FINAL REPORT

WTFRC Project # AH-02-210 **WSU Project # 13C-3661-7367**

Project title: Epidemiology and control of apple powdery mildew

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Objectives:

1. Develop a weather-based model for scheduling fungicide applications to improve disease control and reduce fungicide usage.
2. Evaluate efficacy of various products for control of apple powdery mildew.
3. Evaluate reduced DMI and strobilurin fungicide programs, in combination with inorganic salts, for control of powdery mildew.
4. Evaluate various reduced fungicide programs, alone or in combination with natural products, for control of powdery mildew.
5. Determine relationships between mildew severity during bloom through petal fall and fruit russet at harvest.

New, additional objective for 2004:

Evaluate chemical thinning products in combination with fungicides for both thinning and control of powdery mildew.

Significant findings:

- The model-based spray program (80 CDD plus 14-day intervals) saved one fungicide spray (applying lime sulfur at tight cluster saved two DMI/strobilurin sprays) and provided a good mildew control comparable to the Procure/Flint alternation program or the straight Procure spray program.
- The new fungicide Pristine (pyraclostrobin and boscalid) is expected to be registered in early 2005 for use on apple for control of powdery mildew. Pristine needs to be used in combination with adjuvants to achieve its efficacy. Pristine mixed with either Sylgard (8 oz/100 gallon) or superior oil (0.5-1%) as an adjuvant provided an excellent control of powdery mildew.
- The biocontrol agent Sonata (*Bacillius pumilis* strain 2808) was registered in late 2004. Sonata can be used in alternation with other fungicides for resistance management in the conventional production and could be a good tool in managing powdery mildew in the organic production.
- The new formulation Procure 480SC provided a similar level of control compared to Procure 50WS. Registration of Procure 480SC for use on apple has been submitted to EPA for review.
- Bloom thinning programs (3% lime sulfur plus 2% Crocker's fish oil or 8% lime sulfur applied at 20% bloom and 80% bloom) in combination with 3% lime sulfur at green tip stage and DMIs or strobilurins at other growth stages provided very good control of powdery mildew. Lime sulfur-based bloom thinning programs have the potential to be integrated with other fungicide programs as a season-long program for both bloom thinning and control of powdery mildew. Developing cultivar-specific programs for both thinning and mildew control are needed.

- Flint/Procure/Sovran alternation and Flint/Procure alternation provided a similar control for both foliar and fruit mildew. It appears that alternation of Procure and Flint, starting with Procure, was more effective to reduce early infections than the alternation program starting with Flint. Alternating Flint with Procure and Sovran is a good strategy for using different classes of fungicides for mildew control and fungicide resistance management.
- Under moderate to high mildew disease pressure, products other than synthetic fungicides in general did not provide satisfactory control. Alternation of DMI (Procure) or strobilurin (Flint) with products other than synthetic fungicides varied in their effectiveness. Alternation of 1% stylet oil with Procure, starting with Procure, provided very good control for powdery mildew, compared to the Procure/Flint alternation program. During the early season, the standard fungicide program (Procure/Flint alternation) was better in reducing early infections than the Procure/stylet oil program. However, Procure/stylet oil alternation starting with Procure provided better control later in the season than the standard program, Procure/Flint alternation. Alternation of Procure and Kaligreen provided better control than Kaligreen alone but did not provide satisfactory control. Alternation of 1% mono-potassium phosphate solution with Procure, starting with Procure, provided a good control of mildew till the first cover spray.
- Fruit russet at harvest was significantly correlated with the mildew incidence and severity on leaves at petal fall. Reducing mildew during bloom is critical to improve fruit quality at harvest (low level of fruit russet).
- The experimental product USF 2010, a premixed formulation of Elite and Flint, provided a similar level of control for mildew as the Procure/Flint alternation program.
- Flutriafol is very effective in controlling apple powdery mildew. This fungicide has not been registered in the U.S. Flutriafol is a DMI class fungicide but is a systemic fungicide, which has the potential to offer a flexibility in a mildew control program. Continual efforts are needed to work with the registrant to make this fungicide available to the fruit industry.

Methods:

The experiment was conducted in a research block of Jonagold apple to evaluate various model-based spray programs for control of powdery mildew. Weather variables from PAWS were used to determine cumulative degree-days (> 50ºF). Tree growth stage was monitored, and the first mildew fungicide application was initiated based upon a degree-day model for powdery mildew. Powdery mildew development was evaluated four times. After the first application of fungicides, timing and intervals of subsequent applications of DMI/strobilurin fungicides were determined using a weather-based model of the latent period of powdery mildew and host parameters such as new foliar growth. To determine mildew severity on leaves, 10 vegetative shoots from each tree were selected for mildew rating. All expanded leaves were examined for mildew severity based on a 0-4 rating scale: 0: no visible mildew; 1: 25% leaf area covered by mildew; 2: 25% to 50% leaf area covered by mildew; 3: 50% to 75% leaf area covered by mildew; and 4: more than 75% leaf area covered by mildew.

Experiments were also conducted in a research block of Rome apple to evaluate various reduced DMI/strobilurin fungicide programs, rotation programs, and new fungicide and biocontrol products for control of powdery mildew. Treatments were arranged in a randomized complete block design with four single-tree replicates for each treatment. Foliar incidence and severity of powdery mildew during the growing season were evaluated two times as described above. At harvest, 50 fruits/rep. were picked, then rated for the percentage of the surface of the apple which had net type russet, using the scale: 0: no russet; 1: 1-5% fruit surface russet; 2: 6-10 fruit surface russet; 3: 11-25 fruit surface russet; 4: 26-50 fruit surface russet; and 5: >50% fruit surface russet. Regression analysis was used to determine relationships between foliar mildew at petal fall and fruit russet at harvest.

Results and discussion:

Model-based spray program. In 2004, powdery mildew pressure was high in the Jonagold block used for the experiment. All model-based spray treatments started with a lime sulfur application at tight cluster. The first application of Procure was initiated when the cumulative degree-days (CDD) reached 80, 100, and 120. Fungicides Procure/Flint alternation, starting with Procure, were applied at either 14-day intervals or at an interval adjusted based on the weather. Both the calendar spray and Procure/Flint alternation provided acceptable control, with foliar mildew incidence of around 20% (Table 1). In 2004, the fourth application of the "80 CDD+14-day intervals" program was applied earlier; the result was not compared with other treatments. Fungicides started at 100 CDD and subsequently at 14-day intervals provided a similar level of control for foliar mildew compared to either the calendar spray program or Procure/Flint alternation program (Table 1).

In summary, the model-based spray program (80 CDD+14-day intervals) saved one fungicide spray (applying lime sulfur at tight cluster saved two DMI/strobilurin sprays) and provided a good mildew control comparable to the Procure/Flint alternation program.

Table 1. Powdery mildew on leaves of Jonagold in model-based spray programs in 2004.

	5/28/2004		6/8/2004	
Treatment[1]	Incidence on Leaves (%)	Severity on Leaves	Incidence on Leaves (%)	Severity on Leaves
Nontreated control	88.9a[4]	2.2a	90a	2.47a
80 CDD + 14 days interval	2.1e	0.04f	9.2f	0.17d
100 CDD + 14 days interval	22.7cd	0.27ef	28.2cde	0.39cd
120 CDD + 14 days interval	36.7bc	0.53cd	38.5bcd	0.53bc
80 CDD + adjustable interval	49.2b	0.84b	49.1b	0.83b
100 CDD + adjustable interval	31.9bc	0.36de	25.5de	0.32cd
120 CDD + adjustable interval	47.9b	0.64bc	41.4bc	0.59bc
Calendar spray[2]	10de	0.13ef	23.3e	0.31d
Procure/Flint[3]	4.5e	0.06f	17.1ef	0.22d

[1] All model-based sprays started with lime sulfur at tight cluster. The first application of fungicide was initiated based on the thresholds of cumulative degree-days (average temperature exceeds 50ºF) (CDD).

[2] Lime sulfur at tight cluster and then Procure/Flint alternated at 14-day intervals.

[3] Procure/Flint alternation, starting with Procure.

[4] Values with the same letter in the same column are not significantly different based on the Waller-Duncan Bayesian t-test ($P = 0.05$).

DMI/strobilurin rotation programs for fungicide resistance management. In both 2002 and 2003 experiments, various DMI/strobilurin rotation programs were tested. The data had been presented in previous progress reports. Some specific programs are summarized in Table 2. In each year, all rotation spray programs, Sovran/Procure/Flint, Flint/Procure/Sovran, Flint/Procure, and Procure/Flint, gave similar control for both incidence and severity of powdery mildew on leaves; Sovran and Rally rotation also provided very good control of powdery mildew (Table 2). Our research data also indicated that alternation of Procure and Flint, starting with Procure, was more effective to reduce early infections than the alternation program starting with Flint (data not shown in this report), but foliar mildew was not significantly different between these two programs after the second cover sprays (Table 2). The data indicate that alternating Procure with Flint and Sovran is a good strategy for using different classes of fungicides for mildew control and fungicide resistance management.

Table 2. Leaf powdery mildew of Rome in various fungicide rotation spray programs.

Treatment	6/10/2002		6/9/2003	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	79.4a[6]	2.57a	86.5a	2.43a
Sovran/Procure/Flint[1]	6.9b	0.07b	16.6b	0.18b
Flint/Procure/Sovran[2]	6.0b	0.07b	23.1b	0.27b
Flint/Procure[3]	2.8bc	0.03b	24.8b	0.29b
Procure/Flint[4]	2.9bc	0.03b	19.3b	0.23b
Sovran/Rally[5]	1.5c	0.02b		

[1] Sovran 50WG (4 oz/A) at GT; Procure 50WS (12 oz/A) at PK and PF; Flint 50WG (2.5 oz/A) at1C and 2C.
[2] Flint at GT; Procure at PK and PF; Sovran at 1C and 2C.
[3] AT GT, PK, PF, 1C and 2C, alternation starting with Flint.
[4] AT GT, PK, PF, 1C and 2C, alternation starting with Procure.
[5] Sovan at GT, PF and 2C; Rally at PK and 1C.
[6] Values with the same letter in the same column are not significantly different based on the Waller-Duncan Bayesian t-test ($P = 0.05$).

DMI in combination with other products for disease control and fungicide resistance management.
We have evaluated DMIs in combination with products other than synthetic fungicides for mildew control. Some of the results have been presented in previous reports. Following is brief summary of the results. (1) Mono-potassium phosphate (MKP) solution has been reported to boost the plant immune system to defend itself against powdery mildew. Our study indicated that 1% MKP solution alone did not effectively control mildew compared with either straight DMI (Procure) or strobilurin (Flint) program. However, alternation of MKP with Procure, starting with Procure, provided the same level of control for foliar mildew until the first cover spray, compared to the straight Procure program. (2) Stylet oil (1%) alone applied at 10-day intervals resulted in 35.3% foliar incidence of powdery mildew, which was about 60% reduction in disease incidence compared with the nontreated control. Procure in alternation with 1% stylet oil provided very good control for powdery mildew. During the early season, the standard fungicide program (Procure/Flint alternation) was better in reducing early infections than the Procure/stylet oil program. However, Procure/stylet oil alternation starting with Procure provided better control later in the season than the standard program Procure/Flint alternation. (3) Kaligreen reduced foliar incidence of powdery mildew by 40% compared with the nontreated control, but it did not provide satisfactory control. Alternation of Procure and Kaligreen provided better control than Kaligreen alone but did not provide satisfactory control. (4) Procure in alternation with the biocontrol agent Sonata reduced foliar incidence of powdery mildew by 59% compared with the nontreated control, whereas Procure/Flint alternation reduced the foliar incidence by 88%.

New fungicides and biocontrol agents for control of powdery mildew.
All treatments containing Pristine significantly reduced both incidence and severity of powdery mildew compared with the nontreated control (Table 3). Pristine tank-mixed with adjuvants provided significantly better control of powdery mildew than Pristine alone. Pristine mixed with either Superior oil or Sylgard performed better than Pristine mixed with R56. Rally was still very effective in controlling apple powdery mildew, and provided a similar control as Pristine mixed with either Supreme oil or Sylgard. It appears that Pristine has to be used in combination with an adjuvant in order to achieve control. Pristine is expected to be registered in early 2005 for use on apple for control of apple powdery mildew.

Table 3. Efficacy of Pristine in controlling apple powdery mildew.

Treatment	5/5/2004		6/2/2004	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	24.5a	0.28a	64.6a	1.29a
Pristine[1]	6b	0.06b	25.1b	0.29b
Pristine plus Superior oil[2]	0.3cd	0c	2.9d	0.03c
Pristine plus R56[3]	1.3c	0.01bc	8c	0.09c
Pristine plus Sylgard[4]	0d	0c	1.9d	0.02c
Rally 40%WP @7.5 oz/A	0d	0c	1.6d	0.02c

[1] Pristine 38% WG applied at 0.92 lb/A.
[2] Superior oil at 1% (vol/vol) tank-mixed with Pristine.
[3] R56 at 6 oz/100 gallon tank-mixed with Pristine.
[4] Sylgard at 8 oz/100 gallon tank-mixed with Pristine.

All treatments containing Procure significantly reduced both incidence and severity of powdery mildew compared with the nontreated control (Table 4). The new formulation, Procure 480SC, provided a similar level of control compared to Procure 50WS. Both formulations of Procure provided a better control than the Flint/Procure alternation starting with Flint. Registration of Procure 480SC for use on apple has been submitted to EPA for review.

It appeared that flutriafol was very effective in controlling apple powdery mildew (Table 4). Flutriafol is a DMI-class fungicide. Unlike other current DMIs used for control of powdery mildew, flutriafol is a systemic fungicide, which has the potential to offer a flexibility in a mildew control program.

Elite plus Induce, Flint alone, tank-mixed Flint and Elite, and USF 2010 provided a similar level of control (Table 5). But the pre-mixed formulation of Flint and Elite, USF 2010, appeared to be more consistent in its performance compared with the tank-mixed Flint and Elite in this trial.

All three Sonata treatments significantly reduced foliar powdery mildew compared to the nontreated control (Table 6). Sonata @ 2 quarts/A applied at a 7-day spray interval (8 applications during the season) provided a similar level of control as the standard program of Procure in alternation with Flint (5 applications). Procure in alternation with Sonata (4 quarts/A) was less effective compared with the Procure/Flint alternation. At a 7-day spray interval, Sonata at 2 quarts/A was significantly more effective in controlling powdery mildew compared with the rate at 4 quarts/A.

Table 4. New formulation of Procure and the fungicide flutriafol for control of apple powdery mildew.

Treatment[1]	5/5/2004		6/2/2004	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	24.5a	0.28a	64.6a	1.29a
Procure 50WS @ 12 oz/A	0.6b	0.005b	3.9bc	0.04b
Procure 50WS/Flint 50WG	0.6b	0.005b	7.5b	0.08b
Procure 480SC @ 12 fl oz/A	0.6b	0.005b	3.6bc	0.04b
Flutriafol @ 13 oz/A	0b	0b	2.1c	0.02b

[1] Alternation of Procure 50WS (12 oz/A) and Flint 50WG (2.5 oz/A) starting with Procure at green tip (GT), pink (PK), petal fall (PF), first cover (1C) and second cover (2C). All other treatments were applied at GT, PK, PF, 1C and 2C.

Table 5. New products for control of apple powdery mildew.

Treatment	5/5/2004		6/2/2004	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	24.5a	0.28a	64.6a	1.29a
Elite plus Induce[1]	0.6b	0.01b	5.9b	0.07b
USF 2010 SC[2]	0.3b	0b	6.3b	0.07b
Flint[3]	1.6b	0.02b	10.5b	0.12b
Flint plus Elite[4]	1.1b	0.01b	12.7b	0.14b

[1] Elite 45WP @ 6 oz/A tank-mixed with Induce @0.06% (v/v)
[2] USF 2010 SC @ 4 oz/A
[3] Flint 50 WG @ 2.5 oz/A
[4] Flint 50 WG @ 2.08 oz/A tank-mixed with Elite 45 WP @ 2.32 oz/A

Table 6. Evaluation of the biocontrol agent Sonata for control of apple powdery mildew.

Treatment	5/5/2004		6/2/2004	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	24.5a	0.28a	64.6a	1.29a
Procure/Flint[1]	0.6c	0.01d	7.5d	0.08d
Procure/Sonata[2]	1.5c	0.02cd	26.7c	0.25bc
Sonata @ 2 quarts/A[3]	7.8b	0.08bc	12.9cd	0.15cd
Sonata @ 4 quarts/A[3]	9.9b	0.09b	31.2b	0.38b

[1] Alternation of Procure 50WS (12 oz/A) and Flint 50WG (2.5 oz/A) starting with Procure at green tip (GT), pink (PK), petal fall (PF), first cover (1C) and second cover (2C). GT, PK, PF 1C and 2C were applied on 31 March, 12 April, 29 April, 12 May and 26 May 2004, respectively.
[2] Alternation of Procure 50WS (12 oz/acre) and Sonata (4 quarts/A), starting with Procure, at GT, PK, PF, 1C and 2C.
[3] Applied at 7-day interval (8,15, 22, 29 April and 6, 13, 20 and 26 May).

Relationship between foliar mildew and fruit russet. The data from both 2002 and 2003 experiments were combined and fitted to linear models. In 2004, trees from some treatments did not have enough fruit for fruit russet assessment, thus the data were not included in the analysis. Fruit russet of Rome apple at harvest was significantly correlated with the mildew incidence and severity on leaves at petal fall:

Y (fruit russet incidence) = 7.2 + 0.7 X (foliar incidence at petal fall); (r = 0.6814; n=20)
Y (fruit russet severity) = 0.17 + 1.09 X (foliar severity at petal fall); (r = 0.7845; n=20)

This indicated that reducing the mildew disease level during bloom is important to maintain fruit quality at harvest (low level of fruit russet).

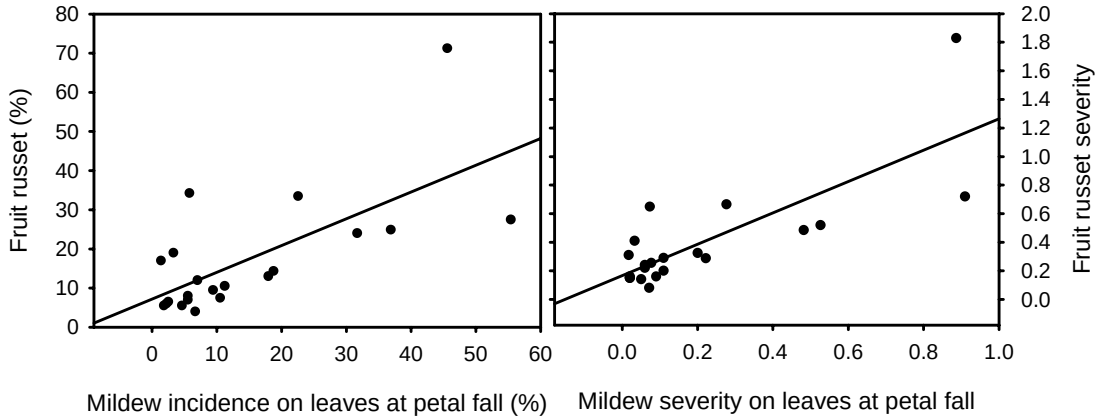

Fig. 1. Relationships between fruit russet at harvest and mildew incidence and severity on leaves at petal fall based on the pooled data from both 2002 and 2003 experiments.

Chemical thinning programs in combination with fungicides for both bloom thinning and mildew control. The bloom thinning programs 1 and 2 provided commercially acceptable control of apple powdery mildew (Table 7). Program 1 was as effective as the standard program, Procure in alternation with Flint, for control of apple powdery mildew. Program 3 was designated for use in organic production. It appears that sulfur is a suitable fungicide that can be integrated into a season-long program for both bloom thinning and mildew control. Further research is needed to evaluate thinning programs in combination with various mildew-control programs to improve disease control. Developing cultivar-specific programs for both thinning and mildew control are needed. In addition to thinning and mildew control, sulfur can also be used for fungicide resistance management.

Table 7. Chemical thinning programs in combination with fungicide programs for both bloom thinning and control of powdery mildew.

Treatment[1]	5/5/2004		6/2/2004	
	Leaf incidence (%)	Leaf severity	Leaf incidence (%)	Leaf severity
Nontreated control	24.5a	0.28a	64.6a	1.29a
Procure 50WS/Flint 50WG	0.6b	0.005b	7.5d	0.08c
Thinning program 1	1.6b	0.02b	7.2d	0.07c
Thinning program 2	0.3c	0.03b	15.1c	0.18c
Thinning program 3	0.4c	0.05b	25.5b	0.31b

[1] Alternation of Procure 50WS (12 oz/A) and Flint 50WG (2.5 oz/A) starting with Procure at green tip (GT), pink (PK), petal fall (PF), first cover (1C) and second cover (2C). GT, PK, PF 1C and 2C were applied on 31 March, 12 April, 29 April, 12 May and 26 May 2004, respectively.

Thinning program 1: lime sulfur (LS) @ 3 gallon/100 gallon at GT, Procure @12 oz/A at PK, LS (3%)+CFO (2%) at 20% bloom and 80% bloom, Procure at 1C and Flint 50WG @2.5 oz/A at 2C.

Thinning program 2: LS (3%) at GT, Procure at PK, LS (8%) at both 20% and 80% bloom, and Flint at 1C.

Thinning program 3: LS (3%) at GT and PK, LS (3%)+CFO (2%) at both 20% and 80% bloom, and then Kaligreen (3 lbs/A) at a 7-day interval till cease of vegetative growth.

Budget:

Project duration: 2002-2004
Current year: 2004
Project total (3 years): $82,642

Year	Year 1 (2002)	Year 2 (2003)	Year 3 (2004)
Total	$25,634	$28,004	$28,004

Current year breakdown:

Item	Year 1 (2002)	Year 2 (2003)	Year 3 (2004)
Salaries[1]	$12,636	$13,141	$15,044
Benefits (39%)	3,538	5,125	5,867
Wages [1]	6,000	6,240	9,000
Benefits (16%)	960	998	1,440
Equipment			
Supplies	1,000	1,000	1,000
Travel[2]	1,500	1,500	1,500
Miscellaneous			
Total	$25,634	$28,004	$33,851 (**received $28,004**)

[1] Salary for a Scientific Assistant and wages for time-slip.
[2] We used a leased vehicle.