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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.

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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.

Dr T M O'Neill
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Signature ..... Date .....

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GROWER SUMMARY

Headline

Powdery mildew on *Crataegus* was significantly reduced by Systhane 20 EW, Stroby WG, Thiovit + non-ionic wetter, Flexity, Torch Extra, Nativo 75 WG and an experimental fungicide. Torch Extra caused damage to *Crataegus* and *Lonicera*.

Background and expected deliverables

Powdery mildew diseases commonly affect both woody and herbaceous perennial ornamentals causing yellow, crinkled and distorted leaves, premature senescence and reduced vigour. Young, soft shoots are particularly affected. Even with slight infections, the white fungal growth on leaves, stems and flowers, and associated leaf yellowing and distortion, make plants unsightly and unsaleable. Some crop species are affected virtually every year (e.g. hawthorn, oak, *Lonicera*, rose, photinia), while a wide range of other species are affected less often.

Powdery mildew diseases are usually managed by regular treatment with fungicides and weekly sprays may be necessary to prevent infection. Cultural practices provide partial control, but fungicides are almost invariably necessary for the production of high-quality, saleable plants.

Numerous fungicides have label recommendations for control of powdery mildew diseases and several new ones have recently become available. Often these are first registered for use on cereals but gain wider crop application with time. Currently (March 2008) any product approved on any outdoor crop can be used on any outdoor ornamental crop, and any product approved on a protected crop can be used on any protected ornamental crop, at growers' own risk, under the Long Term Arrangements for Extension of Use. These arrangements are being withdrawn during 2008 and will be replaced with Specific Off-Label Approvals (SOLAs) for individual products. Products to be covered by SOLAs will be publicised by the HDC. Some fungicides are more effective as protectants while others have eradicant activity. Robust information is required on the relative efficacy and crop safety of new fungicides for control of powdery mildew diseases on Hardy Nursery Stock (HNS) subjects.

Resistance can develop when the same fungicide or products from the same fungicide group are used repeatedly. There is a relatively high risk of fungicide resistance developing in powdery mildew fungi because of their short life cycles and abundant spore production. There are reports of powdery mildews on a range of crops developing resistance to some fungicides.

The expected deliverables from this project are:

- A summary of knowledge on the activity and attributes of fungicides used for control of powdery mildew disease;
- Information on the relative efficacy of selected novel fungicides and industry standards in controlling powdery mildew on *Acer, Crataegus* and *Lonicera;*
- Information on the crop safety of selected fungicides to *Acer, Crataegus* and *Lonicera;*
- A sustainable fungicide programme for control of powdery mildew diseases;
- A Factsheet on control of powdery mildew diseases on hardy nursery stock.

Summary of the project and main conclusions

Review of fungicides for powdery mildew control

Information on the attributes of fungicides with activity against powdery mildew diseases was obtained from the scientific literature, product literature and web searches. This information is summarised in a series of tables.

The first two tables in the Science Section list fungicides with, and without, a recommendation for use on hardy nursery stocks or other ornamentals and with activity against powdery mildew diseases. The tables include information on:

- Fungicide group (for resistance management);
- Active ingredient;
- Product name(s);
- Systemic activity (systemic, non-systemic, translaminar, vapour action);
- Fungicide activity (preventative, curative, eradicant);
- Crop use situation (outdoor, under protection);
- Crop(s) on which approved;
- Recommended rate(s).

Chemical mode of action:

Overall, there are currently 19 different fungicide groups, with one or more active ingredient in each group, which show activity against powdery mildew diseases and can be used on ornamental crops in the UK. Two important fungicide groups, each with several active ingredients used against powdery mildew diseases of ornamentals, are the de-methylation inhibitor (DMI) fungicides (e.g. Bumper 250EC, Systhane) and the strobilurin (QoI) fungicides (e.g. Amistar, Stroby).

Systemic activity:

Some products are reported to have combinations of systemic, translaminar and vapour activity, as follows:

Systemic and translaminar:	Amistar, Cyflamid, Filan, Flamenco,
Systemic and vapour:	Fortress, Lyric, Stroby WG,
Translaminar and vapour:	Twist
Systemic, translaminar and vapour:	Nimrod, Talius

Physical mode of action:

A summary of the reported physical mode of action of fungicides against powdery mildew diseases is shown below.

Table 1: A summary of reported physical mode of action of fungicides against powdery mildew diseases

Product	Protectant	Curative	Eradicant
Label recommendation or SOLA for use on ornamentals			
Amistar	✓	✓	✓
Bravo 500	✓		
Bumper 250EC	✓	✓	
Croptex Fungex	✓		
Cyflamid	✓	✓	
Delsene 50 Flo+	✓	✓	
Karathane Liquid	✓	✓	
Nimrod	✓	✓	
Potassium bicarbonate*	✓		✓
Rubigan	✓	✓	✓
Scotts Octave	✓		✓
Stroby WG	✓	✓	✓
Systhane 20EW	✓	✓	
Topas	✓	✓	
No label recommendation or SOLA for use on ornamentals			
Corbel	✓	✓	
Indar 5EW	✓	✓	
Filan	✓	✓	
Flamenco	✓		✓
Flexity	✓	✓	
Folicur	✓	✓	✓
Fortress	✓		
Frupica	✓		
Fungaflor	✓	✓	
Lyric	✓	✓	
Talius	✓	✓	
Teldor	✓		
Thiovit Jet	✓		
Torch Extra	✓	✓	✓
Twist	✓	✓	
Vivid	✓	✓	

+Use not permitted after 30 June 2008
*Primarily eradicant

Efficacy of fungicides against powdery mildew diseases:

The third table in the Science Section provides information on the efficacy of fungicides against powdery mildew diseases of ornamentals as rated in recent trials. This table includes:

- Treatment ratings on a *, **, ***, **** scale according to efficacy;

- Results evaluating 20 fungicides on a total of 12 crops (*Azalea, Cornus, Delphinium, Gerbera, Hydrangea, Phlox, Poinsettia, Rosa, Scabious, Solidago, Verbena and Zinnia*);
- A mean efficacy rating over all the reported experiments.

The mean efficacy rating of 20 fungicides evaluated in 38 experiments over 12 crops species between 1999 and 2005 is given in Table 2.

Table 2: Overall efficacy of fungicides against powdery mildew diseases as determined by 38 experiments on 12 ornamental crop species, in the USA and UK, between 1999 and 2005

Active ingredient tested	Example product	Number of experiments [a]	Overall efficacy rating			
			*	**	***	****
Azoxystrobin	Amistar	23			✓	
Boscalid	Filan	4				✓
Carbendazim	Delsene 50 Flo	1		✓		
Chlorothalonil	Bravo 500	8			✓	
Copper	Croptex Fungex	4		✓		
Fenarimol	Fubigan	4	✓			
Fenhexamid	Teldor	2		✓		
Fluquinconazole	Flamenco	1			✓	
Flusilazole	Lyric	1		✓		
Imazalil	Fungaflor 100 EC	1			✓	
Kresoxim-methyl	Stroby WG	12			✓	
Mepanipyrim	Frupica	4				✓
Myclobutanil	Systhane 20 EW	35			✓	
Propiconazole	Bumper 250 EC	14			✓	
Pyraclostrobin	Vivid	7			✓	
Quinoxyfen	Fortress	7				✓
Sulphur	Thiovit Jet	8			✓	

Table 2: (Continued)

Active ingredient tested	Example product	Number of experiments [a]	Mean efficacy rating			
			*	**	***	****
Tebuconazole	Folicur	4				✓
Trifloxystrobin	Twist	17			✓	
Potassium bicarbonate	-	11			✓	

[a] More caution is required in interpretation of results where the active ingredient has been tested in only a few experiments.

*slight control; **moderate control; ***good control; ****very good control.

Many products with an overall *** or **** rating are, or were recently, used commonly in the UK for control of powdery mildew and other diseases on HNS and herbaceous

plants (i.e. Amistar, Bumper 250 EC, Bravo 500, Frupica, Fungaflor, potassium bicarbonate, Stroby WG, Systhane 20 EW, Thiovit Jet). The products with an overall *** or **** rating for control of powdery mildew diseases that are not (to the best of our knowledge) currently used commonly in the UK on hardy nursery stock and herbaceous plants for control of powdery mildew are:

Filan (boscalid)
Flamenco (fluquinconazole)
Fortress (quinoxyfen)
Vivid (pyraclostrobin)

All of these fungicides contain one single-site active ingredient and there is a medium to high risk of resistance development (see below).

Fungicide resistance:

The fourth table in the Science Section lists fungicide chemical groups, their mode of action and an assessment of the risk of fungicide resistance. A summary of resistance risk as determined by the Fungicide Resistance Action Committee (FRAC) is given in Table 3.

Table 3: Risk of fungi developing resistance to fungicides in different chemical mode of action groups

Fungicide group	Example active ingredient	Example product	Risk of resistance			
			Low	Low to medium	Medium	High
Anilinopyrimidine	Mepanipyrim	Frupica			✓	
Benzimidazole	Carbendazim	Delsene 50 Flo				✓*
Carbonate	Potassium bicarbonate	Potassium bicarbonate	✓			
Carboxamide	Boscalid	Filan			✓	
Chloronitrile	Chlorothalonil	Bravo 500	✓			
Copper	Copper ammonium carbonate	Croptex Fungex	✓			
DMI	Myclobutanil	Systhane 20 EW			✓*	
Hydroxyanilide	Fenhexamid	Teldor		✓		
Hydroxypyrimidine	Bupirmate	Nimrod			✓*	
Morpholine	Fenpropimorph	Corbel		✓*		
Phenyl acetamide	Cyflufenamid	Cyflamid			✓*	
Quinazolinone**	Proquinazid	Talius			✓	
Quinoline**	Quinoxyfen	Fortress			✓	
Spiroketalamine	Spiroxamine	Torch Extra		✓		
Strobilurin/QoI	Azoxystrobin	Amistar				✓*

Sulphur	Sulphur	Thiovit Jet	✓

* Decreased sensitivity and/or resistance reported in some powdery mildew species to this fungicide group (information from Fungicide Resistance Action Group at: http//frag.csl.gov.uk/cropspecific.cfm).
**Considered to be in the same fungicide group for resistance management purposes.

Efficacy of fungicides against powdery mildew

Eleven fungicides, comprising two grower standard treatments (Systhane 20 EW, Stroby WG) and nine novel products were evaluated for control of powdery mildew diseases on *Acer, Crataegus* and *Lonicera* in a replicated, split-plot experiment in two polythene tunnels. Fungicides were applied as high volume sprays every 2-3 weeks from 15 June to 27 September 2007. A low level of powdery mildew on *Crataegus* (7% leaf area affected on untreated plants) was significantly reduced by Flexity (metrafenone), Nativo 75 WG (tebuconazole + trifloxystrobin), Stroby WG (kresoxim-methyl), Systhane 20 EW (myclobutonil), Thiovit Jet (sulphur) + wetter, Torch Extra (spiroxamine) and an experimental product. No powdery mildew developed on *Acer* or *Lonicera* despite the introduction of infector plants and spray-inoculation with a suspension of powdery mildew spores in water. The cool, wet summer of 2007 probably accounted, as least in part, for the lack of severe powdery mildew diseases in this experiment.

Crop safety

No damage was observed on *Acer campsetre, Crataegus* or *Lonicera* following eight high-volume sprays at the label recommended rate of Cyflamid (cyflufenamid), Flexity, Fortress (quinoxyfen), Nativo 75 WG, Stroby WG, Switch (fludioxonil + cyprodinil), Systhane 20 EW, Thiovit Jet + wetter or two experimental fungicides. Torch Extra caused a leaf scorch on *Crataegus* and *Lonicera*, but did not damage *Acer.* Thiovit + wetter was the only treatment that left an obvious spray deposit, which was visible on all three species.

Spray programmes

In order to reduce the risk of powdery mildew fungi developing fungicide resistance, it is recommended that fungicides from at least two active ingredient groups are used when devising a spray programme. The two products should be used in alternation.

Some fungicide products contain a mixture of two active ingredients (e.g. Signum) and if both active ingredients are active against powdery mildew this also helps to reduce the risk of resistance development. Some fungicides, known as multisite inhibitors, (e.g. Bravo 500, Thiovit Jet) act on fungi in a way which makes the risk of resistance development to these products very low; it is suggested that a fungicide of this type is included in a spray programme (see example below).

An example programme designed to minimise the risk of selecting resistant strains and which has proved effective in control of powdery mildew diseases on some cut flower species is:

- Systhane 20EW alternating with Thiovit Jet

Various factors need to be considered when choosing fungicide products for use in a spray programme on a particular crop including: crop situation (outdoor or protected), crop safety, including any growth regulatory effect and visible spray deposit. Some example programmes will be evaluated on an HNS subject in year 2 of this project. Further information on different approaches to management of powdery mildew diseases is available now in HDC Factsheet BOF 44 - Control of powdery mildew diseases on cut flowers.

Financial benefits

Powdery mildew diseases affect many woody and herbaceous perennials, causing unsightly and poor growth that results in downgrading or rejection of plants. Routine fungicide treatment of susceptible species is therefore necessary for the production of high-quality saleable plants. The potential financial benefit to the industry from improved control of powdery mildew diseases through identification of the most effective and sustainable fungicide treatments is significant.

Action points for growers

- None at this stage.

SCIENCE SECTION

Introduction

A wide range of fungicides are reported to have activity against powdery mildew diseases. Halstead & Scrace (2000) listed 14 active ingredients for control of powdery mildew on outdoor ornamentals and noted that few of them had label recommendations for use on HNS. The European Plant Protection Organisation (EPPO) guidelines of Good Plant Protection Practice for apple and pear lists 16 main fungicide active ingredients for control of powdery mildew (*Podosphaera leucotricha*) (Anon, 1991). These reports illustrate the wide range of fungicides available for use against powdery mildews. Several new active ingredients and products containing mixtures of active ingredients, effective against powdery mildew diseases, have become available since 2000 and warrant testing on HNS species.

Recent work on control of powdery mildew diseases on outdoor and protected cut flowers demonstrated good activity using Systhane 20 EW (myclobutanil), Stroby WG (kresoxim-methyl), Frupica (mepanipyrim) and Thiovit (sulphur) + Agral (O'Neill, 2003). Eight other fungicides tested were either less effective or not suitable for use on cut flowers.

Following recent work evaluating fungicides for crop-safety and control of foliar diseases of rose (Ann e*t al.,* 2003), 18 products that provide some control of rose powdery mildew were listed. On rhododendron, three fungicides, Epic (epoxiconazole), Tern (fenpropidin) and Topas (penconazole), were reported to give substantial control of rhododendron powdery mildew (*Erysiphe* sp.) (Kenyon & Dixon, 1995).

The overall aim of this project is to devise crop-safe and effective fungicide programmes that provide sustainable control of powdery mildew on three commonly affected hardy nursery stock species.

Specific objectives in Year 1 are:

1. To review and summarise knowledge on the activity and attributes of fungicides used for control of powdery mildew diseases;
2. To determine the effectiveness of selected novel fungicides, compared with one or more industry standards in controlling powdery mildew on *Acer campestre*, *Crataegus* and *Lonicera*;

3. To determine the crop-safety of selected novel fungicides to these three nursery stock species.

Review of fungicides for powdery mildew control

Introduction

Fungicides with activity against powdery mildew diseases may differ in their chemical mode of action (those with identical or very similar modes of action are said to be in the same 'fungicide group'), systemic activity, physical mode of action (protectant, curative, eradicant) and the likelihood that fungi will develop resistance to them. These and other factors determine how effective a particular fungicide is against a powdery mildew disease. The aim of this review is to summarise such information about fungicides that are available in the UK and used for control of powdery mildew diseases. Additionally, the results of recent replicated experiments on control of powdery mildew diseases with fungicides are summarised.

Materials and methods

Key references used to source information were:

- The Pesticide Manual;
- *Fungicide and Nematicide Tests*;
- Fungicide Resistance Action Committee (www.frag.csl.gov.uk/frac_table2);
- The UK Pesticide Guide, 2007;
- Product literature;
- CSL LIASION database.

Additional information was obtained from HDC Project Reports and a search of the scientific literature (*Plant Disease, Phytopathology, Annals of Applied Biology*) and a web search using key words.

Results and discussion

Information on the chemical mode of action, systemic activity and physical mode of action of fungicides is summarised for products with (Table 1.1) and without (Table 1.2) a label recommendation for use on ornamental crops.

Chemical mode of action

Fungicides with a label recommendation or SOLA for use on ornamental crops in the UK and with activity against powdery mildew comprise nine different fungicide groups. Five fungicides (Rubigan, Systhane 20 WE, Topas, Scotts Octave and Bumper 250 EC) belong to the DMI group of fungicides and two (Amistar and Stroby WG) to the QoI group of fungicides. For each of the other fungicide groups, there is only one active ingredient with a product recommendation for use on ornamentals.

Fungicides with activity against powdery mildew but without a label recommendation for use on ornamental crops comprise many different fungicide groups. In this report, based on the reports of fungicides evaluated against powdery mildew diseases of ornamentals, and fungicides with good activity against powdery mildew diseases on other crops, we have identified 11 fungicide groups. All groups have only one active ingredient except for the DMI group (five active ingredients) and the QoI group (two active ingredients).

Overall, there are currently 19 different fungicide groups, with one or more active ingredient in each group, which show activity against powdery mildew disease and can be used on ornamental crops in the UK.

Systemic activity

For the products with a label recommendation for use on ornamentals, 10 out of 15 active ingredients are classed as systemic (example products in the UK containing these active ingredients are Bumper 250 EC, Amistar, Cyflamid, Delsene 50 Flo, Nimrod, Rubigan, Scotts Octave, Stroby WG, Systhane 20 EW, Topas), three as translaminar (Amistar, Cyflamid, Nimrod) and three have vapour activity (Cyflamid, Stroby WG and Nimrod).

For the products without a label recommendation for use on ornamentals, 11 are reported to have some systemic activity (Corbel, Filan, Flamenco, Flexity, Folicur, Fortress, Fungaflor, Indar 5EW, Lyric, Talius, Torch Extra), five as translaminar (Filan, Flamenco, Talius, Twist, Vivid) and four have vapour activity (Fortress, Lyric, Talius, Twist).

Some products are reported to have combinations of systemic, translaminar and vapour activity, as follows:

Systemic and translaminar: Amistar, Cyflamid, Filan, Flamenco

Systemic and vapour:	Fortress, Lyric, Stroby WG
Translaminar and vapour:	Twist
Systemic, translaminar and vapour:	Nimrod, Talius

Physical mode of action

For the products with a label recommendation for use on ornamentals, 14 of 15 are reported to have protectant activity (the exception being SB Plant Invigorator where no information was available), 11 are reported to have curative activity, and five are reported to have eradicant activity (Amistar, potassium bicarbonate, Rubigan, Scotts Octave, Stroby). Most products are reported to have both protectant + curative activity, or protectant + eradicant activity, the exceptions, with protectant activity only, being Bravo 500 (and equivalent products), and Croptex Fungex.

For the products without a label recommendation for use on ornamentals, all 16 have protectant activity, 11 have protectant + curative activity, three have protectant + eradicant activity, and two (Folicur and Torch Extra) are reported to have protectant, curative and eradicant activity.

The reported physical mode of action of all the fungicides listed above is summarised in Table 1 in the Grower Summary section of this report.

Permitted situations for use

With the exception of Topas (outdoor use only), all of the products with a label recommendation or SOLA for use on ornamentals can be used on both outdoor and protected crops.

For the products with no label recommendation or SOLA for use on ornamentals, only four (Fortress, Frupica SC, Teldor, Thiovit Jet) can be used on protected crops.

Efficacy of fungicides against powdery mildew diseases or ornamentals – recent trial results

The results of 38 experiments on 12 species (*Azalea, Cornus, Delphinium, Gerbera, Hydrangea, Phlox, Poinsettia, Rosa, Scabious, Solidago, Verbena* and *Zinnia*), evaluating fungicides for control of powdery mildew diseases, are summarised (Table 1.3). All of the experiments were done between 1999 and 2005. A total of 20

fungicides were tested. Fungicide efficacy is summarised for each crop species, and over all species, according to the degree of control recorded; efficacy ratings were usually assigned according to grouping of results as determined by multiple range tests. Broadly, efficacy classes may be described as:

* some control
** moderate control
*** good control
**** very good control

The UK product equivalent of fungicides in the different efficacy classes (grouped over all of the plant species used in the trials), are show below:

* Rubigan
** Croptex Fungex, Delsene 50 Flo, Lyric, Teldor
*** Amistar, Bumper 250 EC, Bravo 500, Flamenco, Fungaflor 100 EC, Potassium bicarbonate, Stroby WG, Systhane 20 EW, Thiovit Jet, Twist, Vivid
**** Filan, Folicur, Fortress, Frupica

The UK product equivalents of fungicides with a **** rating for powdery mildew control on the different crop species were as follows:

Azalea: Bumper 250 EC, Thiovit Jet, Twist
Cornus: Amistar
Delphinium: Amistar, Bumper 250 EC, Folicur, Frupica, Stroby WG, Twist
Gerbera: Filan, Fortress, Twist
Hydrangea: Vivid
Phlox: Bumper 250 EC, Stroby WG, Systhane 20 EW
Poinsettia: Fortress, Systhane 20 EW
Rosa: Folicur, Potassium bicarbonate, Twist
Scabious: Fortress, Systhane 20 EW
Solidago: Folicur, Fortress, Frupica, Systhane 20 EW, Thiovit Jet, Twist
Verbena: Filan, Fortress, Systhane 20 EW
Zinnia: None

Many products with an overall *** or **** rating are, or were recently, used commonly in the UK for control of powdery mildew and other diseases on HNS and herbaceous plants (i.e. Amistar, Bumper 250 EC, Bravo 500, Frupica, Fungaflor, potassium bicarbonate, Stroby WG, Systhane 20 EW, Thiovit Jet).

The products with an overall *** or **** rating for control of powdery mildew diseases that are not (to the best of our knowledge) currently used commonly in the UK on hardy nursery stock and herbaceous plants for control of powdery mildew are:

Filan (boscalid)
Flamenco (fluquinconazole)
Fortress (quinoxyfen)
Vivid (pyraclostrobin)

All of these fungicides contain one single-site active ingredient and there is a medium to high risk of resistance development (see below). Signum is a mixture of two of the fungicides (boscalid + pyraclostrobin). This product is now used in the UK for control of grey mould (*Botrytis cinerea*) and other diseases on ornamentals on some nurseries; resistance risk of mixtures containing two active ingredients, both of which are active against powdery mildew, is likely to be lower than products containing one single-site inhibitor.

None of the above fungicides should be used on a crop for control of powdery mildew without first checking that it does not cause leaf scorch, stunted growth, death of the growing point, or other crop damage. It should also be noted that, with the exception of Fortress and Signum these products can only be used on crops outdoors.

Some products recently introduced have not been widely assessed for control of powdery mildew diseases in replicated experiments on ornamentals and so are not listed here (e.g. Cyflamid, Talius, Flexity).

Risk of fungicide resistance

The mode of action of fungicides available for control of powdery mildew diseases in the UK, and the risk of fungicide resistance arising in pathogens where they are used, as assessed by the Fungicide Resistance Action Committee (FRAC) is given in Table 1.4.

Fungicides with activity against powdery mildew diseases assessed by FRAC comprise 18 different groups. Four groups of fungicide are classed as being at low risk of resistance, three are classed as low to medium, seven as medium risk, and two as high risk: Example products in the different resistance-risk classes are shown below:

Low risk:	Bravo 500, Cuprokylt FL, Thiovit Jet, potassium bicarbonate.
Low to medium risk:	Teldor, Corbel, Torch Extra
Medium risk:	Frupica, Filan, Systhane 20 EW, Nimrod, Cyflamid, Talius, Fortress
High risk:	Amistar, Delsene 50 Flo

A further two groups are described as 'resistance not known' (e.g. Flexity, Dinocap).

Example products where resistance in powdery mildew fungi has occurred to the fungicide group represented by the active ingredient are:

- Systhane 20 EW, Folicur and other DMI fungicides
- Nimrod
- Delsene 50 Flo
- Cyflamid (in *Sphaerotheca* species)
- Amistar

Unpublished reports of experiments evaluating fungicides for control of powdery mildew diseases on ornamentals (information provided by Dr P Sopp, based on work in the Netherlands)

1. Control of powdery mildew on oak
    - Switch (cyprodinil + fludioxinil) was most effective
    - Flint (trifloxystrobin)/Nimrod (bupirimate) was less effective
    - Sulphur and Topas (penconazole) were largely ineffective

2. Control of powdery mildew on rose
    - Switch has incidental control of powdery mildew when used against other diseases on rose; best used in mixture with Topas.

Table 1.1: Fungicides having activity against powdery mildews with label recommendations or a Specific Off-label Approval (SOLA) for use on HNS or other ornamental crops

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			HNS or other ornamental crop on which approved	Rate(s)	Comments
			S / NS / T / V[B]	P / C / E[C]	O / P[D]			
Chloronitrile (M5)	Chlorothalonil	Bravo 500[E]	NS	P	O + P	Protected ornamentals (for Botrytis)	220 mL / 100 L	No specific powdery mildew recs for ornamentals. Powdery mildew recs for fruit and vegetable crops.
Copper (M1)	Copper ammonium carbonate	Croptex Fungex	NS	P	O + P	Chrysanthemum	250 mL / 100 L	
Dinitrophenyl (29)	Dinocap	Karathane Liquid	NS	P + C	O + P	Chrysanthemum, rose	125 mL / 1000 L (glasshouse) 250 mL / 1000 L (outdoors)	

Table 1.1: (Continued)

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			HNS or other ornamental crop on which approved	Rate(s)	Comments
			S / NS / T / V[B]	P / C / E[C]	O / P[D]			
DMI (3)	Fenarimol	Rubigan	S	P + C + E	O + P	Roses	33 mL / 100 L	
	Myclobutanil	Systhane 20EW[E]	S	P + C	O + P	Ornamental plant production, roses	max. 225 mL / 750 L (outdoors) 45 mL/100 L (protected)	Use under protection extrapolated from SOLA 20051189 (various protected fruit crops). Resistant strains may develop.
	Penconazole	Topas	S	P + C	O	Ornamental trees, roses	150 mL / 100 L	Resistant strains may develop.
	Prochloraz	Scotts Octave	S	P + E	O + P	Ornamental plant production, hardy ornamentals, woody ornamentals	100 – 200g / 100 L	Label states 'fungal diseases' but also 'some control of rose powdery mildew'. Resistant strains may develop.
	Propiconazole	Bumper 250EC	S	P + C	O + P	Chrysanthemum, protected chrysanth (for white rust)	max. 40 mL / 100 L	Extrapolation from SOLA 20012142. No specific recs. for powdery mildew on ornamentals, but has for arable crops. Resistant strains may develop.

Table 1.1: (Continued)

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			HNS or other ornamental crop on which approved	Rate(s)	Comments
			S / NS / T / V[B]	P / C / E[C]	O / P[D]			
Hydroxy-pyrimidine (8)	Bupirimate	Nimrod	S + T + V	P + C	O + P	Chrysanthemum, rose	Rose: 250 mL / 100 L	Can increase rate up to 380ml / 100l for 1st spray if mildew present. Resistant strains may develop.
MBC / benzimidazole (1)	Carbendazim	Delsene 50 Flo[E]	S	P + C	O + P	Chrysanthemum, pot plants, bedding plants	max. 50 mL / 100 L	Extrapolation from SOLA 20073111 (expires 30/06/08). Resistant strains may develop.
Phenyl-acetamide (U6)	Cyflufenamid	Cyflamid	S (poor) T + V	P + C	O		0.5 L/ha	Sola 0512/2007 for use on outdoor ornamentals. Resistant strains may develop.
Strobilurin / QoI (11)	Azoxystrobin	Amistar	S + T	P + C + E	O + P	Chrysanthemum (for white rust)	100 mL / 100 L	No specific p. mildew recs for ornamentals. Extrapolation from label recs or SOLAs for many other crops. Resistant strains may develop.
	Kresoxim-methyl	Stroby WG	S + V	P + C + E	O + P	Roses, protected roses	0.3 kg/ha	Recommended on outdoor and protected roses.

Table 1.1: (Continued)

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			HNS or other ornamental crop on which approved	Rate(s)	Comments
			S / NS / T / V[B]	P / C / E[C]	O / P[D]			
Inorganic carbonate (NC)	Potassium bicarbonate	-	NS	P + E	O + P	Outdoor crops, protected crops	max. 2000 g / 100 L	Commodity substance. Food grade potassium bicarbonate must be used.
-	Urea, di-amide of carbonic acid	SB Plant Invigorator	NS	-	O + P	Ornamental plant production, protected ornamentals	1000 mL / 100 L	Acts by physical action. Used mainly against pests, but 'may offer some control of powdery mildew'.

[A] Fungicide Resistance Action Committee (FRAC) codes are used to distinguish between fungicide groups with different modes of action. Use of a range of fungicides from different chemical groups is an essential part of an anti-resistance strategy. When formulating a fungicide programme try to include fungicides from groups with as many different FRAC codes as possible.

[B] S = systemic; N = non-systemic; T = translaminar; V = vapour action

[C] P = preventative – fungicide must be applied before the disease develops
C = curative – fungicide will have an effect post-infection but before symptoms develop
E = eradicant – fungicide will have some effect even if symptoms (e.g. visible mildew growth) are already present

[D] O = outdoor use; P = use under protection

[E] Other products containing the same active ingredient are available.

* Information taken mainly from the Pesticide Manual, 14th edition, with additional information for the newest active ingredients sourced from manufacturer's literature.

Table 1.2: Fungicides with activity against powdery mildews but without approval for use on ornamentals (products can be used at grower's risk under the Long-Term Arrangements for Extension of Use)

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			Rate(s)[F]	Comments
			S / NS/ T / V[B]	P / C / E[C]	O / P[D]		
Anilinopyrimidine (9)	Mepanipyrim	Frupica SC	NS	P	O + P	90mL / 100 L	Extrapolation from on-label use on outdoor and protected strawberries. Certis Technical Note No. 8 gives crop safety lists for some ornamentals.
Benzophenone (U8)	Metrafenone	Flexity	S	P + C	O	0.5 L/ha	Extrapolation from on-label use on cereals. Currently one of the best performing products against cereal powdery mildew (see section 2 for evaluation in this project)
Carboxamide (7)	Boscalid	Filan	S + T	P + C	O	200 g / 100 L	Extrapolation from on-label use on oilseed rape. Label recommendations are for *Alternaria* and *Sclerotinia*. Resistant strains may develop.
DMI (3)	Fenbuconazole	Indar 5EW	S (limited)	P + C	O	1.4 L / ha	Extrapolation from on-label use on apples and pears. Resistant strains may develop.
	Fluquinconazole	Flamenco[E]	S + T	P + E	O	125 mL / 100 L	Extrapolation from on-label use on cereals. Resistant strains may develop. Caused scorch, discolouration and leaf distortion on rose at 2.5 mL/L (twice normal rate) (HDC Factsheet 12/04).
	Flusilazole	Lyric[E]	S + V	P + C	O	0.8 L / ha	Extrapolation from on-label use on cereals. Resistant strains may develop. Used safely on rose at 0.625 mL/L (HDC Factsheet 12/04)
	Imazalil	Fungaflor 100EC	S	P + C	P	50mL/ 100 L	Extrapolation from on-label use on protected cucumbers. Resistant strains may develop.

Table 1.2: (Continued)

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			Rate(s)[F]	Comments
			S / NS/ T / V[B]	P / C / E[C]	O / P[D]		
	Tebuconazole	Folicur[E]	S	P + C + E	O	100 mL / 100 L	Extrapolation from on-label use or SOLAs on various crops. Resistant strains may develop. Used safely on rose at 1.0 mL/L (HDC Factsheet 12/04).
Hydroxyanilide (17)	Fenhexamid	Teldor	NS	P	O + P	max. 100 g / 100 l	Extrapolation from on-label use and SOLAs on various crops for Botrytis. Rate quoted is from SOLA 20042085 (protected cucumbers).
Morpholine (5)	Fenpropimorph	Corbel[E]	S	P + C	O	1.0 L / ha	Extrapolation from on-label use on cereals. Resistant strains may develop.
Morpholine / spiroketalamine (5)	Spiroxamine	Torch Extra	S	P + C + E	O	0.9 L / ha	Extrapolation from on-label use on cereals. Resistant strains may develop.
Phenylpyrrole (12)	Fludioxonil	In: Switch	NS	P	O + P	0.8 kg/ha (protected crops) and 1.0 kg/ha (outdoor)	Switch is a mixture of fludioxonil with cyprodinil, a systemic anilinopyrimidine fungicide (see also pyrimethanil in Table 1.1). Label recommendation for control of botrytis.
Quinazolinone (U7)	Proquinazid	Talius[E]	S + T + V	P + C	O	0.25 L / ha	Extrapolation from on-label use on cereals. Should be considered as same group as quinolines for resistance management purposes. Currently one of the best performing products against cereal powdery mildews. No known evaluation of crop safety or efficacy on ornamentals.
Quinoline (13)	Quinoxyfen	Fortress	S + V	P	O + P	Max. 0.25 L / ha	Extrapolation from outdoor use on cereals and from SOLA 20041923 on outdoor and protected strawberries. Resistant strains may develop.

Table 1.2 Continued

Fungicide group and FRAC code[A]	Active ingredient	Product name	Fungicide activity and crop situation*			Rate(s)[F]	Comments
			S / NS/ T / V[B]	P / C / E[C]	O / P[D]		
Strobilurin / QoI (11)	Pyraclostrobin	Vivid[E]	T	P + C	O	1.0 l / ha	Extrapolation from on-label use on cereals. Max of two sprays. Resistant strains may develop.
	Trifloxystrobin	Twist[E]	T + V 'mesostemic'	P + C	O	200 mL / 100 L	Extrapolation from on-label use on cereals. Max of two sprays. Resistant strains may develop.
Sulphur (M2)	Sulphur	Thiovit Jet[E]	NS	P	O + P	200 g / 100 mL	Outdoors – extrapolation from on-label use on various crops. Protected – extrapolation from SOLA 20023652 (various protected edibles).

N.B. This is not intended to be a comprehensive list of all of the products that can be used under the Long-Term Arrangements for Extension of Use. The products in the table are ones that have been evaluated against powdery mildews of ornamental crops, or which currently give extremely good control of powdery mildews on other crops. Other active ingredients and products are available.

[A] Fungicide Resistance Action Committee (FRAC) codes are used to distinguish between fungicide groups with different modes of action. Use of a range of fungicides from different chemical groups is an essential part of an anti-resistance strategy. When formulating a fungicide programme try to include fungicides from groups with as many different FRAC codes as possible.

[B] S = systemic; N = non-systemic; T = translaminar; V = vapour action

[C] P = preventative – fungicide must be applied before the disease develops
C = curative – fungicide will have an effect post-infection but before symptoms develop
E = eradicant – fungicide will have some effect even if symptoms (e.g. visible mildew growth) are already present

[D] O = outdoor use; P = use under protection

[E] Other products containing the same active ingredient are available.

[F] Rates quoted here cannot necessarily be used on ornamentals. Rates quoted on arable crops are often applied in a low water volume (eg 200 L water/ha), whereas on ornamentals a high water volume is usually used (e.g. 1,000 L/ha). Where an arable rate is translated to an ornamental use, care must be taken not to exceed the maximum application of product/ha when using it in a higher water volume.

* Information taken mainly from the Pesticide Manual, 14th edition, with additional information for the newest active ingredients sourced from manufacturer's literature.

Table 1.3: Fungicide efficacy ratings against powdery mildews of ornamentals in recent trials[A].

Active ingredient	Example of UK product (s) containing active ingredient	Azalea (1 trial, 2000, USA)	Cornus (8 trials, 2000-05, USA)	Delphinium (5 trials (2 USA, 2 UK, 1 Italy) 2001-05)	Gerbera (8 trials, 2002-05, USA)	Hydrangea (3 trials, 1999-2003, USA)
Azoxystrobin	Amistar	**	**** (2)[B]	**** (1)	*** (4)	** (3)
Boscalid	Filan	-	-	-	**** (2)	-
Carbendazim	Delsene 50Flo	-	-	-	-	-
Chlorothalonil	Bravo 500	-	*** (1)	*** (2)	-	-
Copper[C]	Croptex Fungex	-	-	-	** (2)	-
Fenarimol	Rubigan	-	-	* (2)	-	** (2)
Fenhexamid	Teldor	-	-	-	** (1)	-
Fluquinconazole	Flamenco	-	-	-	-	-
Flusilazole	Lyric	-	-	-	-	-
Imazalil	Fungaflor 100EC	-	-	-	-	-
Kresoxim-methyl	Stroby WG	-	-	**** (2)	* (1)	-
Mepanipyrim	Frupica	-	-	**** (2)	-	-
Myclobutanil	Systhane 20EW	***	*** (6)	*** (5)	*** (6)	*** (3)
Propiconazole	Bumper 250EC	****	*** (3)	**** (2)	*** (1)	* (2)
Pyraclostrobin	Vivid	-	-	-	*** (2)	**** (1)
Quinoxyfen	Fortress	-	-	-	**** (1)	-
Sulphur	Thiovit	****	-	*** (4)	-	-
Tebuconazole	Folicur	-	*** (1)	**** (1)	-	-
Trifloxystrobin	Swift (previously also Twist)	****	-	**** (1)	**** (3)	*** (1)
Potassium bicarbonate	-	***	** (3)	** (2)	*** (2)	-

Table 1.3: (continued)

Active ingredient	Example of UK product (s) containing active ingredient	Phlox (3 trials (2 USA, 1 UK) 2001-02)	Poinsettia (3 trials, 1999-2001, USA)	Rose (4 trials (3 USA, 1 UK) 1999-2004)	Scabious (2 trials, 2002-05, USA)	Solidago (1 trial, UK, 2000)
Azoxystrobin	Amistar	*** (2)	*** (2)	*** (3)	*** (1)	-
Boscalid	Filan	-	-	-	-	-
Carbendazim	Delsene 50Flo	-	-	** (1)	-	-
Chlorothalonil	Bravo 500	*** (2)	-	-	-	**
Copper	Croptex Fungex	** (1)	-	-	-	-
Fenarimol	Rubigan	-	-	-	-	-
Fenhexamid	Teldor	-	-	-	-	-
Fluquinconazole	Flamenco	-	-	*** (1)	-	-
Flusilazole	Lyric	-	-	** (1)	-	-
Imazalil	Fungaflor 100EC	-	-	*** (1)	-	-
Kresoxim-methyl	Stroby WG	**** (1)	*** (3)	*** (2)	-	****
Mepanipyrim	Frupica	*** (1)	-	-	-	****
Myclobutanil	Systhane 20EW	**** (2)	**** (3)	*** (2)	**** (2)	****
Propiconazole	Bumper 250EC	**** (1)	-	*** (2)	-	-
Pyraclostrobin	Vivid	-	-	*** (1)	*** (1)	-
Quinoxyfen	Fortress	-	**** (2)	-	**** (2)	****
Sulphur	Thiovit	*** (2)	-	-	-	****
Tebuconazole	Folicur	-	-	**** (1)	-	-
Trifloxystrobin	Swift (previously also Twist)	-	*** (3)	**** (4)	*** (1)	****
Potassium bicarbonate	-	*** (1)	-	**** (2)	-	-

Table 1.3 (continued)

Active ingredient	Example of UK product(s) containing active ingredient	Verbena (5 trials, 2001-05, USA)	Zinnia (2 trials, 2003-04, USA)	Mean rating over all trials	Actual Mean[D]
Azoxystrobin	Amistar	* (2)	*** (2)	*** (23)	**2.7**
Boscalid	Filan	**** (2)	-	**** (4)	**3.8**
Carbendazim	Delsene 50Flo	-	-	** (1)	-
Chlorothalonil	Bravo 500	-	*** (2)	*** (8)	**2.6**
Copper	Croptex Fungex	-	*** (1)	** (4)	**2.3**
Fenarimol	Rubigan	-	-	* (4)	**1.3**
Fenhexamid	Teldor	** (1)	-	** (2)	-
Fluquinconazole	Flamenco	-	-	*** (1)	-
Flusilazole	Lyric	-	-	** (1)	-
Imazalil	Fungaflor 100EC	-	-	*** (1)	-
Kresoxim-methyl	Stroby WG	* (2)	-	*** (12)	**2.8**
Mepanipyrim	Frupica	-	-	**** (4)	**3.5**
Myclobutanil	Systhane 20EW	**** (3)	*** (1)	*** (35)	**3.4**
Propiconazole	Bumper 250EC	*** (1)	*** (1)	*** (14)	**3.0**
Pyraclostrobin	Vivid	*** (2)	-	*** (7)	**3.0**
Quinoxyfen	Fortress	**** (1)	-	**** (7)	**4.0**
Sulphur	Thiovit	-	-	*** (8)	**3.3**
Tebuconazole	Folicur	-	*** (1)	**** (4)	**3.5**
Trifloxystrobin	Swift (previously also Twist	** (2)	-	*** (17)	**3.4**
Potassium bicarbonate	-	-	-	*** (11)	**2.7**

[A] The information in this table should be treated as a guide only. Many of the trials were carried out in the USA, where fungicides containing the same active ingredient as products available in the UK will often have a different formulation and / or percentage active ingredient. The trials also varied in the timing of application of the fungicides (some may be applied prior to the first appearance of the disease, whereas others were applied in response to disease development) and the rates used*some control; **moderate control; ***good control; ****very good control.

[B] Figures in parentheses indicate the number of trials in which that active ingredient was evaluated – the lower the number, the more cautioned required in interpretation.

[C] Copper compounds other than copper ammonium carbonate (the active ingredient in Croptex Fungex) were used.

[D] Rounded up or down to give mean star rating. Not quoted where product only featured in two or less trials.

NB. A trial was also carried out into the control of rhododendron powdery mildew in 1997 as part of HDC project HNS 64. Many of the products evaluated caused damage to the plants, and of those that gave control without phytotoxicity only Epic (expoxiconazole) (**** rating) and Tern (fenpropidin) (*** rating) are still available.

Table 1.4: Chemical Groups, their mode of action and risk of fungicide resistance

Fungicide group and FRAC code	Mode of action	Example effects of active ingredients in group:	Risk of resistance (FRAC Guidelines)
Anilinopyrimidine (9)	Affect amino acid synthesis (methionine biosynthesis)	Mepanipyrim – inhibits appressorium formation and penetration into plant cell.	Medium risk. Resistance known in some fungi (e.g. Botrytis).
Benzophenone (U8)	Unknown	Metrafenone – affects spore formation, spore germination and mycelial growth.	Resistance not known
Carboxamide (7)	Affect respiration (succinate-dehydrogenase)	Boscalid – affects spore formation, spore germination and mycelial growth.	Medium risk. Resistance known for specific fungi
Chloronitrile (M5)	Multi-site activity	Chlorothalonil – affects spore germination.	Low risk
Copper (M1)	Multi-site activity	Copper ammonium carbonate – affects spore germination.	Low risk
Dinitrophenyl (29)	Affect respiration (oxidative phosphorylation)	Dinocap – affects spore germination.	Resistance not known
DMI (3)	Affect sterol biosynthesis in membranes (C14-demethylase)	Various – affect mycelial growth.	Medium risk – resistance known in various fungal species, including powdery mildews.
Hydroxyanilide (17)	Affect sterol biosynthesis in membranes (3-keto reductase, C4-demethylation)	Fenhexamid – affects germ tube elongation and mycelial growth.	Low to medium risk.
Hydroxypyrimidine (8)	Affect nucleic acid synthesis (adenosin-deaminase)	Bupirimate – affects spore germination and appressorium formation.	Medium risk. Resistance known in powdery mildews.
MBC / benzimidazole (1)	Disrupt cell division (mitosis)	Carbendazim – affects spore germination and mycelial growth.	High risk. Resistance common in many fungal species.

Table 1.4: (Continued)

Fungicide group and FRAC code	Mode of action	Example effects of active ingredients in group:	Risk of resistance (FRAC Guidelines)
Morpholine (5)	Affect sterol biosynthesis in membranes (reductase and isomerase enzymes)	Fenpropimorph – affects mycelial growth.	Low to medium risk. Decreased sensitivity in some powdery mildews.
Morpholine / spiroketylamine (5)	As above	Spiroxamine – affects mycelial growth.	As above
Phenyl-acetamide (U6)	Unknown	Cyflufenamid – affects spore formation and infection processes.	Medium risk. Resistance known in powdery mildew of genus *Sphaerotheca*.
Phenyl pyrrole (12)	Unknown	Affects osmotic signal transduction	Resistance found sporadically; low to medium resistance risk
Quinazolinone (U7)	Unknown	Proquinazid – affects spore germination and appressorium formation, and induces host resistance.	Resistance not known. Should be considered to be in the same group as quidelines for resistance management purposes.
Quinoline (13)	Affect signal transduction (G-proteins in early cell signalling)	Quinoxyfen – inhibits appressorium formation.	Resistance known. Medium risk.
Strobiliurin / QoI (11)	Affect respiration (cytochrome enzymes)	Azoxystrobin – affects spore formation, spore germination and mycelial growth.	High risk. Resistance known in various fungal species, including powdery mildews.
Sulphur (M2)	Multi-site activity	Sulphur – affects spore germination.	Low risk
Inorganic carbonate (NC)	Unknown	Destroys spores by various mechanisms.	Resistance not known. Low risk.

Efficacy of fungicides against powdery mildew diseases of hardy ornamentals

Introduction

Information on the relative activity of different fungicides for control of powdery mildew diseases on hardy ornamentals is limited. An experiment was established to determine the activity of two fungicides (Systhane 20EW, Stroby WG) commonly used for control of powdery mildew on hardy ornamentals, and nine fungicides reported to have activity against powdery mildew diseases on other crops but less commonly used on ornamentals. The fungicides were tested on three crop species (*Acer, Crataegus* and *Lonicera*) that are affected by powdery mildew fungi (*Sawadaea bicornis, Podosphaera, clandestina* and *Erysiphe lonicerae*) from three different genera. Additionally, treatments were examined to determine if they caused any crop damage.

Materials and methods

Crop and site details

In April 2007, liners of *Acer campestre* (maple), *Crataegus monogyna* (hawthorn) and *Lonicera* 'Halliana' (honeysuckle) were potted into 3-litre pots in Levington M2 compost amended with Plantacote (NPK 14/18/15) 12-month slow release fertiliser (0.5 kg/75 L bag of compost) on Mypex matting. The *Acer* and *Crataegus* species and the *Lonicera* variety are all reported to be very susceptible to powdery mildew (J. Atwood, pers. comm.). The plants were grown in two adjacent polythene tunnels at ADAS Arthur Rickwood. Plants were watered by hand into the pots. Within each plot, plants were initially well-spaced but were placed close to each other on 15 June to create a dense canopy of growth. Temperature was recorded in each tunnel using a Tiny Tag Logger. Plants of *Lonicera* var, Winchester and *Crataegus* naturally infected by powdery mildew were placed in the tunnels on 2 July and 4 July respectively; 14 infected plants were spread throughout the tunnels. Plants were irrigated by overhead sprinklers for 5 mins each evening after introduction of these infector plants. Powdery mildew spores were collected from *Acer* cv. Flamingo and a spore suspension in sterile distilled water was applied as a spray to one *Acer* plant in each plot on 1 August. Additional *Lonicera* plants affected by powdery mildew were introduced into the tunnels at this time. From July, the plants were watered sparingly

to allow the growing medium to dry, as there is evidence from growers that plants with dry roots are more susceptible to powdery mildew.

Treatments

Product	Active ingredients(s)	Rate of use	Fungicide group	Rate from:
1. Untreated	-	-	-	-
2. Systhane 20 EW	Myclobutanil	0.3 mL/L	DMI	Protected ornamentals
3. Stroby WG	Kresoxim-methyl	0.3 g/L	QoI	Protected ornamentals
4. Thiovit + Activator 90	Sulpur + non-ionic wetter	20 g/L	Sulphur	Protected tomato
5. Cyflamid	Cyflufenamid	0.5 mL/L	Phenyl-acetamide	Outdoor ornamentals
6. Flexity	Metrafenone	1.0 mL/L	Benzophenone	Winter wheat
7. Fortress	Quinoxyfen	0.25 mL/L	Quinazoline gp	Protected strawberry
8. Switch	Fludioxinil+cyprodinil	0.8 g/L	Phenylpyrrole + Anilio-pyrimidine	Ornamentals (outdoor and protected)
9. Torch Extra	Spiroxamine	0.9 mL/L	Amine	Winter wheat
10. Nativo 75 WG	Tebuconazole + trifloxystrobin	0.4 g/L	DMI+QoI	Field veg (broccoli)
11. UKA 379a	New development	1.44 g/L	-	-
12. UKA 383b	New development	0.5 mL/L	-	-

*Based on a spray volume of 1,000 L/ha (100 mL/m^2).

Note: several of the products have a maximum of 2 applications per crop. We used a greater number of applications under an Experimental Permit.

Fungicides were applied as high volume sprays (1,000 L/ha) at 2 bar pressure using a knapsack sprayer with an 02F110 nozzle every 14-21 days from 15 June to 27 September 2007 (8 sprays in total). A spray guard was used to prevent spray drift between adjacent plots.

Experiment design and statistical analysis

Treatments were arranged in a randomised block split-plot design with four-fold replication. Blocks 1 and 2 were located in tunnel 1, blocks 3 and 4 in tunnel 2. Main plots were fungicide treatment and sub-plots were nursery stock species. Each main plot contained five *Acer,* three *Crataegus,* and five *Lonicera* plants. Results were examined by ANOVA or by regression analysis using the Logit Link function (disease incidence data).

Assessments

At 1 week after the fourth and eighth fungicide application, individual plants were assessed to determine the number of plants affected by powdery mildew, and the leaf area affected (%). Other diseases were also recorded.
At 2 weeks after each fungicide application, plants were examined for the presence or absence of leaf scorch, stunted growth, viability of the growing points and obvious spray deposit.

Results and discussion

Control of powdery mildew

Powdery mildew was first recorded on *Crataegus* plants on 13 June, before introduction of the infector plants. On 2 August, after four spray applications the incidence of affected plants was greatest in untreated plots (50%) and was significantly reduced by all treatments except for Switch and UKA 379a (Table 2.1). Systhane 20 EW, Thiovit Jet + Activator 90, Nativo 75 WG and UKA 383b reduced disease incidence to less than 10%. Although the severity of powdery mildew on *Crataegus* was greatest on untreated plants (6% leaf area affected), differences between treatments were not statistically significant ($p=0.170$). There was a significant block effect ($p<0.001$) on the severity of powdery mildew, the mean block levels being 7.1%, 0.5%, 0.3% and 0.2% respectively. The highest level occurred in the block that suffered greatest shade from an adjacent hedge. At the final assessment on 3 October, the disease had declined and only two out of the 12 untreated *Crataegus* plants and one other *Crataegus* plant in the crop was affected by powdery mildew.

No powdery mildew occurred on the *Acer* or *Lonicera* throughout the experiment. No grey mould (*Botrytis cinerea*) or other diseases occurred.

The reason for powdery mildew failing to develop of *Acer* and *Lonicera* and the relatively low disease severity on *Crataegus* is unclear. The species and variety used were highly susceptible to powdery mildew. Infector plants of *Lonicera* naturally infected by powdery mildew were introduced into the experiment and left there throughout the experiment, except when fungicides were being applied; *Acer* plants were sprayed with a suspension of powdery mildew spore freshly collected from *Acer* (i.e. inoculum for infection of both species was present). The most likely explanation is that the environmental conditions were not conducive to development of powdery mildew diseases. The summer of 2007 was generally cool and wet with low levels of

sunshine, whereas warm, sunny weather and humid conditions are considered favourable to development of powdery mildew diseases. Interestingly, there was a significant block effect on the severity of powdery mildew on *Crataegus* with greatest disease severity in block 1 in tunnel 1, which suffered the most shade. The mean daily (24 h) temperatures in the tunnels between 9 June and 30 September ranged from 11.2 to 22.0°C (tunnel 1) and from 13.6 to 23.6°C (tunnel 2), which was probably less than optimum for powdery mildew development, which is around 23°C (Xu & Robinson, 2000).

Crop damage and spray deposit

Leaf scorch damage occurred on all *Lonicera* and all *Crataegus* plants after treatment with Torch Extra at 0.9 mL/L. Damage was evident on around half of the *Lonicera* at the first assessment after four sprays and increased in extent and severity with subsequent spray applications. Damage on *Crataegus* was less obvious but again affected all plants by the end of the experiment. None of the other fungicide treatments caused any leaf scorch, stunted growth, or other crop damage.

Spray deposit was very visible on all three species following treatment with Thiovit Jet + Activator 90. None of the other fungicide treatments left an obvious spray deposit.

Table 2.1: Effect of fungicide treatments on powdery mildew on *Crataegus* – Aug 2007

Treatment	Mean % plants affected	Mean % leaf area affected
1. Untreated	50 (12)	6.6
2. Systhane 20EW	0 (0)	0.0
3. Stroby WG	25 (9)	1.4
4. Thiovit Jet + Activator 90	8 (7)	0.8
5. Cyflamid	25 (9)	2.5
6. Flexity	25 (9)	0.7
7. Fortress	25 (9)	2.3
8. Switch	42 (11)	3.8
9. Torch Extra	25 (9)	0.6
10. Nativo 75 WG	8 (7)	0.2
11. UKA 379a	33 (10)	5.4
12. UKA 383b	8 (7)	0.2
Significance (33 df)	0.0210	0.170

( ) – standard error

CONCLUSIONS

1. Currently, a wide range of fungicides, from 19 different chemical mode-of-action groups, are potentially available for control of powdery mildew diseases on outdoor ornamentals; the range available for use on protected crops is slightly less extensive. Note, however, that future availability of fungicides for use on ornamental crops, if they do not have a label recommendation for this use, will depend on securing a SOLA for each individual product.

2. The incidence of *Crataegus* plants affected by powdery mildew was significantly reduced by Cyflamid, Flexity, Fortress, Nativo 75 WG, Systhane 20 EW, Stroby WG, Thiovit Jet + Activator 90 and an experimental fungicide. The only treatment that maintained plants free from powdery mildew was Systhane 20 EW.

3. Torch Extra (spiroxamine) at 0.9 mL/L caused leaf scorch on *Crataegus* and *Lonicera* and is not suitable for use on these crops at this rate.

4. Thiovit Jet + Activator 90 left a very obvious spray deposit on *Acer, Crataegus* and *Lonicera.*

TECHNOLOGY TRANSFER

Demonstration of the fungicide experiment at ADAS Arthur Rickwod to members of the HTA HNS Technical Committee, 2007.

REFERENCES AND LITERATURE REVIEWED

Anon (1991). Guidelines on good plant protection practice – pome fruits PP 2/18 (1). European and Mediterranean Plant Protection Organisation, Paris.

Ann, D., O'Neill, T.M. & Atwood, J. (2004). Control of the main foliar diseases of container-grown rose. HDC Factsheet 12/04.

Anon (2006). Fungicide Resistance Action Committee (FRAC) Code List 1: Fungicides sorted by FRAC code.

Anon (2006). Fungicide Resistance Action Committee (FRAC) Code List 2: Fungicides sorted by modes of action.

Burgess, C.M. (2000). Roses: Fungicides for the control of powdery mildew, black spot and rust. *HDC Project 106, Annual report*.

Daughtrey, M.L., Tobiasz, M. (2002). Control of verbena powdery mildew with fungicides, 2001. *Fungicide and Nematicide Tests* Volume 57: OT28.

Jeffers, S.N., Miller, R.W., Powell, C.C. (2001). Fungicides for ornamental crops in the nursery. Chapter 93 in: Diseases of woody ornamentals and trees in nurseries. Eds: RK Jones & DM Benson. APS Press, St Paul, USA.

Hagan, A.K., Akridge, J.R. (2005). Comparison of fungicides for the control of Alternaria leaf spot and powdery mildew on zinnia, 2004. *Fungicide and Nematicide Tests* Volume 60: OT023.

Hagan, A.K., Akridge, J.R. (2005). Comparison of selected fungicides for the control of powdery mildew, Cercospora leaf spot, and spot anthracnose on flowering dogwood, 2004. *Fungicide and Nematicide Tests* Volume 60: OT029.

Hagan, A.K., Akridge, J.R. (2005). Comparison of selected fungicides for the control of three foliar diseases on flowering dogwood, 2003. *Fungicide and Nematicide Tests* Volume 60: OT028.

Hagan, A.K., Akridge, J.R. (2006). Comparison of selected fungicides for the control of three diseases of flowering dogwood, 2005. *Fungicide and Nematicide Tests* Volume 61:OT006.

Hagan, A.K., Olive, J.W., Stephenson, J. (2004). Comparison of fungicides for the control of powdery mildew on container-grown flowering dogwood, 2003. *Fungicide and Nematicide Tests* Volume 59:OT039.

Hagan, A.K., Olive, J.W., Stephenson, J. (2005). Curative control of powdery mildew on container-grown dogwood with Milstop fungicide, 2004. *Fungicide and Nematicide Tests* Volume 60:OT030.

Hagan, A.K., Olive, J.W., Stephenson, J., Rivas-Davila, M.E. (2003). Chemical control of powdery mildew on flowering dogwood, 2002. *Fungicide and Nematicide Tests* Volume 58:OT038.

Halstead, A.J. & Scrace, J.M. (2000). Pests and diseases of outdoor ornamentals, including hardy nursery stock. BCPC Pest and Disease Management Handbook. Ed: D.V. Alford. Blackwell Science.

Hausbeck, M.K., Byrne, J., Quackenbush, W.R., Linderman, S.D. (2003). Evaluation of fungicides for the control of powdery mildew of poinsettia, 1999. *Fungicide and Nematicide Tests* Volume 58:OT014.

Hausbeck, M.K., Byrne, J., Quackenbush, W.R., Linderman, S.D. (2003). Evaluation of registered and unregistered fungicides for the control of powdery mildew of poinsettia, 1999. *Fungicide and Nematicide Tests* Volume 58:OT015.

Hausbeck, M.K., Cortright, B.D., Werner, N.A. (2003). Evaluation of registered and unregistered fungicides for the control of powdery mildew of poinsettia, 2001. *Fungicide and Nematicide Tests* Volume 58:OT013.

Hausbeck, M.K., Harlan, B.R., Linderman, S.D. (2003). Control of powdery mildew on pincushion flower with foliar sprays. *Fungicide and Nematicide Tests* Volume 58:OT010.

Hausbeck, M.K., Harlan, B.R., Woodworth, J.A. (2004). Control of powdery mildew on verbena with foliar sprays, 2003. *Fungicide and Nematicide Tests* Volume 59:OT014.

Hausbeck, M.K., Harlan, B.R., Woodworth, J.A. (2005). Evaluation of curative and preventative treatments for controlling powdery mildew on verbena, 2004. *Fungicide and Nematicide Tests* Volume 60:OT007.

Hausbeck, M.K., Harlan, B.R., Woodworth, J.A., Sconyers, L.E. (2005). Evaluation of a biopesticide and fungicides for controlling powdery mildew on verbena, 2004. *Fungicide and Nematicide Tests* Volume 60:OT008.

Hausbeck, M.K., Quackenbush, W.R., Linderman, S.D. (2003). Evaluation of fungicides for the control of powdery mildew of greenhouse-grown African daisy, 1999. *Fungicide and Nematicide Tests* Volume 58:OT007.

Hausbeck, M.K., Quackenbush, W.R., Linderman, S.D. (2003). Evaluation of new fungicides in managing powdery mildew on field-grown African daisies, 2002. *Fungicide and Nematicide Tests* Volume 58:OT004.

Hausbeck, M.K., Quackenbush, W.R., Linderman, S.D. (2003). Evaluation of strobilurin-based and other fungicides in managing powdery mildew on field-grown African daisies, 2002. *Fungicide and Nematicide Tests* Volume 58:OT005.

Hausbeck, M.K., Wagstaff, S.A., Harlan, B.R. (2006). Evaluation of curative versus preventative fungicide treatments for controlling powdery mildew on verbena, 2005. *Fungicide and Nematicide Tests* Volume 61:OT013.

Hausbeck, M.K., Wagstaff, S.A., Harlan, B.R. (2006). Evaluation of biopesticides, reduced-risk, and unregistered fungicides for the control of powdery mildew on verbena, 2005. *Fungicide and Nematicide Tests* Volume 61:OT014.

Hausbeck, M.K., Wagstaff, S.A., Harlan, B.R., Sconyers, L.E. (2006). Evaluation of curative versus preventative fungicide treatments for controlling powdery mildew on Gerbera daisy, 2005. *Fungicide and Nematicide Tests* Volume 61:OT010.

Hausbeck, M.K., Wagstaff, S.A., Harlan, B.R., Sconyers, L.E. (2006). Evaluation of curative fungicide treatments for controlling powdery mildew on Gerbera daisy, 2005. *Fungicide and Nematicide Tests* Volume 61:OT011.

Hewitt, H.G. (1998). Fungicides in crop protection. CAB International. 221pp.

Jacobi, J.C., Caylor, A.W. (2004). Field evaluation of fungicides for control of powdery mildew on Zinnia, 2003. *Fungicide and Nematicide Tests* Volume 59:OT045.

Kenyon, D. & Dixon, G. (1995). The chemical control of rhododendron powdery mildew. Final Report for HDC Project HNS 64.

Kenyon, D. & Dixon, G. (1997). New fungicides for rhododendron. *HDC Project News,* 43, p6.

LaMondia, J.A. (2002). Evaluation of fungicides for control of powdery mildew in Monarda and Phlox, 2001. *Fungicide and Nematicide Tests* Volume 57:OT21.

Mulrooney, R.P., Gregory, N.F. (2004). Evaluation of fungicides for control of powdery mildew on flowering dogwood, 2003. *Fungicide and Nematicide Tests* Volume 59:OT028.

Mulrooney, R.P., Gregory, N.F. (2005). Evaluation of fungicides for control of powdery mildew on flowering dogwood, 2004. *Fungicide and Nematicide Tests* Volume 60:OT016.

Nelson, M.E., Grove, G.G., Glawe, D.A. (2006). Evaluation of fungicides for control of pincushion flower powdery mildew, 2005. *Fungicide and Nematicide Tests* Volume 61:OT032.

O'Neill, T.M. (2000). Protected and outdoor cut flowers: development of effective and crop-safe fungicide treatments for control of powdery mildew 2000-2001. *HDC Project BOF 44, Annual Report.*

O'Neill, T.M. (2002). Protected and outdoor cut flowers: development of effective and crop-safe fungicide treatments for control of powdery mildew. *HDC Project BOF 44, Annual Report.*

O'Neill, T.M. (2003a). Protected and outdoor cut flowers: development of effective and crop-safe fungicide programmes for control of powdery mildew. *HDC Project BOF 44, Final Report.*

O'Neill, T.M. (2003b). Control of powdery mildew on cut flowers. HDC Factsheet 11/03.

Pasini, C., D'Aquila, F., Curir, P., Sacco, M. (2001). Evaluations of SBI fungicides, strobilurins and some natural products for control of powdery mildew on perennial Aster and Delphinium grown in protected cultivations. *Informatore Fitopatalogico*, 3: 43-45.

Pemberton, H.B., Philley, G.L., Roberson, W.E. (2001). Fungicide evaluation for powdery mildew control on miniature rose, 1999. *Fungicide and Nematicide Tests* Volume 56:OT33.

Psheidt, J.W. (2001). Comparison of fungicides for control of powdery mildew on deciduous azalea, 2000. *Fungicide and Nematicide Tests* Volume 56:OT2.

Sconyers, L.E., Hausbeck, M.K. (2005). Evaluation of biological and biorational products in managing powdery mildew of African daisy, 2004. *Fungicide and Nematicide Tests* Volume 60:OT001.

Sconyers, L.E., Hausbeck, M.K. (2005). Evaluation of reduced-risk fungicides in managing powdery mildew of African daisy, 2004. *Fungicide and Nematicide Tests* Volume 60:OT002.

Sconyers, L.E., Hausbeck, M.K. (2005). Evaluation of registered and unregistered fungicides for controlling powdery mildew on African daisy (trial 1), 2004. *Fungicide and Nematicide Tests* Volume 60:OT003.

Sconyers, L.E., Hausbeck, M.K. (2005). Evaluation of registered and unregistered fungicides for controlling powdery mildew on African daisy (trial 2), 2004. *Fungicide and Nematicide Tests* Volume 60:OT004.

Thevenot, E., Robbins, J., Klingaman, G., Cartwright, R.D. (2004). Evaluation of fungicides and biorational products for control of powdery mildew of phlox, 2001. *Fungicide and Nematicide Tests* Volume 59:OT031.

Tjosvold, S.A., Koike, S.T. (2001). Evaluation of reduced risk and other biorational fungicides on the control of powdery mildew on greenhouse roses. *Acta Hort.* 547, 59-67.

Tomlin, C.D.S. (ed) (2006). The Pesticide Manual, 14th Edition. British Crop Protection Council. 1349pp.

Trinci, A.P.J., Ryley, J.F. (1984). Mode of action of anti-fungal agents. Pitman Press. 405pp.

Wegulo, S.N., Vilchez, M. (2006). Evaluation of fungicides for control of powdery mildew of Delphinium, 2002. *Fungicide and Nematicide Tests* Volume 61:OT024.

Wegulo, S.N., Vilchez, M. (2006). Evaluation of fungicides for control of powdery mildew of Delphinium, 2003. *Fungicide and Nematicide Tests* Volume 61:OT025.

Wegulo, S.N., Vilchez, M. (2006). Evaluation of fungicides for control of powdery mildew of rose, 2004. *Fungicide and Nematicide Tests* Volume 61:OT026.

Whitehead, B.A. (ed) (2007). The UK Pesticide Guide 2007. BCPC / CABI 685pp.

Williams-Woodward, J.L. (2001). Control of powdery mildew (on hydrangea) with preventative fungicide applications, 1999. *Fungicide and Nematicide Tests* Volume 56:OT15.

Williams-Woodward, J.L. (2001). Control of powdery mildew (on hydrangea) with curative fungicide applications, 1999. *Fungicide and Nematicide Tests* Volume 56:OT16.

Williams-Woodward, J.L. (2005). Evaluation of fungicides to control powdery mildew on hydrangea, 2003. *Fungicide and Nematicide Tests* Volume 60:OT032.

Xu X-M., Robinson, J.D. (2000). Effectso f temperature on the incubation and latent periods of hawythorn powdery mildew. *Plant Pathology* 49: 791-797.