Project Title	**Management and biology of flea beetle species and other key pests of leafy Brassica crops**
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The results and conclusions in this report are based on a series of experiments conducted over a one-year 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

We declare that this work was done under our 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

- Netting covers, bifenthrin, spinosad and clothianidin in formulated products, all reduced flea beetle damage significantly, although to different extents. Netting covers had the additional benefits of providing protection against a complex of pests and of increasing the rate of crop growth, which resulted in significantly greater and higher quality yields.

NOTE: None of these actives are approved for use on baby leaf brassicas in the UK.

Background and expected deliverables

Growers identified the Brassica flea beetle complex as an increasingly important problem and designated it a research priority (HDC research strategy & Pesticide Gap Analysis, 2005). Feeding activity by flea beetle adults causes 'shot-holes' in the leaves of the crop and this significantly reduces quality and thus marketability and revenue. In addition to flea beetles, speciality salad and leafy vegetables are also attacked by a range of other insect pests including caterpillars such as the diamondback moth.

Brassica flea beetle control is a challenge, partly because some insecticides that were used in the past are no longer available to growers. The situation is made worse by the increase in rape acreage (source of immigrant pests) and because of reduced use of insecticide on rape. Several potentially useful insecticides such as spinosad and neonicotinoids that could offer growers some additional choices to manage flea beetles are being evaluated within this project. It is also an option within the project to assess the potential of some new experimental products, because there is a risk that flea beetles will develop insecticide resistance, if growers are forced to rely only on the existing small number of active substances.

In addition to the use of insecticidal sprays, there are some other potentially useful pest management technologies. One possibility is the use of seed coated with a film of pesticide. Such seed treatments are already available for several fodder Brassica crops. Previous research on cabbage and cauliflower has shown that flea beetle damage could be reduced with imidacloprid. However imidacloprid was ineffective at controlling cabbage root fly and caterpillars. Results with spinosad have been inconclusive. Ester *et al*., 2003 found that it was ineffective at controlling flea beetles, but gave good control of cabbage root fly. Other work seems to indicate that spinosad may have a useful effect on flea beetles, so there was a need for further work to clarify the situation.

Another potential non-chemical control tactic is the use of trap crops. This has been investigated recently in the UK, but few practical recommendations of use to growers came out of this research (Parker *et al*., 2002). The main problem with using trap crops is that high-value leafy Brassicas are extremely attractive in their own right to Brassica-feeding flea beetles.

One well proven control technique is use of physical barriers, particularly meshes such as Wondermesh and Enviromesh, although some growers use fleece, plastic sheets or glass to protect this category of high value crop. Meshes protect crops against many insect pests but are expensive. They are considered cost-effective, particularly on crops for which very low numbers of insects can quickly destroy the quality and value of the crop. A physical pest management technique such as a mesh barrier is not always enough to protect the crop from insect damage. Some pests can either feed through the mesh or enter the crop underneath the mesh at the edges. Insecticidal sprays are the normal practice to reduce this problem.

There is little published data available on the biology of flea beetles in the United Kingdom and so information on emergence patterns, the sources of infestation, movement and behaviour of different flea beetle species is limited or unavailable.

The project aims to carry out research on new pest management technologies and practices of potential use to speciality salad and leafy vegetable growers, as well as to provide an improved understanding of Brassica flea beetle life-history traits and behaviours which should aid the development of more effective pest-management practices.

The project has several main lines of research. One aim is to find out if it is possible to reduce reliance on mesh barriers, use them more cost-effectively, or use mesh impregnated with insecticide. A second aim is to identify additional insecticides that could potentially be used to bolster the limited range currently available to growers of speciality salad and leafy vegetables. The third aim is to find out more about the behaviour and biology of flea beetles in relation to current pest management practices.

This report describes the findings of the first year of the project, which involved the following activities:

- Assess whether or not any flea beetle larvae over-winter or develop in the various types of cropping areas on the farm.
- Prioritise experimental treatments with stakeholders in the industry.
- Obtain product samples from manufacturers.
- Establish flea beetle colonies in the NRI insectary.
- Obtain experimental approval and a licence from the PSD.
- Carry out a field trial to compare different treatments that use insecticides, meshes, or both. Three insecticide treatments were assessed, which are not currently registered for use on leafy Brassicas. One of the mesh treatments used a woven plastic that had been impregnated with deltamethrin during manufacture.
- Analyse the data in order to assess the efficacy of the different treatments (year 1)
- Prioritise treatments for the next field season in 2008 (year 2).
- Translate findings into control tactics or recommend products suitable for registration for use on leafy Brassicas.

Summary of the project and main conclusions

Six treatments involving various combinations of meshes and/or insecticides were tested on farm to assess ways to improve flea beetle protection on leafy Brassica crops. The trials were carried out on a farm near Deal in Kent during June 2007. The main conclusions that can be drawn from the data collected this year are that:

- Flea beetle adults migrated into the crop fields, rather than emerged from the soil within the fields.
- All of the mesh treatments protected the crops from damage caused by insect pests to a significant degree.
- Meshes gave improved protection from insect pests when insecticide sprays were also applied periodically.
- Meshes increased plant growth rate significantly.
- Meshes protected crops from bird and mammal attack.
- Holes in non-insecticide impregnated mesh allow insects to enter the crop and reduced their pest control benefits significantly. Meshes can be joined or holes repaired using a hot glue gun.
- Several insecticides provided significant protection even when the crop was not covered by mesh.
- The two most promising insecticides tested were bifenthrin and spinosad and these may potentially be worth registering for use on these or other Brassica crops.
- Flea beetles can escape from some sticky trap surfaces and so other ways of monitoring the population are required.
- The flea beetle species life cycles take between 6 to 8 weeks in the insectary and involve a relatively long component as root feeding larvae in the soil. This period is longer than the duration of most leafy Brassica crops and so carry over of pests from one crop to the next on the farm is highly unlikely.

Financial benefits

A cost-benefit analysis of the different treatments has not been carried out, but some are clearly highly effective at protecting the crop. The research has identified two insecticides that are potentially of use for flea beetle management.

The insecticide-impregnated netting is potentially interesting. Although it is significantly more expensive to produce than untreated meshes, it potentially eliminates the need and costs of spraying. However the treated netting used in the trials was new and it is probable that its efficacy would decrease over time. Growers use their current netting continuously for up to 5 years and so, ideally, the insecticide-impregnated netting would need to retain its activity for this long.

Action points for growers

- Products containing bifenthrin and spinosad may be considered suitable candidates for registration for use on leafy Brassicas against flea beetles.
- When using meshes, holes and unsealed edges are the main entry points for flea beetles into the crop and result in damage from immigration. For periods when the immigrant pest pressure is particularly high, it may be worth developing a technique that creates a better seal at the edges of the mesh.
- Holes in mesh can be patched using a hot glue gun to fix the patch in place.
- Flea beetle immigrants were detected as soon as the first crops germinated and so it may be worth using protective mesh covers earlier in the season
- Meshes appear to affect the crop microclimate and have a highly significant additional effect of speeding up the rate of crop growth.

Science Section

Introduction

The Brassica flea beetle complex was identified as a priority researchable topic (HDC research strategy & Pesticide Gap Analysis, 2005). The increasing importance of these pests on Brassicas and, in particular speciality salad and leafy vegetables, may be related to reduced insecticide use on oil seed rape crops, which allows high populations to build up and subsequently emigrate from them. P*hyllotreta undulate*, *P. atra* and *P. diademata* are the main species in the pest complex. Adult feeding causes 'shot holes' in the crop (Fig. 1), which significantly reduce quality and thus marketability. In addition to flea beetles, speciality salad and leafy vegetables are also attacked by a range of other insect pests including caterpillars such as the diamondback moth (DBM), the cabbage stem weevil, *Ceutorhynchus pallidactylus*, and the cabbage stem flea beetle, *Psylliodes chrysocephala*, which has become the most important establishment pest in autumn grown crops in the UK (Winfield, 1992; Walters *et al*., 2001). Control of flea beetles is an increasing challenge, because some insecticides that were used in the past are no longer available to growers. However, several potentially useful insecticides such as spinosad and neonicotinoids could offer growers some additional choices to manage these highly damaging pests. It may also be useful to assess the potential of some new unregistered products, because there is risk of resistance developing if growers are forced to rely on the existing small number of active substances.

Figure 1. Flea beetle adult and shot holed leaves. Pigeon damage to leaf in bottom left-hand-side of the picture.

Some previous work with insecticides such as spinosad and imidacloprid gave equivocal results. A report on field experiments with cabbage and cauliflower crops indicated that flea beetle damage could be reduced with imidacloprid, but that it was ineffective at controlling cabbage root fly and caterpillars. Previous experimental trials with spinosad (Ester *et al*., 2003) had indicated that spinosad was ineffective at controlling flea beetles, but gave good control of cabbage root fly, while other work indicated that spinosad may have a useful effect on flea beetles. These conflicting findings indicated that further work was needed to clarify the potential usefulness of these insecticides.

Another potential non-chemical control tactic was the use of trap crops, and this has been investigated recently in the UK. Unfortunately, few practical recommendations came out of this research (Parker *et al*., 2002). One serious problem with using trap crops would be that high-value leafy Brassicas are extremely attractive in their own right to Brassica-feeding flea beetles and it is unlikely that there are plant species that are more attractive than the crops themselves. Research on Chinese cabbage as a trap crop grown in white cabbage showed no difference in the numbers of flea beetle adults or in the damage when the crop was grown either in monoculture or as a mixed crop (Trdan *et al*., 2005). Trap crops have several other drawbacks in that they utilise space and resources, may sometimes draw more pests into the area, and trap crops do not generally address the problems caused by other key pests that attack the crop.

One control technique with proven success is use of physical barriers that prevent the pest from having access to the crop. Growers use various types of barriers such as fleece, plastic sheets, glass or meshes such as Wondermesh and Enviromesh to protect high value crops. For the leafy vegetable (salad) crops, meshes protect against several insect pests and despite their significant cost (*c*. £400 for a 13 m width x 50 m length) they are considered necessary and cost-effective, because even a very low numbers of insects can destroy the quality of the crop. Physical barriers alone are not always enough to protect from insect damage and additional sprays of insecticide may be needed. Reasons for this are that insects get in at the edges or lay eggs on the mesh and the tiny newly hatched first instar larvae crawl through the mesh on to the crop, where they cause damage. Meshes also prevent the departure of any pests that manage to reach the crop or emerge from within the soil so in some circumstances they may be counter productive unless combined with pesticides.

There is little published data available on flea beetles in the United Kingdom so information is sparse describing their patterns of emergence, movement and behaviour. Flea beetle pressure is not constant throughout the season and unpublished trap data for 2004 and 2005, provided by Intercrop Ltd, showed that there are two peak periods of adult flea beetle immigration into the crops in late May to early June, and August to September. The flea beetle control trial crop was sown at the start of June 2007 to target the first of these two peaks.

Materials and Methods

Establishing a flea beetle colony

At the start of the project in September 2006, *P. atra* flea beetle adults were collected from the Intercrop farm and maintained under a long photoperiod 14:10 h (L:D) and relatively high temperatures (23-25oC) in the NRI insectary. Insects were confined in perspex cages and were fed on trays of leafy salad Brassica species growing in soil. The adult insects were left to oviposit and the larvae were allowed to develop in the soil.

In early July 2007, adult populations of *P. undulate*, the small striped flea beetle, and *P. nigripes*, one of the turnip flea beetles, were collected from the Intercrop farm and maintained under a long photoperiod 14:10 h (L:D) and relatively high temperatures (23-25oC) in the NRI insectary. Groups of five adults of the same species were introduced onto Pak choi plants growing in plastic pots that were covered with ventilated clear plastic propagator lids. The adult insects were left to oviposit and the larvae were allowed to develop in the soil. Any surviving adults were removed after three to four weeks.

Adult specimens of each of the flea beetle species have been stored in 70% alcohol, so that their identity can be confirmed by a coleopteran taxonomist.

The flea beetle over-wintering and emergence study

One of the key questions posed at the start of this study was the extent to which flea beetle adults emerge from the soil in the fields that are used to grow leafy Brassica crops. If this proved to be a significant source of flea beetles, it would be problematic for growers because the meshes covering the crops would prevent the departure of the emerging adults – a scenario which would potentially result in very high levels of damage. It was important, therefore, to determine whether or not any beetles emerged from the soil in the farm's fields, particularly early in the year, as these individuals that had over-wintered successfully on the farm would need to be controlled before sowing new season crops.

Two types of trap (Fig. 2) were used in five locations on the farm to assess emergence. One design consisted of a wire frame covered with mesh. The frame was bent into a tunnel to allow the unrestricted growth of enclosed plants and to leave space for a yellow sticky trap to be positioned in the middle of the emergence cage. The other trap type consisted simply of a length of mesh, under which two grey cylinders were placed vertically. The outer surface of the cylinders was covered in yellow sticky 'roller trap', in order to catch any emerging insects. The mesh edges of both types of trap were carefully buried under the soil to prevent any beetles entering or escaping via the edges of the cages. The yellow sticky traps, the netting and the plants within the emergence cages were examined periodically for flea beetles.

Figure 2. The two types of emergence cage in a caliente crop. The yellow sticky traps can be seen inside.

On the 3rd March 2007, the second type of emergence cage was set up at four locations on the farm. These cages were covered in the finer Wondermesh as the hole size of the original mesh could have allowed the small species of flea beetles to pass through. The locations were as follows:
Location 1 - under an enclosed, covered growing area;
Location 2 - a field growing Caliente
Location 3 - a tilled field devoid of vegetation near Closes' Bottom;
Location 4 - rows of an old crop of Red mustard.

On the 23rd March, an additional cage was set up at a fifth location, Donkey Bottom, in a Tatsoi crop. The Wondermesh in this instance was placed underneath the perforated plastic, which is used at the beginning of the season to raise soil temperature.

The emergence cages and yellow traps underneath them were monitored periodically until the 18th May 2007 to look for emerged insects.

On the 2nd February, soil samples taken from an old crop of red mustard were collected and brought back to NRI, where they were kept outdoors, covered with netting and periodically moistened. Samples were checked weekly for any insect emergence.

Experimental field trial

Decisions about experimental control treatments and obtaining samples from manufacturers

In consultation with HDC personnel and the Intercrop farm staff, seven insecticides that were considered to be potentially useful against flea beetles were obtained from agrochemical companies. Some of these were coded development products that have not yet been registered in the United Kingdom. Others were products registered for other crops (not including leafy salads), but which fulfilled the criteria of being active against species of Coleoptera and/or flea beetles specifically, and had a short pre-harvest interval. For the field trial in this first year, the registered products spinosad, clothianidin and bifenthrin were considered to be the ones of most immediate interest and so these were the insecticides used in the trial. In all there were six treatments plus an untreated control and each treatment was replicated three times.

Compliance with statutory regulations

In order to carry out field trials in the United Kingdom, it is necessary to comply with criteria laid down by the Pesticides Safety Directorate. An Administrative Experimental Approval for Research and Development Work was obtained and the personnel that carried out the trial had obtained certification (PA1 and PA6) in application of pesticides in accordance with the regulations on use of experimental pesticides.

Experimental crop and timing

The crop Tatsoi, variety 'Tozer', was used in the trial as it highly attractive to flea beetles and they can cause damage that reduces the value significantly, even at low levels of infestation. Tatsoi has a short growth period and flea beetle and other types of damage are clearly visible on the crop, making it a good choice for the trial.

Insect trapping data for 2004 and 2005, provided by Intercrop Ltd, showed that flea beetle pressure is not constant throughout the season and that there are two peak periods of the adult flea beetle populations that occur in late May to early June and in August-September. It was therefore decided to start the field trial using a crop sown at the beginning of June to target the first attack peak.

Treatments in the field trial

[Table 2 contains details of the product and rates applied]

1. Untreated control. No insecticides were applied or meshes used to cover beds.
2. Wondermesh alone (without any sprays). The plots were covered with Wondermesh three days after sowing. The edges of the mesh in this treatment were buried under soil to prevent insect movement into or out from underneath the mesh. No insecticides were used on this treatment.
3. Wondermesh with deltamethrin (Protech®) sprays (standard farm practice). Plots were covered in Wondermesh at the standard time (three days) after sowing and during the experimental period the crop was sprayed using the same timing as used by the farm agronomist for the rest of the crop and using

the same product – deltamethrin (rate and dates when crop was sprayed appear in Tables 1 and 2). Plot edges were not sealed with soil, but were pinned down every metre with tent pegs.

4. Yellow insecticide-impregnated mesh. Plots were covered an experimental yellow mesh that had been impregnated with deltamethrin during manufacture. This treatment was not sprayed with any additional insecticide during the trial. Plot edges were not sealed with soil, but were pinned down every metre length.
5. Clothianidin (coded product). Plots were sprayed with clothianidin (rate and dates in Tables 1 and 2). These plots were not covered with mesh.
6. Spinosad (Tracer®). Plots were sprayed with spinosad (rate and dates in Tables 1 and 2). These plots were not covered with mesh.
7. Bifenthrin (Talstar®). Plots were sprayed with bifenthrin (rate and dates in Tables 1 and 2). These plots were not covered with mesh.

Table 1. Timing of the trial activities during the 2007 season.

Date	Assessment of crop for damage and pests	Spay treatments applied and weather notes
Day 1 Crop sown (2nd June) Tatsoi	No	No
Day 2 Plots irrigated	No	No
Day 3 Propachlor herbicide applied to all plots	No	No
Day 4 Plots marked out	No	No
Day 7 Meshes applied Wednesday 6 June	No	No
Day 9 (start of spraying) Monday 11 June 2007	Yes	Yes (farm sprayed adjacent crops the same day but they mix the fertiliser phosphate in the spray).
Day 14 Friday 15 June	No	Yes. Note heavy rain between spray 1 and 2
Day 18 Tuesday 19 June	Yes	Yes. Heavy rain between spray 2 and 3
Day 21 Friday – crop harvested after 18 days from sowing	Yes and yield weight of 4 samples per plot recorded	No

Table 2. The volumes and weights (for granules) of the different products and active substances used in the trial plots*

Product and recommended dose rate	**Quantity (units) per experimental plot**	**Quantity (units) for three plots**	**Quantity prepared allowing for dead spray in tank**
Tracer (Spinosad) 480 g/l Use at 250 ml/ha	0.25 (ml)	0.75 (ml)	1.0 (ml)
Talstar (Bifenthrin) 80g/l use at 90 ml/ha	0.09 (ml)	0.27 (ml)	0.36 (ml)
Coded product (Clothianidin) 150g/ha every 2 weeks	0.15 (g)	0.45 (g)	0.60 (g)
Protech (Deltamethrin) 1.5% Farm rate is 0.42l/ha	0.42 (ml)	1.26 (ml)	1.68 (ml)
Volume of spray liquid per plot	400 (ml)	1200 (ml)	1600 (ml)

*The rate of product in column 1 was that recommended by the company that supplied the sample. For all sprays the volume rate was equivalent to 400 litres per hectare as used on the farm.

Simulation of the farm's spray regime

In order to use the same spray volume rate as that applied on the farm (400 litres per hectare), the volume of spray liquid applied to each plot was 400 ml. The spray was applied using a Hozelock 5 litre compression sprayer. Sprayers (one was used to apply each treatment) were calibrated on the 1st June 2007. The sprayers were set to give a flow rate of 400 ml per minute. This was achieved by pumping 50 times after 1600 ml of spray liquid had been put in the sprayer. Although only 1200 ml (400 ml x 3) was needed for the trial, dead volume in the sprayer (spray liquid remaining after the spray became intermittent) meant that an additional 400 ml was required in the container (making a total of 1600 ml of spray liquid for each treatment).

Spray protocol to ensure a precise insecticide dose

Compression sprayers are pumped up before use. In this case, 50 compressions (pumped 50 times) gave the desired flow rate for treating a plot. When liquid is emptied from the reservoir during spraying, the pressure falls and the flow rate is reduced. Laboratory tests prior to the fieldwork had showed that this would have affected the dose applied to the second plot. To compensate for the fall in pressure after one minute of spraying (spraying a single plot) it was found that the sprayer needed to have 7 additional pumps before the next minute of spraying to reinstate the original pressure. After the second plot had been sprayed another 7 pumps were needed. In this way the same flow rate of 400 ml per minute and spray quality was retained for all three replicates.

The trial land

The trial was carried out on the Intercrop farm in fields at Bramble Hill (Grid ref. from GPS: N 51o 14' 21.8'' E 001o 18' 47.1'') on land kindly provided by Intercrop (Figures 3 and 4). Originally we had planned to do a fully randomised trial and confine the 21 plots in the experiment to a single bed of crop. However with such a long linear layout of plots (approx 130 m) we concluded that significantly different conditions would be likely between the plots at the far extremes of the proposed layout. We therefore agreed with the Farm Manager to use three adjacent beds along a 40 m length of the field. The experimental area also included an untreated guard strip at each end of the layout. An un-sprayed area of crop separated the plots along each row.

Figure 3. Trial layout at the beginning of the experiment.

	Bed 1		Bed 2		Bed 3	
	Yellow treated mesh		Clothianidin		Control	
	W. Mesh + deltamethrin		Bifenthrin		W. Mesh only	
	Bifenthrin		Control		Clothianidin	
	Spinosad		W. Mesh + deltamethrin		Yellow treated mesh	
	W. Mesh only		Yellow treated mesh		Bifenthrin	
	Control		W. Mesh only		Spinosad	

Figure 4. Layout of trial plots. The trial was surrounded by an unsprayed row of guard crop to provide a buffer between it and the surrounding commercial crops, which were sprayed regularly with insecticide.

Spray application parameters

Sprayers used on farm are fitted with flat Lurmark Drift-beta nozzles in front of flat fan nozzles. Both apply spray simultaneously at a total rate of 400 litres per Ha. For the experimental spray treatments, compression sprayers (Hozelock 5 litre Killaspray) were used to apply the sprays including the spray treatment that simulated the standard farm practice (treatment 3). The volume for experimental spray plots to mimic the farm application rate is calculated as: 400 * 10/10000 litres = 0.4 litres per plot.

There were three replicates for each treatment. Total spray liquid applied to plots for each spray treatment was 3 x 0.4 = 1.2 litres. However, to allow for the dead volume in the bottom of the spray tank we mixed 1.6 litres. Surplus spray liquid was applied to an adjacent grassed area of the farm.

When treating the plots, the operator sprayed from the side of the plot to avoid walking on the bed. The spraying operation was rehearsed several times with water to practice achieving an even coverage at the required volume rate. The compression sprayers (one for each chemical) had been set to give 400ml/min flow rate before the trial, so each plot had to be sprayed for 60 seconds. To help pace the operator, ten second intervals were called out by a colleague.

The flow rate of 400ml/min was set by putting into the sprayer 1600 ml of spray liquid, then pumping 50 times before spraying the first plot. After completing a plot the sprayer was then pumped a further 7 times before spraying the next plot to maintain pressure and flow rate.

The plots required small quantities of the four supplied pesticide formulation (three liquids, one solid) so these quantities (Table 2) were measured by weight on a four figure balance. All samples were pre-prepared and held in sealed, labelled glass bottles before use.

Mesh-based treatments

The farm's standard treatment involves mesh placed over the beds with weighted bags used to hold down the edges and the ends. The hole size is approximately 0.6 mm. Farm mesh is 13 m x 50m (cost £400). The 13 m width can cover five beds.

To simulate this standard treatment, the mesh in treatment 3 was pinned down with tent pegs along the sides of the bed and covered with soil at the ends of the plots. The ends were covered, because it was considered that there would be much more opportunity for insect entry at these points, which would not be present in the standard treatment.

The Wondermesh only treatment (number 2) was sealed with soil all around the edge to prevent insects from moving in or out of this treatment.

The yellow mesh (treatment 4) was an experimental product. It consisted of a wide-weave fabric, with variable ovoid holes that ranged in size between 0.5 – 1.3 mm in length and 0.3 – 0.8 mm in width, which had been impregnated during manufacture with deltamethrin. Supplied in widths of 1.5 metres, this particular mesh required that two widths be joined to make a sufficiently wide piece for the beds. After experimenting with a range of adhesives, a hot glue gun was found to make sufficiently strong joints between two strips. The glue had to be worked into the double layer of mesh with a wood spatula before the glue cooled. After joining the two lengths, the mesh (now 3 m wide) was cut down to a width of 2.5 m. No sprays were applied to this treatment.

Assessment of crop damage and counts of insects

Before the trial and periodically following treatment, the crop was inspected and assessed quantitatively for presence of insects in the crop and for damage to the leaves. Twenty plants in each plot were selected randomly for assessment (30 plants in the final assessment). To select individual plants for assessment a die was thrown on to the soil. The nearest plant to the die was assessed. If two or more plants appeared to be equidistant from the die, the plant which faced either the facet with two spots or one spot was assessed. The number of points of damage were counted and recorded. Care was taken to avoid confusing marks caused by soil splash with damage caused by flea beetles. Holes per plant were counted and recorded after examining every leaf of the selected plant.

Flea beetle movement

Insect pests are commonly captured on a glue-covered surfaces referred to as a sticky traps. Yellow is known to be attractive to a wide range of insects and so this colour of sticky trap was tried. To hold the sticky traps, 2 inch diameter grey drain pipes were inserted into the soil as vertical poles. Yellow Roller trap was then applied around the pipes in 6” bands. At the start of the trial, these were at placed at 65 cm above ground level. Additional traps were added at a height of 8” from the soil surface, when it was realised that the initial set of traps were not catching any flea beetles. Counts were made of the numbers and species of trapped insect.

Flea beetle behaviour and emergence in relation to the mesh covers

On a warm sunny day during the trial (day 9), the rate of insects landing on the different mesh treatments and was recorded and their subsequent behaviour observed.

Survey of flea beetle management practices

It is planned to carry out this activity during the coming winter months, when growers will have more time to interact with the research team.

Results and Discussion

Flea beetle colonies

The *P. atra* colony was maintained for two generations in the insectary (Figure 5). Adults survived three to four weeks and the larvae caused substantial damage to the roots of young plants, some of which were killed by their feeding. The egg and larval developmental period was approximately eight weeks and there was no evidence of individuals entering diapause (a physiological state of arrested development for avoiding adverse environmental conditions such as cold temperatures), under the rearing conditions experienced in the insectary. In the second generation, only four adults emerged and it is thought that the reduction in the population was due to the difficulty in keeping the host plants healthy in the perspex cage for the two month period. The colony did not produce a third generation of adults and another attempt is being made to establish this species this autumn (August-September 2007).

The *P. undulate* and *P. nigripes* adults survived for up to four weeks on the Pak choi plants and emergence of the first generation began on 14/08/07 for both species. The developmental period for the eggs and larvae of both species, therefore, was approximately six weeks. For the colony, this result is encouraging because if larger populations can be maintained, flea beetles will be available for experimentation throughout the year. For all species, however, the numbers of adults emerging declined each generation. A probable reason for this is that the quantity and quality of host-plant roots may not be sufficient to support a large number of flea beetle larvae. We therefore intend to try rearing the beetles on wild Brassica species such as Field mustard (charlock), *Sinapis arvensis*, and Black mustard, *Brassica nigra*. Seeds of these potential host-plants have been obtained and sown.

Figure 5. Newly emerged flea beetle adults in the insectary at NRI (LHS). Damage caused to host-plants by the feeding activity of five adult *P. undulata* (Kutschera), the small striped flea beetle (RHS).

Overwintering and emergence study

Monitoring of the flea beetle populations began on the 23rd February 2007 and low numbers of adults were observed in the farm fields, particularly near an old crop of Red mustard.

The mesh size used for the original tunnel-shaped emergence cages proved to be slightly too large, which allowed the smallest species of flea beetle to pass through the mesh. The information that could be obtained for these species, therefore, was of limited value, i.e. it was not possible to determine whether or not the flea beetles observed inside the cage had emerged from the soil underneath it (see below). The larger flea beetle species, that was present at the end of the previous summer, was not observed either within or outside these cages.

From February to May and beyond, in the vicinity surrounding the farm, there were large areas of mature Brassica crops, such as cauliflower, as well as large areas of grassland with wild and volunteer Brassicas. There is clearly a Brassica 'green bridge' throughout the winter period in this area, which could support all of the developmental stages of the smaller flea beetle species. On the 16th of March, for instance, the numbers of flea beetles landing on the external surface of the emergence cages was 4-5 adults every 10 minutes. No flea beetles, however, were either seen or caught inside the flat Wondermesh emergence cages, so no emergence from sampled areas of farm soil occurred.

By the 18th of May, a large number of fly (Diptera) species and some diamondback moths had been caught on the yellow traps underneath the emergence cages. The only flea beetles that were caught appeared on the 16th of March in the emergence cage covering the Red mustard. Six adults were trapped on the yellow sticky traps. Due to the amount of old foliage present underneath the emergence cage when it was set up, it is possible that these adults may also originally have been immigrants.

The emergence cage placed underneath the perforated plastic at the fifth location proved informative. Immigrant flea beetle adults were already clearly already active at this time of year (March) and passed through the perforated plastic into the germinating Tatsoi crop. When the emergence cage was removed on the 18th May 2007, the crop underneath the emergence cage showed no sign of flea beetle damage, but shot holes were present in the adjacent crop, which had been unprotected at germination.

No flea beetles emerged from the field soil brought back to NRI.

The conclusions that can be drawn from the emergence study are that:

- Old Brassica crops, such as the location with the Red mustard, may provide a limited source of emerging flea beetle adults early in the season;
- No flea beetle emergence took place within the emergence cages in the crop-free tilled field, the winter planted Caliente, the sealed and covered tunnel location or the newly planted Tatsoi crop.
- Immigration of flea beetle adults onto the farm probably took place at a low level throughout the winter and pest pressure was already high by the 16th of March 2007.

Field trial

On day 18 of the trial, a damage assessment was conducted. Mesh covers, bifenthrin, spinosad and clothianidin had all reduced flea beetle damage significantly, although to different extents. Even with a mesh hole size through which the smaller flea beetle species could theoretically pass, the insecticide-impregnated netting was highly effective at reducing damage (Figure 6). Dead insects of several Diptera (fly), Coleoptera (beetle) and Lepidoptera (moth) species were observed frequently on the surface of this mesh (Figure 7).

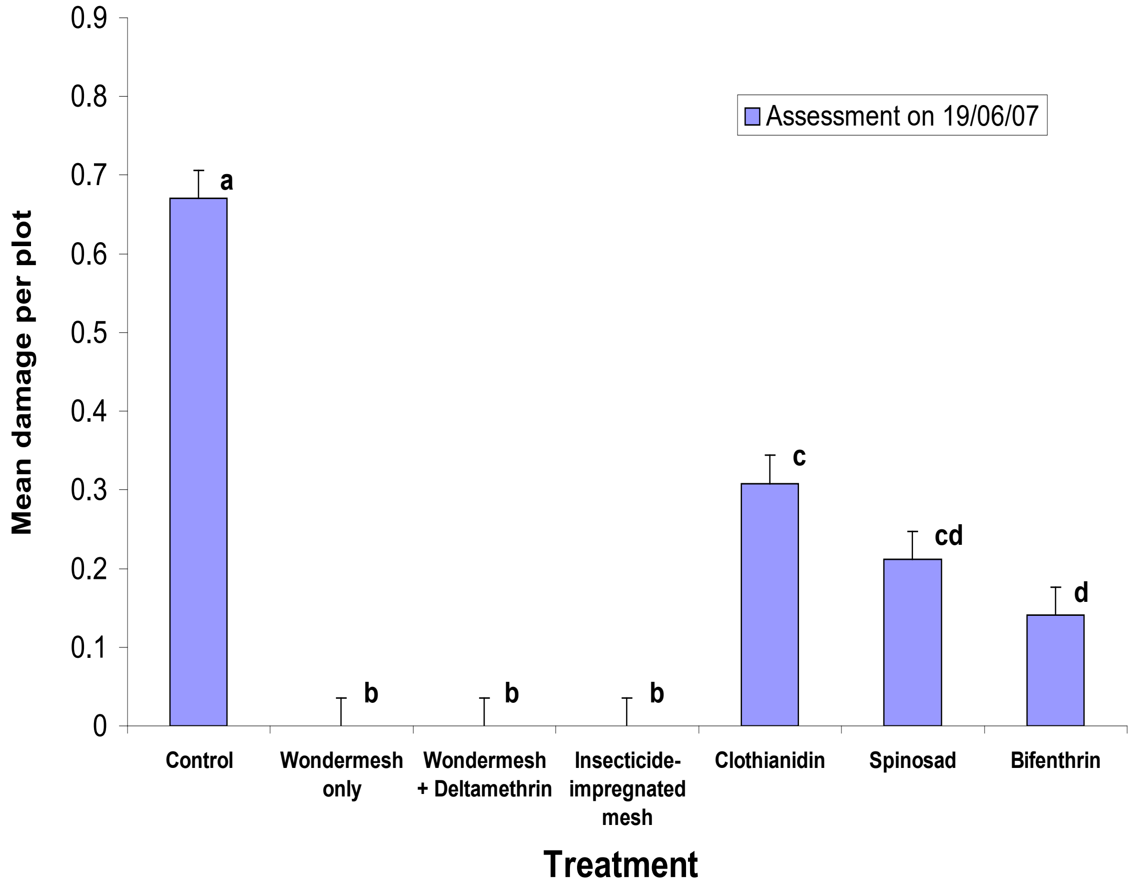

Figure 6. The mean damage caused to the plots of Tatsoi by flea beetles in the experimental trial on 19/06/07 (day 18 after sowing)*

*Damage data were collected by counting the number of shot holes in 20 randomly selected plants per plot, which were $Log_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of differences of means.

Figure 7. Photo showing diamondback moth killed on insecticide-impregnated yellow mesh.

The trial ended on 22/06/07 (day 21) and a second damage assessment was carried out. The same pattern was apparent, except that by then there had been some slight damage to the mesh-covered treatments (Figure 8). This was almost all due to diamondback moth larvae that had successfully managed to enter these plots. The insecticide treatments, spinosad and bifenthrin, provided reasonable protection against flea beetle damage, although this level is probably not acceptable to the growers, customers or consumers. For growers of other types of Brassica crops such as Brussels sprouts and cabbage, the reduced level of damage might be acceptable at some times in the crop growing cycle. The degree of protection from insect attack may mean that these insecticides may be of interest.

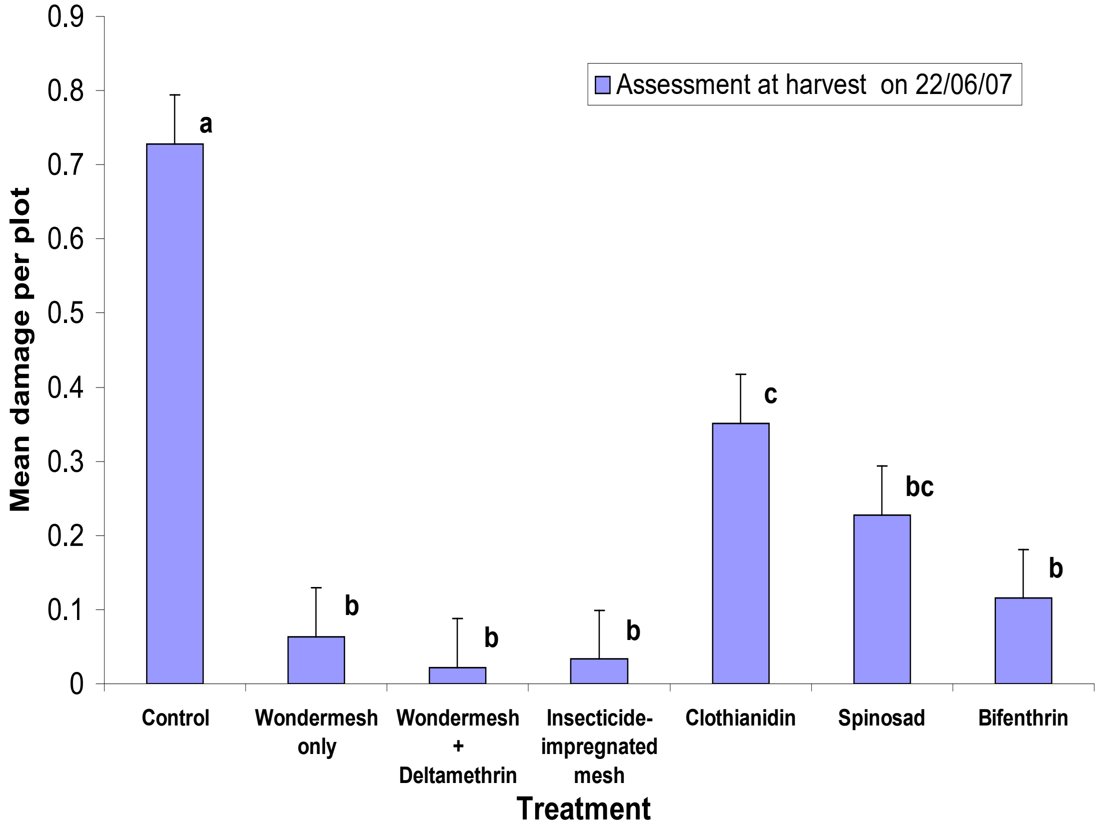

Figure 8. The mean damage caused to the plots of Tatsoi by flea beetles in the experimental trial at the point of harvest on 22/06/07*

*Damage data were collected by counting the number of shot holes in 30 randomly selected plants per plot, which were $Log_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of differences of means.

The uncovered treatments (plots without mesh) also suffered damage by pigeons (see Figures 1 and 9) and farm staff informed us of damage to un-covered crops also caused by hares and rabbits. It is apparent, therefore, that leafy Brassica growers are faced with a complex of serious pests and the mesh covers provide good protection against more than just insect pests.

The yellow insecticide-impregnated mesh, which received no additional insecticide during the trial, provided the same level of protection as the other mesh treatments. Its main attraction to growers is that it would reduce the need for spraying, saving on product, machinery and labour costs. Its main drawbacks, however, are that it is more expensive to produce than non-impregnated mesh and the current activity of the deltamethrin it contains may drop off significantly after one year. This is a major consideration for growers, who get intensive and prolonged use from their current mesh, i.e. the same mesh is used both in southern Europe and the UK and its life-expectancy is five to six years.

The mesh covers had the additional benefit in that they increased the rate of growth of the crop, resulting in significantly greater yields for the period of the trial (Figure 10). This must be due to the different micro-climates experienced by the plants in these plots, which were growing in a windy location. Thus, the advantage of the mesh goes beyond that of insect protection and brings a very significant secondary benefit. A faster growing crop has several advantages in that crop turn-around is quicker, the time available for pest attack is reduced as well as the number of pesticide sprays that are needed.

Leaf samples from each of the treatments have been kept at -80^{o}C at NRI for residue analysis, if required.

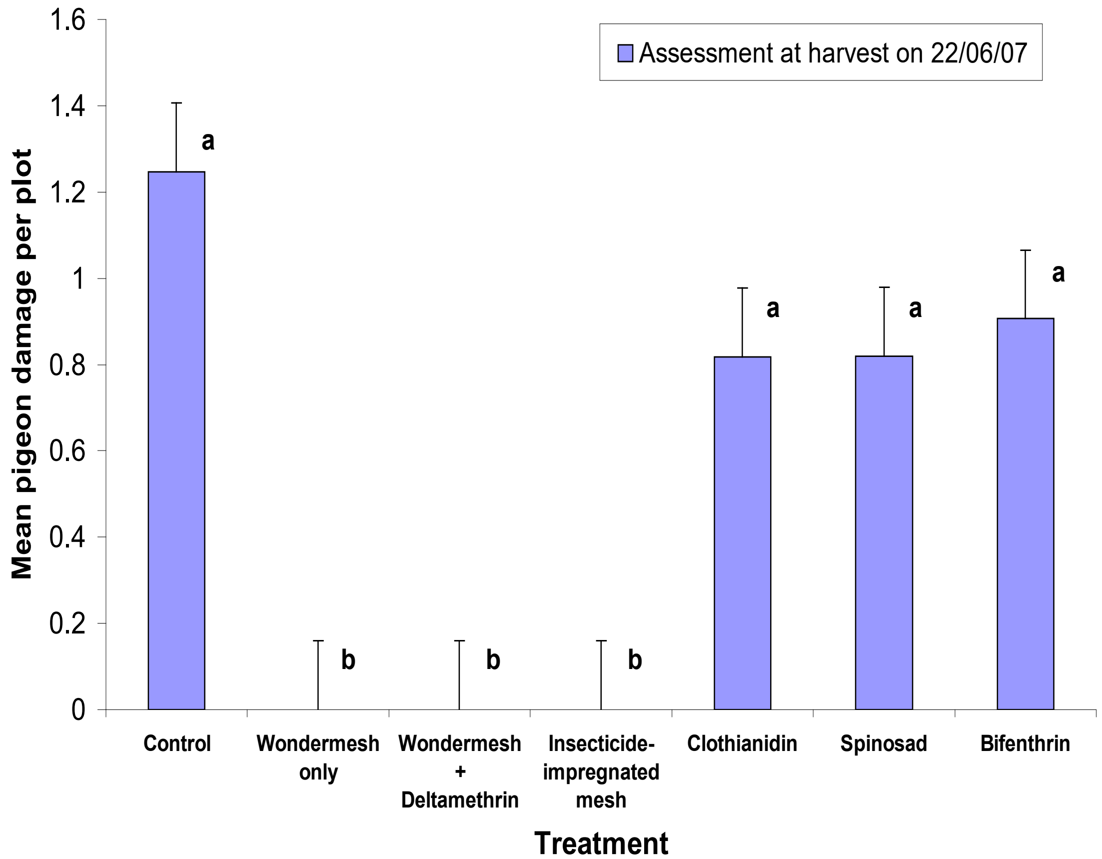

Figure 9. The mean damage caused to the plots of Tatsoi by pigeons in the experimental trial at the point of harvest on 22/06/07*

Pigeon damage

*Damage data were collected by counting the number of plants with pecked leaves in 30 randomly selected plants per plot. The data were arcsine transformed and an ANOVA was carried out followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of differences of means.

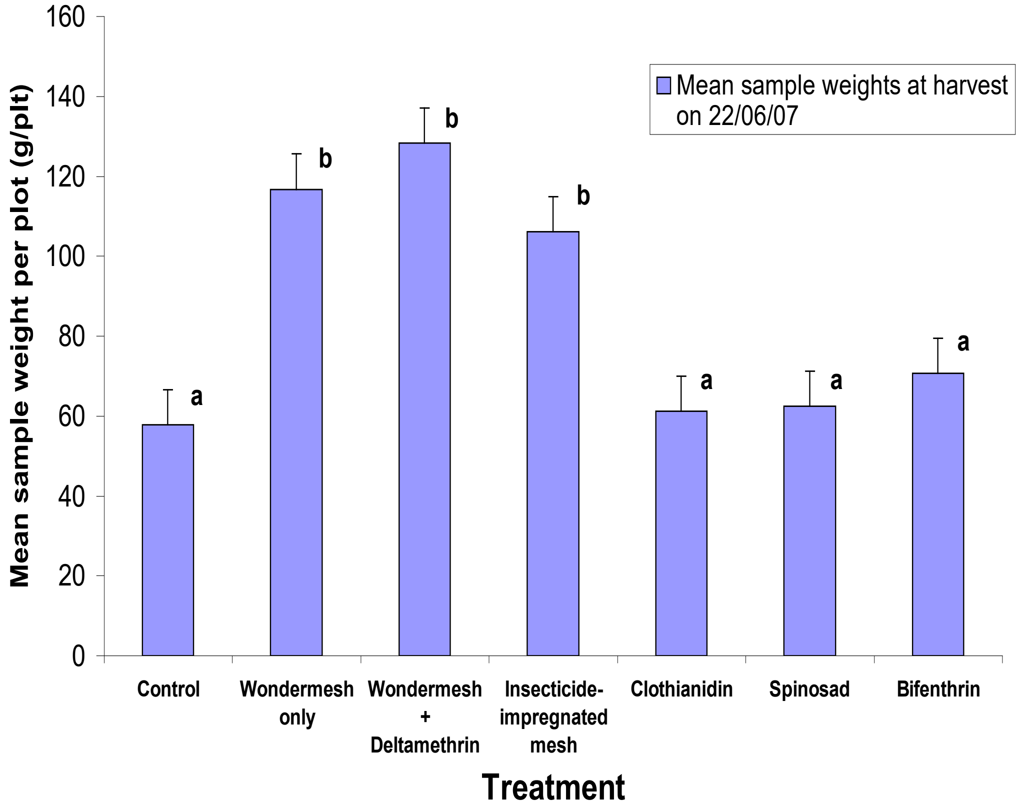

Figure 10. The mean weights harvested from the Tatsoi in the experimental trial at the point of harvest on 22/06/07*

Yield assessment

* Data were collected by harvesting plants from five randomly selected non-overlapping quadrats and a mean quadrate weight calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of differences of means.

Flea beetle movement

Trapped insects were mainly flies, and it was observed that that both pollen beetles and flea beetles were able to escape from the sticky surface. This type of sticky trap, therefore, is not suitable for assessing flea beetle populations and alternatives will be tried in the forthcoming field season.

Flea beetle behaviour and emergence in relation to mesh covers

No flea beetle adults were observed under any of the experimental mesh covers. The behaviour of the flea beetles that landed on the different mesh types, however, differed greatly. When landing on the yellow insecticide-impregnated mesh, the insects immediately appeared agitated and some experienced a rapid knocked-down effect, while others flew off if they were still capable of flight. In contrast, flea beetle adults landing on the unsprayed mesh began to walk across it, presumably in search of an opening that would allow them to reach the plants underneath.

Conclusions

The conclusions from the first year of work are:

1. No emergence of flea beetles was observed under meshes placed over soil or crops (apart from an old bed of Red mustard) on the farm and so pest pressure is due to immigrant flea beetle adults.

2. Meshes protect the crops from most damage caused by insect pests to a highly significant extent.

3. Minor insect damage did occur under meshes, either because early instar DBM larvae dropped through the mesh or because of immigration underneath the edges. This minor damage was reduced by spraying the crop regularly, although the effect was not significantly different to the mesh only treatment.

4. Meshes improve the crop growth rate very significantly, apart from their role in providing protection from insect and other pest attack.

5. Meshes also protect crops from damage caused by birds and small mammals.

6. The cropped area adjacent to the trial plots was covered with mesh that had been used several times previously and suffered damage. The crop was damaged by pests at the site of holes and the damage extended from the holed area into nearby crop. Holes in meshes, therefore, can reduce the pest control benefits.

7. One of our treatments required that two strips of mesh be joined. After trying several glues it was found that an electric glue gun achieved the necessary strength of joint, so meshes can be joined or holes repaired using a hot glue gun.

8. Even with a hole size through which the smaller flea beetle species could pass, the insecticide-impregnated netting was highly effective at reducing damage. Dead insects of several species were observed frequently on this treatment, demonstrating knock down and kill by contact action.

9. Even though they did not prevent insect damage completely when used on their own, bifenthrin and spinosad did provide significant levels of protection. This level of protection may be enough for other Brassica crops. Alternatively, the products may provide good alternatives to the deltamethrin used currently on leafy Brassicas, if used in combination with mesh. As such, they may also be worth registering for use on leafy Brassicas

10. Flea beetles can escape from some sticky trap surfaces and other types of glue and/or other ways of monitoring flea beetles are needed.

11. Flea beetle life cycle takes six to eight weeks in an insectary under conditions: 14:10 h (Light:Dark) and a temperature of 23-25^{o}C. The beetle life cycle involves a relatively long proportion of time as root feeding larvae in the soil. This period is longer than the period over which most leafy Brassica crops are in the ground and as the ground is cultivated between crops, carry over of pests from one crop to the next on the farm is unlikely.

Technology transfer

Agreement was reached with suppliers of experimental products that the results could be circulated and that the report could refer to the product names and active substances within them.

The researchers have had a meeting to discuss results with the HDC project co-ordinator, his Drilling and Irrigation Manager and the representative of VF (who supplied the insecticide-impregnated netting). The discussions took place at Intercrop farm where the field trials took place.

We also envisage making a brief presentation to growers of these findings if the client and HDC members consider it worthwhile. Such a meeting would be an opportunity to discuss and prioritise the next stage of the research project in 2008.

We will be guided by HDC management in regard to whether findings could be summarised in an HDC members' journal or newsletter.

The findings of the work may be of interest to a scientific or technical journal. This will be discussed with HDC managers.

The companies which supplied the sample products used in the trial will be interested in the findings. A copy of this report has been sent to Vestergaard-Frandsen, with whom there is a confidentiality agreement.

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