to be very harmful to adults (>75% mortality).
- The sub-lethal effects of abamectin on the parasitoids are unknown.
- The effects of immature parasitoids feeding on intoxicated leaf miner are unknown.

***Opius* spp.:**
- Nielsen *et al.* (1989) found little effect on the mortality of adult *O. pallipes*.
- The sub-lethal effects of abamectin on the parasitoids are unknown.
- The effects of immature parasitoids feeding on intoxicated leaf miner are unknown.

4.2. Tomato moth parasitoid

***Trichogramma* spp.:**
- Castelo-Branco & Franca (1995) showed in laboratory assays that abamectin was highly toxic to adult *T. pretiosum*; the LC_{50} being was 200 times lower than the recommended field rate.
- Consoli *et al.* (1998) demonstrated three sub-lethal effects. When parasitised *Ephestia kuehniella* (Mediterranean flour moth) eggs were dipped in abamectin at the recommended dilution, the development time of the parasitoid was reduced, the parasitism capacity of the emerging parasitoids was reduced, and the mortality of the emerging parasitoids was increased.
- Biocontrol companies' report a harmful (>75% mortality) effect of abamectin on adult *T. evanescens*.

4.3. Aphid natural enemies

***Aphidius colemani* and *Aphidoletes aphidimyza*:**
- Biocontrol companies' report that adults and larvae of both species are very susceptible (>75% mortality) to abamectin and the effects against *Aphidius colemani* persist for one week.
- The sub-lethal effects of abamectin on the parasitoids are unknown.
- The effects of the parasitoids feeding on intoxicated aphids are unknown.

4.4. Whitefly natural enemies

***Encarsia formosa*:**

- There have been several reports of abamectin having a direct effect on *E. formosa*. Helyer & Ledieu (1986) showed the formulation, MK-936, to be very toxic to *E. formosa* when applied to parasitized *Trialeurodes vaporariorum* (glasshouse whitefly) scales. Zchori-fein *et al.* (1994) demonstrated 47% mortality of *E. formosa* in parasitized whitefly pupae on bean leaves dipped in abamectin (Avid). In contrast, Helyer & Ledieu (1986) showed that the majority of adult *E. formosa* emerged from treated whitefly scales although they all subsequently died.
- Lindquist & Casey (1991) demonstrated an indirect effect of abamectin (Avid); the product was found to prevent parasitism when applied to adult and nymph stages of *E. formosa* on poinsettias.
- Zchori-fein *et al.* (1994) showed an indirect effect of adult female *E. formosa* feeding on intoxicated whitefly scales, *i.e.* high mortality in the short term.
- Zchori-fein *et al.* (1994) found that the residual effect of abamectin against adult *E. formosa* on beans and poinsettias declined rapidly from 100% mortality at exposure 2h after spraying, to 0% mortality after 24h.
- Perhaps suprisingly, Zchori-fein *et al.* (1994) found that in the glasshouse, abamectin and *E. formosa* reduced the numbers of whitefly better than abamectin alone. Although the average number of parasitized pupae was significantly higher where abamectin was not applied, the average percentage parasitism did not differ between plants treated or not treated with abamectin.
- Biocontrol companies' list abamectin as very harmful to adults (>75% mortality) with a persistence of three weeks, but with little effect on pupae.
- The sub-lethal effects of abamectin on the parasitoids are unknown.

***Macrolophus caliginosus*:**

- Trottin-Caudal & Millot (1994) found that abamectin applied to tomatoes reduced numbers of larvae and numbers of larvae hatching from eggs by 50%. However, there was little recorded effect on adults. The residual effect of the chemical was 18 days.
- The biological control companies' report abamectin to be very harmful (>75% mortality) to adults and larval stages of *M. caliginosus* and that the effects persist for three weeks.
- The sub-lethal effects of abamectin on the predators are unknown.
- The effects of the predators feeding on intoxicated white flies are unknown.

4.5. Spider mite predators

***Phytoseiulus persimilis*:**

- In a laboratory examination of eggs and adult female *P. persimilis* on bean leaves, abamectin (Avid) was found to be much less toxic to *P. persimilis* than to spider mites (Zhang & Sanderson, 1990). However, five applications of abamectin (12ppm at three to five day intervals) to greenhouse roses eliminated both species (Sanderson & Zhang, 1995).
- Zhang & Sanderson (1990) demonstrated several sub-lethal effects of abamectin on *P. persimilis*. Although survival of adults placed on leaf discs sprayed with abamectin was not effected, their reproduction was reduced by approximately

50% at rates higher than 4 ppm (recommended rate was 6 ppm). Zhang & Sanderson (1990) also found that offspring of *P. persimilis* from eggs dipped in abamectin had reduced mobility, survival and egg to adult development time at 8 and 16ppm.

- Zhang & Sanderson (1990) also demonstrated indirect effects on *P. persimilis* that fed on intoxicated spider mites. Adult female *P. persimilis* survived feeding on spider mites treated with abamectin but their reproductive capacity was reduced by 27-53%.
- Biocontrol companies' record the effect on adult and nymphal stages of abamectin as being very harmful (>75% mortality), with a persistence of two weeks, but only slightly harmful to the egg stage.

***Feltiella acarisuga*:**

- Field observations suggest that there may be no direct effect of abamectin on the larval stage of *F. acarisuga* but the larvae die due to starvation following the death of the spider mites (Walker, BCP Ltd, pers. comm., 1999).
- Biobest list abamectin as being harmful to adult *F. acarisuga* (>75% mortality).
- The sub-lethal effects of abamectin on the predators are unknown.
- The effects of the predators feeding on intoxicated spider mites are unknown.

4.6. Thrips predators

***Amblyseius (Neoseiulus) cucumeris*:**

- All stages of the predatory mite, *A. cucumeris*, were found to be very susceptible to abamectin for 48h following application to bean plants (Staay van der, 1991).
- Biocontrol companies' list the effects of abamectin as being very harmful to all stages of the mite with a persistence of two weeks.
- The sub-lethal effects of abamectin on the predators are unknown.
- The effects of the predators feeding on intoxicated thrips are unknown.

***Orius* species:**

- Biocontrol companies' report abamectin to be 'moderately toxic to harmful' (i.e. 50% to >75% mortality) to the nymph and adult stages of *Orius* bugs with a persistence of three weeks.
- The sub-lethal effects of abamectin on the predators are unknown.
- The effects of the predators feeding on intoxicated thrips are unknown.

5. GAPS IN THE COMPATIBILITY INFORMATION

5.1. Direct mortality of natural enemies exposed to recommended doses

The existing information on the direct mortality effect of abamectin on natural enemies has been produced by many different methods and is sometimes contradictory. To provide a complete data package for those natural enemies most commonly released in UK cucumber and tomato crops, it is important that indisputable data is produced for the following life cycle stages:

Diglyphus isaea	- eggs, larvae, pupae and (to clarify) adults
Dacnusa sibirica	- eggs, larvae and pupae
Opius spp.	- eggs, larvae and pupae
Aphidius colemani	- eggs, larvae, pupae and adults
Aphidoletes aphidimyza	- eggs, larvae, pupae and adults
Encarsia formosa	- clarify ambiguous data
Macrolophus caliginosus	- eggs and adults
Phytoseiulus persimilis	- clarify ambiguous data
Feltiella acarisuga	- eggs, larvae, pupae and adults
Orius spp.	- eggs, larvae, pupae and adults

Many of the pesticides used in IPM programmes have been tested against beneficials in the Joint Testing Programmes organised by the IOBC/WPRS Pesticides and Beneficials Working Group. These tests are standardised and the work is done by an international group of experienced scientists. Abamectin has not yet been included in the published programmes but it will be included in the current phase to be completed between 2000 and 2002 (Sterk and Lewis, IOBC, pers. comm., 2000). The full details of the methods to be used are not yet available.

5.2. Sub-lethal effects of abamectin on natural enemies

Sub-lethal effects can fall into three main categories, *i.e.* effects on reproduction, feeding inhibition and developmental abnormalities (Strong & Brown, 1987). They could occur when any life cycle stages are exposed to low doses or partially degraded residues of the pesticide. The impact that such exposures may have on populations of natural enemies is illustrated by the work that has been done with *Trichogramma spp* and *P. persimilis* (Sections 4.2. and 4.5.). However, sub-lethal effects of abamectin are unknown for the other natural enemies released in UK cucumber and tomato crops. This must be a high priority for future research.

5.3. The indirect effects of natural enemies feeding on intoxicated prey

After application of abamectin, pests can vary in the time taken to die. Abamectin is known to be relatively slow acting (Dynamec Product Label) and the intoxicated prey may remain available to natural enemies for several days. Zhang & Sanderson (1990) showed that *P. persimilis* feeding on spider mites treated with a high dose of abamectin had significantly reduced fecundity. The effect of other predators or parasitoids feeding on potentially toxic prey is largely unknown but could result in direct mortality, delayed mortality or sub-lethal effects. This must be a high priority for future research.

5.4. Indirect effect of starvation due to reduced numbers of prey

Applications of abamectin may reduce pest numbers to below thresholds at which natural enemies can detect them. If the natural enemies are short lived (eg. *D. isaea*), they may die of starvation before the pest population becomes re-established. This will allow the pest population to grow subsequently without constraint and the overall effect may be detrimental. It is currently difficult to determine the actual risk that this presents in IPM programmes because there is so little reliable information. This must be a high priority for future research.

5.5. The effect of environment on residual activity of abamectin

Most of the testing of natural enemies was done under constant laboratory conditions. Although it is known that the persistence of abamectin on plants varies considerably under different environmental conditions (Bull *et al.*, 1984; Horowitz *et al.*, 1997) and on different plant types (Iqbal *et al.*, 1996), the actual rate of degradation of abamectin under typical UK glasshouse conditions at different times of the year is not currently published. This is clearly important because it influences direct mortality, sub-lethal effects and indirect effects on natural enemies. To make informed decisions about the compatibility of abamectin with natural enemies, the rate of degradation and the residual effect of abamectin should be determined on tomato and cucumber plants during winter, spring and summer conditions.

5.5. The effect of the use of oils as an adjuvant on beneficials

The mixture of adjuvants with Dynamec is not advised under the directions for use on the product label due to risks of plant damage. However, this condition is not statuatory and thus growers can mix adjuvants such as Codacide Oil with Dynamec but do so at <u>USERS RISK</u>. Trials have shown that mixture with oils has improved the efficacy and residual activity of abamectin (Lasota & Dybas, 1991; Horowitz *et al.*, 1997). If such mixtures increase efficacy against pests, it is highly likely that they will also increase the harmful effects on natural enemies. Therefore, the effects on beneficial species must be determined before UK growers consider using Codacide oil as an adjuvant with abamectin.

6.1. Abamectin resistance in cucumber and tomato pests

Resistance to the main pests attacking tomatoes and cucumbers has developed in several situations around the world. In some instances resistance has been recorded in countries where the product had not yet been registered for use on crops (Immaraju *et al.*, 1992):

Two-spotted spider mites (*T. urticae*):

- Resistance to abamectin has been recorded in both outdoor and protected crops.
- Initial tests on mite populations from pome fruit orchards in Washington and Oregon USA, in the first three years of abamectin use, showed no resistance (Hoy & Conley, 1987; Knight *et al.,* 1990). However, after seven to eight years of widespread commercial use, all *T. urticae* populations collected from pears showed low to moderate levels of resistance (Beers *et al.*, 1998).
- Abamectin largely replaced fenbutatin oxide in pome fruit orchards in Washington and Oregon during the period described above. As a consequence, LC_{50}'s for *T. urticae* declined considerably. The implications of this for resistance management are discussed below (Section 6.2).
- Even greater levels of abamectin resistance have been recorded in protected crops where use of the chemical, and therefore selection pressure, has been greater. Campos *et al.* (1995) tested populations of *T. urticae* from 10 ornamental nurseries in California in which abamectin had been used. Resistance correlated with the number of applications and the total time of abamectin use. Resistance was not detected in nurseries that had used the product less than six times per year or less than 30 times over six-years.
- In contrast, in Dutch ornamental nurseries, resistance has developed where the chemical was only used twice per year with a total of 12 applications. This suggests that the mechanism of resistance development may differ between mite populations (Clark *et al.,* 1994).

Western flower thrips (*F. occidentalis*):

- The first record of abamectin resistance in a population of *F. occidentalis* was in a Californian glasshouse, despite the fact that the chemical was not yet registered for the control of that pest (Immaraju *et al.*, 1992). At the time, there were reports of control failures with many of the insecticides being used, suggesting that there was a need for better pest and resistance management strategies.
- Resistance has also been recorded in *F. occidentalis* collected from greenhouse flower crops in Israel (Kontsedalov *et al.*, 1998).

Leaf miners (*Liriomyza spp.)*:

- No published data has been found on abamectin resistance in populations of *Liriomyza* spp.
- However, control failures have been reported in Dutch and USA flower crops where abamectin has been used repeatedly against *L. huidobrensis* and resistance has been implicated.

6. RESISTANCE TO ABAMECTIN

Since the commercial release of abamectin (1984), there has been an increase in the number of species cited in the literature that have developed resistance to the product, as well as an increase in resistance levels (Table 2). Several mechanisms have been implicated in abamectin resistance, including cross-resistance following the repeated use of pyrethroids (Appendix). The amount of resistance clearly reflects the amount of selection pressure to which the insects have been subjected.

Table 2. Published records of insect and mite resistance to abamectin

Species	Year	Years of use	Origin of samples	Resistance factor	Crop	Author
T. urticae	1987	-	California USA	None	Ornamentals	Hoy & Conley, 1987
	1990	1	Washington USA	None	Pome fruits	Knight *et al.*, 1990
	1994	-	The Netherlands	x 7	Ornamentals	Clarke *et al.*, 1994
	1995	[38]	Laboratory USA	x 1597	Ornamentals	Campos *et al.*, 1995
	1998	8	Washington USA	x 5 to 27	Pome fruits	Beers *et al.*, 1998
L. trifolii	1988	-	Michigan USA	None	Celery	Grafius & Hayden, 1988
F. occidentalis	1992	0	California USA	x 8 to 798	Ornamentals	Immaraju *et al.*, 1992
Musca domestica	1991	-	Laboratory USA	>60,000	[Dairy]	Konno & Scott, 1991
Leptinotarsa decemlineata	1992	-	USA	-	Potatoes	Argentine *et al.*, 1992
Plutella Xylostella	1994	[7]	Malaysia	x 220	Brassicas	Iqbal & Wright, 1997
Metaseiulus occidentalis	1989	[20]	Laboratory	x 3.8	Pome fruits	Hoy & Ouyang, 1989

[ ] = number of generations for laboratory experiments
- = unknown

Resistance in natural enemies:

- It is possible for natural enemies, as well as pest species, to develop resistance to abamectin.
- Some workers advocate the creation of resistant natural enemy populations to improve integrated pest management strategies. In laboratory studies, a heterogeneous colony of *Metaseiulus occidentalis* was treated 20 times with increasing concentrations of abamectin (Hoy & Ouyang, 1989). This selection process yielded an increased rate of adult female survival and an increase in the number of eggs produced by surviving females. It was concluded that the availability of an abamectin resistant strain could be of practical value in integrated pest management programmes in deciduous orchards and vineyards.

6.2. Managing resistance

Insects and mites are able to develop resistance to some insecticides relatively quickly through a number of different mechanisms. This is true of abamectin (See Appendix 1). However, resistance often confers other disadvantages and the resistant individuals may not compete well with susceptible members of the population. This means that the population often reverts to susceptible status when the selection pressure of the chemical is removed. Hence, resistance levels may fluctuate depending on chemical usage and this can be used to form a resistance management strategy. Important factors in resistance management are:

Minimise the numbers of applications:

- Do not use the chemical unnecessarily.
- Wherever possible use non-chemical control methods.

Application rates:

- Do not use rates below those recommended on the product label.

Rotation of different active ingredients:

- There are a number of precedents in the literature that demonstrate that the rotation of pesticides with different modes of action can reduce resistance levels (Bruce-Oliver & Grafton-Cardwell, 1997, Flexner *et al.*, 1988).
- Rotation of abamectin with Torq (fenbutatin oxide) for *T. urticae* control will reduce the selection pressure exerted by both chemicals. This will help to prevent resistance developing to abamectin and reduce resistance levels to fenbutatin oxide.
- The principal chemical control measure against *F. occidentalis* on cucumbers in recent years has been dichlorvos but resistance has been reported in UK populations (MacDonald, 1995). Rotation of dichlorvos with abamectin should reduce selection pressure exerted by both products.

Leave untreated areas:

- By treating only part of the crop, a wider genetic base is maintained in the pest population and the untreated individuals are likely to out-compete any resistant individuals.
- Restricting sprays to the parts of the plants that are most affected by the pest will also help to maintain a wider genetic base in the pest population (Sanderson & Zhang, 1995).

7. RECOMMENDATIONS AND SUGGESTIONS FOR THE USE OF DYNAMEC ON PROTECTED TOMATO AND CUCUMBER CROPS

7.1. Summary of existing label recommendations

- Dynamec is approved for the control of spider mites and western flower thrips on cucumbers, and spider mites and leaf miners on tomatoes.
- Dynamec may be applied to seedling tomato and cucumber crops which have not started to flower or set fruit, at any time of year.
- Do not apply to flowering or fruiting crops during the period 1 November until the end of February.
- Dynamec is not approved for use on cherry tomatoes.
- The maximum number of applications is 6 per crop, of which 4 can be made when the flowers or fruit are present.
- Application Timing:
    - **Two-spotted spider mite:** Apply as soon as mites are seen, preferably before leaf damage becomes apparent or 'webbing' has occurred. If required, a repeat application may be made seven days later. It is advisable not to make more than two sequential applications without changing to a product with a different mode of action.
    - ***Liriomyza* leaf miner:** Apply as soon as the first feeding marks or evidence of mines are observed and repeat every 7 days. It is good practice to rotate the use of Dynamec with other suitable insecticides where a persistent problem occurs.
    - **Western flower thrips:** Apply as soon as the first nymphs are seen in the crop. A programme of up to three sprays usually 7 days apart is required to achieve control. Where a persistent problem occurs, Dynamec treatment should be rotated with other insecticides suitable for controlling this pest.

7.2. How to avoid the development of resistance

- Wherever possible use non-chemical control methods.
- Do not use the chemical unnecessarily.
- Do not use rates below those recommended on the product label.
- Rotate Dynamec with Torq for *T. urticae* control to help prevent resistance developing to both products.
- Rotate Dynamec with dichlorvos for *F. occidentalis* control on cucumbers to help prevent resistance developing to both products.
- Do not spray entire crops. Limit treatments by one of the following methods:
    - Restrict treatments to "hot spots" of pest activity.
    - If more general treatments are required, identify the least infested areas and leave these unsprayed.
    - Only spray the parts of the plant that are most heavily infested (*eg.* tops of plants infested with spider mites in mid-summer).

7.3. Possible opportunities to incorporate Dynamec in the IPM programme

The literature review reported in Sections 4 and 5 identified many gaps in the information currently available regarding the effects of abamectin on the natural enemies used in IPM programmes in cucumber and tomato crops. Furthermore, where information is available in the literature, it is sometimes contradictory. Until irrefutable data become available, suggestions and recommendations must be based on the "worst case scenario". This is unfortunate because it means that a potentially useful weapon in the pest control armoury will probably be used to less than its full potential.

Despite the lack of a complete data set, it is possible to suggest the following opportunities to incorporate Dynamec in IPM programmes for cucumber and tomato crops. However, it is impossible to anticipate all the implications to IPM at this stage and each suggestion must be executed with care and the results monitored carefully.

Against *T. urticae* on recently re-planted mid-season cucumber crops:

- Due to the rapid "turn-round" of cucumber crops in mid-season, it can be difficult to prevent the "carry-over" of *T. urticae* from the old to the new crop.
- Abamectin is extremely effective against motile stages of spider mites and it could be used soon after planting to kill invading mites and thereby reduce the pressure on the subsequent biological control programme.
- The main reservation concerning this strategy is the possibility of residues of the product harming biocontrol agents that are subsequently released in the crop. However, this is unlikely to be a problem during mid-season because:
    - The pesticide degrades quickly at this time of year.
    - The plants grow away from the abamectin treatment very quickly.

Against *T. urticae* on cucumbers and tomatoes during cropping:

- There are often occasions when *T. urticae* "out-strip" the predatory mite, *P. persimilis*, during cropping. This most commonly occurs during hot weather when the pests congregate at the tops of plants while the predators prefer the cooler environment in the middle of the crop canopy.
- In most cases, the first response would be to apply the spider mite specific chemical, Torq. However, control may be inadequate if there have been several applications of Torq in recent times.
- Where Torq fails, an application of Dynamec to the tops of the plants may redress the predator-prey balance.
- The main reservation concerning this strategy is the possibility of harming biocontrol agents that are already operating in the crop. This may not be ruled out entirely. However, the risks should be minimal because:
    - The pesticide degrades quickly under such conditions.
    - The principal biocontrol agents used against other pests are active lower down the plant.

Against *F. occidentalis* on cucumbers during cropping

- In most situations, the predatory mite, *Amblyseius cucumeris*, should suppress the development of *F. occidentalis* populations throughout the duration of the cucumber crop. However, there are occasions when the pest "out-strips" the predator and remedial action is required.
- When this happens, action must be taken quickly to contain the pest in localised areas of the crop.
- A series of two or three Dynamec treatments in the "hot spot" will help to contain the problem.
- The main reservation concerning this strategy is the possibility of harming biocontrol agents already operating in the crop. This may not be ruled out entirely. However, the risks should be minimal because:
    - Such problems would usually occur mid-season when the pesticide degrades quickly.
    - Biocontrol agents can be re-released locally soon after treatment.
    - Biocontrol agents can move into the area from surrounding untreated plants.

End of season "clean-up" treatments in cucumber and tomato crops

- Pest numbers sometimes increase towards the end of cucumber and tomato crops because the efficiency of biocontrol agents decreases during the shortening days.
- It is important to prevent the carry-over of these pests to the next crop because this will reduce the pressure on the new IPM programme.
- If *T. urticae* numbers are still large at the end of the season, a single application of Dynamec within a few days of the last harvest should reduce numbers significantly. However, as many areas should be left unsprayed as possible.
- If *Liriomyza* spp. numbers are too large at the end of the season, two applications of Dynamec at a three-week interval just before the end of cropping should reduce mnumbers significantly. Again, leave as many areas unsprayed as possible.
- Co-ordinate clean-up treatments against the various pests to avoid unnecessary repetition.
- The main reservation concerning this strategy is the possibility of harming biocontrol agents that are controlling other pests, resulting in an alternative pest problem. This may not be ruled out entirely. However, the risks can be minimised if the treatments are delayed as late as possible.

7.4. How not to use Dynamec in the IPM programme

- As an entire crop treatment; particularly if the plants are growing slowly in early/ mid-season. Some areas of the crop should always remain untreated.
- Do not use Dynamec at key times of *D. isaea*, *E. formosa* or *A. cucumeris* establishment. This is particularly important early in the year when the chemical could persist on plants for over three weeks.

8. RECOMMENDATIONS FOR FURTHER RESEARCH

The following topics have been identified as high priority for future research:

- **Direct mortality of natural enemies exposed to recommended doses.**
  It is important that indisputable data are produced for the effect of abamectin on the life cycle stages of the natural enemies listed in Section 5.1.

- **Sub-lethal effects of abamectin on natural enemies.**
  This has serious implications for the establishment of natural enemies and must be a high priority for future research.

- **The indirect effects of natural enemies feeding on intoxicated prey.**
  This hazard is not immediately obvious but could have a serious impact on the success of IPM programmes and should be a high priority for future research.

- **Indirect effect of natural enemy starvation due to reduced numbers of prey.**
  This affects the continuity of IPM programmes and should be better understood.

- **The effect of environment on residual activity of abamectin.**
  To make informed decisions about the compatibility of abamectin with natural enemies, the rate of degradation and the residual effect of abamectin should be determined on tomato and cucumber plants during winter, spring and summer conditions.

- **The effect of the use of oils as an adjuvant on beneficials.**
  The effects on beneficial species must be determined before UK growers consider using Codacide oil as an adjuvant with abamectin.

- **Resistance tests.**
  The efficacy of abamectin should be regularly monitored in pest populations on cucumber and tomato crops to aid resistance management strategies.

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APPENDIX 1: ABAMECTIN RESISTANCE MECHANISMS

Although abamectin provided a different mode of action to existing pesticides, some insect and mite populations developed resistance relatively quickly. The resistance has been found to be polygenic and several major mechanisms (e.g. excretion, oxidative xenobiotic metabolism, reduced peneratration) and minor factors (e.g. altered target site, lactone hydrolysis/sequestration, conjugation) have been implicated (Table 3).

Table 3. Mechanisms of resistance to avermectins in *Leptinotarsa decemlineata* (Colorado potato beetle), *Musca domestica* (house fly) and *T. urticae* (two-spotted spider mite) (after Clark *et al.*, 1994).

Resistance	Pest		
Mechanisms	CPB	HF	TSSM
Penetration	-	++	+
Excretion	+	-	++
Oxidative metabolism	++	+	+
Lactone hydrolysis/ sequestration	+	-	-
Altered target site	NA	++	+
Conjugation	-	-	+

\- indicates absence of mechanism
\+ indicates possible presence of mechansim
++ indicates presence of mechanism
NA indicates mechanism has not been assessed.
Abbreviations:
CPB, Colorado potato beetle; HF, house fly; TSSM, two-spotted spider mite.

Cross-resistance:
Cross-resistance to abamectin was found in two pyrethroid-resistant strains of *M. domestica* (Scott, 1989). One strain was one laboratory selected and the other field collected (Dairy, from New York State) and they had 25 and 5.9 times cross-resistance respectively. Cross-resistance in the laboratory strain was found to be polygenic. Based on genetic and toxicological data, the mechanisms associated with the pyrethroid-induced cross-resistance to abamectin appear to be due to increased oxidative metabolism and decreased cuticular penetration. Cross-resistance has also been identified in a field strain of *Plutella xylostella* (diamondback moth) (Abro *et al.*, 1988) and a multi-resistant strain of *Blatella germanica* (german cockroach). No cross-resistance has been observed between abamectin and acylurea insecticides (e.g. teflubenzuron) (Ismail & Wright, 1991) or dicofol resistant *T. urticae* (Kim *et al.*, 1995).

Genetic base of resistance to abamectin:
Abamectin is recessive in *M. domestica* and incompletely recessive in *L. decemlineata* but this recessive character is readily selected for in the laboratory and the field because of the multiple resistance mechanisms involved. This suggests that abamectin should be used in moderation. As multiple-resistance mechanisms exist in each of the insect species examined, the likelihood of reduced fitness being associated with resistance is likely to be increased (Clark *et al.*, 1994). The implications of this are that, although resistance develops quickly, resistance levels may decline again once the selection pressure of exposure to the chemical is removed.