Efficacy of New Synthetic and Soft Fungicides for Management of Apple Scab Fungus *Venturia inaequalis*

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Our results with the new synthetic SDHI, DMI and soft fungicides show there is an opportunity to effectively control apple scab fungus *V. inaequalis* for years to come, with minimal risks for development of resistance. However, to be fully successful in long-term we recommend growers incorporate both the synthetic and soft fungicides in an alternating spray schedule during the primary scab season to broaden the spectrum of efficacy of spray mixtures by impacting multiple targets in the fungal pathogen.

Apple scab fungus *Venturia inaequalis* continues to be the major concern of apple growers in the Eastern U.S. In the last 30 years, there has been an increasing pressure on apple producers to reduce pesticide use while maintaining a high level of crop quality (Carisse et al. 2006). However, achieving sustainable management of fruit crop diseases is a growing challenge due to pathogen-favorable humid tropical, subtropical, and continental climate types in the Eastern US and an increasing frequency of extreme weather patterns favoring infections by fungal pathogens (Melillo et al. 2014). Application of fungicides for control of apple scab is dictated by the weather conditions, apple bud tissue expansion, and disease pressure, and is often decided upon by using apple scab prediction models like RIMpro (https://rimpro.eu/) and NEWA (http://newa.cornell.edu/index.php?page=apple-diseases). Judicious use of fungicides is secured by accurately timing the spray applications just before severe infections are predicted with apple scab models, which are based on weather forecast and pathogen ecological requirements, and by incorporating new fungicide classes i.e. groups developed in the last 15 years along with the classic ones. Apple scab prediction models like RIMpro also help growers to select and apply highly effective fungicides when high and extreme infections risks warrant these.

The introduction of new fungicide classes like succinate dehydrogenase inhibitors (SDHIs, group 7) helps growers avoid strong selection of fungicide resistant individuals in *V. inaequalis* populations by alternating the old and new site-specific and soft fungicides from week to week. In addition, each single-site fungicide application must always be made in tank mix with at least one contact i.e. multisite fungicide so as to broaden the efficacy by impacting multiple targets in the fungal pathogen body or their germinating spores. The objective of this work was to evaluate efficacy of several new fungicides in apple scab control under heavy infection pressures of 2019 and 2020 growing seasons and compare them with the other fungicides in the same group/s, so as to facilitate their implementation into the commercial apple production in the U.S.

New Synthetic Fungicides

Cevya aka Revysol is a new demethylation inhibitor (DMI) fungicide for apple scab containing the active ingredient mefentrifluconazole (group 3). This fungicide from BASF is registered in New York, excluding Long Island. As a unique chemistry, it inhibits sterol biosynthesis in membranes of plant pathogenic fungi and features an isopropanol-azole chemistry that helps ensure binding capacity and adaptability through its molecule flexibility. Cevya offers control even on plant pathogen strains that are insensitive to DMIs and is recommended for 7-to-10-day application interval. Cevya is labelled for different fungal pathogens of pome and stone fruit, tree nuts, and grapes (table, raisins, wine, but not on *Vitus labrusca* or *V. labrusca* hybrid varieties). It is recommended for use from 3 to 5 oz/A, with a total of 15 fl oz/A per year allowed, which allows three applications of 4 or 5 fl oz rates or five applications of a 3 fl oz rate. It must not be applied more than two sequential applications before alternating to a non-group 3 fungicide labeled for apple scab fungus. Cevya has zero days pre-harvest interval. Restricted-entry interval for an orchard treated with Cevya is 12 hrs.

Aprovia aka Solatenol is the new SDHI fungicide for apple scab control registered in New York, including Long Island, containing the active ingredient benzovindiflupyr. This new fungicide from Syngenta belongs to the group 7 of fungicides which inhibit respiration in fungal plant pathogens. Aprovia is recommended for 7-to-10-day application interval and is limited to 27.6 fl oz/A per year, which allows 5 to 4 applications with either 5.5 or 7 fl oz/A. It has been primarily intended for controlling apple scab and powdery mildew early in the spring and cannot be applied within 30 days of harvest. However, due to its good efficacy in control of apple bitter rot caused by *C. fioriniae*, saving one to two applications of this fungicide in mix with captan or ziram for mid-summer (July, August) would be preferable (Aćimović et al. 2020). This can help prevent buildup of *C. fioriniae* symptomless presence in leaves, forming of quiescent infections on fruit, and slow or prevent buildup of potential *C. fioriniae* individuals resistant to currently effective strobilurin i.e. QoI fungicides (group 11).

Miravis aka Adepidyn is Syngenta's latest SDHI fungicide registered in New York, including Long Island, which contains new active ingredient pydiflumetofen from group 7. It has been tested and is recommended at a rate of 3.4 fl oz/A every 7-10 days. Besides control of apple and pear scab, Miravis is labeled for control of cedar apple/quince rust, sooty blotch and flyspeck, apple powdery mildew and few other diseases. Only two consecutive applications of Miravis or other group 7 fungicide are allowed, after which alternating to a non-group 7 registered fungicide is necessary. A maximum application rate of 13.6 fl oz/A per year is allowed which means only four applications per year of 3.4 fl oz are allowed. Miravis is listed to only suppress *Colletotrichum* spp. that cause apple bitter rot, but in our inoculated orchard trial in 2020 we detected no significant control of bitter rot caused by *C. fioriniae* on 'Honeycrisp' with this fungicide (Aćimović et al. 2020).

Excalia aka Indiflin is the new SDHI fungicide from Valent USA, which contains new active ingredient inpyrfluxam, from group 7 fungicides, and has just been registered by EPA in September of 2020. However it is not yet registered in New York but it is anticipated it will be sometime in 2022. Excalia is currently being tested in multiple sites across the USA. The EPA label lists it for use at 3 to 4 fl oz/A on apples, it can be used only for two spray applications in total per year, 10 days apart, and cannot be applied after petal fall. The total amount of Excalia that can be applied per year is 8 fl oz/A.

Pyraziflumid 20SC is the new SDHI fungicide by Nichino America, which contains active ingredient pyraziflumid from group 7, but is not yet registered by EPA. Registration by New York DEC is assumed to follow EPA registration. It is being tested for control of apple scab, *Botrytis* bunch rot/grey mold, and many other fungal plant diseases. Our tests from 2017 showed equal control of apple powdery mildew in low infection pressure conditions at three different rates: 0.93, 1.86 and 2.79 fl oz/A (Aćimović and Meredith, 2017).

New Soft Fungicides

Stargus is a new biological fungicide which contains living cells of bacterium *Bacillus amyloliquefaciens* strain F727 and spent fermentation media. It belongs to BM02 group of biologicals with multiple modes of action (formerly in group F6, FRAC 44 of microbial disrupters of pathogen cell membranes). Stargus is listed to only suppress apple scab. It is recommended at 1 to 4 quarts in 50 to 100 gallons of water per acre at 7 to 10 day intervals, but during the periods of rapid apple bud tissue development and frequent scab infections, it should be applied at 3 to 7 day intervals. Stargus has zero days pre-harvest interval and is approved for organic use i.e. it is OMRI listed (Organic Materials Review Institute).

Vacciplant is a stimulant of plant defense reactions from Arysta LifeScience North America which contains a natural active ingredient laminarin. This is a polysaccharide (oligosaccharin) extracted from of a brown seaweed, *Laminaria digitata*. It belongs to its own P4 subgroup of polysaccharide elicitors within the host plant defense inducers and is labelled on pome fruit for apple scab and powdery mildew at 14 to 60 fl oz/A at 10 to 14 day application intervals. When less than 100 gal/A of water is used for spraying, use rate of 14 fl oz/A of Vacciplant. Vacciplant has zero days pre-harvest interval and besides being recommended for control of apple scab and apple powdery mildew it is listed to only suppress apple bitter rot caused by *Colletotrichum* spp., among many other fungal pathogens. We hope to evaluate this effect in future trials. Vacciplant is considered a biorational disease control material that has not yet been evaluated or listed by OMRI for compliance, however, aquatic plant extracts (other than hydrolyzed) are listed as synthetic substances allowed for use in organic crop production as plant or soil amendments (laminarin is not yet listed for pest control).

Table 1. SDHI fungicide spray programs evaluated in trial (I) in 2019. Treatments were applied: 7 Apr – GT, green tip; 11 Apr – HIG, half-inch green; 17 Apr – TC, tight cluster; 25 Apr – PK, pink; 29 Apr – EB, early bloom; 3 May – MBL, mid-bloom; 6 May – FB; 13 May – PF, petal fall; 23 May – ½ INF; 25 May – 1C, first cover; 4 Jun – 2C, second cover; 19 Jun – 3C, third cover; 14 Jul – 4C, fourth cover; 25 Jul – 5C, fifth cover.

	Treatment program with amount per Acre	Spray Timing
1	Untreated control	/
2	Vangard 75 WG 5 oz Mancozeb 75 WG 3 lb Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb Miravis A19649[B] 3.42 fl oz Inspire Super 12 fl oz Captan 80 WDG 3 lb	GT TC PK, EB FB, PF 1C 2C – 5C
3	Vangard 75 WG 5 oz Mancozeb 75 WG 3 lb Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb Miravis A19649[H] 3.42 fl oz Inspire Super 12 fl oz Captan 80 WDG 3 lb	GT TC PK, EB FB, PF 1C 2C – 5C
4	Vangard 75 WG 5 oz Mancozeb 75 WG 3 lb Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb Aprovia 5.5 fl oz Inspire Super 12 fl oz Captan 80 WDG 3 lb	GT TC PK, EB FB, PF 1C 2C – 5C
5	Vangard 75 WG 5 oz Mancozeb 75 WG 3 lb Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb Luna Sensation 4.17 SC 5 fl oz Inspire Super 12 fl oz Captan 3 80 WDG lb	GT TC PK, EB FB, PF 1C 2C – 5C
6	Mancozeb 75 WG 3 lb Cevya 3.34SC 4 fl oz + LI700 16 fl oz/100gal + Mancozeb 75 WG 3 lb Captan 80 WDG 3 lb	HIG TC, EB, MB, PF 1C – 5C
7	Mancozeb 75 WG 3 lb Cevya 3.34SC 5.0 fl oz + LI700 16 fl oz/100 gal + Mancozeb 75 WG 3 lb Captan 80 WDG 3 lb	HIG TC, EB, MB, PF 1C – 5C
8	Mancozeb 75 WG 3 lb Inspire Super 12 fl oz + LI700 16 fl oz/100gal + Mancozeb 75 WG 3 lb Captan 80 WDG 3 lb	HIG TC, EB, MB, PF 1C – 5C
9	Pyraziflumid 3.1 fl oz + Mancozeb 75 WG 3 lb + Silwet 16 fl oz/100 gal Captan 80 WDG 3 lb	HIG, PK, FB, PF, ½ INF, 1C 2 – 5C
10	Pyraziflumid 3.1 fl oz + Mancozeb 75 WG 3 lb Captan 80 WDG 2.5 lb	HIG, PK, FB, PF, ½ INF, 1C 2 – 5C
11	Pyraziflumid 4.65 fl oz + Mancozeb 75 WG 3 lb Captan 80 WDG 2.5 lb	HIG, PK, FB, PF, ½ INF, 1C 2 – 5C
12	Indar 6 fl oz + Mancozeb 75 WG 3 lb Rally 5 oz + Mancozeb 75 WG 3 lb Luna Sensation 5 oz + Mancozeb 75 WG 3 lb Captan 80 WDG 3 lb/A (1-5C)	HIG, TC PK MB, PF 1C–5C
13	Fontelis 16 fl oz + Indar 8 fl oz Captan 80 WDG 3 lb/A (1-5C)	TC, PK, MB, PF 1C – 5C

Laminarin is not yet listed in the Organic Foods Production Act of 1990 (OFPA) and it is not specifically listed in the National Organic Program organic regulations. It seems that synthetic/nonsynthetic classification of laminarin is still debated due to the extraction process during manufacturing and its status depends on the synthetic residuals in this process (sodium and sulfate ions) (USDA Technical Evaluation Report – Limited Scope, Laminarin – Crops).

Materials and Methods

Trial 2019 (I). We conducted an apple scab trial in Highland, NY (Table), to evaluate efficacy of multiple SDHI-s, including

Table 2. spray programs of SDHI fungicide Excalia evaluated in trial (II) in 2019. Treatments were applied: 7 Apr – GT, green tip; 17 Apr – HIG, half-inch green; 25 Apr – LTC, late tight cluster; 29 Apr – PK, pink; 3 May – BL, bloom; 8 May – PF, petal fall; 25 May – 1C, first cover; 19 Jun – 2C, second cover; 14 Jul – 3C, third cover; 25 Jul – 4C, fourth cover.

	Treatment program with amount per Acre	Spray Timing
1	Untreated control	/
2	Vangard 5 oz + Manzate Pro-Stick 75 WG 3 lb Inspire Super 12 fl oz + Manzate Pro-Stick 75 WG 3 lb Merivon 5.5 fl oz/A + Manzate Pro-Stick 75 WG @ 3 lb Excalia 3 fl oz + Syl-Coat 0.062% v/v (8 fl oz/100 gal) Inspire Super 12 fl oz Excalia 3 fl oz + Syl-Coat 0.062% v/v (8 fl oz/100 gal) Captan 80 WDG 3 lb	GT HIG LTC PK BL PF 1C – 4C

new SDHI-s Miravis (pydiflumetofen), labeled in this report as two formulations A19649[B] and A19649[H], and pyraziflumid, as well as a triazole fungicide Cevya 3.34 SC (34.93% W/W mefentrifluconazole; FRAC 3). We used 24-yr-old apple trees on M.9 rootstock planted in discrete three-cultivar replicated plots at 25 ft between rows, 10 ft between trees within rows, and 20 feet between plots within rows. We replicated treatments four times using a complete randomized design (CRD). Each replicate plot consisted of three trees of three apple cultivars ('Jerseymac', 'Cortland' and 'Golden Delicious'). We spray applied treatments dilute to drip (300 gal/A) using a tractor-carried handgun sprayer (Rear's Pak-Tank 100-gal sprayer, 250 PSI) at various day intervals and depending on apple bud growth development and weather conditions, as shown in Table 1. We applied insecticides during the trial with an air-blast sprayer to all plots including control trees, using Unigreen Turboteuton Mistblower air-blast sprayer (Uni–green Crop Protection, S.p.A., Reggio Emilia, Italy) delivering 45 gal of spray solution per acre. There were nine major infection events in 2019 as determined by RIMpro apple scab prediction model (RIMpro B.V., Zoelmond, Netherlands) connected to an on-site NEWA-RainWise weather station in Highland, NY. These infection periods occurred on 26, 28 and 30 Apr and 3, 5, 7, 10, 12 and 28 May. To correctly calibrate RIMpro apple scab model, thus increasing the accuracy of predictions of apple scab infections and their severity on test location, we used two biofixes: green tip date and the date of first ascospore release from leaf litter. Using vacuum spore trap tower, first apple scab ascospores released in Highland, NY, were detected on 28 March, but due to the abundance of caught ascospores we adjusted this date to 26 March. We rated apple scab incidence on spur leaves from 2 – 7 Jul and on fruit from 12 – 19 Aug. The percent incidence on spur leaves was calculated from the number of leaves with scab lesions versus the leaves without lesions on 20 randomly selected leaf clusters per tree. The percent incidence on fruit was calculated from the number of fruit with at least one scab lesion versus the fruit without lesions on 20 randomly selected fruit clusters per tree, for a total of up to 50 fruits per tree replicate. Disease incidences were subjected to Wilcoxon nonparametric test, Tukey's or LSD test ($\alpha = 0.05$), for a completely randomized design using JMP pro v.14 or PROC MIXED procedure in SAS Studio software (SAS Institute Inc. 2017, Cary, NC). Where needed, data were transformed prior to analysis.

Trial 2019 (II). We conducted a trial in Highland, NY, to evaluate efficacy of a new SDHI Excalia (indiflin) in apple scab control (Table 2). We used 4-yr-old apple trees on M.9 rootstock, of three cultivars: 'McIntosh', 'Gala', and 'Honeycrisp', planted in completely randomized design at 14 ft between rows, and 6 feet between trees within rows. We replicated treatments three times using a complete randomized design (CRD). Each replicate consisted of three trees each of the apple cultivars. Treatments were sprayed dilute to drip (300 gal/A) using a tractor-carried handgun sprayer (Rear's Pak-Tank 100-gal sprayer, 250 PSI) at various day intervals depending on apple flower bud growth development and weather conditions as shown in Table 2. Insecticides during the trial were applied with an air-blast sprayer to all plots including control trees, using Unigreen Turboteuton Mistblower air-blast sprayer (Uni–green Crop Protection, S.p.A., Reggio Emilia, Italy) delivering 45 gal of spray solution per acre. There were nine apple scab infection events as determined by RIMpro prediction model (RIMpro B.V., Zoelmond, Netherlands) connected to an on-site NEWA-RainWise weather station in Highland, NY. These infection periods occurred on 26, 28 and 30 Apr and 3, 5, 7, 10, 12 and 28 May. We calibrated RIMpro apple scab model to increase the accuracy of predictions and their severity by using two biofixes in the model: green tip date and the date of first ascospore release from leaf litter. The first apple scab ascospores released in Highland NY were detected using vacuum spore trap tower on 28 March. Due to the abundance of detected ascospores we adjusted this second biofix date to 26 March. Primary scab season ended on 4 Jun. Apple scab incidence on spur leaves was rated from 2 – 7 Jul and on fruit from 12 – 19 Aug. We calculated percent scab incidence on spur leaves from the number of leaves with scab lesions versus the leaves without lesions on 20 randomly selected leaf clusters per tree. The percent scab incidence on fruit was calculated from the number of fruit with at least one scab lesion versus the fruit without lesions for all fruit per tree replicate. Disease incidences were subjected to Wilcoxon nonparametric test or LSD test ($\alpha = 0.05$), for a completely randomized design using JMP pro v.14 or PROC MIXED procedure in SAS Studio software (SAS Institute Inc. 2017, Cary, NC). Where needed, data were transformed prior to analysis.

Trial 2020. In an apple scab trial in Highland, NY, we evaluated efficacy of a biological Stargus (*Bacillus amyloliquefaciens* strain F727, 96.4%), plant resistance activator Vacciplant (laminarin, 3.51%; FRAC P4), a DMI Cevya (mefentrifluconazole; FRAC 3) and SDHIs (FRAC 7) Excalia (indiflin) and Miravis (pydiflumetofen) (Table 3). In addition, a spray program with Luna Sensation (trifloxystrobin 21.4%; FRAC 11; fluopyram 21.4%; FRAC 7) at mid-bloom and petal fall was initiated with Indar (fenbuconazole; FRAC 3) at tight cluster and continued with Rally (myclobutanil; FRAC 3) at pink bud (Table 3). We used 25-yr-old apple trees of 'Jerseymac', 'Cortland' and 'Golden Delicious' on M.9 rootstock planted in discrete three-cultivar replicated plots at 25 ft between rows, 10 ft between trees within rows, and 20 feet between plots within rows. We replicated treatments three times using a complete randomized design (CRD). Each replicate plot consisted of three trees of each apple cultivar. We spray applied treatments dilute to drip (300 gal/A) using a tractor-carried handgun sprayer (Rear's Pak-Tank 100-gal sprayer, 250 PSI) at various day intervals and depending on apple flower bud growth development and weather conditions, as shown in Table 3. During the trial, we applied streptomycin + Regulaid on 25 May for fire blight control and insecticides with an air-blast sprayer to all plots including control trees, using

Unigreen Turboteuton Mistblower air-blast sprayer (Uni–green Crop Protection, S.p.A., Reggio Emilia, Italy) delivering 49 gal of spray solution per acre. There were only three major infections of *V. inaequalis* as determined by RIMpro apple scab prediction model (RIMpro B.V., Zoelmond, Netherlands: https://rimpro.eu/) connected to a nearby RainWise weather station in New Paltz, NY. These infection periods occurred on 29 Mar at green tip, 30 Apr at pink bud stage and on 28 May. To correctly calibrate RIMpro apple scab model, thus increasing the accuracy of predictions of apple scab infections and their severity on test location, we used two biofixes in this model: green tip date and the date of first ascospore release from leaf litter. Using vacuum spore trap tower, first apple scab ascospores released in Highland NY were detected on 20 Mar, but due to the abundance of caught ascospores we adjusted this date to 17 Mar. We rated apple scab incidence on spur leaves from 10 – 14 Jul, on fruit from 14 – 15 Jul, and on shoot leaves on 17 Jul – 4 Aug. The percent scab incidence on spur leaves was calculated from the number of leaves with scab lesions versus the leaves without lesions on 20 randomly selected leaf clusters per tree. The percent scab incidence on fruit was calculated from the number of fruits with at least one scab lesion versus the fruit without lesions on 20 randomly selected fruit clusters per tree, for a total of 50 or more fruit per tree replicate. The percent scab incidence on shoot leaves was calculated from the number of leaves with scab lesions versus the leaves without lesions on 10 randomly selected shoots per tree. Disease incidences were subjected to ANOVA and post-hoc analysis using LSD or Tukey's test ($\alpha = 0.05$), for a completely randomized design using PROC MIXED procedure in SAS Studio software (SAS Institute Inc. 2017, Cary, NC). Where needed data were transformed prior to analysis.

Results

In 2019, Apple scab had 8 major infection periods based on the RIMpro apple scab prediction model (from pink bud to petal fall, Fig. 1 below). Before the first major infection on the 26 April at pink bud stage, three ascospore germination periods did not lead to significant infections that would warrant fungicide application/s in most commercial orchards that did not have visible scab symptoms last year and because conditions after rainfall were cold and unfavorable for the germinating spores to establish infections (Fig. 1A, B). In Highland we found the first apple leaf scab symptoms on 10 May in untreated control plot with 'Jersey Mac' trees in Highland, NY. These infections were probably initiated on the first major scab infection periods of 26 April (Fig. 1). In Highland NY, primary scab season was over on 4 June according to RIMpro. In RIMpro's ascospore maturity model, the primary scab season is over when predicted infection events fail to reach RIM threshold values of 300 for scab clean orchards or 100 for high-inoculum orchards and petal fall has passed. This usually occurs after ascospores remaining to be discharged are at less than 5% of the season total (Figs 1 and 2, middle graph labeled "Maturation").

In 2020, very cold weather that slowed initial apple growth stages did not favor apple scab infections in 2020. Before the first major infection on the 30 April at PK bud stage, one medium infection period was recorded on 29 March at green tip and was worth protecting against only in the orchards that had visible scab symptoms last year (leaves and/or fruit). This was followed

Table 3. SDHI fungicide spray programs evaluated in 2020 trial. Treatments were applied: 22 Mar – GT, green tip; 6 Apr – HIG, half-inch green; 14 Apr – TC, tight cluster; 23 Apr – TC, tight cluster; 29 Apr – PK, pink bud; 4 May – MB, mid-bloom; 16 May – PF, petal fall; 26 May – 1C, first cover; 13 Jun – 2C, second cover; 7 Jul – 3C, third cover.

	Treatment program with amount per Acre	Spray Timing
1	Untreated control	/
2	Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Cevya 3.34SC 4 fl oz + Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Captan 80 WDG 3 lb	HIG TC TC PK, MB, PF 1C 2C, 3C
3	Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Cevya 3.34SC 5 fl oz + Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Captan 80 WDG 3 lb	HIG TC TC PK, MB, PF 1C 2C, 3C
4	Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Inspire Super 12 fl oz + Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Captan 80 WDG 3 lb	HIG TC TC PK, MB, PF 1C 2C, 3C
5	Manzate Pro-stick 75 WG 3lb - Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Excalia 4 fl oz Inspire Super 12 fl oz Excalia 4 fl oz Manzate Pro-stick 75 WG 3lb Captan 80 WDG 3 lb	GT HIG TC TC PK MB PF 1C 2C, 3C
6	Manzate Pro-stick 75 WG 3lb - Manzate Pro-stick 75 WG 3lb Manzate Pro-stick 75 WG 3lb Miravis 3.42 fl oz Inspire Super 12 fl oz Miravis 3.42 fl oz Manzate Pro-stick 75 WG 3lb Captan 80 WDG 3 lb	GT HIG TC TC PK MB PF 1C 2C, 3C
7	Stargus 3 qts + Microthiol Disperss 20 lbs - Stargus 3 qts + Microthiol Disperss 20 lbs + NuFilm P 32 fl oz/100 gal	GT HIG TC, TC, PK, MB, PF, 1C
8	Stargus 2 qts + Manzate Pro-stick 75 WG 3lb - Stargus 2 qts + Manzate Pro-stick 75 WG 3lb	HIG, TC, TC PK, MB PF, 1C
9	Stargus 3 qts - Stargus 3 qts + NuFilm P 32 fl oz/100 gal	GT HIG TC, TC, PK, MB, PF, 1C
10	Microthiol Disperss 20 lbs - Microthiol Disperss 20 lbs + NuFilm P 32 fl oz/100 gal	GT HIG TC, TC, PK, MB, PF, 1C
11	Indar 8 fl oz + Manzate Pro-stick 75 WG 3lb Rally 8 oz + Manzate Pro-stick 75 WG 3lb Luna Sensation 4.17SC 5 fl oz + Manzate Pro-stick 75 WG 3lb PF) Manzate Pro-stick 75 WG 3lb Captan 80 WDG 2.5 lb	TC, TC PK MB, PF 1C 2C, 3C
12	Vacciplant 14 fl oz	TC, TC, PK, MB, PF, 1C
13	Untreated control High	/

by 9 ascospore germination periods up to petal fall that did not lead to significant infections warranting fungicide application/s in commercial orchards that did not have visible scab symptoms last year, since conditions after rainfall were cold and unfavorable for germinating spores to establish infections. First apple leaf scab lesions were visible on 11 May in the untreated control plot on 'Jersey Mac' trees in Highland NY and correspond to the first 100 RIM infection on 29 March. In Highland NY, primary scab season was over on 31 May.

Trial 2019 (I). On 'Jersey Mac', when compared to untreated control, management of leaf scab was excellent with Cevya (low and high rate), Inspire Super, both in mix with LI 700, Aprovia, Luna Sensation, Miravis A19649[B] and A19649[H], and pyraziflumid in mix with Silwet (#2 – 9) (Fig 3A). Pyraziflumid, Luna Sensation and Fontelis spray programs (#10 – 13) applied without adjuvants or at slightly to very different growth stages

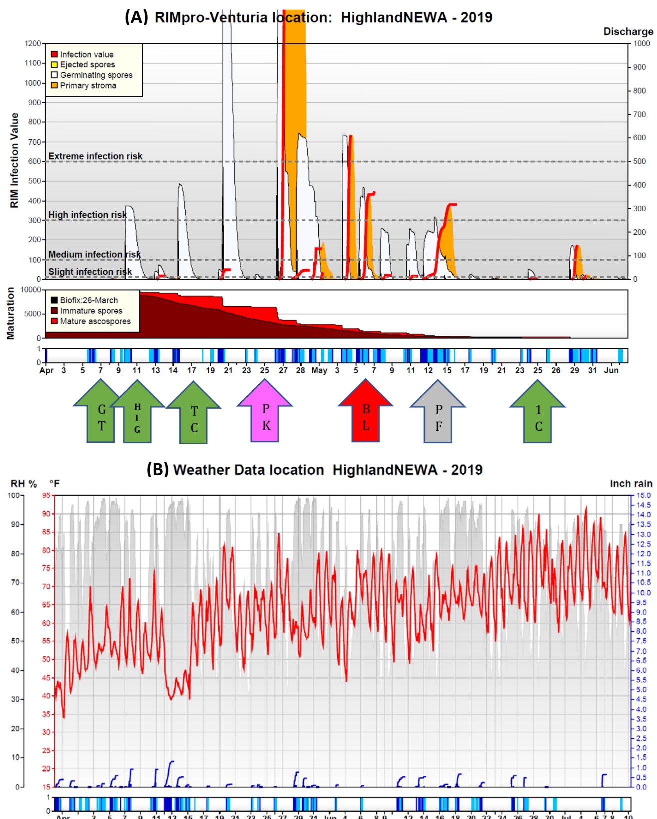

Figure 1. (A) Apple scab infection periods in 2019 for Highland NY in RIMpro model. White camel hump-like areas labelled "Germinating spores" show cumulative number of *Venturia inaequalis* ascospores that germinate over time and are read on the right-side vertical Y-axis scale that is labelled "Discharge". The red curved lines are the RIM infection values which, when divided by 100, are roughly the percentage of the total season's ascospores that are likely to cause infection in any given infection period. Read each curve's peak RIM infection value/s using the vertical Y-axis scale on the left side of the graph labelled "RIM Infection Value". Orange areas called "Primary stroma" just after each red curved RIM line represent scab lesions that were initiated by infection and are incubating in the leaf. Orange depicts the time during which kick-back fungicides can be applied. The light red areas in the middle "Maturation" graph is the proportion of mature ascospores that are ready for discharge with wetting events, whereas the dark red area is the proportion of immature ascospores remaining in leaf litter. GT - green tip, HIG - half-inch green, TC - tight cluster, PK - pink bud, BL - bloom, PF - petal fall, 1C - first cover. (B) Weather conditions during the trial in 2019 for Highland, NY, recorded by a weather station. Top graph: red line shows temperatures (left y-axis in red), blue curved lines show rain lengths and amounts in inches (right y-axis in blue), grey background represent relative air humidity (RH) in % (far left y-axis in black). Bottom graph in (A) and (B) with dates shows the length of rain (dark blue) and of wetting periods after the rain stopped or from dew (light blue). Used by permission of RIMpro B.V., Netherlands: https://www.rimpro.eu/

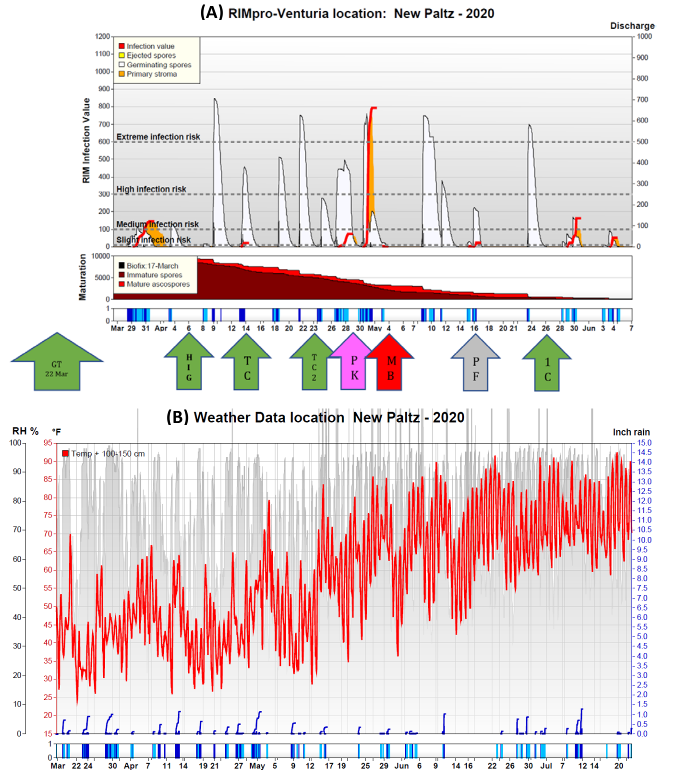

Figure 2. (A) Apple scab infection periods in 2020 for New Paltz NY in RIMpro model. Please refer to the caption of Fig. 1A for specific graph visual parts explanations. GT - green tip, HIG - half-inch green, TC - tight cluster, TC2- tight cluster, PK - pink bud, BL - bloom, PF - petal fall, 1C - first cover. (B) Weather conditions during the trial in 2019 for New Paltz, NY, recorded by a weather station. Please refer to the caption of Fig. 1B for specific graph visual parts explanations. Used by permission of RIMpro B.V., Netherlands: https://www.rimpro.eu/

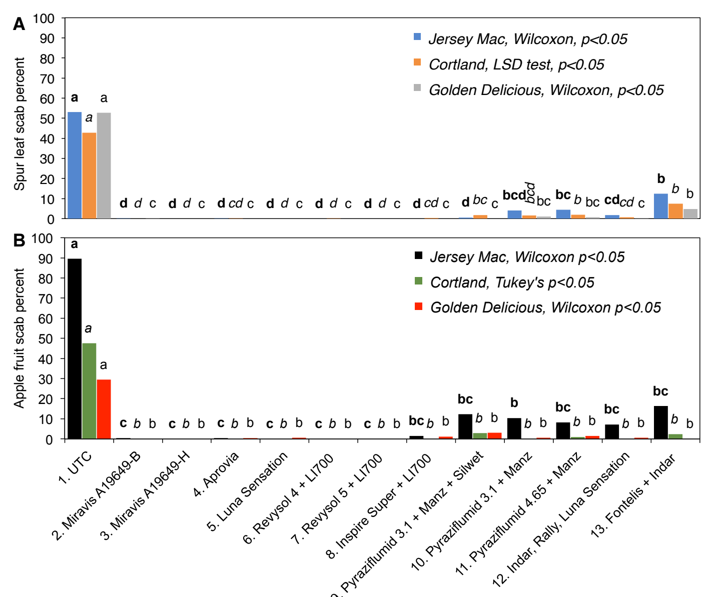

Figure 3. Apple leaf (A) and fruit (B) scab incidence on 7 July and 19 July 2019, respectively, after evaluation of different SDHI and DMI fungicides. Means within each cultivar i.e., bar color followed by different letters, are significantly different within each date i.e. graph. Each mean consists of four replicate trees. Treatment names on x-axis apply for both graphs.

i.e. times, provided very good to good leaf scab control but allowed some disease to develop (up to 12.3% in #13). This indicates on the absence of beneficial effect of adjuvant/s expressed as higher uptake of SDHI fungicides into green tissues, likely facilitating better scab control, and on the importance of a better time schedule for spray applications closer to the infection periods (Fig. 1). This was especially important in programs #10 and 11 that delivered a total of six applications of pyraziflumid without Silwet and at a stretched i.e. irregular intervals of 14 days (HIG – PK), 12 days (PK – FB), 7 days (FB – PF), 10 days (PF – ½ inch fruit size) and 2 days (½ inch fruit size – 1C). Similar excellent to good control of scab was observed on 'Jersey Mac' fruit, but from 7 – 16% fruit scab incidence developed in programs #9 – 13 (Fig. 3B). Factors contributing to an excellent control of leaf and fruit scab in programs #2 – 9 on 'Jersey Mac' are well timed applications of SDHI-s to infection periods (I), followed by Inspire Super at first cover in #2 – 5 programs (II), the very well timed four applications of Cevya from TC – PF in programs #6 – 8 (III), a total of six applications of pyraziflumid in programs #9 – 11 (IV), and addition of adjuvants LI700 and Silwet in programs #6 – 9 (Fig. 3). However, program #9 with pyraziflumid allowed 12% of fruit scab indicating that besides the unfavorable effect of different spray timings in comparison to other SDHI programs, Silwet benefited the effectiveness of this SDHI on leaves but not on fruit (Fig. 3B). In spray programs #10 – 13, established primary scab infections on 'Jersey Mac' leaves led to development of a slightly higher incidence of secondary scab infections on fruit (Fig. 3B). In contrast, on 'Cortland' and 'Golden Delicious' fruit, scab control was excellent in all spray programs (Fig. 3B), indicating that primary scab infections on leaves were prevented to establish the secondary infections of fruit and this was facilitated by the applied fungicides and by some level of genetic resistance ofl these two cultivars to *V. inaequalis*.

Trial 2019 (II). Results in Fig. 4, under high infection pressure, show control of leaf apple scab on cultivars with different susceptibility level to *V. inaequalis* was excellent with the Excalia spray program ('McIntosh' – very

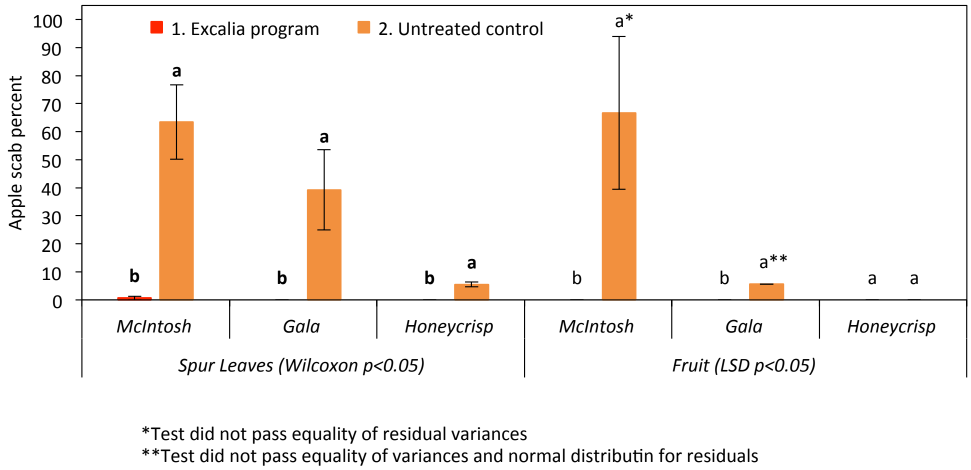

Figure 4. Apple leaf scab incidence on 7 July (left) and fruit scab incidence (right) on 19 July 2019, after evaluation of an SDHI fungicide Excalia. Incidence means followed by different letters within the same cultivar i.e. bar color and apple organ are significantly different (*p* < 0.05). Each mean consists of 4 replicate trees.

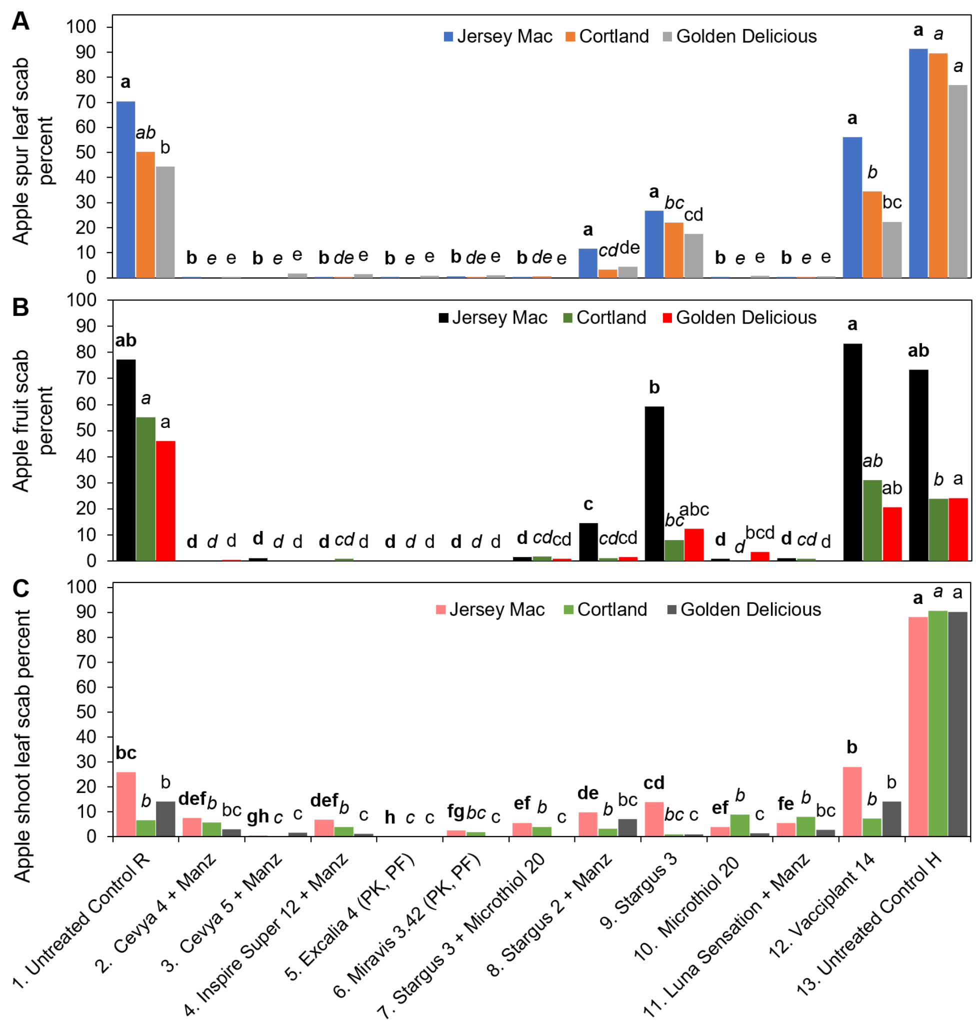

Figure 5. Apple scab incidence on spur leaves (A), fruit (B) and shoot leafs (C) on 14 July, 15 July and 4 Aug 2020, respectively, after evaluation of different SDHI, DMI and two soft fungicides. Means within each cultivar i.e. bar color followed by different letters are significantly different within each date i.e. graph (A, B: Tukey's test, *p*<0.05; C: LSD test, *p*<0.05). Each mean consists of four replicate trees. Treatment names on x-axis apply for all three graphs.

susceptible, 'Gala' – susceptible, 'Honeycrisp' – moderately resistant). However, the results on controlling fruit scab were confounded by the fact that one out of three replicate trees of both 'McIntosh' and 'Honeycrisp', and two out of three replicate trees on 'Gala', did not develop fruit so no scab rating could be collected. This led to failed test for equality of residual variances in 'McIntosh' and 'Gala' data and to the failed test for normality of residuals in 'Gala' (Fig. 4). This data indicated on the need for one more year of testing to confirm Excalia's effectiveness.

Trial 2020. On all cultivars, when compared to untreated controls (#1, 13) management of spur leaf scab and fruit scab was excellent with Cevya (both rates), Inspire Super, Excalia, Miravis, Stargus + Microthiol Disperss, Microthiol Disperss and Luna Sensation (#2 – 7, 10, 11), with Stargus + Manzate (#8) being very similar in efficacy to these programs and providing significant control (Fig. 5A, B). Stargus (# 9) performed relatively well on 'Cortland' and 'Golden Delicious' spur leaves, allowing only 22.1 and 17.5% incidence, respectively, as these cultivars bear some genetic resistance to *V. inaequalis*, and this effect was consistent with fruit scab control (8.1 and 12.3%) (Fig. 5A, B). This was not the case on highly susceptible 'Jersey Mac'. The comparison of #7, 9 and 10 in control of spur leaf and fruit scab incidences clearly indicated that sulfur, at the highest labelled rate of Microthiol Disperss, and not Stargus, was responsible for good disease control (Fig. 5A, B). When compared to the second untreated control (#13), Vacciplant (#12) performed relatively well only on spur and shoot leaves of 'Cortland' and 'Golden Delicious' that are more resistant to scab, showing statistical reduction of the disease to 34.4 and 22.3% incidence on spurs, and 7.3 and 14% incidence on shoots (Fig. 5A, C). On fruit, this effect did not occur (Fig. 5B). On shoot leaves, control of scab followed largely similar patterns except for Cevya, low rate, Inspire Super, Miravis, Stargus + Microthiol Disperss (#2, 4, 6, 7), and Microthiol Disperss and Luna Sensation (#10, 11), where slightly more scab developed than expected (Fig. 5C). However, the untreated control (#1) indicated that drier weather conditions that lasted from May 3 to June 27 (Fig. 2) did not favor onset of secondary scab infections on shoot leaves (Fig. 5C), indicating that scab infection pressure from conidia on the established lesions on spurs and fruit for shoot infections was very low, while the primary scab infections were largely thwarted by the unfavorable cold and dry weather conditions from 4 to 28 May (Fig. 2).

Conclusion

The addition of new synthetic SDHI, DMI and soft fungicides we found effective gives growers a significant opportunity to effectively control apple scab fungus *V. inaequalis* in years to come, with minimal risks for development of resistance mutations in its populations to single-site fungicides. However, to be fully successful in long-term preservation of high efficacy of single-site fungicides for apple scab control, we recommend growers in conventional apple production to: (1) Incorporate both the synthetic and soft fungicides in alternating spray schedule during the primary scab season to broaden the spectrum of efficacy of spray mixtures by impacting multiple targets in the fungal pathogen, (II) Use the RIMpro apple scab prediction model to accurately time the preventive application/s of soft and/or contact fungicides, alone or in a tank mix, for periods when infection severity is predicted to be medium to low (before pink bud and after petal fall), (III) Use the RIMpro apple scab prediction model to accurately time the preventive application/s of highly effective single-site synthetic fungicides, in a tank mix with contact ones, for periods when infection severity is predicted to be high or extreme (from pink bud to petal fall), and (IV) Whenever possible apply fungicides preventively, i.e. before the wetting event that will trigger infection/s. Curative i.e. post-infection or kick-back activity of systemic fungicides against *V. inaequalis* should only be reserved for emergency or unpredicted situations when no fungicide or insufficient amount of it was applied before the infection due to alternate-row spraying, lack of enough air-blast sprayers to cover the whole farm in 48 to 96 h, or their unpredicted malfunction. Even here RIMpro can critically help to time the curative application by indicating the incubating infections as orange area/s called "Primary stroma" which represent scab lesions that were initiated by infection from germinating spores and that are incubating in the leaf but are not yet visible (Figs 1 and 2). Knowledge of real time occurrence of incubating infections in RIMpro model is worth gold because, if no or limited fungicide was in place before the infection event, some or all of the incubating infections can still be eliminated by timely applying fungicides with post-infection activity (Aćimović et al. 2018). Only by applying the above outlined or similar strategies, growers, private consultants, and extension fruit specialists will be good stewards of preserving the efficacy of classic and new fungicides and keeping their apple scab management toolbox rich with tools for years to come.

Literature Cited

Aćimović S. G., Meredith C. L. 2017. Preliminary Report on Pyraziflumid SC effect on apple powdery mildew 2017 in Highland, NY. Acimovc Lab, Pesticide/Cultivar Trials, Online: http://blogs.cornell.edu/acimoviclab/pesticide-efficacy-trials/

Aćimović, S. G., Martin, P. L., Khodadadi, F., and Peter, K. A. 2020. One Disease Many Causes: The Key *Colletotrichum* Species Causing Apple Bitter Rot in New York, Pennsylvania and Virginia, Their Distribution, Habitats and Management Options. Fruit Q. 28:13–21.

Aćimović, S. G., Wallis, A. E., and Basedow, M. 2018. Two Years of Experience with RIMpro Apple Scab Prediction Model on Commercial Apple Farms in Eastern New York. Fruit Q. 26:21–27.

Carisse, O., Jobin, T., and McFadden-Smith, W. 2006. *Apple scab: Improving understanding for better management*. Agriculture and Agri-Food Canada.

Melillo, J. M., Richmond, T. C., and Yohe, G. W. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Government Printing Office. Available at:http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf

USDA Technical Evaluation Report – Limited Scope, Laminarin – Crops. Online: https://www.ams.usda.gov/sites/default/files/media/Laminarin%20TR.pdf

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