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The results and conclusions in this report are based on a survey of commercial growers. The results of the survey have been reported with detail and accuracy. However, 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 interpretation of the results especially if they are used as the basis for commercial product recommendations.

CONTENTS

PRACTICAL SECTION FOR GROWERS

BACKGROUND AND OBJECTIVES

This project was prompted by the apparent increase in mealybug incidence and damage to protected tomato crops in the UK. Despite the pests' long life cycle and slow dispersal rate, mealybugs appeared to be spreading to previously uninfested nurseries and to larger areas within infested nurseries. Further information was required on the reasons for this increase and on the identification and behaviour of the species concerned so that control actions could be properly targeted. Growers had tried different chemical, physical and biological control methods but with varying success. Improved control recommendations were required.

The commercial objective of this project was to determine the pest status of mealybug on protected tomato crops in the UK, to provide growers with information on the efficacy of current control techniques and advice on improving that control. The specific objectives for the first year were to:

1. Determine the pest status of mealybug on protected tomato crops in the UK.
2. Review the efficacy of current control methods available to growers.
3. Identify the location of egg masses between crops.
4. Produce a fact sheet based on the results.

SUMMARY OF RESULTS

Pest status of mealybug on UK protected tomato crops

Mealybug is a sporadic pest on UK protected tomato crops. In the 1998 season, at least thirteen tomato nurseries from different parts of England were infested with mealybugs. Mealybugs infested approximately 20 hectares (ha), which is 7% of the total UK tomato growing area. All specimens collected from these crops were identified as the obscure mealybug, *Pseudococcus viburni*. Mealybug incidence has increased on UK tomato crops in recent years with 70% of infestations occurring for the first time in the last decade. It is not known whether the increase on protected tomato crops is due to reduced chemical use, which has given mealybugs a better chance of establishment, or to a general increase in numbers outside tomato nurseries.

Pseudococcus viburni caused a range of damage symptoms. All infested nurseries reported damaged stems and sticky honeydew. Half the infested nurseries had dead plants and yield loss. Mealybug damage was also thought to increase the incidence of grey mould (*Botrytis cinerea*). Crop losses could be severe, one nursery lost nearly 50,000 plants in July and August, another estimated yield losses of £15,000. The cost of controlling *P. viburni* averaged £3,100 / ha / season, of which 75% were labour costs.

The spread of mealybugs between and within glasshouses

Mealybugs were usually transported by people onto new nurseries, either on infested plants (typically ornamental 'house plants') or on equipment. They may also travel short distances unaided between infested glasshouses. Spread within infested nurseries was also aided by people. The most rapid spread was observed in two nurseries where irrigation lines and packing boxes were moved from mealybug infested areas to new areas without being sterilising in between. The waxy filaments make egg masses and mealybugs sticky and they are spread down crop rows attached to crop workers or animals. Ants feed on mealybug honeydew and are known to move mealybugs to new plant hosts. Wagtails were thought to be spreading the pest at one site.

Timing and location of infestations

To time control treatments, growers needed to know when *P. viburni* first appeared in new crops and where they were located. Crop monitoring confirmed that most individuals survived between crops as eggs. These were located in a variety of hidden areas but were most frequent in the concrete bases of roof supports and on irrigation drippers. They were also found inside slabs, on packing crates, on strings, in dried up plant debris, in cracks in the soil, on / in hollow metal posts and along the concrete roadways. These are the areas that need most attention during the clean-up process. At the start of the season *P. viburni* eggs hatched in response to raised temperatures and continued to breed throughout the season.

The success of different control methods used against *P. viburni*.

A wide variety of control methods are available and an integrated control programme using a combination of different methods has been the most successful.

Hygiene and quarantine are important to limit the spread of *P. viburni* within or between glasshouses. Growers are advised not to bring ornamental 'house' plants on to tomato nurseries and to restrict movement of plant material or equipment from infested areas unless they are sterilised first. Crop workers should visit infested areas at the end of the day if possible and use protective clothing.

Chemical control can be difficult because mealybugs are covered with a water-repellent waxy covering and live in hidden areas. Several chemicals were effective against the active mealybug stages including Applaud (buprofezin), Decis (deltamethrin) and Malathion 60 (malathion). Applaud is recommended as it is very effective and the least damaging to biological control. As none of the chemicals were effective against eggs, two to three applications where permitted, are required at 14-day intervals to achieve control. End of season treatments are recommended. Growers should aim to kill all the active stages at least two weeks before the crop is pulled out to minimise survival of eggs to the next crop. If mealybugs reappear in the new crop two treatments of Applaud are recommended against the first generation of nymphs. Repeated use of Applaud through the season is not recommended as it may lead to the development of pesticide resistance or disrupt whitefly control by depriving *Encarsia formosa* of prey. Decis and Malathion 60 were as effective as Applaud but were not compatible with biological control programmes and their use may result in a whitefly resurgence the following season. They are only recommended as end of season treatments for outbreaks that are restricted to small areas.

Physical control methods included rubbing the mealybugs off by hand, burning with a propane burner or spraying with oils and soaps. These were found to be less effective than chemicals but were sufficient to maintain low numbers of *P. viburni* and prevent crop damage. None had fumigant or residual effects, so control relied on achieving direct contact with the insects and repeated treatments were therefore required. Physical methods could be used throughout the summer months with minimal disruption to biological control programmes. Rubbing off by hand was the most effective and cleanest option as workers were able to separate the stems and remove mealybugs from hidden areas that were hard to hit with a spray or flame. The level of control achieved varied according to the time available to workers and their attention to detail. The main problem with these methods was that they were labour intensive and therefore expensive.

Between crops none of the available treatments were successful in killing all the eggs. Effort should be made to remove as many mealybugs as possible within the crop at the end of the season. Once all crop debris had been removed it was possible to reduce the number of nymphs emerging onto the new crop by painting dollies in affected areas with a thick paint, by wrapping the dollies in sticky traps / glues or by sealing polythene over the top of the concrete dollies. Where all the joints between plastic sheeting were sealed with tape or glue fewer nymphs emerged. This method was labour intensive but effective.

Biological control agents have not been successful against *P. viburni* on protected tomato crops for a number of different reasons. Further evaluation is required before biological control can be recommended.

Eradication of *P. viburni* from nurseries

Four growers have been successful in eradicating *P. viburni* from their nurseries, although *P. viburni* infestations were restricted to a few plants in all but one of these cases. Eradication was achieved by the combined use of chemical treatments (Applaud or Decis) at the end of the season together with a strict hygiene programme during the clean-up period between crops and the use of glues and traps to prevent emergence of nymphs the following season.

Eradication may not be possible in nurseries that have a continuous invasion pressure from a nearby nursery, in organic nurseries or in nurseries that have a pesticide free policy. Further research is required to identify integrated pest control strategies for these nurseries.

ACTION POINTS FOR GROWERS

<u>For growers without mealybugs:</u>

- Inspect all incoming plant material to ensure that it is clear of pests.
- Ensure that no infested equipment is brought in from other nurseries.
- Avoid bringing ornamental species (e.g. house plants) onto tomato nurseries.

<u>For growers with mealybugs:</u>

At the end of the season

- Spray infested plants with two high volume sprays of Applaud (30ml/100l) at 14-day intervals. Control all active stages at least two weeks before the crop is removed.
- If the infestation is limited to very small areas, Decis and Malathion 60 may be used as an alternative but they may disrupt biological control for up to three months.
- Include the structural areas, where mealybugs collect, in your spray programme (e.g. concrete dollies and irrigation tubes).
- De-leaf before treatment to improve penetration.
- Remove the crop and crop debris extremely carefully making sure you pick up and destroy any small pieces of infested leaves or stems.
- Remove and destroy or treat infested ornamental plants.

Between crops

- Replace irrigation lines and drippers from infested areas.
- Steam sterilise or replace rockwool/ stonewool slabs.
- High pressure wash all structures.
- Paint concrete dollies in a thick paint, glue or wrap them in sticky traps.
- Replace plastic. Seal all the gaps between sheets with glue. Draw plastic sheets over the top of the concrete dollies, concrete paths and pipe rail posts and seal with glue.
- Maintain good weed control.
- Inspect all plant material for mealybugs before introducing it into the greenhouse.

In the new crop

- Monitor weekly for mealybugs by visual inspection. Concentrate on areas where the mealybug was found in the previous season and on the plants beside posts.
- At the first sign of mealybugs, spray Applaud at 30 ml/ 100l water on the infested areas. Repeat after 14 days. Do not apply more than 2 sprays within a 65 day period.
- If a few plants are heavily infested they should be removed and destroyed

During the season

- Ensure that no infested plant material (e.g. from deleafing) or equipment (e.g. packing crates) is moved to other areas.
- Crop workers should visit infested areas at the end of the day and wear protective clothing that remains in that area.
- Control ants as they move mealybugs to new areas and guard them from natural enemies.

- Prevent mealybug numbers from increasing during the season and prevent crop damage by rubbing off mealybug colonies by hand every seven to 14 days. Alternatively use flaming or spray with soaps and oils.

RECOMMENDATIONS FOR FURTHER RESEARCH WORK

Following a review meeting in February 2000, the following research areas were agreed:

1. Evaluate the following biological control measures as potential control agents of *P. viburni* in protected tomato crops:

    a) *Hypoaspis* sp.
    b) *Beauvaria bassiana*
    c) *Verticillium lecanii*
    d) *Leptomastix epona* – subject to further evidence of efficacy and /or support from a biological control company.

2. Identify a product that can be used to control mealybug eggs in concrete dollies, irrigation lines and elsewhere.

3. Screen Chess (pymetrozine) as a possible chemical control measure for the active stages of mealybug.

4. Evaluate a pheromone trap for catching male mealybugs.

PRACTICAL AND FINANCIAL BENEFITS FROM THE STUDY

Immediate benefits:

1. Improved control of mealybugs in protected tomato crops.

2. Prevention of direct damage and financial losses caused by this pest.

3. Reduced labour costs.

Future benefits:

1. Minimising chemical use following development of non-chemical methods.

2. Reducing disruption to biological control agents and crop pollination due to chemical use.

3. Satisfying demands of the UK's food retailers for reduced pesticide use and thereby improving competitiveness.

4. Improved control of mealybugs in protected ornamental crops.

SCIENCE SECTION

1. INTRODUCTION

Mealybugs are soft-bodied insects with sucking mouthparts in the Homopteran family (the same family as aphids, whiteflies and scale insects). Females are covered in white waxy filaments, which gives them a 'mealy' appearance. World-wide they are one of the most significant pest groups, with over 3000 species feeding on a range of plant families in habitats as varied as underground roots to tree tops. Mealybugs thrive in the warm, humid tropics. In the UK, they are most common on protected crops.

This project was prompted by the apparent increase in mealybug incidence and damage to protected tomato crops in the UK. This increase was also observed in the Netherlands and France (Schoen and Martin, 1999). Further information was required why mealybugs had increased and on the identification and behaviour of the species concerned so that control actions could be properly targeted. Growers had tried different chemical, physical and biological control methods with varying success. Improved control recommendations were required.

The commercial objective of this project was to determine the pest status of mealybug on protected tomato crops in the UK, to provide growers with information on the efficacy of current control techniques and advice on improving that control. The specific objectives for the first year were to:

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2. SPECIES IDENTIFICATION AND BIOLOGY

Objective

To identify which species of mealybug is attacking UK tomato crops and find out what is known about its biology.

Methods

Six growers provided mealybug samples from their tomato nurseries. These were sent to Dr Chris Hodgson (University of Wye) for confirmed identification (Key: Miller *et al.*, 1984). Specimens from three other nurseries had been identified previously. It was not possible to get samples from the remaining four nurseries as they had successfully controlled their mealybug populations at the time of the survey. Once the species had been confirmed, a literature search was carried out on its biology and photographs were taken of the different stages (Appendix 1).

Results and discussion

All mealybug specimens collected from UK protected tomato crops were identified as *Pseudococcus viburni* (Signoret) (Homoptera, Coccoidea, Pseudococcidae).

Synonyms: *Pseudococcus affinis* (Maskell), *Pseudococcus latipes* (Green), *Pseudococcus obscurus* (Essig).

Common names: Obscure mealybug, vine mealybug or glasshouse mealybug.

Description: Females are 4 mm long, wingless, sucking insects with oval shaped, pink bodies. They are covered in white waxy filaments with approximately 17 pairs of short filaments surrounding the body and one pair of tail filaments that are half as long as the body. (For a full taxonomic description see Miller *et al.*, 1984). Males are delicate insects, less than 1mm long, with long tails and two pairs of wings. They do not feed and have no mouthparts.

Host plants: *Pseudococcus viburni* attacks a range of plant species from 46 different families. Host plants include *Abutilon*, *Amarylis*, *Azalea*, *Cactus*, *Eucalyptus*, *Ficus*, *Fuchsia*, *Geranium*, *Lycoperisicum*, *Nevium*, *Nicotiana*, *Passiflora* and *Pelargonium*.

Biology and life cycle: *Pseudococcus viburni* is the most common mealybug species in Britain (Williams, 1985). The life cycle consists of an egg, three immature nymphal stages and an adult stage. Females lay 100 - 500 yellow eggs, which are 0.3 mm long and protected inside a cotton-like pouch made of wax filaments. The eggs are often laid in protected areas such as depressions or between stems. Once the female has mated and laid her eggs she shrivels and dies. Unfertilised females do not lay eggs and can survive for up to 8 months. The female nymphal stages appear very similar. The first instars are small and pink (< 2 mm) and each instar gets increasingly larger, slower moving and with more waxy filaments. Once female nymphs find a suitable host plant they tend to stay there for the rest of their lives. In males, the third nymphal stage takes place inside a white cocoon (Panis, 1969). Adult males are very active, they have a short lifespan and die soon after mating.

Development time is relatively long but temperature dependent with the life cycle taking 56 days at 20°C and 37 days at 30°C (Islam *et al.*, 1995). *Pseudococcus viburni* is slightly more cold tolerant than other mealybug species (Copland *et al.*, 1969) and can survive most temperatures that commonly occur in UK greenhouses. The lower threshold for development is 11.4°C but all stages can survive up to 19 days at 0°C (Hoy and Whiting, 1997). In the UK, most stages can survive in glasshouses during the short period between tomato crops and under favourable conditions. *Pseudococcus viburni* can over-winter at in stage but most commonly as third or fourth instars (Heidari, 1989). This species does not have a winter diapause and crop monitoring demonstrated that during winter, eggs hatch in response to raised glasshouse temperatures (see pg. 13). *Pseudococcus viburni* breeds continuously throughout the year in protected tomato crops.

3. GROWER SURVEY

Objectives

To determine the pest status of mealybug in UK protected tomato crops and the efficacy of different control measures.

Methods

A survey form was designed (Appendix 2) and sent to 260 UK tomato growers in early 1999.

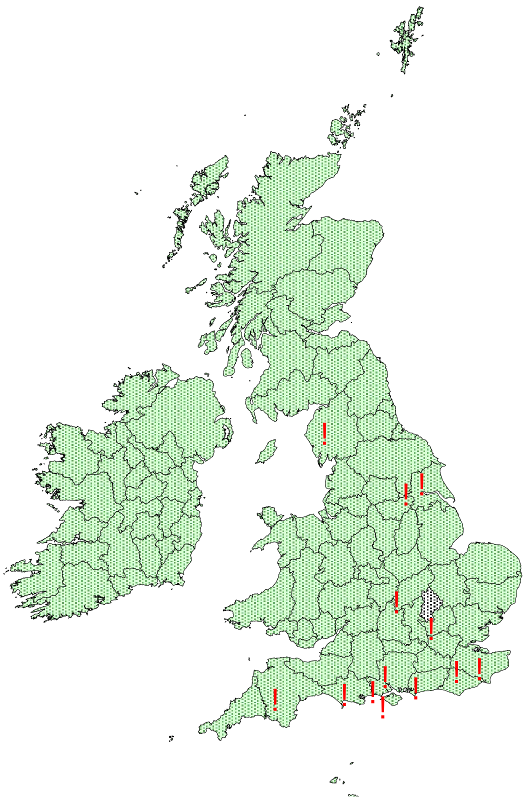
Results and discussion

One hundred and one growers responded to the survey (39%). Of these, thirteen (13%) had seen mealybugs in their tomato crops. Six of the respondents no longer grew tomatoes. The following summarises the results of the survey.

3.1 *Pseudococcus viburni* occurrence

Thirteen (13%) of responding tomato nurseries had seen mealybugs in their crops. The infested areas within those nurseries totalled approximately 20 ha (7% of the total UK tomato growing area). Mealybug infestations were sporadic throughout the tomato growing regions of England but none were reported in Scotland (Figure 1).

Figure 1: Mealybug infested tomato nurseries in the UK



3.2 History of *P. viburni* attack on infested nurseries

Table 1 summarises when mealybugs were first found on tomato nurseries in the UK. Most new infestations appeared in the last decade. Incidence has also increased in mainland Europe. *Pseudococcus viburni* was first recorded on Dutch tomatoes in 1990 and on French tomatoes in 1997 (Schoen and Martin, 1999). As growers have not reported increased incidence in other crops, it is possible that the increase in protected tomato crops is a result of reduced chemical use. This has given mealybugs a better chance of survival and establishment once introduced to the nursery.

Table 1: The years when growers with *P. viburni* first recorded the pest on their nurseries.

Years	**Before 1980**	**1981 -1990**	**1991-2000**
Number of nurseries	1	3	9
Percentage of infested nurseries	8 %	23 %	69 %

3.3 Sources of *P. viburni* infestations and spread within glasshouses

People transported mealybugs onto nurseries, either on plants or equipment, in all but one of the known cases (Table 2). At five nurseries, *P. viburni* was brought in on ornamental plants (house plants or for commercial production). Plant species included *Ficus benjamina*, geraniums and fuchsias. At another nursery *P. viburni* came in on packing crates from a shared packhouse. One site was immediately adjacent (<10m) to a heavily infested tropical garden centre. Wagtails were seen feeding on mealybugs in the garden centre and nesting in the tomato nursery. It is likely that the wagtails were spreading the mealybugs which appeared in new areas each season.

Table 2: The sources of *P. viburni* infestations cited by growers.

Source	**Ornamental plants**	**Packing crates**	**Invasion**	**Unknown**
Number of nurseries	5	1	1	6
Percentage of infested nurseries	38 %	8 %	8 %	46 %

The wax filaments surrounding egg masses are very sticky and eggs have been found attached to peoples clothes, animals and equipment. Within glasshouses, mealybugs may be moved down crop rows by workers or on trollies and packing crates. Ants may also be responsible for local movements because they pick up mealybugs and carry them to fresh feeding sites (Uichanco & Villanueva, 1932; Bushinger *et al.*, 1987). Two examples were given where *P. viburni* spread rapidly through glasshouses. One grower removed irrigation lines from an infested area and replaced them in different areas the following season without sterilising them first. As a result, *P. viburni* spread from eight rows in one glasshouse to throughout four glasshouses over the course of two seasons. At another site *P. viburni* was moved around a glasshouse on packing boxes. Packing boxes used to collect fruit from an infested area were emptied and reused in different areas without being sterilised first. Several growers have succeeded in limiting *P. viburni* infestations to small areas by careful monitoring, early control action and strict hygiene.

3.4 Damage symptoms

The type and extent of mealybug damage reported by growers on infested nurseries is shown in Table 3. All nurseries reported stem damage but it only caused plant death and sticky honeydew in about half of the infested nurseries. Severe damage was usually restricted to discrete areas. One grower observed increased incidence of *Botrytis cinerea* in mealybug infested plants.

Table 3: The numbers (percentages) of infested nurseries out of a total of 13, showing different damage symptoms.

Damage symptoms	**Number (and %) of infested nurseries affected**	**Area of crop showing damage (% nurseries)**		
		A few plants	**Large areas**	**Whole crop**
Damaged stems	13 (100%)	6 (46 %)	6 (46 %)	1 (8 %)
Honeydew	7 (54%)	4 (31 %)	3 (23 %)	0
Dead plants	6 (46%)	4 (31 %)	2 (15 %)	0

3.5 Crop losses caused by *P. viburni*

In the 1998 season, five nurseries reported crop losses due to *P. viburni*. Most of the crop losses were the result of plants dying from severe stem damage. Different nurseries reported the losses as follows:

- Two nurseries reported less than ten dead plants during the season.
- At one nursery, 9,500 plants died in July and 40,000 plants died in August.
- Yield losses at two other nurseries were estimated as 3,600 lb. reduction in fruit yield and £15 ,000 yield losses respectively.
- One grower reported indirect damage resulting from increased incidence of *Botrytis cinerea*, but this was not quantified.

3.6 <u>Control measures used against *P. viburni* and their relative success</u>

The different methods of control used and their relative success reported by growers are summarised in Table 4. These are discussed in more detail in section 5 (Pg. 15).

Table 4: Relative success of different control methods reported by the 13 nurseries.

Control method	**Number of nurseries using method**	**Number of growers reporting different success ratings**			
		good	**moderate**	**Poor**	**unknown**
Chemical control: Plant treatments					
Applaud*	7	4	2	1	
Decis*	8	4		3	1
Hostaquick	1			1	
Malathion 60*	3	3			
Physical controls					
Glues*	9	5	1	1	2
Oils	7	1	5	1	
Propane Burner	6	2	2	1	1
Rubbing off *	7	4	2	1	
Soaps	7	1	2	4	
Structural washes					
Chlorine	3			3	
Cuprokylt	1				1
Jet 5	1				1
Sistan/formaldehyde	2			2	
Biological controls					
Chrysoperla spp.	2			2	
Cryptolaemus sp.	4			4	
Hypoaspis spp.	6	1		4	1
Leptomastix spp.	6			6	
Pseudaphycus sp.	1			1	
(*Verticilium lecanii*) Mycotal	2		1		1

* = most effective treatments

3.7 Cost of *P. viburni* control measures

The total mealybug control costs at nine infested nurseries was estimated as £56,760 for the 1998 season (average of £3,100 per ha). Of this, at least £43,000 were labour costs (75%). Labour costs were incurred by staff rubbing off, flaming or spraying stems through the summer months, on a weekly or fortnightly basis.

3.8 Eradication

Four growers successfully eradicated *P. viburni* from their nurseries. Three of these only had small numbers of mealybugs in limited areas. Eradication was achieved by concerted action at the end of the season and during the clean-up period between crops. Where integrated methods were used, it was not possible to separate the control effect of each method.

Nursery 1 – Mealybugs spread to 8500 m² over a three-year period before eradication was achieved by use of an intensive control programme. The cost was estimated as £2500 per ha, including 130 hours of labour. The following actions were taken with close attention to detail:

- The old crop was carefully folded into the floor plastic and removed.
- The structure was pressure washed with water.
- The structure, walls and floor were pressure washed with formaldehyde.
- The floor was sprayed with Decis (deltamethrin) and Cuprokylt (opper oxychloride) (300ml and 680ml/500 gals water respectively), then covered with plastic as soon as it was dry.
- Trappit glue was used to seal all the polythene joints including the wall and path joints. Post and structure joints were then sealed with electrical tape.
- Pipe supports were covered in polythene tubes sealed with electrical tape.
- Applaud (buprofezin) was applied to plants twice at 30 ml /100l water in December at a ten day interval.
- *Hypoaspis miles* was released at 40 / m² in weeks 1, 15 and 30.

Nursery 2 – *Pseudococcus viburni* was restricted to an area of less than 20 plants for seven years. During the season, good control was maintained by rubbing the mealybugs off by hand and spraying Savona (fatty acids) on affected stems on a regular basis. The predator *Cryptolaemus montrouzieri* was released but not recovered. Eradication was achieved by a rigorous clean-up and hygiene programme at the end of the season. Decis (deltamethrin) was sprayed on the plants before they were pulled out. The entire superstructure was power washed with Jet 5 (peroxy acetic acid) and irrigation lines from the affected area were removed and destroyed. Thripstick (deltamethrin) was used to seal up all the joints in the floor plastic around the affected area in preparation for the following season.

Nursery 3 – The infestation was restricted to a few plants for less than one season. Control action was taken as soon as the pest was observed. Affected plants were sprayed three times with Decis (delamethrin) at two-week intervals.

Nursery 4 – A few plants were infested and mealybugs were eradicated using Decis (delamethrin) and Ambush C at the end of the season.

4. CROP MONITORING

Objectives

i) To determine when *P. viburni* become active in greenhouses and how numbers build up during the season.

ii) To determine the distribution of *P. viburni* egg masses on tomato plants and greenhouse structures.

Methods

Six infested tomato nurseries were visited. The nurseries were spread throughout England from North Yorkshire to Somerset and the Isle of Wight. At each nursery the history of *P. viburni* infestation and success of various control methods used were discussed in detail. Infested areas were examined and the location of egg masses identified.

To gain further information on the population development of *P. viburni*, four growers looked for the first occurrence of *P. viburni* in new crops and monitored ten marked plants periodically through the season (see recording sheet in Appendix 3).

Results and discussion

i) The occurrence of *P. viburni* in newly planted crops and population build up

Pseudococcus viburni were observed on plants 12 to 29 days after the glasshouses were warmed up at the start of the season. All the first sightings were young nymphs. These would have hatched from eggs that had survived the clean up process. This indicates that eggs hatch in response to raised glasshouse temperatures and that there is no winter diapause.

Where no control measures were taken, *P. viburni* numbers increased steadily through the season, peaking in late October. All the growers who made detailed counts of *P. viburni* numbers carried out rigorous control programmes. These data could not, therefore, be used to show population development through the season but were included in the section on different control methods where relevant (Section 5, Pg. 15).

ii) Location of egg masses

The distribution of *P. viburni* egg masses varied according to the greenhouse structure and population size.

On plants, where *P. viburni* numbers were low, egg masses were confined to the mainstem, usually below the bottom truss. As numbers increased and there was more competition for space, mealybugs and their egg masses were found higher up the plants with a few individuals at wire height. The egg masses were most frequent in cryptic habitats such as between tomato stems, on the undersides of layered stems, at stem internodes and along the veins on the undersides of leaves.

On greenhouse structures, egg masses were observed in a number of habitats. These are listed below in order of prevalence:

- In small depressions in concrete bases of the roof supports (dollies).
- On irrigation dippers and irrigation pipes.
- On rockwool / stonewool blocks, inside the plastic covering.
- On packing / picking crates.
- On / in the strings.
- Amongst dried up plant debris.
- Inside the metal posts that hold the pipe rail system.
- Under loose soil (one cm deep), especially around the concrete dollies.
- On / in smooth metal posts (to at least two m height).
- In concrete walls and along the edge of the concrete roadways.

In sites with concrete dollies, the first *P. viburni* were found on the plants immediately beside the posts in gutter rows. At some sites several hundred nymphs emerged within a few days. Nymphs were also found on top of the plant cubes around the irrigation drippers.

5. EFFICACY OF CURRENT CONTROL METHODS

Objectives

To collate published and unpublished information on the efficacy of the different control methods used against *P. viburni.*

Methods

A literature search was carried out and growers, consultants and biological control suppliers, who had experience of *P. viburni* control, were asked to discuss the efficacy of various control methods used.

Results and discussion

The results below are largely based on grower experience without the use of untreated controls. Care must be taken with the interpretation of the results, especially if they are used as the basis for commercial product recommendations.

<u>Chemical control methods</u>

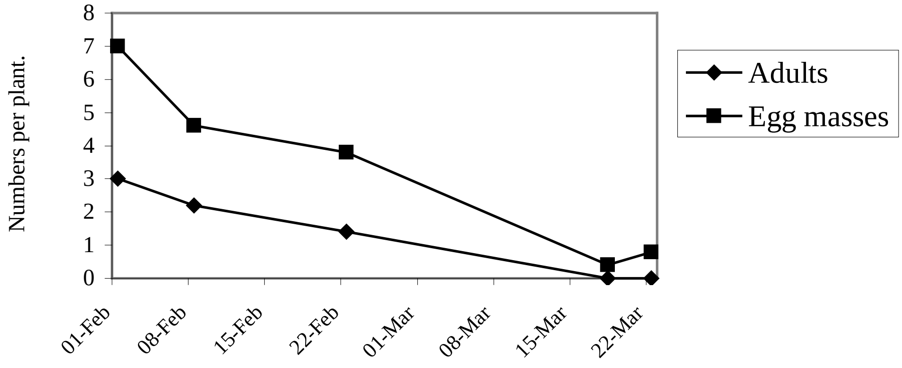
Chemical treatments of plants:

A number of approved products were extremely effective against the active stages of *P. viburni* where there was good contact with the insects. High volume sprays were required to penetrate the areas where *P. viburni* live. However, none of the treatments were totally effective against eggs. This was because the eggs were hidden in crevices and protected by hydrophobic waxy filaments. The use of oils and soaps in combination with chemicals was thought to improve penetration and control.

5.1 <u>Applaud</u> (buprofezin): A thiadiazine moulting (chitin) inhibitor, that has contact, residual and some vapour activity.

Ninety-five percent control of the citrus mealybug, *Planococcus citri* Risso, was achieved with a single application of Applaud applied at 75 parts per million (p.p.m.) (30 ml product/ 100l water). Control did not increase significantly (97%) when the rate was doubled to 150 p.p.m.. No phytotoxicity was observed at either of these rates. (Bedford *et al.*, 1996). Similar levels of control have been observed with *P. viburni* on tomatoes. Four growers who made two applications of Applaud at a 14 day interval during December or January reported between 80% and 100% reduction in numbers for 10 weeks. Figure 2 shows the average number of *P. viburni* adults and egg masses following two treatments of Applaud (30ml per 100 litres) in weeks one and three at on of the commercial sites (n=10 plants). There was no untreated control. By the end of March all the mealybugs in the monitored area appeared to be dead although live mealybugs were found in other areas on 21st April.

Figure 2. Mean numbers of *P. viburni* adults and egg masses per plant following two applications of Applaud.



Young nymphal stages were most susceptible to Applaud. Adults may not be killed, although egg production is reduced significantly (Tucker [Zeneca], pers. comm.). Where Applaud was soaked into the concrete dollies that contained egg masses, it failed to prevent emergence of nymphs the following season. As there was some survival from a single application, two treatments were required at 14-day intervals for complete control. As the insects only die when they change stage, numbers decline gradually after treatment and control is usually observed about 21 days from the first application.

The rate of 30 ml product per 100 litres of water, approved for whitefly control, is sufficient to control *P. viburni*. Higher rates do not improve control significantly. It is reported that Dutch growers have been using, illegally, five times the recommended rate (van Aalst, pers. comm.). It is possible that Dutch populations have developed resistance to Applaud although this has not been tested.

Applaud is quite persistent on plant surfaces but has no translaminar activity so it is essential to get good cover. Good fumigant activity and control has been recorded over the winter period when the vents are closed. However, there is less control in the summer when the chemical may evaporate before it has achieved control (Helyer, pers. comm.). The most effective treatments were found to be as an end of season clean up programme and against the first generation of nymphs in the new crop.

Despite the excellent control using Applaud, none of the growers achieved eradication of *P. viburni* in the 1998 season. A maximum of eight Applaud treatments per crop is permitted. One grower applied two sprays of Applaud at 14-day intervals four times approximately every 65 days, starting 5th January, 30th March, 4th June and 9th August but mealybugs were still active at the end of the season.

5.2 Decis (deltamethrin): A broad-spectrum, contact and stomach acting pyrethroid insecticide with residual activity.

Four growers reported good control of *P. viburni* by spraying Decis onto plants but there was no monitoring data to confirm this. Reduced control resulted when growers were unable to penetrate the haulm effectively. Three applications of Decis applied at 14-day intervals have been used to eradicate small areas of *P. viburni*. Use should be restricted to pest hot-spot areas if possible. Widespread use at the end of the season may disrupt biological control in the following season and Decis cannot be recommended during the growing season. Mixing Decis with oil was thought to improve control but may also increase the residual effect.

Decis was considered less effective on greenhouse structures. No control effect was observed when it was used as a floor treatment between cropping. When Decis was soaked into the concrete dollies at three times the recommended rate, it failed to prevent emergence of nymphs the following season.

5.3 Malathion 60 (malathion): A broad spectrum contact organophosphorous insecticide.

Malathion 60 killed 100% of *P. citri* nymphs, 83% of adults and 4% of eggs in Potters tower experiments (Hwang *et al.*, 1986). Three growers reported excellent (up to 100%) control of all active stages of *P. viburni* but there was some re-infestation from eggs. Treatment of the concrete dollies also failed to kill the egg masses. Two to three treatments at 14-day intervals are required to achieve eradication.

Although effective, Malathion 60 was found to be very disruptive to the establishment of natural enemies for the control of other species. Extensive use during the clean-up period disrupted biological control for nearly three months after planting. Whitefly control by *Encarsia formosa* and leaf miner control by *Diglyphus isaea* were most affected. At one site the pest control costs (increased numbers of natural enemies as well as remedial treatments) from early December to the end of March were £3140 / ha in the glasshouses treated with Malathion 60 as compared to £493 / ha in other glasshouses. At another site, use of Malathion 60 in mid September disrupted pollination and one pick of tomatoes had to be dumped because of the four-day harvest interval. A single treatment at the beginning of October caused a resurgence of whiteflies in mid-November. Growers who used Malathion 60 could not supply tomatoes to Tesco under the Natures Choice Label. Mixing Malathion 60 with Codacide oil improved the penetration and efficacy but was also thought to increase the residual effect against natural enemies.

5.4 Other chemical treatments

Growers also tried Hostaquick (heptenophos) and Ethanol spray treatments experimentally in crops. Both treatments resulted in poor control of *P. viburni*.

Neem treatments were found to kill first instar cassava mealybugs, *Phenacoccus manihoti* (Mournier, 1997). **Neem is not currently approved for use on UK tomato crops.**

Chemical treatment of the soil and glasshouse structures between cropping:

There is an opportunity to eradicate *P. viburni* between crops, as they are slow moving and there is little re-invasion pressure. However, the following chemicals were used experimentally by growers with little success. This may be because they have failed to hit the target. Control was only achieved when infested equipment was completely immersed.

5.5 Actellic 2% Dust (pirimiphos-methyl**)**: A contact, fumigant, translaminar organophosphorous insecticide.

Hwang *et al.* (1986) reported 98% to 100% reduction of *P. citri* nymphs, 95% reduction of adults but only 2% reduction of eggs using Actellic in a Potters tower experiment. **Actellic 2% Dust is not approved for use on protected tomato crops in the UK.**

5.6 Ambush C (cypermethrin): A broad-spectrum, contact and stomach acting pyrethroid insecticide.

Four growers used Ambush C to treat floors and structures but no pest control effect was observed.

Ambush C (cypermethrin) has been withdrawn as a registered pesticide for use in the UK

5.7 Fumite Lindane pellets (gamma HCH): A contact acting organochlorine insecticide.

Two growers used gamma HCH as a floor treatment between cropping but no pest control effect was observed.

5.8 Talstar (bifenthrin): A contact and residual pyrethroid acaricide / insecticide.

Some growers used Talstar experimentally but the pest control effect was not quantified. **Talstar is not approved for use on protected tomato crops in the UK.**

5.9 Nitric acid: A dessicant.

When irrigation pegs were dipped in Nitric acid (60%), all stages of mealybug were killed. Treatment of posts with acid did not kill *P. viburni* as the acid ran off without penetrating the wax.

5.10 Chlorine: A dessicant.

A 1% solution of chlorine was used to flush out irrigation tubes but this failed to kill mealybugs. Treatment of posts with chlorine also had no pest control effect.

Physical control methods

A number of physical treatments were used successfully to maintain low numbers of *P. viburni* and to prevent crop damage. Repeated treatments were required every seven to 14 days in order to achieve this. The advantage of these methods was that they could be used throughout the summer months without disrupting biological control. The disadvantage was that they were very labour intensive and therefore expensive.

5.11 Glues (Thripstick, Superstick, Master traps, Oeco stick, Hyvor 80, Silicone Mastic)

A number of growers found that the use of glues of various types contributed significantly to the control or eradication of *P. viburni*. Where master traps or glues were used to surround concrete dollies, further emergence of *P. viburni* was prevented. Glues were also used to seal the joints between plastic sheets and onto concrete roads as well as over the pipe rails and dollies. Where all the gaps were sealed there was reduced emergence of *P. viburni*.

5.12 Oils (Hortichem Spraying Oil, White oil, Codacide)

Growers used oils in two ways. Oils have been used directly as a pesticide against all stages of *P. viburni*. Where there was a direct hit, good control was achieved, as mealybugs are not very mobile. However, the insects need to be completely covered as the action is by suffocation and there is no fumigant or residual effect. A single treatment did not achieve control as many individuals were hidden or protected and repeated treatments were required. Weekly applications during the summer months achieved moderate levels of control and were sufficient to prevent crop damage.

One problem cited by growers was that oils made the floor sticky and slippery which was unsafe for workers. Phytotoxicity could occur if leaves were treated when plants were under water stress. Oils can kill slow moving natural enemies but when used at the base of plants cause little disruption to established biological control programmes on the leaves above.

Oils were also used as an adjuvant to improve the efficacy of insecticide treatments. It is possible that they help to penetrate the waxy coat. However, when mixed with broad-spectrum insecticides they increase the residual effect against natural enemies.

5.13 Propane burning

The use of propane burners to flame stems achieved good control of exposed mealybugs but failed to reach those individuals that were protected between stems and in crevices. One grower maintained *P. viburni* numbers below 10 per plant throughout the 1999 season by treating weekly. Despite weekly treatments the infestation spread from 1000 m^2 to approximately 1200 m^2 during the season. One problem cited was that flaming left black deposits on the plants, which were unsightly.

5.14 Rubbing off by hand

Rubbing mealybugs off stems by hand was more effective than spraying with oil, soaps or flaming as workers were able to separate stems and remove mealybugs from the undersides of stems. Although effective, this method was very time consuming and individual mealybugs were missed so the treatment had to be repeated at regular intervals.

5.15 Soaps (Savona)

Savona (3% a.i.) was less effective than oils against *P. viburni*. However, weekly use prevented crop damage. Savona was found to wash the mealybugs off plants but did not always kill them. In hard water areas the addition of a water softener improved control. When whole plants were treated in summer conditions, some stunting has been observed

Growers reported improved control when oils and soaps were mixed than when either product was used alone. However, weekly treatments of Savona plus Hortichem spraying oil failed to achieve complete control.

5.16 Steaming

Steam heat at 46.6°C for one hour killed mealybugs on tropical cut flowers for export (Hansen *et al.,* 1992). One grower reported that steaming rockwool blocks at 120°C killed all stages of *P. viburni.*

5.17 Cold temperatures

Extended periods of low temperature killed *P. viburni*. A large scale test on apples at 0°C resulted in complete mortality of all life stages after 42 days (Hoy & Whiting, 1997).

5.18 Other physical methods

Sterilants and high-pressure water washes only achieved partial control of *P. viburni*, even where the insects were exposed (Table 4). At an apple pack house the use of two high pressure water washes at 1500 and 2300 kg / square centimetre only resulted in 40% removal and mortality of *P. viburni* (Whiting *et al.*, 1998).

Biological control methods

Over 70 parasitoid species and 46 predatory species have been released to control different mealybug species around the world (Moore, 1988). Most successful control has been achieved using host specific parasitic wasps from the Encyrtidae family. Only two predatory species have achieved successful control; a beetle *Cryptolaemus montrouzieri* and a midge *Kalodiplosis pseudococci* (Carter, 1944). Seven species have been released into tomato nurseries in the UK but poor control has resulted. A number of factors may have contributed. Several growers commented that mealybug natural enemies were not available in sufficient quantities when needed. In addition, tomato crops are difficult host plants as they have hairy stems and the temperature and humidity conditions are not favourable. Tingle and Copland (1988) investigated several mealybug parasitoid species and found that parasitism rates were positively correlated with temperature. Most mealybug natural enemies prefer a temperature range of 22°C to 27°C and fail to achieve control below 17°C (Hennekam *et al.*, 1987; Philip & Sherk, 1991). Ants were found to attend *P. viburni* colonies in all the tomato nurseries visited. If ants are not controlled they protect mealybugs from natural enemy attack (Beardsley, 1960). Because of growers have not have had firm release recommendations, some natural enemy species have been released that do not attack *P. viburni*.

5.19 *Chrysoperla carnea* (green lacewing) (Neuroptera: Chrysopidae). A generalist predator with a preference for Hemiptera.

Lacewings feed on several mealybug species in the wild. The larvae are the main predatory stage and they can eat over 200 mealybug nymphs during their lives (Krishnamoorthy & Mani, 1989). However, none have been cited as achieving control (Moore, 1988). Two growers released larvae into UK tomato crops but none were recovered and no control was observed. Lacewing larvae are nocturnal and the larvae camouflage themselves with wax from their prey (Eisner and Siberglied, 1988), so it is possible that the larvae were present but not seen.

5.20 *Cryptolaemus montrouzieri* (ladybird) (Coleoptera: Coccinellidae). A predatory beetle.

Cryptolaemus montrouzieri is an effective predator of *P. viburni* in warm humid climates such as tropical hot houses. All active stages of *C. montrouzieri* are predatory on mealybugs. They prefer mealybug colonies and the adult beetles fly away in search of prey if there are insufficient numbers. Four growers released *C. montrouzieri* into infested tomato crops but no control was observed. Several reasons may account for this. *Cryptolaemus montrouzieri* are most effective at temperatures of around 30ºC (Babu & Azam, 1987; Heidari & Copland, 1992) and they become torpid below 16°C. Low humidities also dry up the eggs. In addition, the dense hairs on tomato stems reduce the walking speed of the beetles, which spend most of their time preening because of the sticky hairs (Copland *et al.*, 1993). One grower achieved establishment of two generations by burning the hairs off the tomato stems before release. A polythene sheet was also placed over the affected area in order to keep the predators in but they still disappeared and no lasting control was achieved.

5.21 *Hypoaspis* species (Acarina: Laelapidae). A generalist predatory mite.

This small (1 mm) predatory mite mainly lives in the soil and around the base of plants. *Hypoaspis* spp. tolerate a variety of environmental conditions and survive mild winters but they are inactive below 18ºC. *Hypoaspis* spp. feed on a variety of different invertebrate larvae, eating one to five prey items per day. However, they can survive as scavengers by feeding on algae and plant debris. Four growers released *Hypoaspis miles* and reported poor success, although one grower thought that three applications per season at 100 mites per m^2 prevented re-establishment of low numbers of *P. viburni*. Live mites have been recovered from a tomato nursery two months after release. A small commercial rearing unit of mealybugs was eradicated by *Hypoaspis* (Hodgson, pers. comm.), which suggests that control may be possible if the predator is present in sufficient numbers. Further evaluation is required.

5.22 *Leptomastix epona* (Hymenoptera: Encyrtidae). A specific parasitoid

Leptomastix epona are known to parasitise *P. viburni* and will establish in tomato nurseries (Koppert, 1993). They attack third instar nymphs and adult mealybugs. It takes about four weeks for the new wasp to emerge from its cocoon at 20°C. *Leptomastix epona* establish at low mealybug densities as they search for individual mealybugs and only lay one egg per host. Under ideal conditions the wasps live for four weeks and lay up to 100 eggs during this time. In the Netherlands, several releases of between 1 and 5 adults /m² are recommended. They are released near to infestations as soon as the first mealy bugs are seen. Each pest infestation should be treated as *L. epona* do not travel between rows very easily and prefer to walk across the top of the crops. However, several UK growers have released *L. epona* but none have observed any control. Poor supply of *L. epona* at critical times of the year may have contributed to these control failures. Further evaluation is required.

5.23 *Leptomastix dactylopii* (Hymenoptera: Encyrtidae). A specific parasitoid

Although some growers have released this species to control *P. viburni* it is a specific parasitoid that only controls *Planococcus citri.* As all mealybug specimens identified from UK tomato crops were *P. viburni*, use is not recommended on protected tomatoes.

5.24 *Pseudaphycus affinus* (Hymenoptera: Encyrtidae). A specific parasitoid

This parasitoid attacks mealybugs at the egg or larval stage. There is no published literature showing that this species attacks *P. viburni*. One UK grower released *P. affinus* but no control was observed. Further evaluation is required.

5.25 *Verticillium lecanii* (Deuteromycota: Hyphomycetes) (Mycotal). An endopathogenic fungus

Two growers applied *V. lecanii* (Mycotal) and thought that there was some control effect although this was not quantified. *Verticillium lecanii* requires warm temperatures (23º to 24ºC) and high humidities (>80%) for optimum growth. If humidities are high *V. lecanii* remains effective down to 15ºC. Further evaluation is required.

5.26 Other biological control agents

Successful control of *P. viburni* has been reported using the parasitic wasp *Chrysoplatycerus splendens* (Moore, 1988) but this species is not commercially available in the UK.

Other entomopathogenic fungi have been recorded as attacking *P. viburni* which may be potential control agents. These include *Hirsutella kirchneri* (Sztejnberg *et al.*, 1997), *Beauvaria bassiana* (Srivastava & Fasih, 1988) and *Aspergillus* spp. (Drummond & Pinnock, 1990). **Commercial preparations of *Beauveria bassiana* have been developed but none are yet approved for use in the UK.**

The entomopathogenic nematode *Heterorhabditis bacteriophora* induced significant mortality (>65%) of *Dysmicoccus vaccinii* at doses of 500 to 1000 infective juveniles per individual. Treatment with another entomopathogenic nematode, *Steinernema carpocapsae* did not result in significant control (Stuart *et al.*, 1997).

5.27 Pheromone trapping

Pheromone traps have been developed for the control of male citrus mealybug, *Planococcus citri* (Hwang and Chu, 1987). About 50% of males were caught with a cylyndrical plastic trap placed about 100 cm above the floor. Males were attracted to red colours and were most active early in the morning. Bichina *et al.* (1984) found that white light caught more males than ultra-violet light and that more males were caught in roof or funnel-shaped traps than in cylindrical ones. These techniques have not been investigated in Europe or for *P. viburni*.

6. GENERAL SUMMARY AND CONCLUSIONS

Pest status of mealybug on UK protected tomato crops

Mealybug is a sporadic pest on UK protected tomato crops. Thirteen nurseries from different parts of England reported infestation on 20 hectares of tomatoes in the 1998 season. This is approximately 7% of the total UK tomato growing area. All specimens collected from these crops were the obscure mealybug, *Pseudococcus viburni*. Mealybug incidence has increased on UK tomato crops in recent years with 70% of new infestations occurring in the last decade. A similar pattern has been observed in France and The Netherlands. It is not known whether the increase of *P. viburni* on protected tomato crops was because reduced chemical use has given introduced mealybugs a better chance of establishment, or whether there is an increase in numbers outside tomato nurseries.

Pseudococcus viburni caused a range of damage symptoms. All infested nurseries reported damaged stems and sticky honeydew. Dead plants and yield losses were reported on half of the infested nurseries. Mealybug damage was also thought to increase the incidence of *Botrytis cinerea*. Crop losses could be severe, one nursery lost nearly 50,000 plants in July and August, another estimated yield losses of £15,000. The cost of controlling *P. viburni* averaged £3,100 / ha / season, of which 75% were labour costs.

The spread of *P. viburni*, between and within glasshouses

Mealybugs were usually transported by people onto new nurseries, either on infested plants (typically ornamental 'house plants') or on equipment. They may also travel short distances unaided between infested glasshouses. Spread within infested nurseries was also aided by people. The most rapid spread was observed in two nurseries where irrigation lines and packing boxes were moved from mealybug infested areas to new areas without being sterilising in between. The waxy filaments make egg masses and mealybugs sticky and they get moved down rows attached to crop workers or animals. Ants feed on mealybug honeydew and are known to move mealybugs to new plant hosts. Wagtails were thought to be spreading the pest at one site.

Timing and location of infestations

Crop monitoring indicated that *P. viburni* eggs hatched in response to raised temperatures at the start of the season and that there was no winter diapause. Mealybugs continued to breed throughout the season with numbers peaking in mid October. Most of the survivors between crops were in the egg stage. These were located in a variety of hidden habitats but were most frequent in the hollows of concrete dollies and on irrigation drippers. They were also found inside the slabs, on packing crates, on strings, in dried up plant debris, in cracks in the soil, on / in hollow metal posts and along the concrete roadways. These are the areas that need most attention during the clean-up process.

The success of different control methods used against *P. viburni*

Hygiene and quarantine

Hygiene and quarantine are the most important factors in preventing or delaying the spread of *P. viburni* either between sites or within glasshouses. It is recommended that growers:

- Inspect all incoming plant material to ensure that it is clear of pests.
- Ensure that no infested equipment is brought in from other nurseries.
- Avoid bringing susceptible ornamental species (houseplants) onto the nursery.
- Remove and destroy, or treat infested ornamental plants.
- If a few plants are infested they should be removed and destroyed.
- Dispose of irrigation lines from infested areas between seasons.
- Steam sterilise or dispose of slabs from infested areas between seasons.
- Ensure that no infested plant material (e.g. from deleafing) is moved to other areas.
- Crop workers should visit infested areas last and wear protective clothing that remains in that area.
- Control weeds, which may be a reservoir of mealybug infestation.
- Control ants, which move mealybugs to new areas and guard them from parasitoids.

Chemical control methods

Chemical control can be difficult because mealybugs are covered with a water-repellent waxy covering that prevents insecticides from making contact with the insect. As mealybugs are located in inaccessible areas such as within layered stems and at the base of leaf petioles accurately placed high volume sprays are essential for control. The use of a spreader-sticker may improve coverage. Stripping leaves off before treatment also improves penetration and control. The best opportunity for controlling or eradicating *P. viburni* is at the end of the season and during the clean up period between crops.

Several chemicals were effective against the active mealybug stages including Applaud, Decis and Malathion 60. Applaud is recommended as it is very effective and the least damaging to biological control. As none of the chemicals were effective against eggs, two to three applications are required at 14-day intervals in order to achieve control. Growers should aim to kill all the active stages at least two weeks before the crop is pulled out. Although effective, repeated use of Applaud may lead to the development of resistance or disrupt whitefly control by depriving *Encarsia formosa* of prey. If mealybugs reappear in the new crop two treatments of Applaud are recommended against the first generation of nymphs. Decis and Malathion 60 were as effective as Applaud but were not compatible with biological control programmes and their use may result in a whitefly resurgence the following season. They are only recommended as end of season treatments for outbreaks that are restricted to small areas.

Physical control methods

A number of physical control methods were available included rubbing the mealybugs off by hand, flaming or spraying with oils and soaps. These were found to be less effective than chemical control methods but were sufficient to maintain low numbers of *P. viburni* and prevent crop damage. None of the physical treatments had fumigant or residual effects, so control relied on achieving direct contact with the insects. As *P. viburni* lives in hidden areas, contact was difficult and repeated treatments were required. Physical methods could be used throughout the summer months with minimal disruption to biological control programmes. Rubbing off by hand was the most effective and cleanest option as workers were able to separate the stems and remove mealybugs from hidden areas that were hard to hit with a spray or flame. The level of control achieved varied according to the time available to workers and their attention to detail. The main problem with these methods was that they were labour intensive and therefore expensive.

Between crops none of the available treatments were successful in killing all the eggs. Maximum effort should be made to remove as many mealybugs as possible with the crop at the end of the season. Once all crop debris had been removed it was possible to reduce the number of nymphs emerging onto the new crop by painting dollies in affected areas with a thick paint, by wrapping the dollies in sticky traps / glues or by sealing polythene over the top of the concrete dollies. Where all the joints between plastic sheeting were sealed with tape or glue fewer nymphs emerged.

Biological control methods

Several biological control agents were used for the control of *P. viburni* on protected tomatoes but for different reasons none provided effective control. Further evaluation is required before these can be recommended.

Eradication

By using a combination of the control techniques above, it is possible to eradicate *P. viburni* in some situations. Four growers have been successful in eradicating *P. viburni* from their nurseries although *P. viburni* infestations were restricted to a few plants in all but one of these cases. Eradication was achieved by the combined use of chemical treatments (Applaud or Decis) at the end of the season together with a strict hygiene programme during the clean-up period between crops and the use of glues and traps to prevent emergence of nymphs the following season.

Eradication may not be possible in nurseries that have a continuous invasion pressure from a nearby nursery, in organic nurseries or in nurseries that have a pesticide free policy. Further research is required to identify integrated pest control strategies for these nurseries.

7. RECOMMENDATIONS FOR FURTHER RESEARCH WORK

Most growers now rely on Applaud for *P. viburni* control. Despite its efficacy, none of the growers with extensive areas of mealybugs achieved eradication in the 1999 season. In addition, eradication may not be possible for sites with a continuous invasion pressure, for organic growers or for growers who have a pesticide free policy. As *P. viburni* incidence is increasing in protected tomato crops, a sustainable control strategy is needed. Reliance on a single chemical for control is likely to lead to resistance and other methods of control need to be identified that will reduce the selection pressure on Applaud.

The following areas of research are proposed:

1. **Evaluate the following natural enemies as potential control agents of *P. viburni* in protected tomato crops**:
    - *Hypoaspis* sp. - This predator is known to feed on *P. viburni* and will establish in tomato nurseries. It has the advantage that it will survive on other species when *P. viburni* numbers are low. It is not known how many need to be released and at what frequency in order to achieve control.
    - *Verticillium lecanii* – One grower has reported some effect but this has not been quantified. Koppert have developed a new oil based formulation that may work at lower relative humidities.
    - *Beauvaria bassiana* – *Beavaria bassiana* is known to attack mealybugs but has not been evaluated against *P. viburni*.
    - *Leptomastix epona* – This parasitoid will search for individual mealybugs and can work at lower host densities than the predators. Although results in UK nurseries have been disappointing to date, it is thought that insufficient parasitoids were released and that further evaluation is required. This species will only be investigated further if biological control companies can provide evidence that it is effective in tomato nurseries.

2. **Identify a product that can be used to control mealybug eggs that are on or in glasshouse structures**.
   None of the available chemical treatments have been successful in controlling *P. viburni* eggs. A review of possible new treatments should be carried out and the most promising products tested.

3. **Evaluate a pheromone trap for catching male mealybugs**.
   Pheromone traps have been developed against a closely related species, *P. citri*, for use as a monitoring tool and as a method of control. Development of a new trap for *P. viburni* is not thought to be cost effective. However, as the species are closely related, the existing trap should be tested against *P. viburni*.

4. **Determine the effect of Chess (Pymetrozine) on *P. viburni* actives.**
   Chess (Pymetrozine) offers a possible alternative to Applaud. If effective it would provide a resistance management strategy. It has the advantages of being systemic and IPM compatible. **Chess (prymetrozine) is not currently approved for use on tomato crops in the UK.**

References

Babu, T.R.; Azam, K.M. 1987. Biology of *Crytolaemus montrouzieri* Mulant, (Coccinellidae: Coleoptera) in relation with temperature. *Entomophaga*. 32:4, 3831-386.

Beardsley, J.W. 1960. Observations on sugarcane mealybugs in Hawaii. *Proceedings of the International Society of Sugar Cane Technologists*. 10, 41-51.

Bedford, ID; Kelly, A; Markham, PG; Tucker, RP. 1996. The effects of Buprofezin against the citrus mealybug, *Planococcus citri*. *Brighton Crop Protection Conference.* 1065-1070.

Bichina, T.I.; Rotar, M.G.; Rozinskaya, E.M. 1984. The effect of light and trap construction on catches of coccids. *Zashchita-Rastenii*. 8, 38.

Buschinger, A.; Heinze, J.; Jessen, K.; Douwes, P.; Winter, U. 1987. The first European record of a queen ant carrying a mealybug during her mating flight. *Naturwissenschaften.* 74, 139-140.

Carter, W. 1944. Biological control of *Pseudococcus brevipes* (Ckll.). *Proceedings of the Hawaiian Entomological Society*. 12, 15.

Copland, MJW; Tingle, CCD; Saynor, M; Panis, A. 1985. Biology of glasshouse mealybugs and their predators and parasitoids. In : Hussey, NW; Scopes, NEA (eds) *Biological Pest Control: The glasshouse experiences*. Blandford Press, Poole. 82-86.

Copland, MJW; Perera, HAS; Heireri, I. 1993. Influence of host plant on biocontrol of glasshouse mealybug. *Bulletin OILB-SROP* . 16:8, 44-47.

Drummond, J.; Pinnock, D.E. 1990. Aflatoxin produced by entomopathogenic isolates of *Aspergillus parasiticus* and *Aspergillus flavus*. *Journal of Invertebrate Pathology*. 55: 3, 332-336.

Eisner, T.; Silberglied, R.E. 1988. A chrysopid larva that cloaks itself in mealybug wax. *Psyche*. 95: 1-2, 15-19.

Hansen, J.D.; Hara, A.H.; Tenbrink, V.L. 1992. Vapour heat: a potential treatment to disinfest tropical cut flowers and foliage. *HortScience* 27:2, 139-143.

Heidari, M. 1989. Biological control of glasshouse mealybugs ising Coccinellid predators. *PhD thesis, Wye College*. University of London. 64-65.

Heidari, M; Copland, MJW. 1992. Host finding by *Cryptolaemus montrousieri* (Col., Coccinellidae) a predator of mealybugs (Hom., Pseudococcidae). *Entomophaga*, 37:4, 621-625.

Hennekam, M.M.B.; Kole, M.; van Opzeeland, K.; van Alphen, J.J.M. 1987. Biological control of citrus mealybug in a commercial crop of ornamental plants in the Netherlands. *Mededelingen van de Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent*. 52:2a, 329-338.

Hoy, L.E.; Whiting, D.C. 1997. Low temperature storage as a postharvest treatment to control *Pseudococcus affinis* (Homoptera: Pseudococcidae) on Royal Gala apples. *Journal of Economic Entomology*. 90:5, 1377-1381.

Hwang, J.S.; Hsieh, F.K.; Wu, I.S. 1986. The toxicity of insecticides to various life stages of the citrus mealybug (*Planococcus citri* (Risso)) and its predator, *Cryptolaemus montrouzieri* Mulsant. *Plant Protection Bulletin, Taiwan.* 28, 155-161.

Hwang, J.S.; Chu, Y.I. 1987. The development of sex pheromone traps for the citrus mealybug, *Planococcus citri* (Risso). *Plant Protection Bulletin, Taiwan*. 29:3, 297-305.

Islam, K.S.; Copland,M.J.W.; Jahan, M. 1995. Laboratory studies on the development of *Planococcus citri* (Risso) and *Pseudococcus affinis* (Mask) at different temperatures. *Bangladesh Journal of Entomology*. 5: 1-2, 19-24.

Koppert b.v. 1993. New natural enemy for the mealy bug. *Groenten en Fruit*. Nov, 5-6.

Krishnamoorthy, A.; Mani, M. 1989. Records of green lacewings preying on mealybugs in India. *Current Science*. 58;3, 155-156.

Miller, D.; Gill, R. and Williams, D. 1984. Taxonomic analysis of *Pseudococcus affinis* (Maskell), a senior synonym of *Pseudococcus obscurus* Essig, and a comparison with *Pseudococcus maritimus* (Erhorn) (Homoptera: Coccoidea: Pseudococcidae). *Proceedings of the Entomological Society of Washington*. 86: 703-713.

Moore, D. 1988. Agents used for biological control of mealybugs (Pseudococcidae). *Biocontrol News and Information*. 9:4, 209-225.

Mournier, M. 1997. Effects of neem (*Azadirachta indica*) kernal water extracts on cassava mealybug, *Phenacoccus manihoti* (Hom., Pseudococcidae). *Journal of Applied Entomology*. 121:4, 231-236.

Panis, A. 1969. Observations faunistics et biologiques sur quelques Pseudococcidae (Homoptera:Cocciidea) vivant dans la midi de la France. *Ann. Zool. Ecol. Anim*. 1: 211-244.

Philips, P.A.; Sherk, C.J. 1991. To control mealybugs, stop honeydew seeking ants. *California Agriculture*. 45: 2, 26-28.

Schoen, L; Martin, C. 1999. A “new” type of scale on tomatoes. *Pseudococcus viburni*, a potential greenhouse pest. *Phytoma*. 514, 39-40.

Srivastava, RP; Fasih, M. 1988. Natural occurrence of *Beauvaria bassiana*, an entomogenous fungus on mango mealy bug, *Drosicha mangiferae*. *Indian Journal of Plant Pathology*. 6: 1, 8-10.

Stuart, R.J.; Polavarapu, S.; Lewis, E.E.; Gaugler, R. 1997. Differential susceptibility of *Dysmicoccus vaccinii* (Homoptera: Pseudococcidae) to entomopathogenic nematodes (rhabditida: Heterorhabditidae and Steinernematidae). *Journal of Economic Entomology*.90:4, 925-932.

Sztejnberg, A.; Doron-Shloush, S; Gerson, U. 1997. The biology of the acaropathogenic fungus *Hirsutella kirchneri*. *Biocontrol Science and Technology*. 7:4, 577-590.

Tingle, CCD; Copland, MJW. 1988. Effects of temperature and host-plant on regulation of glasshouse mealybug (Hemiptera: Pseudococcidae) populations by introduced parasitoids (Hymenoptera: Encyrtidae). *Bulletin of Entomological Research*. 78, 135-142.

Uichanco, L.B.; Villanueva, F.E. 1932. Biology of the pink mealybug of sugarcane, *Trionymus sacchari* (Cockerell) in the Philippines. *Philippine Agriculturist*. 21, 205-276.

Whiting, D.C.; Hoy, L.E.; Maindonald, J.H.; Connolly, P.G.; McDonald, R.M. 1998. High-pressure washing treatments to remove obscure mealybugs (Homoptera: Pseudococcidae) and lightbrown apple moth (Lepidoptera: Tortricidae) from harvested apples. *Journal of Economic Entomology*. 6, 1458-1463.

Williams, DJ. 1985. Australian mealybugs. *British Museum*. London, vii, 430.pp.

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Appendix 1: The different life stages of *Pseudococcus viburni*.

Photograph 1 : *P. viburni* adult female

Photograph 2 : *P. viburni* adult male

Photograph 3 : The 3 female nymphal instars.

Photograph 4 : *P. viburni* eggs.

Appendix 2: MEALYBUG INCIDENCE SURVEY IN TOMATO CROPS

Survey Form Explanatory Notes

In recent years, UK growers have reported increased incidence of mealybugs in protected tomato crops.

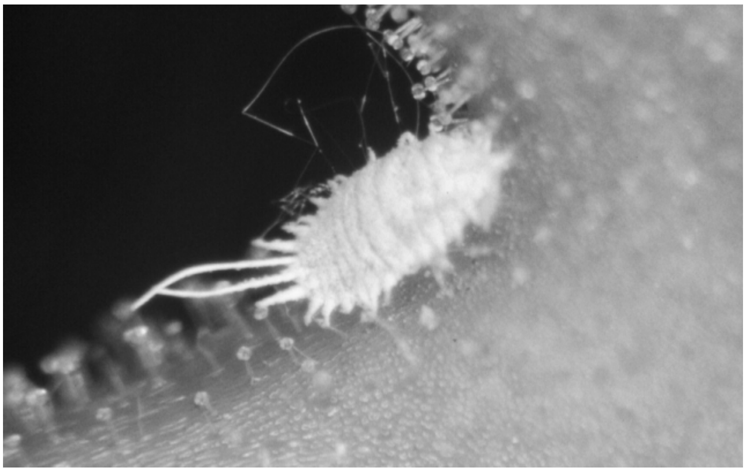
The aim of this survey is:

- to gather data on the incidence of mealybugs in protected tomato crops
- to identify factors that may be responsible for the apparent increase
- to determine the economic importance of mealybugs to tomato growers
- to review the various control methods available and their efficacy

The survey results will only be as good as the information returned by growers, so please take the time to fill in the form (if possible by 30th April 1999), even if you do not have mealybug on your nursery. We have tried to keep it short and easy to complete. Once the survey is completed, a fact sheet will be produced for growers. If required, the project will be extended to investigate improved control methods. Information regarding specific nurseries will be kept confidential.

A few facts about Mealybugs

Mealybugs are soft bodied insects with sucking mouthparts, in the same family as greenfly, whiteflies and scale insects. The adult female cannot fly and is covered in white waxy filaments. Females lay 100 - 500 eggs that are protected by a cotton like pouch made of wax filaments. Both adults and nymphs suck sap from plants, causing loss of vigour and impaired growth. When severe, the damage to stems can kill plants. Honeydew and sooty moulds (*Cladisporium* spp.) occur, which reduce fruit quality. Mealybugs are usually introduced onto nurseries on plant material.



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