Project title:	Baby-leaf Cruciferae: leaf miner identification, biology and control.
Project number:	FV 376
Project leader:	Mike Lole, ADAS
Report:	Final report, March 2011
Previous report:	None
Key staff:	Mike Lole Tom Pope Harriet Roberts
Location of project:	ADAS Rosemaund, ADAS Boxworth & growers' holdings in Norfolk and Kent
Industry Representatives:	Graham Clarkson, Vitacress Ltd. David Norman, Fresh Produce Consultancy.
Date project commenced:	21st April 2010
Date project completed (or expected completion date):	31st March 2011

The results and conclusions in this report are based on an investigation conducted over a 15-month period. The conditions under which the experiments were carried out and the results have been reported in detail and with 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.

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

The insect responsible for leaf puncturing and the development of leaf mines in salad Crucifers is the fly *Scaptomyza flava*. The challenge to control it remains due to the pest's biology and the development of insecticide resistance within the species.

Background

Before the summer of 2009 leaf miners were not considered to be significant pests of watercress or Cruciferae grown as baby-leaf salads. However, from mid-summer onwards serious economic damage was recorded widely in these crops in central, eastern and southern England, with reports of up to 40% of harvested leaves affected by puncturing or mines. Economic losses resulted from crop rejection, additional pack house labour inputs and the cost of increased insecticide application.

The species involved was not understood at the time the damage occurred and there were at least five candidate leaf miners that might have been responsible for the 2009 damage. To manage a pest effectively it is vital to know its identity, as only then can the biology and population dynamics of the insect be confirmed, both of which strongly influence how the pest may be controlled. The first step was therefore to confirm the identity of the pest responsible for the damage in the range of crops in question, which included rocket, tat-soi, mizuna, pak-choi and watercress.

Having identified a pest it then becomes possible to monitor its activity and establish details of its biology. Information on the number of generations that occur, and the timing and duration of periods of activity, may be useful in devising methods of reducing damage. Establishing the host range of the pest, together with information on aspects such as the effects of natural enemies, can also be advantageous.

Management of a pest frequently requires chemical intervention. Although knowledge of the biology of the insect can guide the need for, and timing of, such intervention, the relative efficacy of differing candidate materials can only be established by practical comparison in the field.

This project was therefore instigated with the following objectives:

I. To identify the leaf miners responsible for the commercial damage seen in baby-leaf Cruciferae and watercress in 2009.

II. To secure information on the biology and population dynamics of the leaf miner(s) identified in objective I.

III. To evaluate the efficacy of control treatments

These objectives were all completed within the project. However, as the work progressed it was decided that the possibility of insecticide resistance should be investigated in addition. This was added as objective IV.

Summary

The insect responsible for significant plant damage and economic losses in salad Cruciferae in 2009 and 2010 has been identified as the Drosophilid fly *Scaptomyza flava* (Fallén, 1823) – see image below:

Adult *S flava.* Note the overall pale brown colouration, with faint paler/darker stripes on the thorax, and red eyes. The wings are unusually long for a small fly, about 50% longer than the head and thorax combined.

This was identified after rearing larvae found in leaf mines, by sampling insects in affected crops and by direct observation in the field. No other leaf-mining insects were found in significant numbers.

S. flava is active between April and September, with a number (probably 3 or 4) of generations during the summer months. Populations seem to fluctuate from site to site, but from the data gathered by monitoring with sticky traps in 2010 it is now known that sudden, unpredictable and large increases can occur at different times on different sites.

A leaf-dip bioassay and a 'pollen beetle' glass vial resistance test both indicated that the field dose of the widely-used pyrethroid insecticide Hallmark with Zeon Technology (lambda-cyhalothrin) would not give control of *S. flava* taken from a crop of rocket in Norfolk, although a dose five times this rate was effective in the glass vial test. It is suspected therefore that *S. flava* has acquired resistance to this class of insecticides. Pyrethroids are used frequently on salad Cruciferae for the control of caterpillars, sawflies etc., and it may be the case that the natural enemies of *S. flava* are being reduced by such treatment, exacerbating the *S. flava* problem.

A trial was conducted investigating the effectiveness of a range of treatments on the level of leaf miner damage occurring in a crop of wild rocket. The only insecticide that gave a significant reduction in damage 9 days after treatment was BASF Dimethoate 40 (dimethoate), an organophosphate pesticide with contact and systemic action that has no approval for use on salad crops and which was only included in the trial as a basis for comparison with other candidate pesticides. Decis (deltamethrin), Conserve (spinosad), Movento (spirotetramat), Biscaya (thiacloprid), HDCI 035, Savona (soft soap) and Garlic Barrier Plus (garlic extracts) had no significant effect on the level of leaf puncturing in the trial. The most successful treatment consisted of covering the crops from emergence to harvest with Enviromesh insect-proof netting, which produced a significant reduction in leaf miner puncturing throughout the trial.

Financial Benefits

Whilst low levels of leaf miner puncturing in salad Cruciferae seem to be tolerated by retailers and the public, higher levels can result in total crop write-off, for major producers resulting in five-figure losses for each week's lost production. The ability to recognise, monitor and control this insect in salad Crucifer crops therefore has considerable financial benefits for some producers at times of high pest pressure.

Action Points

- Become familiar with the appearance of *Scaptomyza flava* adults.
- Use white sticky traps in fields of salad Cruciferae to monitor the activity of *S. flava*.
- Do not rely on frequent application of pyrethroid insecticides to control *S. flava* as this is unlikely to be effective due to insecticide resistance (though it may be necessary for the control of other pests such as turnip sawfly)
- Be prepared to cover crops with insect-proof netting when the activity of *S. flava*, as indicated by the sticky traps, is on the increase.

SCIENCE SECTION

Introduction

Before the summer of 2009 leaf miners were not considered to be significant pests of watercress or Cruciferae grown as baby-leaf salads. However, from mid-summer onwards serious economic damage was recorded widely in these crops in central, eastern and southern England, with reports of up to 40% of harvested leaves affected by puncturing or mines. Economic losses resulted from crop rejection, additional pack house labour inputs and the cost of increased insecticide application.

The species involved was not understood at the time the damage occurred (although this did not prevent at least one pesticide distributor producing a ‘factsheet’ about leaf miners in brassicas, erroneously naming a non-indigenous species). There were at least five candidate leaf miners that might have been responsible for the 2009 damage. These were *Phytomyza rufipes; Chromatomyia horticola; Liriomyza strigata* (all Agromyzidae); *Scaptomyza flava;* and *S. griseola* (both Drosophilidae). To manage a pest effectively it is vital to know its identity, as only then can the biology and population dynamics of the insect be confirmed, both of which strongly influence how the pest may be controlled. The first step was therefore to confirm the identity of the pest responsible for the damage in the range of crops in question, which included rocket, tat-soi, mizuna, pak-choi and watercress.

Having identified a pest it then becomes possible to monitor its activity and establish details of its biology. Information on the number of generations that occur, and the timing and duration of periods of activity, may be useful in devising methods of reducing damage. Establishing the host range of the pest, together with information on aspects such as the effects of natural enemies, can also be advantageous.

Management of a pest frequently requires chemical intervention. Although knowledge of the biology of the insect can guide the need for, and timing of, such intervention, the relative efficacy of differing candidate materials can only be established by practical comparison in the field.

This project was therefore instigated with the following objectives:

IV. To identify the leaf miners responsible for the commercial damage seen in baby-leaf Cruciferae and watercress in 2009.

V. To secure information on the biology and population dynamics of the leaf miner(s) identified in objective I.

VI. To evaluate the efficacy of control treatments

These objectives were all completed within the project. However, as the work progressed it was decided that the possibility of insecticide resistance should be investigated in addition. This was added as objective IV.

i) Identification of leaf miners

Materials and methods

Specimens of leaf miners for identification were obtained from commercial crops of salad rocket, wild rocket, mizuna and watercress. In some cases, these were obtained as live larvae in mines in leaf tissue, thus confirming their direct association with the crop. Some adults observed feeding in a crop were also taken directly using a ‘pooter’ (a form of hand-held collection apparatus operated by suction). Further examples were obtained on sticky traps placed in crops. These sticky traps (AgriSense BCS) consisted of a white styrene sheet coated on one side with a high-grab, non-drying glue and in use were attached to a 6 mm plywood backing board using fold-back clips. The backing boards were attached to short posts pushed into the ground in a growing crop so that they were at approximately crop height.

It is possible to identify leaf miner larvae to family by observing the form of the anterior and posterior spiracles (breathing holes). This can be done on live larvae extracted from mines, and the larvae can then be returned to the leaf tissue to complete their development.

To identify leaf miner larvae to species it is necessary to rear them through to the adult stage. This was done by putting leaf tissue with mines onto a 10mm layer of damp soil or soil-based compost inside a clear polycarbonate box, then closing the box and keeping it at a suitable temperature. The boxes used had a small vent covered in insect-proof mesh to allow gaseous exchange to take place without excessive dehydration of the samples. A facility at ADAS Rosemaund with a constant temperature of 20°C was used as a rearing room. Daily examination of the contents of the boxes allowed newly-emerged adult insects to be observed and they were then collected for identification purposes.

Adult flies were killed using ethyl acetate vapour in a closed jar and were identified to species under the binocular microscope.

Results

Larvae in leaf mines

Plant material containing leaf mining larvae was sent to ADAS from a number of locations in Cambridgeshire, Dorset, Hampshire, Kent, Norfolk and Shropshire. All larvae found in leaf mines and examined prior to incubation belonged to the family Drosophilidae. This family contains a number of species, including the well-known fruit flies (*Drosophila* spp.) which feed in fruit and decaying vegetable material. It also contains a number of leaf-mining species, including one genus, *Scaptomyza* spp., recorded previously in Cruciferae. Direct identification of Drosophilid larvae to species is not possible.

No larvae of the family Agromyzidae were found in any samples. This family is the one to which the most familiar leaf miners of horticultural crops, such as the tomato leaf miner *Liriomyza bryoniae* and the chrysanthemum leaf miner *Phytomyza syngenesiae*, belong. It does contain at least three species previously recorded from Cruciferae (*Liriomyza strigata, Phytomyza rufipes, Chromatomyia horticola*) although none are normally regarded as major pests.

No parasitoid wasps were found in any of the mines.

Adults reared from leaf material

A high proportion of the leaf miner larvae incubated in the polycarbonate boxes as described above were later recovered as adults. All those recovered were identified as *Scaptomyza flava* (Fallén 1823) (Diptera, Drosophilidae). The same species is sometimes referred to in the literature as *Scaptomyza apicalis* or *S. flaveola*, but these are later synonyms and are therefore incorrect (See Appendix 1).

Adults obtained in the field

Adults observed feeding in the field and collected by means of the pooter were confirmed as *Scaptomyza flava*, as above. This was also the leaf-mining species that was caught most frequently on the sticky traps. A small number of Agromyzidae (*Phytomyza* and *Liriomyza* species) were also trapped, but the numbers were so small in relation to those of *Scaptomyza flava* that they can be discounted as important contributors to the leaf-mining problem (Table 1).

Table 1: Numbers of adult leaf miners caught on sticky traps at 2 sites.

Site	Period	No. of *Scaptomyza*	No. of Agromyzidae
Minster, Kent	18 May – 21 July	1,342	17
Martham, Norfolk	21 May – 23 July	10,645	5

ii) Biology and population dynamics of the leaf miner.

Materials and methods

The species of fly now known to have been responsible for the leaf mining in 2009 and 2010, *Scaptomyza flava*, has been previously recognised as a widespread pest in the UK (albeit in some cases misidentified as other species) and its biology is at least partly understood and is recorded in textbooks of agricultural zoology (e.g. Alford, 1999). The adult is known to be active from April until September (with larval activity in leaf mines persisting later in a mild autumn). Eggs are laid in punctures made with the ovipositor on the underside of leaves of a wide range of Cruciferae and a few plants of other families (see Appendix 2 for a list). These hatch quickly and the larvae feed between the upper and lower epidermes of the leaf, either singly or gregariously, producing a blotchy mine often at the centre of the leaf. Larvae either pupate within the mine or drop from the leaf and pupate in the soil. The new adults can be produced in as little as 10 days after the larvae have hatched, and as a result there are ‘several generations’ a year.

Although the basic biology is therefore understood, there is no precise information on the frequency or relative size of each generation of adults. Since this information appeared to be potentially useful, firstly in helping to understand the insect and secondly with the development of control measures, the activity of the fly was monitored, using sticky traps. This was done at two sites in order to detect any differences in fly activity between geographically-dispersed areas. Cruciferous salad crops had been grown at both sites for a number of years and both had experienced damage due to leaf miners in 2009.

Site 1, Martham, Norfolk.

The main crop is wild rocket, grown in rented fields in the vicinity of Martham. The crops are grown sequentially in each field to give a continuity of supply, before moving on to the next field, which may be several miles distant. Crops are grown on a bed system and irrigation is available.

Site 2, Minster, Kent.

The salad crop produced is wild rocket, grown in brick-earth soils on one site in Thanet. Crops are grown on a bed system, sequentially sown to give continuity of supply. Fields are relatively close to each other.

Monitoring was started at both sites in mid-May 2010. This is slightly later than would have been ideal, considering that the activity of the species now known to be involved begins in April, but funding was only confirmed in time for the mid-May start. The method of monitoring chosen involved the use of sticky traps deployed in the field. This method means that monitoring can be continuous and that specimens caught can be retained until identifications can be made and numbers counted. The sticky traps used consisted of a thin white styrene sheet 30 cm x 20 cm, coated on one side with a non-drying, high-grab glue (AgriSense BCS Ltd). In general, white is preferred to other colours of sticky trap for monitoring flies because it attracts the species of interest and is much less likely than the common alternative, yellow traps, to attract other insects such as flea beetles, pollen beetles and sawflies which can confuse the issue. However, no direct comparison of the relative efficacy of different colours in trapping *Scaptomyza flava* has been made and it may be the case that other colours are also effective. For use in crops of rocket, which are low-growing plants, the sticky traps were attached to wooden holders. The holders comprised a rectangle of 6 mm exterior-quality plywood 30 cm x 20 cm screwed to a single 'leg' consisting of a 50 cm length of 38 mm x 19 mm tanalised roof batten. The leg was fixed centrally on the ply with its long axis parallel to the short sides of the rectangle and its top in line with one long side. The other end of the batten was sharpened. In use, a holder was pushed (or hammered) into the ground so that the lower edge of the rectangle was at crop height and then a trap was attached using fold-back clips. Weekly, used traps were recovered and replaced with a fresh trap. The used traps were then sent to ADAS for examination and recording of the leaf-mining fly species present. Three traps were generally used at each site each week. Monitoring at the Martham site took place between 21st May and 1st November 2010, and at Minster between 18th May and 15th September.

Results

Scaptomyza flava flies were caught at each of the two sites from the start of the monitoring. Numbers were small at first, but eventually at each of the sites more than three thousand of the flies were caught on a single trap in a single week. The catches at the two sites are illustrated in figure 1.

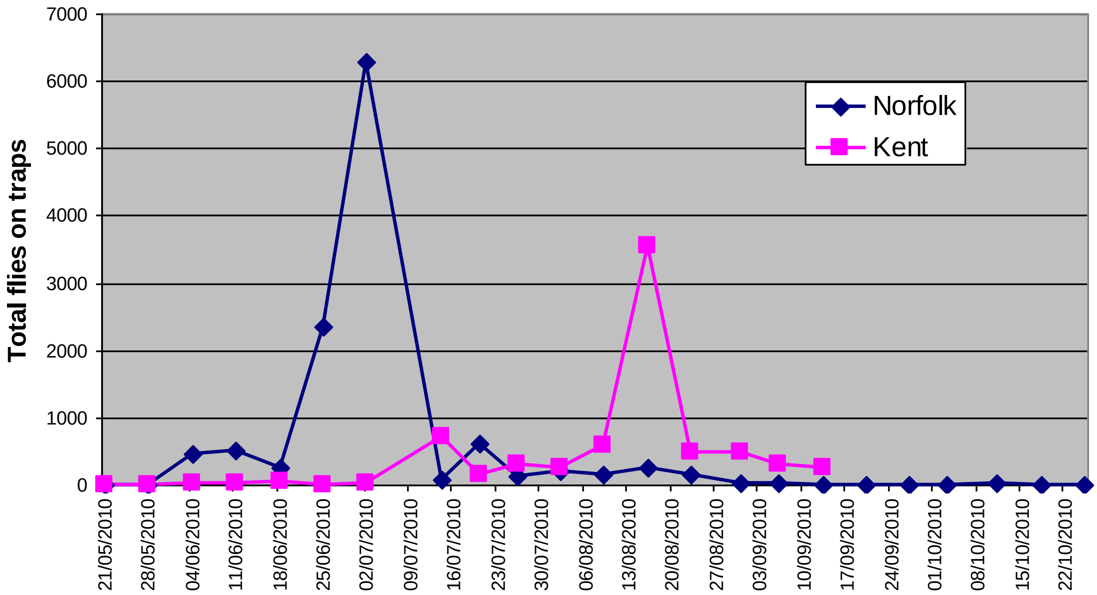

Figure 1: Scaptomyza activity in 2010 - weekly total trap catches of *Scaptomyza flava* at two monitored sites

Very few leaf miners of other species were caught during the monitoring (see Table 1 above).

iii) The efficacy of control treatments.

Materials and methods

The efficacy of potential control treatments was evaluated in a field trial conducted on deep sandy loam soil at Thrigby, Great Yarmouth, Norfolk, courtesy of East Coast Salads. The trial was situated in part of a field in which a commercial crop of wild rocket was being produced. Such crops are grown on a bed system, width 1.6 m., so beds were also used in the trial. Details were as follows:

Trial design	Randomised block, 10 treatments, four replications.
Plot size	1.6 m x 5 m.
Crop	Wild rocket cv. CN 902
Seed rate	2 kg/ha.
Drilling date	5th August 2010
Previous crop	Spinach
Fertiliser	144 kg/ha ammonium nitrate; Farmfos foliar feed, 1x 2.5 l/ha, 3x 5 l/ha
Pesticides	Dacthal W75 2 kg/ha 5th August (post drilling)
	Invader 2 kg/ha + Contest 0.067 kg/ha 13th August (post emergence)
	Fubol Gold WG 1.9 kg/ha + Signum 0.5 kg/ha + Hallmark with Zeon Technology 0.075 kg/ha 17th August (pre-covering)
Crop covered	17th August 2010
Crop uncovered	1st September 2010

The trial area was treated with a residual herbicide (Dacthal) immediately post-drilling. At crop emergence a pyrethroid insecticide (Contest) was applied (to control flea beetles) together with a fungicide (Invader). Just before the crop was covered a further pyrethroid insecticide (Hallmark with Zeon Technology) was applied (to control flea beetles, turnip sawfly etc), along with 2 fungicides (Fubol Gold and Signum). These applications were standard practice in commercial crops at the trial site. The beds in the trial area were then covered with Enviromesh to prevent any further insect invasion until the crop was sufficiently developed to be suitable for the trials work, 15 days later. The beds were subsequently uncovered on the day that the first round of treatments was applied.

Table 2: List of treatments applied

No.	Product	Active ingredient	Concn.	Rate/ha product	Water vol. (litres/ha)
1	-	control	-	-	-
2	Decis	deltamethrin	25 g/l	300 ml	300
3	BASF Dimethoate 40	dimethoate	400 g/l	850 ml	220
4	Conserve	spinosad	120 g/l	240 ml	300
5	Movento	spirotetramat	150 g/l	500 ml	300
6	Biscaya	thiacloprid	240 g/l	300 ml	300
7	HDCI 035	HDCI 035	100 g/l	500 ml	300
8	Savona	Fatty acids	49% w/w	6 litres	300
9	Garlic Barrier Plus	Garlic extract	Not stated	3 litres	300
10	Enviromesh	Crop covers	-	-	-

* 250 ml/ha Codacide Oil adjuvant also applied with this product on advice of the manufacturer.

Treatments were applied on two occasions. The first round was on 1st September 2010, when all treatments were applied using a backpack-mounted sprayer powered by compressed gas and fitted with a hand-held spray boom. It was intended to apply the second round of treatments 5 days after the first, but weather conditions (wind and rain) were not conducive to spraying until 9th September, 8 days after the first round. On each occasion, the treatments applied were as listed in Table 2.

Assessments of the efficacy of the treatments were made by taking samples of 25 leaves at random from each plot and recording the presence or absence of punctures and/or mines in each leaf. These assessments were made on five occasions: immediately pre-treatment; 1 day after treatment (DAT); 8 DAT; 9 DAT and 12 DAT. The original intention had been to complete assessments 1, 5, 9 and 13 DAT, but weather events and impending crop harvest dictated the assessment dates actually used.
The crop in the treated plots was destroyed by ploughing-in at the completion of the work.

Results were subjected to analysis of variance using the Genstat package.

Results

The mean % of leaves in each treatment showing evidence of leaf miner damage (mainly feeding punctures) is recorded in table 3 below.

Table 3: Mean % of leaves in each treatment with *Scaptomyza* leaf miner damage

Treatment	mean % leaves with leaf miner damage				
	Pre-treatment	1 DAT	8 DAT	9 DAT	12 DAT
Untreated	13	3	14	19	17
Decis	4	1	3	12	7
BASF Dimethoate 40	9	6	4	5	8
Conserve	13	9	5	12	11
Movento	8	2	11	20	11
Biscaya	13	8	10	9	18
HDCI 035	13	7	1	9	2
Savona	13	6	10	11	10
Garlic Barrier Plus	9	6	12	24	17
Enviromesh	8	0	3	1	7
Mean	10.3	4.8	7.3	12.2	10.8
F.pr.	0.662	0.058	0.189	0.021	0.061
d.f.	27	27	27	27	27
l.s.d. (p=0.05)	10.61	6.076	10.74	12.36	10.32

The mean proportion of leaves showing damage symptoms pre-treatment was 10.3%, ranging between 4% and 13%, with no significant difference between treatments. One day later, the mean level of damage symptoms on the newest fully-formed leaves was 4.8%. It then increased during the following 8 days, reaching a peak of 12.2% damaged 9 days after the original treatment, after which it declined slightly. The mean levels of damaged leaves in each of the treatments when the damage was at its peak 9 days after the original treatment are indicated in Figure 2 below.

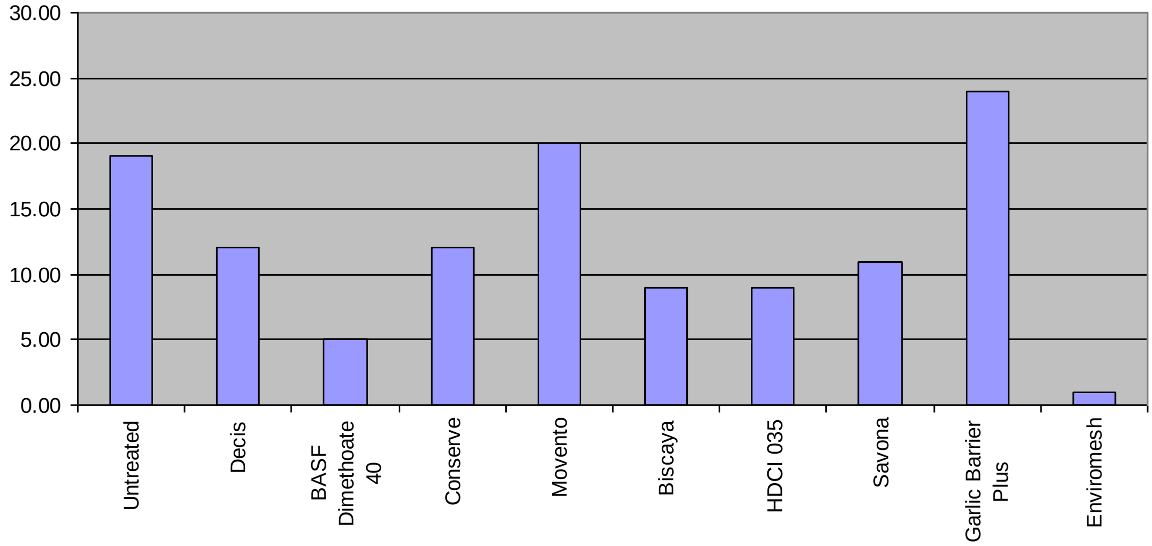

Figure 2: Mean percentage of leaves showing leaf puncturing 9 days after treatment.

Only the plants treated with BASF Dimethoate 40 or those covered with Enviromesh had significantly less damage than the untreated control plots.

iv) Investigation of insecticide resistance

Field observations made during the early part of this project raised the possibility that *Scaptomyza flava* may have developed resistance to pyrethroid insecticides. It was noted that these pesticides were being used on a regular basis (up to twice a week) on commercial crops of rocket, to control brassica flea beetles, turnip sawfly, caterpillars etc., but this had little apparent effect on *S. flava* present in the crop at the time of treatment. One possible explanation for this was pesticide resistance, which would have important ramifications for the control of *S. flava*, so it was decided that this required investigation.

Materials and Methods

Two separate bioassays were conducted to assess pesticide resistance in *S. flava*. The first of these was a leaf-dip bioassay and the second was a glass vial test originally designed for use with pollen beetles. Individuals of *S. flava* for testing were caught using pooters (hand-held suction insect samplers) on wild rocket in the field at Martham, Norfolk on 11th August 2010.

Table 4: Composition of dips used in the leaf-dip bioassay

Treatment	Rate of product	Rate of a.i. in dip
Untreated	water only	-
Full field rate Hallmark	75 ml in 200 l water/ha.	0.0375 g lambda-cyhalothrin/litre
10% field rate Hallmark	75 ml in 2000 l water/ha.	0.00375 g lambda-cyhalothrin/litre
Full field rate Biscaya	400 ml in 200 l water/ha.	0.48 g thiacloprid/litre
10% field rate Biscaya	400 ml in 2000 l water/ha.	0.048 g thiacloprid/litre

Leaf dip bioassay

In this test freshly-caught *S. flava* adults were enclosed in a glass tube along with a single leaf of wild rocket that had been dipped in a solution of an insecticide immediately before the test and allowed to dry. There were 5 replicates of 5 treatments, each involving 5 adult flies per replicate. Mortality of the insects was assessed 1, 19 and 43 hours after they were enclosed. The leaf-dip solutions employed were as in Table 4.

'Pollen beetle' glass vial test

This test utilised glass vials coated internally with lambda-cyhalothrin at different rates to assess insecticide resistance. The original purpose of these vials was to test for insecticide resistance in pollen beetles (*Meligethes* spp.) and they were supplied by researchers in Germany. These vials are produced by introducing pesticide in solvent to the vial and then allowing this to dry off whilst rotating the vial, to ensure an even coating over the inside of the vial. A list of rates used is in table 5. Rates are quoted in microgrammes (µg) per cm² of inner surface of the vial.

Table 5: Rates of lambda-cyhalothrin in glass vial 'pollen beetle' bioassay

Treatment	Rate of lambda-cyhalothrin	Comment
Untreated	-	
Hallmark very low	0.003 µg/cm²	4% of field rate
Hallmark low	0.015 µg/cm²	20% of field rate
Hallmark field rate	0.075 µg/cm²	Equivalent to field rate
Hallmark high	0.375 µg/cm²	5x field rate

As before, adult *S. flava* were collected from a commercial crop of rocket in Martham, Norfolk on 11th August 2010 using hand-held pooters. Five were introduced into each vial. Mortality was assessed 2.5, 18 and 42 hours after the insects were introduced to the vials.

Results

The survival of *S. flava* adults in the leaf-dip bioassay test is illustrated in Figure 3. The rate of survival is the mean for all replicates of each treatment.

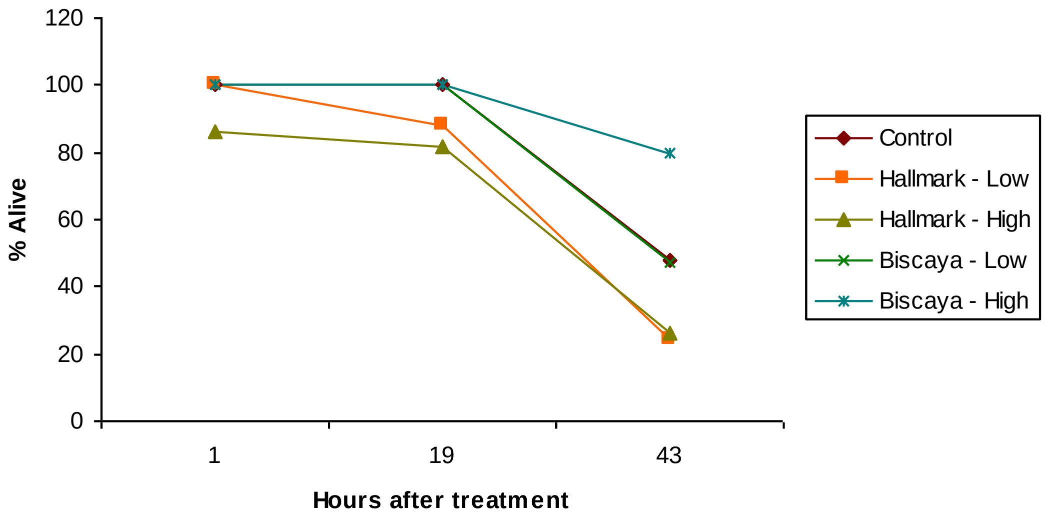

Figure 3: Survival of *Scaptomyza flava* adults on insecticide-treated leaf material

The survival of *S. flava* adults in the 'pollen beetle' glass vial test is illustrated in Figure 4. The survival rate given is the mean of the two replicates in each treatment. Note that the results for the 0.015 µg/cm² and 0.075 µg/cm² rates are identical, so the two lines are superimposed on the graph, and the result for the 0.375 µg/cm² rate coincides with the X-axis of the graph.

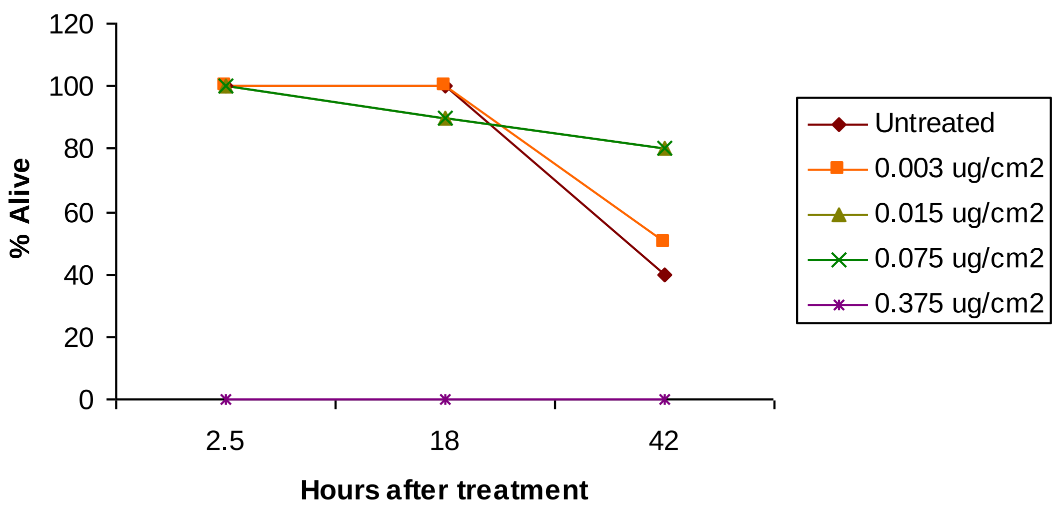

Figure 4: Survival of *Scaptomyza flava* adults in insecticide-treated glass vials.

Overall discussion

Species

Identification of larvae in mines, adults reared from mined material and adults captured in the field by pootering/sweep netting or on sticky traps all confirms the same observation. That is, the insect responsible for the leaf puncturing and leaf mining seen in baby-leaf salad Cruciferae in 2009 and 2010 was *Scaptomyza flava* (family Drosophilidae). Very few other leaf mining flies (e.g. Agromyzidae) were observed either in mined material or in the field.

Scaptomyza flava is illustrated below (Figure 5). Note the overall pale brown colouration, with faint paler/darker stripes on the thorax, and red eyes. The wings are unusually long for a small fly, about 50% longer than the head and thorax combined.

Figure 5: Adult *Scaptomyza flava*

Typical leaf puncturing by *S. flava* (on the underside of an oilseed rape cotyledon) is illustrated in Figure 6. Note the wide-open nature of the holes, with the ruptured lower epidermis pushed back to the periphery.

Figure 6: Leaf punctures made by *Scaptomyza flava* on the underside of an oilseed rape cotyledon.

This damage is distinguishable from the punctures made by Agromyzid flies, which are normally much more delicate and pin-prick-like. This is because the ovipositors of *S. flava* and Agromyzidae are quite different. The latter are pointed and needle-like, whereas the former are robust, square in profile, toothed and horny (Figure 7)

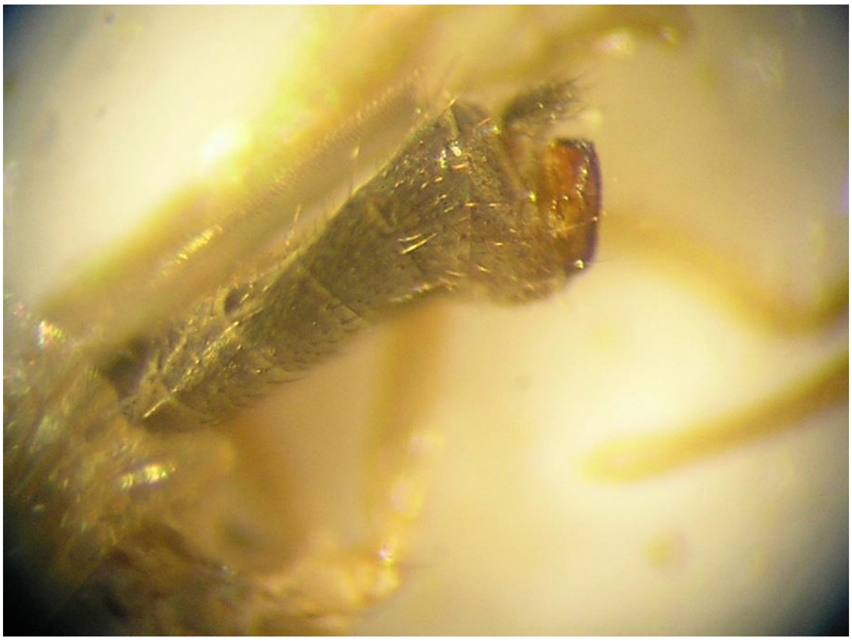

Figure 7: Abdomen of female *Scaptomyza flava*, ovipositor at terminus.

Biology

Scaptomyza flava is active over a long period in the UK. In 2009, adults were laying eggs in oilseed rape in September and active mines were visible during October. In spring 2010, adults were observed in oilseed rape in April, presumably being the overwintered progeny of the previous autumn's adults, and adults were caught through to late September on sticky traps. According to the literature, *S. flava* goes through 3-4 overlapping generations a year, but the monitoring undertaken during this project did not confirm this. Activity was more-or-less continuous, though fluctuating, throughout the April-September period, generally at a moderate level, but at each of the sites there was a single, sudden, massive increase in activity over a period of about 2 weeks, which declined as quickly as it arose. These peaks of activity (which led to serious economic loss at one site) did not occur at the same time at the two sites. In Norfolk, the peak was in early July, whereas in Kent it occurred in mid-August. The reasons for the differences in activity at the two sites are not known, but on this evidence it seems unlikely that peaks of activity could be forecasted with any accuracy and it would therefore be better for growers to monitor at each individual site as an aid to pest management.

It was originally intended that investigations into the host-range of the leaf miner(s) responsible for the damage to salad Cruciferae would be completed. However, once it had been established that the insect responsible was *Scaptomyza flava* such an investigation was rendered unnecessary, because the host range of this species has already been established and is recorded in detail (see Appendix 2). There are just over 100 known host plants, in six families. The majority of these are Cruciferae, and the list includes a number of widely-grown crop plants as well as several common farm weeds. Prospects for reducing the damage potential of *S. flava* by managing its host plants are not therefore encouraging.

Control

The trial on chemical control measures for *S. flava* was done at a time when activity was expected to be at a peak (according to the literature), in order to ensure that meaningful results could be obtained. Unfortunately, in the event the population at the trial site was not at its highest level in early September, and in addition the weather was cold, windy and wet for part of the trial period, which did not encourage fly activity. The level of damage recorded on the untreated control plots during the trial was, as a result, disappointing. Another difficulty was that the sampling system used (removal of 25 newly-developed leaves from each plot, followed by recording the presence/absence of leaf miner damage symptoms on those leaves) meant that different leaves were assessed on each occasion, introducing some variability into the system. Nevertheless, the trial did provide some useful information on the control of *S. flava*.

Because *S. flava* is an active, mobile pest with much of the commercially-important damage (leaf punctures) caused by the adult, successful chemical controls are likely to have a quick knock-down effect on the flies or to act as feeding deterrents. Typically, pyrethroid insecticides, e.g. Decis in this experiment, are considered to have these properties and would have been expected to be effective in reducing *S. flava* damage in the trial. The results did not confirm this, however, perhaps for reasons discussed later. Most of the other products used in the experiment would not be considered to be quick knock-down materials.

None of the relatively novel pesticides included in the trial (Biscaya, Conserve, Movento, HDCI 035 plus Codacide oil) had any significant effect on the level of leaf miner puncturing recorded. This is not entirely surprising, as none of these would be considered quick knock-down products and their effects on a mobile insect such as *S. flava* adults would be difficult to detect in a trial such as this. If there had been more leaf mines, rather than leaf punctures, in the trial, this may have allowed a better assessment of the effects of these novel products to have been made. The low levels of leaf mining found do not permit any conclusions to be drawn on this.

The contact pesticide Savona did not produce any reduction in leaf miner puncturing in the trial. This product has contact action only, not ideal for a pest that is highly mobile and tends to feed on the underside of leaves, where it would be sheltered.

Garlic Barrier Plus did not deter adult *S. flava* from making punctures in the leaves of rocket in the trial.

The only pesticide that had a significant effect on leaf puncturing at the height of the damage in the trial area, 9 days after the first treatment was applied, was BASF Dimethoate 40. This is a translocated organophosphate insecticide and would be expected to control both adult *S. flava* and larvae. It has no approval for use on salad crops and was included in the trial mainly as a basis for comparison of the effectiveness of the other materials.

The remaining method of managing the leaf miner that was included in the trial comprised the use of insect-proof mesh (Enviromesh), which was put over the crop after emergence and was not removed until harvest. This was the only approved method of control that gave a significant reduction in leaf puncturing. The reduction was consistently present 1, 8, 9 and 12 days after the original treatment date.

Insecticide resistance

The results of the leaf-dip bioassay and the ‘pollen beetle’ glass vial bioassay corroborate each other. In both cases, the field rate of the pyrethroid insecticide lambda-cyhalothrin failed to give any significant control of adult leaf miners after short exposure (1 hour and 2.5 hours respectively) or intermediate exposure (19 hours and 18 hours respectively) to the insecticide. Mortality increased with exposures of 43 or 42 hours respectively, but as this occurred to the same extent in the control treatments as in the insecticide treatments it seems most likely that the insects died due to starvation or dehydration rather than to the effects of the insecticide. Pyrethroid insecticides would normally be expected to quickly knock-down susceptible target species. It should be noted that in the glass vial test the 5x field rate treatment gave 100% mortality of *S. flava* in less than 2.5 hours.

The most likely explanation for the failure of the field dose of pyrethroids to kill *S. flava* seems to be that the insect has developed resistance to this group of insecticides, but further confirmation of this is desirable. Pyrethroids are frequently used on Cruciferous salad crops, which are hosts of *S. flava*, to control other pests, and they are also used widely on oilseed rape, another host. Perhaps the level of exposure of *S. flava* to pyrethroids on various hosts has resulted in the selection of a pyrethroid-resistant strain of this insect.

The use of pyrethroids in salad Crucifers is likely to continue because these insecticides are relatively inexpensive, will control a range of pests such as caterpillars, flea beetles and sawflies and have short harvest intervals. This is likely, however, to exacerbate the leaf miner problem as there will be continued selection pressure for resistance, and at the same time, adverse effects on the natural enemies of *Scaptomyza*.

Thiacloprid was included in the leaf-dip bioassay because this pesticide has a different mode of action to the pyrethroids and there are as yet few cases of resistance to this insecticide recorded in UK pest insects. It does not have a quick knock-down action but is a contact or ingested poison, most effective as an insecticide when ingested. It was postulated that *S. flava* might encounter a lethal dose of thiacloprid when making oviposition holes in treated leaves and/or when drinking sap from leaf wounds. There was however no evidence of any lethal effect of thiacloprid on *S. flava* in the leaf-dip bioassay.

Conclusions

- The insect responsible for leaf puncturing and causing leaf mines in Cruciferous salads grown for baby-leaf production in 2009/10 is *Scaptomyza flava*, a small fly of the family Drosophilidae. The adult insect causes the leaf puncturing and the mines result from larval activity.

- *S. flava* is a widespread insect in the UK with a host range of over 100 plants, including Cruciferous crops and common farm weeds.

- *S. flava* is active between April and September in the UK, with multiple overlapping generations through the summer months. Population fluctuations are unpredictable, with sudden population booms recorded at two monitored sites in 2010.

- Strains of *S. flava* occur that appear to be resistant to the field dose of pyrethroid insecticides commonly applied to salad Cruciferae in the UK.

- The prospects for chemical control of this species on salad Cruciferae are currently limited. Only one of the candidate materials tested gave a reduction in leaf puncturing in a trial, and this was an organophosphate insecticide with no approval for application to the crop.

- The pest might be managed by a combination of monitoring to detect changes in population, plus approved insecticides that control larvae in leaf mines, plus the use of crop covers during times of high pest pressure.

Knowledge and Technology Transfer

A presentation was made, with the permission of the HDC, at an ADAS seminar on vegetable crop protection held at the Holbeach campus of Lincoln University on December 8th, 2010.

An article for the HDC News and a factsheet are both in preparation. References

Alford, D.V. (1999). A Textbook of Agricultural Entomology. Blackwell Science, Oxford.

Appendix 1. Nomenclature of *Scaptomyza flava.*

Source: P. J. Chandler (Ed). (1998). Handbooks for the Identification of British Insects, Volume 12. Checklists of Insects of the British Isles (New Series); Part 1: Diptera. Royal Entomological Society, London.

Current designation:	*Scaptomyza flava*. (Fallén, 1823)
Original designation:	*Drosophila flava*. Fallén, 1823
Synonyms:	*Scaptomyza flaveola*. (Meigen, 1830 – *Notiphila*)
	S. apicalis. Hardy. 1849
	S. montana. Wheeler, 1949

Appendix 2. Host Plant List of *Scaptomyza flava.*

Source: Brian Pitkin, Willem Ellis, Colin Plant and Rob Edmunds. The leaf and stem mines of British flies and other insects. http://www.ukflymines.co.uk/Flies/Scaptomyza_flava.html

The following is a list of just over 100 plants recorded as hosts of *Scaptomyza flava* in Europe. The family of plants in is the left-hand column in bold; the genus is in italic with a capital; where known, the specific name follows the genus. Common names, where known, are in the right-hand column.

Asteraceae	
Hypochaeris	
Brassicaceae (=Cruciferae)	
Aethionema	
Alliaria petiolata	Garlic Mustard
Alyssum	
Anastatica	
Arabidopsis thalaiana	Thale Cress
Arabis alpina	Alpine Rock-cress
Arabis arenosa	Sand Rock-cress
Arabis glabra	Tower Mustard
Arabis hirsuta	Hairy Rock-cress
Armoracia rusticana	Horseradish
Aubrieta deltoidea	Aubretia
Barbarea stricta	Small-flowered Winter-cress
Barbarea vulgaris	Winter-cress
Berteroa incana	Hoary Alison
Biscutella	
Brassica campestris	Wild Turnip
Brassica napus	Rape
Brassica nigra	Black Mustard
Brassica oleracea	Wild Cabbage

Brassica rapa	Turnip
Braya	
Bunias erucago	Southern Warty-cabbage
Bunias orientalis	Warty-cabbage
Cakile maritima	Sea Rocket
Calepina	
Camelina	
Capsella bursa-pastoris	Shepherd's Purse
Capsella heegeri	
Capsella rubella	Pink Shepherd's Purse
Cardamine amara	Large Bitter-cress
Cardamine bulbifera	Coralroot
Cardamine enneaphyllos	
Cardamine glanduligera	
Cardamine hirsuta	Hairy Bitter-cress
Cardamine impatiens	Narrow-leaved Bitter-cress
Cardaminopsis	
Cheiranthus	
Cleome dodecandra	
Cleome spinosa	
Cochlearia auriculata	
Cochlearia officinalis	Common Scurvy-grass
Conringia orientalis	Hare's-ear Mustard
Coronopus didymus	Lesser Swine-cress
Crambe cordifolia	Greater Seakale
Crambe koktebelica	
Crambe maritima	Seakale
Crambe tatarica	
Diplotaxis muralis	Annual Wall-rocket
Diplotaxis tenuifolia	Perennial Wall-rocket
Draba	

Eruca vesicaria	Garden Rocket
Erysimum cheiranthoides	Treacle Mustard
Erysimum helveticum	
Erysimum sylvestre	
Hesperis matronalis	Dame's Violet
Hirschfeldia incana	Hoary Mustard
Iberis amara	Wild Candytuft
Iberis crenata	
Iberis imperialis	
Iberis odorata	
Iberis pinnata	
Iberis sempervirens	Perennial Candytuft
Isatis tinctoria	Woad
Lepidium cartilagineum	
Lepidium draba	Hoary Cress
Lobularia maritima	Sweet Alison
Lunaria annua	Honesty
Malcolmia africana	
Matthiola	
Moricandia arvensis	Violet Cabbage
Myagrum perfoliatum	Mitre Cress
Neslia	
Peltaria	
Raphanus raphanistrum	Radish
Raphanus sativus	Garden Radish
Rhynchosinapis	
Rorippa amphibia	Great Yellow-cress
Rorippa nasturtium-aquaticum	Watercress
Rorippa palustris	Marsh Yellow-cress
Sinapis alba	White Mustard
Sinapis arvensis	Charlock

Sisymbrium altissimum	Tall Rocket
Sisymbrium officinale	Hedge Mustard
Sisymbrium orientale	Eastern Rocket
Sisymbrium supinum	
Teesdalia nudicaulis	Shepherd's Cress
Thlaspi arvense	Field Penny-cress
Thlaspi brevistylum	
Thlaspi perfoliatum	Perfoliate Penny-cress
Zilla spinosa	
Fabaceae	
Anthyllis vulneraria	Kidney Vetch
Medicago	
Pisum sativum	Garden Pea
Trifolium	
Papaveraceae	
Chelidonium	
Meconopsis	
Papaver	
Resedaceae	
Reseda alba	White Mignonette
Reseda crystallina	
Reseda lutea	Wild Mignonette
Reseda muricata	
Reseda odorata	Garden Mignonette
Tropaeolaceae	
Tropaeolum majus	Nasturtium
Tropaeolum peregrinum	Canary Creeper