I am glad I am not driving a 1970 Ford Pickup Truck

It was the summer of 1970. I was just home from Cornell for the summer. My uncle had just driven into our driveway with a new Ford pickup. He said it was very best he ever had. It cost him just a little over $2000. He was in his 70s at the time. He wanted to know where I would be plowing that afternoon. I told him and really put it out of my mind. Later that afternoon I saw him standing in the dead furrow at the end of my field. He motioned me to stop. He climbed up on the fender. Motioned me to make a round. Upon doing this he told me to stop. He jumped down. I will never forget what he said next. He said when he was my age, he also did a lot of the plowing. In his day he walked behind a team of horses.

The amount of soil we turned over in that single round would have taken him a full day with that team of horses. He asked me when I am his age what will it be like?

I tell you this because we do not have a crystal ball on the future. We live in an age where the only constant is that tomorrow will in some way be altered. Because of all the advances we have enjoyed in the last hundred years, a higher percentage of our population can work off the farm. This freedom allows creative minds to dream and develop new ways to do the same tasks.

The Fruit Quarterly four times a year brings you samples of this progress. Each issue is new and different. Each season creates new challenges. It is vitally important that those of us in the field support research. It is work often done out of the attention of most of us. Every project is not a success. Yet every project allows us to reduce the wrong path we might have followed.

The New York State Horticulture Society has successfully obtained matching funds from NY State to help on these programs. Each year we enter the request not knowing how the funds will be best applied. Without applied research we have no growth. We would still be walking behind a team of horses.

Supporting research is the most unselfish thing you can do. Today we are farming because of the research funded by our fathers and grandfathers. I know every day there are a myriad of financial requests placed on your desk. Even though there is no guarantee of success for every program we must continue to support the search for the next “Honeycrisp”.

Paul Baker
Executive Director of the NY State Horticultural Society

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<table>
<thead>
<tr>
<th>CROP</th>
<th>PHI</th>
<th>PEST SPECTRUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>7 days</td>
<td>Apple Maggot, Codling Moth, Sawfly, Curculio, + 14 other insect pests.</td>
</tr>
<tr>
<td>Tart Cherries</td>
<td>7 days</td>
<td>Curculio, Spotted Wing Drosophila + 6 other insect pests.</td>
</tr>
<tr>
<td>Peaches</td>
<td>14 days</td>
<td>Japanese Beetle, Oriental Fruit Moth, Peach Twig Borer, Plum Curculio, Rose Chafer, San Jose Scale, Spotted Wing Drosophila</td>
</tr>
<tr>
<td>Blueberries</td>
<td>3 days</td>
<td>Blueberry Maggot, Spotted Wing Drosophila + 14 other insect pests.</td>
</tr>
</tbody>
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Dynamic Controlled Atmosphere (DCA) Storage Delays Development of Flesh Browning of ‘Gala’ Apples

Chris B. Watkins, Jacqueline F. Nock and Yosef Al Shoffe

School of Integrative Plant Science, Horticulture Section, College of Agriculture and Life Sciences, Ithaca, NY 14853

Keywords: Stem end flesh browning, Gala apple, dynamic controlled atmosphere

‘Gala’ apples are susceptible to a flesh browning disorder that originates in the stem end of the fruit that is often referred to as stem end flesh browning (SEFB). The disorder becomes progressively worse with longer storage periods with all the flesh eventually becoming brown in severe cases. As a result, SEFB is becoming a limitation to long term storage and marketing of the variety, and therefore is a critical problem for the industry as increased plantings are resulting in the need to store larger volumes of fruit.

Factors that affect development of the disorder include strain, with higher colored ones being less susceptible, and harvest date, with fruit harvested later typically having greater risk of disorder development than those harvested earlier. The effect of strain is likely due in part to the growers being able to harvest fruit earlier while meeting color requirements for marketing. We reported in a previous NY Fruit Quarterly article that the same conditioning treatment of seven days at 50°F used for ‘Honeycrisp’ as well as preharvest 1-MCP (HarvistaTM) delayed development of SEFB in ‘Gala’ (Doerflinger et al., 2017). We found that ReFine is also highly effective; these results will be presented in a subsequent issue of the NY Fruit Quarterly.

We also have been investigating the effects of dynamic controlled atmosphere storage (DCA) on quality of ‘Gala’ apples. DCA is a relatively new technology in which oxygen levels in the storage atmosphere are lowered until the lower oxygen limit is reached, below which fruit metabolism changes from aerobic to anaerobic. Once the stress has been detected, the oxygen concentration is increased by about 0.2%. The lower oxygen limit of the fruit can change during storage, and the storage operator can adjust the safe oxygen concentrations accordingly, hence the name ‘dynamic’.

Fruit quality is typically better at the lowest safe oxygen concentrations. A major impetus for the development of DCA technology was as a non-chemical means of superficial scald control, usually controlled by diphenylamine (DPA), which is effectively banned outside of North America, or 1-methylcyclopropene (1-MCP).

The lower oxygen limit is assessed by at least three different DCA methods:

1. The fluorescence of the chlorophyll in fruit skin in response to low oxygen stress (described in Watkins, 2008). This system is known as DCA- chlorophyll fluorescence (DCA-CF) and marketed as HarvestWatch.

2. The respiratory quotient (DCA-RQ), which is based on the increase of carbon dioxide production when the lower oxygen limit is reached. In New York, the DCA-RQ system is marketed as the SafePod system.

3. Ethanol accumulation in the fruit that is associated with increased fermentation as the lower oxygen limit is reached. DCA-CF and DCA-RQ are being increasingly used by New York growers. The results obtained by either system are similar, although a significant difference in that DCA-RQ is based in a single bulk sample to represent all fruit in the storage room, while DCA-CF allows assessment of individual orchard blocks within a room.

We have been investigating the use of DCA for New York-grown apples for several years. One of the pronounced and exciting responses of fruit to DCA has been its effects on some internal browning disorders, including SEFB of ‘Gala’ apples.

Materials and Methods

Three experiments comparing CA and DCA are described here:

1. Fruit of the Fulford strain of Gala with and without 1-MCP treatment at 33°F for 3 and 6 months of storage.

2. Fruit of the Fulford strain with and without 1-MCP treatment with 1% or 2% carbon dioxide, and at 33°F or 38°F for 5 and 8 months of storage.

3. Fruit of the Brookfield strain from four orchard blocks stored at 33°F for 5 and 8 months.

Fruit were transported from the Fowler Farms (experiments 1 and 2) and from KM Davies (experiment 3) on the day of harvest and cooled overnight. Fruit were either untreated or treated with 1-MCP and stored following our standard procedures. DCA-CF units were set up in each experimental chamber. Although the lower oxygen limit of fruit in all experiments was less than 0.5%, we followed safe protocols and established the set point at 0.5%, approximately 0.2% higher than the fluorescence stress signal.

Quality assessment on the fruit were carried out after seven days at 68°F following removal from storage.

Results

**Experiment 1.** The internal ethylene concentration (IEC) of the fruit was 1.49 ppm. The starch pattern index (SPI) was 4.0, flesh firmness was 17.9 lb-f, and the soluble solids concentration (SSC) was 12.2%.

Incidence of SEFB increased from 3 to 6 months of storage in both CA and DCA, but overall was lowest in fruit from the DCA treatment (Table 1). Trace incidence of SEFB was detected at 3 months, and while these increased by month 6, they were 25-32% lower than those in the CA regime. 1-MCP treatment either...
Firmness of fruit in all treatments is shown in Table 4. The important findings are:

1. Overall, firmness was higher with 1-MCP (15.6 lb-f) than without 1-MCP (15.0 lb-f).
2. No significant differences were found between CA and DCA stored fruit at 5 months but by 8 months, fruit were 15.5 lb-f in DCA compared with 14.1 lb-f in CA.
3. No significant differences were found between CA and DCA stored fruit at 33°F but at 38°F, fruit were 15.8 lb-f.

### Table 3. Stem end flesh browning (%) of ‘Gala’ apples with and without 1-MCP treatment after storage in CA (2% oxygen/1% or 2% carbon dioxide) and DCA (0.5% oxygen/1% or 2% carbon dioxide) at 33°F or 38°F for 5 or 8 months. Fruit quality was assessed after 7 days at 68°F. Different letters indicate significant differences among means at P=0.05.

<table>
<thead>
<tr>
<th>Pre-storage treatment</th>
<th>2% oxygen/1% carbon dioxide</th>
<th>2% oxygen/2% carbon dioxide</th>
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<tr>
<td></td>
<td>5 months</td>
<td>8 months</td>
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<td></td>
<td>33°F</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>63c</td>
<td>86ab</td>
</tr>
<tr>
<td>1-MCP</td>
<td>53cd</td>
<td>87ab</td>
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<tr>
<td>0.5% oxygen/1% carbon dioxide</td>
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<td>8 months</td>
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<tr>
<td>None</td>
<td>30ef</td>
<td>79c</td>
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<td>1-MCP</td>
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<td>70c</td>
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<td>0.5% oxygen/2% carbon dioxide</td>
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<td>8 months</td>
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<tr>
<td>None</td>
<td>0h</td>
<td>36e</td>
</tr>
<tr>
<td>1-MCP</td>
<td>0h</td>
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<tr>
<td>1-MCP</td>
<td>0h</td>
<td>28ef</td>
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</tbody>
</table>

### Table 4. Flesh firmness (lb-f) of ‘Gala’ apples with and without 1-MCP treatment after storage in CA (2% oxygen/1% or 2% carbon dioxide) and DCA (0.5% oxygen/1% or 2% carbon dioxide) at 33°F or 38°F for 5 or 8 months. Fruit quality was assessed after 7 days at 68°F. Different letters indicate significant differences among means at P=0.05.

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<td></td>
<td>33°F</td>
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<tr>
<td>None</td>
<td>15.7ab</td>
<td>13.5ab</td>
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<tr>
<td>1-MCP</td>
<td>15.9ab</td>
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<td>5 months</td>
<td>8 months</td>
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<tr>
<td>None</td>
<td>14.9ab</td>
<td>13.4b</td>
</tr>
<tr>
<td>1-MCP</td>
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<td>13.6ab</td>
</tr>
<tr>
<td>0.5% oxygen/2% carbon dioxide</td>
<td>5 months</td>
<td>8 months</td>
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<tr>
<td>None</td>
<td>15.7ab</td>
<td>15.4ab</td>
</tr>
<tr>
<td>1-MCP</td>
<td>15.9ab</td>
<td>15.9ab</td>
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</table>

Reduced incidence or had no statistical effect on SEFB incidence. Core browning was totally controlled by the DCA treatment (data not shown).

Flesh firmness of fruit was similar in fruit from both CA and DCA storage at the 3-month assessment (Table 2). In contrast, fruit were about 2 lb-f firmer after storage in DCA than in CA at the 6-month assessment. No effect of 1-MCP on firmness was detected.

**Experiment 2.** The objective of this experiment was to investigate the effects of carbon dioxide concentration because not only the oxygen concentrations were different in experiment 1, so too were the carbon dioxide concentrations (1% in DCA and 2% in CA). We were also interested in investigating if low oxygen atmospheres would allow storage of fruit at warmer temperatures, such as 38°F, and result in energy savings.

At harvest, the IEC of the fruit was 1.86 ppm, and the SPI, flesh firmness and SSC were 4.7, 17.3 lb-f and 11.3%, respectively. SEFB incidence increased over time (Table 3). The data are complex as different effects were found at different storage times, and it is important to note that the effects of carbon dioxide are different according to oxygen concentration. We highlight the following:

In CA –

1. SEFB incidence was at least 50% lower in CA-stored fruit with 1% carbon dioxide than with 2% carbon dioxide at 38°F than at 33°F after 5 months of storage. These differences were smaller at 8 months of storage because of the overall much higher disorder incidence.

2. SEFB incidence was increased by 1-MCP at 2% carbon dioxide in fruit at both storage temperatures but to a greater extent at 33°F than at 38°F.

In DCA –

1. Control of SEFB was total at 5 months regardless of storage temperature, carbon dioxide concentration or 1-MCP treatment.

2. After storage for 8 months, SEFB incidence tended to be lower in fruit stored with 2% carbon dioxide than 1% carbon dioxide.

### Table 1. Stem end flesh browning (%) of ‘Gala’ apples with and without 1-MCP treatment after storage in CA (2% oxygen/2% carbon dioxide) and DCA (0.5% oxygen/1% carbon dioxide) at 33°F for 3 or 6 months. Fruit quality was assessed after 7 days at 68°F. Different letters indicate significant differences among means at P=0.05.

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<tbody>
<tr>
<td></td>
<td>3 months</td>
<td>6 months</td>
</tr>
<tr>
<td>None</td>
<td>17cd</td>
<td>68a</td>
</tr>
<tr>
<td>1-MCP</td>
<td>7de</td>
<td>40b</td>
</tr>
</tbody>
</table>

### Table 2. Firmness (lb-f) of ‘Gala’ apples with and without 1-MCP treatment after storage in CA (2% oxygen/2% carbon dioxide) and DCA (0.5% oxygen/1% carbon dioxide) at 33°F for 3 or 6 months. Fruit quality was assessed after 7 days at 68°F. Different letters indicate significant differences among means at P=0.05.

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</tr>
<tr>
<td>None</td>
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<td>13.5ab</td>
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<td>5 months</td>
<td>8 months</td>
</tr>
<tr>
<td>None</td>
<td>14.9ab</td>
<td>13.4b</td>
</tr>
<tr>
<td>1-MCP</td>
<td>16.0ab</td>
<td>13.6ab</td>
</tr>
<tr>
<td>0.5% oxygen/2% carbon dioxide</td>
<td>5 months</td>
<td>8 months</td>
</tr>
<tr>
<td>None</td>
<td>15.7ab</td>
<td>15.4ab</td>
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### Table 3. Stem end flesh browning (%) of ‘Gala’ apples with and without 1-MCP treatment after storage in CA (2% oxygen/1% or 2% carbon dioxide) and DCA (0.5% oxygen/1% or 2% carbon dioxide) at 33°F or 38°F for 5 or 8 months. Fruit quality was assessed after 7 days at 68°F. Different letters indicate significant differences among means at P=0.05.

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<td>8 months</td>
</tr>
<tr>
<td>None</td>
<td>15.7ab</td>
<td>15.4ab</td>
</tr>
<tr>
<td>1-MCP</td>
<td>15.9ab</td>
<td>15.9ab</td>
</tr>
</tbody>
</table>
in DCA compared with 14.4 lb-f in CA.

4. 1-MCP maintained firmness at 1% carbon dioxide but not 2% Carbon dioxide.

Experiment 3. The fruit maturity at harvest is shown in Table 5. Although the harvest date of September 15, 2015 was relatively early, the overall SPIs of fruit from all orchard blocks were advanced. No differences among orchard blocks were detected for firmness, but all other indices were variable.

SEFB incidence was much higher after 8 months of storage than at 5 months, with large variation in incidence across orchard blocks (Figure 1). No effect of 1-MCP treatment was detected. After 5 months of CA storage, incidences ranged from 0% to 67%, and after 8 months from 37% to 78%. Development of SEFB was inhibited by DCA storage; the average of all orchard blocks was 20% and 60% in CA-stored fruit at 5 and 8 months, respectively, and <1% and 43% in DCA-stored fruit at 5 and 8 months, respectively.

Firmness of the fruit was also variable (Figure 2). There was no effect of 1-MCP treatment, but overall DCA-stored fruit were firmer at month 5, being 17.0 lb-f in that treatment compared with 16.4 lb-f in CA-stored fruit. However, firmness was not affected by storage treatment at month 8.

Discussion

The results presented here indicate that DCA has great potential to delay development of SEFB of ‘Gala’ apples during long term storage. SEFB incidence can be high as early as 3 months under standard CA conditions, while negligible under DCA conditions. While the disorder develops under longer term storage such as 6 to 8 months, disorder incidence is much lower. In separate experiments, we have found that it is possible to obtain disorder-free fruit from some orchard blocks. Also, Harvista and ReTain can have further additional benefits not only on reducing SEFB incidence in CA, but also under DCA conditions.

1-MCP, overall, slightly decreases or has no effect on SEFB incidence, although it aggravated the disorder in 2% oxygen with 2% carbon dioxide but not 1% carbon dioxide. Interestingly, we were not able to find consistent effects of 1-MCP on flesh firmness.

Table 5. Internal ethylene concentration (IEC), starch pattern index (SPI), flesh firmness and soluble solids concentration (SSC) of ‘Gala’ apples from four orchard blocks used in Experiment 3.

<table>
<thead>
<tr>
<th>Orchard #</th>
<th>IEC (ppm)</th>
<th>SPI (1-8)</th>
<th>Firmness (lb-f)</th>
<th>SSC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.16b</td>
<td>6.0a</td>
<td>17.4</td>
<td>11.6c</td>
</tr>
<tr>
<td>2</td>
<td>0.52c</td>
<td>4.3b</td>
<td>18.3</td>
<td>12.9b</td>
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<tr>
<td>3</td>
<td>1.23b</td>
<td>4.9ab</td>
<td>17.7</td>
<td>13.3b</td>
</tr>
<tr>
<td>4</td>
<td>2.64a</td>
<td>5.6a</td>
<td>17.8</td>
<td>14.0a</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>0.014</td>
<td>0.416</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Figure 1. Stem end flesh browning (SEFB) incidence (%) of ‘Gala’ apples from four orchard blocks that were untreated or treated with 1-MCP and then stored in CA (2% oxygen/1% carbon dioxide) or DCA (0.5% oxygen/1% carbon dioxide) at 33°F for 5 or 8 months. Fruit were assessed after 7 days at 68°F.

Figure 2. Flesh firmness (lb-f) of ‘Gala’ apples from four orchard blocks that were untreated or treated with 1-MCP and then stored in CA (2% oxygen/1% carbon dioxide) or DCA (0.5% oxygen/1% carbon dioxide) at 33°F for 5 or 8 months. Fruit were assessed after 7 days at 68°F.
The effects of storage temperature on responses of fruit to CA and DCA storage show little differences indicating that warmer storage temperatures may be possible. However, full understanding of these temperatures on acidity and sensory factors is necessary.

The effects of carbon dioxide concentration require more research. As mentioned above, higher concentrations resulted in more SEFB in CA. However, 2% carbon dioxide reduced SEFB incidence in DCA compared with 1% carbon dioxide.

These results, while showing the beneficial effects of DCA, indicate that the interactions with carbon dioxide and storage temperature deserve more investigation, and in fact, also with respect to standard CA. We have used 0.5% oxygen routinely for studies of fruit without any negative effects. In addition, currently we are comparing results for 0.5% oxygen with those in 1% and 2% oxygen.

**Summary**

We are able to obtain fruit that are free of any internal browning in some orchard blocks. A clear understanding of the role of maturity and the role of the plant growth regulators Harvista and ReTain in combination with DCA, is needed for operators to routinely increase the storage period for ‘Gala’ apples with confidence in maintaining high fruit quality.

**Literature Cited**


**Acknowledgments**

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**Dr. Chris Watkins** is professor of horticulture located at Cornell's Ithaca campus who leads Cornell's postharvest physiology program for horticultural crops. **Jackie Nock** is a research support specialist, and **Yosef Al Shoffe** is a research associate who work with Chris Watkins.
Can Strawberry Flavor be Influenced by Growing Practice?

Anya Osatuke and Marvin Pritts

School of Integrative Plant Science, Cornell University, Ithaca, NY

Keywords: fruit soluble solids, flavor profile, organic management, conventional management

Nothing beats a quart of fresh-picked strawberries after a long New York winter. Locally-grown berries boast increased freshness and better flavor compared to store-bought strawberries sourced from distant farms, so are highly sought after during the short three or four week season. Between 2012 and 2018 in New York, the average retail price for strawberries has grown by 37%, while U-Pick strawberry prices have grown, on average, by 30% (Davis et al, 2018). In contrast, the price received by growers in California and Florida has stayed relatively flat during this time period and per capita consumption has fallen recently (Shahbandeh, 2019). Almost 95% of strawberries consumed in New York State are produced in Florida, California and Mexico because they are available over a longer season, but consumers consider these strawberries among the most inconsistent fruits at the retail outlet (Azodanlou et al. 2003). Improvements in flavor could reverse the decrease in price and consumption.

One reason why local berries have increased in price relative to berries from other places is their consistently better flavor. A grower may want to enhance berry flavor even more by altering production practices and improving market appeal. But is this even possible? Obviously, the variety grown makes a difference. ‘Earliglow’ has long been the standard by which other varieties are judged. But can the flavor of a variety be enhanced by the way it is grown?

Would adopting organic or low-spray field management, a choice that can also lead to increased appeal to consumers, be accompanied by better flavor? Might too much fertilizer detract from flavor? Does the amount of pesticide used on a field impact flavor? How much of the variation in flavor depends on the soil and microclimate of the farm where they are grown? How much of the flavor is dependent on the weather during fruit development?

We wanted to compare the variation in strawberry flavor attributes across farms and years, and determine how much variation we could recreate in our own experimental field by varying growing conditions on the same farm. Our study examined nine growing methods, including conventional methods, to determine if we could detect differences in sweetness and aroma, while also measuring yield.

Material and Methods: Farm Trial

In June and July of 2018 and 2019, we visited farms across New York State to collect samples of ‘Jewel’ strawberries (22 farms in 2018, and re-visited 10 of those farms in 2019). After obtaining 2 quarts of red, fully ripe ‘Jewel’ berries, we froze them and later analyzed the berries for sugar content (Brix), acidity (TA), and their volatile profile. Aromas were analyzed with a solid-phase micro-extraction followed by gas chromatography-mass spectrometry.

We created a miniature volatile profile for ‘Jewel’ using these findings, identifying six molecules that have easy-to-detect scent and are found in relatively high concentrations in ‘Jewel’ berries. We wanted to see whether sugar, acidity, and aroma would vary in the same strawberry collected from different farms in the region, and from year to year on the same farm.

Results: Farm Trial

We found variation from one year to the next was quite large, as was variation from farm to farm. The coefficient of variation is a measure of the difference surrounding an average measurement. Variation from farm-to-farm in Brix was 18%. This means that, as the average Brix measurement of all of the farm strawberries was 6.3, most of the samples were either 9% sweeter or 9% less sweet than 6.3 degrees Brix— from 5.7 to 6.8 degrees Brix. Acidity had the same coefficient of variation (18%), but the aromatic molecules we measured had coefficients of variations close to, and even over, 100% - meaning that they varied immensely from farm to farm (Table 1).

Even greater variation was found from year-to-year. We found that strawberries sampled in 2019 were always higher in sugar (Figure 1) and acid (Figure 2) than those sampled in 2018. This suggests that weather plays a major role in flavor development since the change was always in the same direction for each farm.

The coefficient of variation of the difference between sugar content from one year to the next was 66%, compared to 18% among farms in the same year. Another finding from this study was that changes in acid and sugar were often in parallel (result-
Table 2: Treatment combinations and descriptions at the East Ithaca Research Farm for ‘Jewel’ field trials. ORG = organically-sourced inputs; COV = conventionally-sourced inputs; LOC = low carbon inputs; L = low input intensity; H = high input intensity.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N form</th>
<th>lb N acre/yr</th>
<th>Input type</th>
<th>Soil Carbon inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORG L</td>
<td>Urea</td>
<td>50</td>
<td>Devrinol</td>
<td>Incorporated cover crop + straw mulch</td>
</tr>
<tr>
<td>ORG H</td>
<td>Urea</td>
<td>100</td>
<td>Devrinol + Sinbar</td>
<td>Incorporation cover crop + straw mulch</td>
</tr>
<tr>
<td>ORG +</td>
<td>Urea</td>
<td>100</td>
<td>Microbiological soil supplements</td>
<td>Incorporated cover crop + straw mulch</td>
</tr>
<tr>
<td>COV L</td>
<td>Urea</td>
<td>50</td>
<td>Devrinol</td>
<td>None - black plastic mulch</td>
</tr>
<tr>
<td>COV H</td>
<td>Urea</td>
<td>100</td>
<td>Devrinol + Sinbar</td>
<td>None - black plastic mulch</td>
</tr>
<tr>
<td>COV +</td>
<td>Urea</td>
<td>100</td>
<td>Devrinol</td>
<td>None - black plastic mulch</td>
</tr>
<tr>
<td>LOC L</td>
<td>Urea</td>
<td>50</td>
<td>Devrinol</td>
<td>None - black plastic mulch</td>
</tr>
<tr>
<td>LOC H</td>
<td>Urea</td>
<td>100</td>
<td>Devrinol + Sinbar</td>
<td>None - black plastic mulch</td>
</tr>
<tr>
<td>LOC +</td>
<td>Urea</td>
<td>100</td>
<td>Devrinol + Sinbar</td>
<td>None - black plastic mulch</td>
</tr>
</tbody>
</table>

Results: Field Trial

We found no significant differences between treatments in terms of flavor attributes, and taste testers were not able to distinguish between strawberry fruits from differently-managed plots. Similar to the sampling results from different farms, variation in flavor volatiles was much greater than variation in sugar or acid content. Variation in sugar and acid content in plots treated the same was only 10%, meaning that if real differences existed between treatments, they likely would have been detectable. However, variation in flavor volatiles was large within the same treatment, making it difficult to detect differences if they existed. We found no significant associations between management practice and any of the six aromatic volatiles, total volatile content, or total phenolic content. Size and shape of berries within a single harvest was also large (Photo 1).

The only strong significant differences between treatments was in yield (Fig. 3) and foliar N content (Fig. 4). Plots that received 100 lbs/acre-year of N in the form of urea had a higher

![Figure 1. ‘Brix in ‘Jewel’ strawberries collected from farms across New York State between 2018 and 2019.](image)

![Figure 2. Titratable acidity in ‘Jewel’ strawberries collected from farms across New York State between 2018 and 2019.](image)

Material and Methods: Field Experiment

Our experiment established several different management practices on the same farm so that the variety, soil type and weather were consistent. We examined the effects of four factors on strawberry quality: source of inputs (organic or conventional), N quantity (50 or 100 lbs/acre-year), intensity of input use, and amount of soil carbon inputs (straw mulch, cover crops, etc.). We combined these factors to create a total of nine treatments (Table 2).

Organic forms of N are known to break down in soil much slower than urea. While nearly all applied urea converts into ammonium within the same growing season and is available to the plant, about 55% of the total N in poultry manure is released in the same time frame, and 12% of the total N is released in the following year (Nutrient Management Spear Program, 2005). So even though the same amount of total N may be applied, N from organic sources is less available over a short time span than from chemical sources.

Each treatment in our experiment was replicated 8 times in randomly distributed 10’ x 8’ plots. Strawberries were planted in May 2017 and flowers were pinched off in summer 2018. Harvest data were collected in June and July 2019 and aromas were quantified as described previously. Taste testers were recruited to determine if they could detect flavor differences between specific treatments.

![Figure 3. Total yield and marketable yield of ‘Jewel’ harvested from 2 meter of row. Fruits collected between 19 June and 10 July 2019. Standard error for total yield: 2.76 lbs. Standard error for marketable yield: 2.23 lbs. Management regimes: Conventional (COV), Organic (ORG), and Low Carbon Conventional (LOC). Treatments fertilized with 50 lbs/N/acre/year (L), 100 lbs/N/acre/year (H), or 100 lbs/N/acre/year in addition to high inputs of agricultural chemicals or amendments (+).](image)
Nitrogen form and concentration played a major role in productivity. Strawberries fertilized with urea at the highest rate (100 lbs/A-year) also has the highest yields. Strawberries fertilized with composted chicken manure at the same N rate did not produce higher yields. In fact, the lower foliar N values in organic plots, regardless of rate applied, suggest that N availability was limited even at 100 lbs/A actual N.

Others have found that organically-grown strawberries have higher firmness and greater concentrations of vitamin C and sugar (Reganold et al. 2010). This improved quality might be explained by lower N availability from organic sources. A greenhouse trial comparing fruit quality at different rates of inorganic N found the highest sweetness, firmness, and vitamin C content in strawberries fertilized at the lowest rate. Supra-optimal N applications have been found to cause poor color, flavor, and reduced sweetness and firmness in strawberry (Perkins-Veazie, 1995, and Taghavi et al. 2004). We did not find that strawberries from low N plots had better flavor attributes, although there was a tendency for them to have softer fruit.

Organic sources of N frequently contribute additional nutrients to the soil, such as phosphorous and sulfur. Supplemental fertilization with soluble P, particularly phosphoric acid, has been found to increase sugar content in strawberry fruits (Cao et al. 2015; Darrow, 1966; Zhang et al. 2017). Sulfur-containing compounds form a sizeable component of strawberry aroma (Dirinick et al. 1981), so it would be reasonable to expect an increase in aroma with increasing S and P fertilization. We did not find this relationship, perhaps because these nutrients were not limiting.

In addition to fertility decisions, growers must choose if, and how, they will incorporate cover crops and mulch to their fields. We wanted to see whether the carbon inputs inherent in applying straw mulch and incorporating a pre-plant cover crop would affect the performance of the strawberry plant. Straw mulching has been found to increase strawberry sugar content (Zamorska, 2014) and cover crops have been found to reduce disease inci-
seem to contribute little to flavor variation in short-day varieties under our conditions, although they contribute significantly to yield. Yield does not appear to be negatively correlated with flavor attributes, so following the management practices most commonly used by New York growers to optimize productivity does not appear to detract from flavor.

**Literature Cited**


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**Anya Osatuke** is a graduate student who works with Dr. Marvin Pritts. **Marvin Pritts** is a professor of Horticulture at Cornell’s Ithaca campus who leads Cornell berry crop management program.
Honeycrisp has been characterized as one of the most profitable apples grown, yielding significantly higher returns than other major varieties (Gallardo, et al., 2015). As the planted acreage has grown, the need to extend the marketing season has intensified, leading to the development of storage protocols that will optimally preserve fruit quality.

However, storing Honeycrisp apples is not simple. This cultivar is unique in its extreme sensitivity to storage atmosphere and temperature (Fig. 1) and losses due to chilling injury or CO2 injury can be extensive (Contreras et al., 2014; Watkins and Rosenberger, 2000; Watkins et al., 2004, 2005). A practical solution to suppress chilling- and atmosphere-related disorders in Honeycrisp is the use of a pre-storage conditioning period (a.k.a., preconditioning, storage delay, or delayed cooling) in which the fruit are held at temperatures well above that used for their final storage regimen (Watkins and Rosenberger, 2000; Watkins and Nock, 2003; DeLong et al., 2004; Watkins et al., 2004, 2005; Contreras et al., 2014).

Pre-storage conditioning to suppress chilling injury

The use of pre-storage conditioning to reduce sensitivity to chilling injury has a long history (Pierson, et al., 1971; Snowdon, 1990). In 1925, Plagge found soft scald declined as the pre-storage conditioning period was extended for Jonathan apples. Harley and Fisher (1930) found exactly the opposite results: delaying storage at low temperatures increased soft scald in Jonathan apples. In a more complete treatment of the injury, Plagge (1934) found that the ability to suppress chilling injury differed from year to year for the same cultivar and that the susceptibility of various apple cultivars varied from year to year. Thus, when early work was done to evaluate conditioning to prevent soft scald and soggy breakdown in Honeycrisp, the outcome was unsure. The first studies to report on conditioning treatments for Honeycrisp (DeLong et al., 2004; Watkins and Nock, 2003; Watkins et al., 2004) determined that 5 to 7 days at 50 to 70 °F markedly suppressed chilling injury in Honeycrisp and that the degree of injury could be limited further by storing the fruit at 38 °F. This result has been replicated numerous times by several research groups and some form of conditioning treatment (usually 5 to 7 days at 50 °F) is now an industry standard for this cultivar.

Watkins et al. (2004, 2005) found that sensitivity of Honeycrisp fruit to low temperature increased as maturity increased. However, this relationship is not always observed; Moran et al. (2010), found an inconsistent relationship with maturity with less mature fruit sometimes exhibiting more severe symptoms. This variable response of chilling injury to maturity is not without precedent. Plagge (1934) found that susceptibility to soft scald often depended on maturity for several cultivars, but oddly, in some years, sensitivity increased as maturity increased and in other years, it declined with more mature fruit. Overall, it appears that the relationship between maturity and chilling sensitivity for Honeycrisp more often than not is one of increasing severity of the disorder with increasing maturity.

Pre-storage conditioning procedures are relatively simple, requiring only that fruit be harvested and held at a temperature of 50 to 70 °F for a few days. Some commercial operators use a dedicated storage facility maintained at a target temperature, which presents both risks and opportunities. A closed room with warm and actively ripening apple fruit in it will cause the concentration of CO2 to climb. For most apple cultivars, this would not be of significance, but unfortunately; Honeycrisp is highly sensitive to CO2, which causes internal cellular breakdown and a type of internal browning that looks very much like soggy breakdown (Fig. 1). Anecdotal reports suggested that this short exposure to carbon dioxide might have caused injury in commercial storages. In a limited test of this possibility, in 2018, we stored Honeycrisp apples from 5 different orchards in 1, 3, 5, and 10 percent CO2 and 3% O2 for 4, 12, 48, and 120 hours (i.e., ¼, ½, 2, and 5 days) during conditioning at 50 °F, but were unable to generate injury.

Keywords: pre-storage conditioning, soft scald, bitter pit, Honeycrisp, controlled atmosphere storage

This work was supported by the Michigan Apple Committee

Our work has shown that the use of pre-storage conditioning (5 to 7 days at 50 °F) is very effective in preventing the chilling-related disorders of soggy breakdown and soft scald. CA storage of Honeycrisp is more problematic but our current recommendation for CA storage is to keep CO2 levels at or below 0.5% for at least the first six weeks in storage. The target oxygen level in CA varies from region to region, but the lower oxygen limit may be quite low. While 1-MCP use can slow ripening during conditioning and in storage, it can also enhance some storage problems for Honeycrisp in CA storage (e.g., CO2 injury and leather blotch development), so it is not as easy to fit it into CA storage protocols.

Figure 1. Disorders in Honeycrisp controlled by conditioning treatments. Left image: soggy breakdown; middle image: soft scald; right image: CO2 injury
symptoms. Likely this study bears repetition, but it may be that Honeycrisp is less sensitive to CO2 at elevated temperatures. Serban et al. (2019) took advantage of the opportunity a conditioning room provides to evaluate the benefits of establishing controlled atmosphere (CA) conditions during conditioning. They found that CA applied at this time could suppress bitter pit development.

**Pre-storage conditioning to control CO2 injury**

CA storage poses its own set of risks for Honeycrisp storage (Contreras et al., 2014; Watkins and Nock, 2012). Honeycrisp fruit respond to elevated CO2 by the formation of internal brown lesions and/or the development of lens-shaped cavities within the first six weeks of storage. The development of CO2 injury can be nearly completely controlled by treatment of the fruit with diphenylamine (DPA) early in storage or by pre-storage conditioning in much the same way we protect against chilling injury in this sensitive variety (Beaudry, 2014; Contreras et al., 2014). The investigators also found that the concentration of oxygen in the storage environment affected the injury level such that high O2 levels suppressed the injury. The involvement of O2 in the development of this disorder led the researchers to refer to the disorder as ‘CA injury’, but it is often referred to as CO2 injury. Interestingly, in this study there was always some level of injury found even when the CO2 in the environment was near zero. It may well be that the low levels of CO2 that normally exist within the fruit cause the injury. Consistent with this interpretation, use of DPA completely eliminated this injury in air-stored fruit. Contreras et al. (2014) found that fruit from early harvests having low ethylene levels were more likely to develop CA injury.

Pre-storage conditioning treatments provide incomplete control of CO2 injury unless the conditioning treatment is relatively intense. Beaudry (2014) determined that 3 days at 77 °F or 5 days at 60 to 68 °F were required to reduce CO2 injury. However, ripening was measurably advanced as determined by an enhancement in aroma compounds associated with overripe fruit.

To attempt to overcome this issue, in 2018, we treated fruit with the ethylene inhibitor 1-methylcyclopropene (1-MCP, 1 ppm overnight on the first day of conditioning) to retard ripening during the conditioning period. CA storage (3% O2 and 5% CO2) caused severe injury, whereas air-stored fruit had no injury (Table 1). Conditioning (5 or 7 days at 20 to 25 °C) controlled CO2 injury in CA-stored fruit, for both 1-MCP treated and untreated fruit.

However, the 1-MCP treatment exacerbated CO2 injury to such an extent that injury was unacceptable even in well-conditioned fruit (Fig. 2) in a manner consistent with the findings of Watkins and Nock (2012).

A satisfactory level of CO2 injury control can be gained by ‘conditioning’ Honeycrisp fruit at low temperature prior to the introduction of CO2 into the atmosphere. While this treatment does not fit our traditional idea of delayed cooling, it does provide for a period in which the physiological changes needed to reduce CO2 sensitivity can be engaged. Holding Honeycrisp fruit in air at 38 °F for 4 to 8 weeks prior to the application of CA controlled CO2 injury without compromising other quality traits (DeEll et al., 2016). Currently, it is common to simply recommend the use of low oxygen environments (1 to 3%) with low levels of CO2 (~0.5 %) for the storage of Honeycrisp; if DPA is being used, an atmosphere of 3% CO2 in CA is not harmful and benefits the retention of quality by suppressing ethylene action and slowing ripening.

**Negative effects of pre-storage conditioning**

As noted, holding Honeycrisp fruit at elevated temperatures for an extended period is not without its risks in terms of quality losses due to problems associated with ripening. For most apple cultivars, the greatest risks of short-term elevated temperatures include excessive softening, bitter pit development, the formation of greasiness on the skin, and the development of off-flavors. Fortunately for Honeycrisp, fruit softening is minimal during ripening. This trait is one of the primary reasons for its appeal (Gallardo, et al, 2015; Luby and Bedford, 1992), but also makes Honeycrisp particularly amenable to the use of pre-storage conditioning treatments. If Honeycrisp were as sensitive to softening as, for instance, McIntosh or Jonagold, it is highly doubtful that pre-storage conditioning would be used as widely as it is.

As Honeycrisp also has a high propensity for development of bitter pit on and off the tree, pre-storage conditioning can also negatively impact quality by exacerbating this disorder. Studies on the effects of conditioning have yielded mixed results in this regard; some have found that pre-storage conditioning can lead

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**Table 1. CA injury in Honeycrisp apple fruit that had 5 or 7 days conditioning at 20 to 25 °C as a function of storage in air or CA (3% O2 and 5% CO2) with and without 1-MCP treatment. 1-MCP enhanced injury in CA-stored fruit even for conditioned fruit.**

<table>
<thead>
<tr>
<th>MCP trt</th>
<th>Atmosphere</th>
<th>Internal injury (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-MCP</td>
<td>Air</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>CA</td>
<td>45.1</td>
</tr>
<tr>
<td>Untreated</td>
<td>Air</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>CA</td>
<td>17.0</td>
</tr>
<tr>
<td>ANOVA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2. CO2 injury for fruit held in a combination of 3% O2 and 5% CO2 following conditioning for 7 d at 0, 3, 10, 15, 20 and 25 °C (32, 38, 50, 59, 68, and 77°F, respectively) and treatment with 1-MCP (MCP) or left untreated as controls (UTC). CO2 injury was enhanced by 1-MCP application, but was reduced by conditioning treatment.**
to greater incidence of bitter pit (DeEll et al., 2016; Watkins et al., 2004), while others have found no effect (Contreras et al., 2014; Delong, et al., 2004), and yet others have found sporadic negative effects (Moran et al., 2010). Given the risk of quality loss through bitter pit development, efforts to minimize bitter pit during conditioning are warranted. Perhaps the safest recommendation is to condition only those fruit thought to have a low likelihood of developing bitter pit. Techniques such as those explored by Serban et al., (2019) using low CO2 CA during conditioning may be an option to keep this disorder in check.

1-MCP application during conditioning has the potential to slow ripening and preserve some aspects of quality (e.g., titratable acids, soluble solids) that benefit Honeycrisp fruit flavor (DeEll and Ehsani-Moghaddam, 2010). While bitter pit development is generally associated with advancing fruit ripeness, 1-MCP application has no reliable capacity to suppress bitter pit development in Honeycrisp (Serban et al., 2019; Watkins and Nock, 2012). Further, it can enhance the risk of CO2 injury and the development of leather blotch (typically linked to bitter pit presence), so its use must be considered carefully.

Honeycrisp is highly susceptible to the development of a ‘greasy’ skin when ripening advances. Pre-storage conditioning treatment has been found to enhance greasiness in some instances (Watkins and Nock, 2012; Serban et al., 2019), but a few studies did not find this relationship to hold (Delong, et al., 2004). This may reflect the maturity of the fruit at the time of harvest or regional differences in susceptibility. Application of 1-MCP reduces the enhancement of greasiness associated with conditioning (Watkins and Nock, 2012).

**Summary**

Given that low temperatures must be used to preserve quality during extended storage of this cultivar, there appears to be no good alternative to the use of pre-storage conditioning to prevent the chilling-related disorders of soggy breakdown and soft scald. The generally accepted conditioning treatment (5 to 7 days at 50 °F), coupled with storage at 37 °F gives reliable control of chilling injury for this cultivar.

CA storage alone or in combination with 1-MCP markedly extends the duration we can store a quality Honeycrisp relative to low temperature alone. CA storage is therefore a needed tool in the marketing of Honeycrisp apple fruit. While pre-storage conditioning can prevent CO2 injury during CA storage, the treatment needs to be more intense than the conditioning needed to control chilling injury to be sufficiently effective. Unfortunately, these higher conditioning temperatures and longer treatment durations result in additional challenges to the maintenance of fruit quality. While 1-MCP use can slow ripening during conditioning and in storage, it can also enhance some storage problems for Honeycrisp in CA storage (e.g., CO2 injury and leather blotch development), so it is not as easy to fit it into CA storage protocols. For successful CA storage, scrubbing CO2 from the CA atmosphere using lime and/or mechanical scrubbing technologies will help minimize CO2 injury while preserving quality. Near complete control of CO2 injury occurs if DPA is applied, but DPA is currently registered for superficial scald control and is not registered for use for CO2 injury. Additionally, DPA use on apple fruit is not permitted for some markets and its long-term availability is not certain. The current recommendation in essentially all production regions is to keep CO2 levels at or below 0.5% for at least the first six weeks in storage. The target oxygen level in CA varies from region to region, but the lower oxygen limit may be quite low. This past year we stored Honeycrisp apples at 0.4% O2 for several months with no apparent problems.

It is probably safe to say that the recommendations for the storage of Honeycrisp apples will continue to evolve, but for the time being, pre-storage conditioning is an integral part of the playbook.

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**Literature Cited**


**Randy Beaudry** is a professor of Horticulture who leads Michigan State University’s postharvest physiology program. **Carolina Contreras** was a graduate student with Dr. Beaudry and Diep Tran was a visiting scientist in Dr. Beaudry’s lab.
A New Interface for NEWA’s Decision Support Tools: Tailored by User Preferences

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Keywords: degree day models, forecast models, decision support system, IPM, crop management, pest management, weather data, user experience, responsive website

Users of the Network for Environment and Weather Applications (NEWA) include growers of horticultural and agronomic crops, consultants, ag industry personnel, Extension educators, and faculty. NEWA is an open-access website and the second iteration of the website has a collection of 35 tools, “version 2.0”, which can be found at http://newa.cornell.edu (Olmstead et al 2020). An updated NEWA with responsive web design to make information easily and readily available on smart phones and tablets has been needed for some time (Olmstead and Carroll 2018). NEWA also needed updated technology to provide better and more efficient weather data quality assurance. We are pleased to announce that an updated “Version 3.0” of NEWA is nearing completion and we are in the phase of tool rebuilds – insect models are complete; plant disease and crop production models are underway.

Our major goals in updating NEWA included facilitating access to tools and improving weather data quality. NEWA connects 717 weather stations in 28 states. The network combines meteorological data with interactive IPM and crop management tools to save sprays and improve crop quality. Growers benefit from NEWA’s interactive IPM and crop production tools because NEWA enhances and guides more precise use of IPM and crop production practices on the farm. Everyone using NEWA would recommend NEWA to other growers (Carroll 2018, Olmstead and Carroll 2018, Olmstead et al 2008).

Our first objective was to create a responsive design for mobile-optimized user experience with geo-specific attribution. A responsive design makes the user-interface more intuitive and NEWA tools easier to use and view, whether on desktop or mobile devices. We prioritized the building blocks for NEWA, defined the requirements for all components of the responsive NEWA website, and conducted user tests. The mobile-ready NEWA website addresses the end-user priorities of providing local attribution, saving biofix and user input information, and instantly delivering IPM decision support.

Our second objective was to improve data quality via automated screening and coordinated communication. We developed a system to facilitate the correction of erroneous precipitation, temperature, relative humidity, solar radiation, and wind speed data to enhance the accuracy of the weather-driven crop and IPM tools in NEWA. These variables are essential to the algorithms used in the decision support tools available in NEWA. Improved data handling is the foundation of being able to instantly deliver results.

Methods

A project advisory panel was formed with 42 members, including growers, faculty, Extension specialists, state partners, weather station owners and other stakeholders, who contributed to and advised us on user experience, website architecture, tool design, tool functionality and beta testing. Our project advisory panel participated in specific areas to advise NEWA development. We sent out mini-surveys to growers via the Your NEWA blog and to NEWA State Coordinators via email on topics related to user experience research and geo-specific content. Our grower advisory panel took part in user experience (UX) research on an insect degree-day model and two plant disease forecast models comparing the existing design with a draft responsive design to determine needed visual elements to allow at-a-glance pest status or crop risk, as well as perspectives on tables and charts of model outputs.

Our Extension stakeholders gave 155 invited presentations about NEWA at numerous Extension meetings, grower meetings, conferences, and other venues. At each, they informed the audience about NEWA, the improvements underway, and the positive impact on IPM practices of using the NEWA decision support system, frequently asking the audience about their ideas for improving NEWA. We published 85 articles, and produced seven podcasts on NEWA for grower audiences, climatologists, meteorologists, and agricultural scientists. The venues for these have included journals, the Your NEWA blog, newsletters, trade magazines, and technical and annual reports.

Input from stakeholders was obtained through our project advisory panel via Extension-led meetings, grower conferences, a Computing and Information Science (CIS) undergraduate internship, a CIS Master of Professional Studies project, a survey of NEWA users (Olmstead and Carroll 2018), user experience and web architecture analyses conducted by Cornell Information Technologies Computer Development (CIT CD), and web strategy workshops. During the Stakeholder Innovation Workshop led by ITX Corp, Rochester, NY we identified the NEWA mission, major areas of need, and set the stage for reviewing and prioritizing web content. The NYS IPM Program, the Northeast Regional Climate Center (NRCC) and CIT CD worked together on various aspects of the project.

An innovative approach for developing the NEWA website and associated user profile, weather station metadata, model results, and weather data displays was finalized. One-on-one, UX research on navigation, existing content labels, ease-of-use,
and conceptual understanding of webpages by CIT CD informed NEWA’s design. Our project advisory panel aided this effort. Geo-specific partner logos and resources were obtained. We worked with CIT CD for architecture, design and Americans with Disabilities Act (ADA) compliance to heighten UX when interacting with the responsive NEWA decision support system.

Databases required for NEWA's back-end were created: weather station metadata, Auth0 login, user input, common model template, and regional content system. To protect our users and our network, we put in place NEWA data use policy agreements and disclaimers. The 35 distinct NEWA model specifications were analyzed to aid modernization via a common model template fostering implementation into tools and enhancing UX.

Weather data quality control tools that allow viewing, selecting, invalidating or editing weather data were developed to support communication between growers and NEWA personnel on erroneous data, fostering the ability to edit data of concern. A portal for NEWA State Coordinators to access the tools and query the main weather variables on secure websites was developed. We provided training to state coordinators and other key personnel on how to use the data quality processes and its web interface.

Results and Discussion

The NEWA user interface features partner institution logos and resources of the user, based on geographic location, and responds to whatever device is being used. The regional content system database benefits the NEWA end user by creating an experience that is in accordance with their local and regional expectations for crop production and IPM.

NEWA Home now displays weather data from the weather station closest to the user and acknowledges the weather station owner that provides data to NEWA. The interactive weather station map loads quickly supporting searching, zooming, and panning. Two landing pages, Weather Tools and Crop & IPM Tools, buoy simplified navigation. Using a strong call out, “The Tools I Want, Where I Want” in Home’s center, the user is invited to login and create a profile for their Dashboard (Fig. 1). Recent Your NEWA blog posts are featured. The NEWA Blog, Get Help, Profile and Login reside in the header and Partners, Become a Partner, About Us, and Press Room in the footer.

The user interface for each NEWA tool, shown for Apple Maggot in Figure 2, features controls on the left: station selection, date of interest, hide/show toggles for tool elements. Tool elements are grouped in user input, management guide, results table, results graph, and environmental variables table. Background information for each tool is found in more info, acknowledgements, and references. Users can download results data as Excel-compatible comma-separated values (CSV) files, and graphs as portable network graphics (PNG) files. All 35 NEWA insect degree-day models, plant disease forecast models, crop production models, and weather data queries will use the model UX template so NEWA users have consistent feel and reliable access to the weather-based, real time crop and IPM tools.

The user input database automatically stores a user’s Dashboard profile preferences and model-specific information, such as the green tip biofix date for apple scab. This database directly benefits the NEWA stakeholders, especially growers, because they won’t have to repeatedly enter their IPM or crop data into the NEWA tool each time, saving them a significant amount of time over the course of the season.

NEWA’s weather data uses a single common access routine for all models, improving model-to-model fidelity, limiting data passed from the server to the user’s device, and returning only data needed by the specific model. The common access routine and computation on the server improves model responsive- ness, especially needed in rural locations with limited internet bandwidth. Our database of the National Digital Forecast Data predicts future conditions and is obtained in the same way as the observed data, streamlining data access. The improved data handling will boost UX and enhance NEWA’s capacity to build future tools.

Our partner NEWA State Coordinators have access to their state’s weather station data via an online data entry system. The Weather Station Database will benefit all NEWA stakeholders (growers, consultants, and extension educators) and will provide reporting on outages and attribution for the weather station to the owner of the station.

For temperature and precipitation, hourly observations are compared to published state records for the highest and lowest daily temperatures and most daily precipitation. The observations are further compared to independent gridded daily temperature and precipitation data sets and flagged if over a pre-set limit. Temperature observations also are compared to two neighboring stations, from NEWA and the National Oceanic and Atmospheric Administration, and flagged if over a pre-set limit. The between-station check is also applied to humidity and solar radiation. Humidity values are flagged if they exceed or fall below the physical limits of 100% or 0%, respectively. For solar radiation, physical limit checks are also applied, between zero and a high limit not possible astronomically. Additional quality screening algorithms for soil temperature, soil moisture and leaf wetness are being adapted by the NRCC from work, funded by the USDA Natural Resources Conservation Service, to screen these variables in the Soil Climate Analysis Network (SCAN) and Tribal SCAN station networks.

The quality control checks run automatically every week, examining the prior 14 days and returning a count of flagged observations, to identify stations that chronically report suspect data. A human analyst can query counts of flagged data and the total number of days and hours that failed a particular check for the weather station is tabulated. Using this tool, the analyst can determine if the site is problematic, contact the owner to suggest maintenance, and edit invalid data.

The National Digital Forecast grid data are being integrated as a backup data source for weather stations that fail to report data, either intermittently or for a period of up to one month. Inclusion of these data greatly improves the reliability and loading speed of the NEWA tools.

We are building an accurate, responsive and geographically relevant NEWA website. We are now completing rebuilds of all tools — insect models are complete, plant disease and crop production models are underway. The complexity of rebuilding all models into interactive tools with responsive architecture created challenges, as well as opportunities, for the NEWA team.

Beta testers unanimously praise design and navigation, which makes sense because we listened to our stakeholders and built the NEWA UX they envisioned. The NEWA community is keenly interested in continuing to learn about project outcomes.
The mechanical hoe for vineyards and orchards that is right next to the tractor operator for maximum control and plant protection.

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- Vine Replacement Auger
- 3 Tooth Cultivator Rolling Cultivator Undercut Blade

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and how to use the responsive NEWA tools to benefit their crop production practices. The NEWA version 3.0 website will launch in 2021.

Conclusions

Increased use of digital IPM decision support systems like NEWA results in more growers making better pest management decisions with less pesticide input (Carroll 2008, Olmstead and Carroll 2018). NEWA’s renewed architecture now delivers geospecific attribution for appropriate place-based extension outreach on devices as small as phones. Common building blocks used to reconstruct the 35 IPM models into responsive NEWA tools (Fig. 2) were delineated and paved the way for future growth and easy upgrades.

A NEWA Dashboard (Fig. 1) will display what the user wants from the locations they want: easy to set up through NEWA’s user profile. The profile backend will store essential biofix and crop information to drive fast and accurate IPM forecasts for growers. We have developed the required back-end databases and front-end design elements that will heighten positive user experiences when interacting with the responsive NEWA decision support system.

To support NEWA data quality, we utilize forecast data and our weather station data editor tool to provision an accurate and reliable decision support system. Improved navigation comes via an interactive NEWA map and streamlined landing page designs that echo our UX research.

When growers have access to reliable, weather-based, real time NEWA models, IPM practices increase on the farm, preventing plant disease, insect, and crop loss, reducing unnecessary inputs, and minimizing health, economic and environmental risks.

Acknowledgements

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Literature Cited


Juliet Carroll is a Senior Extension Associate with the NYS IPM Program of Cornell Cooperative Extension and serves as Fruit IPM Coordinator. Dan Olmstead is an Extension Associate with the NYS IPM Program of Cornell Cooperative Extension and serves as the NEWA Coordinator. Art DeGaetano is a Professor in the Department of Earth and Atmospheric Sciences and is the Director of the Northeast Regional Climate Center. Alejandro Calixto is a Senior Extension Associate and the Director of the NYS IPM Program of Cornell Cooperative Extension. Jennifer Grant is a retired Senior Extension Associate and past Director of the NYS IPM Program of Cornell Cooperative Extension.
A pple 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 mefentrilflaconazole (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 *Vitis 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 benzoindiflupyr. 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 inpyrflurin, 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).

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**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.**

<table>
<thead>
<tr>
<th>Treatment program with amount per Acre</th>
<th>Spray Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Untreated control</td>
<td>/</td>
</tr>
<tr>
<td>2 Vanguard 75 WG 5 oz</td>
<td>GT</td>
</tr>
<tr>
<td>Manncozeb 75 WG 3 lb</td>
<td>TC</td>
</tr>
<tr>
<td>Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb</td>
<td>TK, PK, EB, FB, PF</td>
</tr>
<tr>
<td>Miravis A19649(1) 3.4 fl oz</td>
<td>TC</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>1C</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>2C – 5C</td>
</tr>
<tr>
<td>3 Vanguard 75 WG 5 oz</td>
<td>GT</td>
</tr>
<tr>
<td>Manncozeb 75 WG 3 lb</td>
<td>TC</td>
</tr>
<tr>
<td>Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb</td>
<td>TK, PK, EB, FB, PF</td>
</tr>
<tr>
<td>Miravis A19649(1H) 3.42 fl oz</td>
<td>TC</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>1C</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>2C – 5C</td>
</tr>
<tr>
<td>4 Vanguard 75 WG 5 oz</td>
<td>GT</td>
</tr>
<tr>
<td>Manncozeb 75 WG 3 lb</td>
<td>TC</td>
</tr>
<tr>
<td>Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb</td>
<td>TK, PK, EB, FB, PF</td>
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<tr>
<td>Aprovia 5.5 fl oz</td>
<td>TC</td>
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<tr>
<td>Inspire Super 12 fl oz</td>
<td>1C</td>
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<tr>
<td>Captan 80 WDG 3 lb</td>
<td>2C – 5C</td>
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<tr>
<td>5 Vanguard 75 WG 5 oz</td>
<td>GT</td>
</tr>
<tr>
<td>Manncozeb 75 WG 3 lb</td>
<td>TC</td>
</tr>
<tr>
<td>Mancozeb 75 WG 3 lb + Captan 80 WDG 2.5 lb</td>
<td>TK, PK, EB, FB, PF</td>
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<tr>
<td>Luna Sensation 4.17 SC 5 fl oz</td>
<td>TC</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>1C</td>
</tr>
<tr>
<td>Captan 3.80 WDG 6 lb</td>
<td>2C – 5C</td>
</tr>
<tr>
<td>6 Manncozeb 75 WG 3 lb</td>
<td>HIG</td>
</tr>
<tr>
<td>Cevya 3.34SC 4 fl oz + U700 16 fl oz/100gal + Manncozeb 75 WG 3 lb</td>
<td>TC, EB, MB, PF</td>
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<tr>
<td>Captan 80 WDG 3 lb</td>
<td>1C – 5C</td>
</tr>
<tr>
<td>7 Manncozeb 75 WG 3 lb</td>
<td>HIG</td>
</tr>
<tr>
<td>Cevya 3.34SC 5.0 fl oz + U700 16 fl oz/100gal + Manncozeb 75 WG 3 lb</td>
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<tr>
<td>Captan 80 WDG 3 lb</td>
<td>1C – 5C</td>
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<tr>
<td>8 Manncozeb 75 WG 3 lb</td>
<td>HIG</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>TC, EB, MB, PF</td>
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<tr>
<td>Captan 80 WDG 3 lb</td>
<td>1C – 5C</td>
</tr>
<tr>
<td>9 Pyraziflumid 3.1 fl oz + Manncozeb 75 WG 3 lb + Silwet 16 fl oz/100gal</td>
<td>HIG, PK, KB, PF, ½ INF, 1C</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>2 – 5C</td>
</tr>
<tr>
<td>10 Pyraziflumid 3.1 fl oz + Manncozeb 75 WG 3 lb</td>
<td>HIG, PK, KB, PF, ½ INF, 1C</td>
</tr>
<tr>
<td>Captan 80 WDG 2.5 lb</td>
<td>2 – 5C</td>
</tr>
<tr>
<td>11 Pyraziflumid 4.65 fl oz + Manncozeb 75 WG 3 lb</td>
<td>HIG, PK, KB, PF, ½ INF, 1C</td>
</tr>
<tr>
<td>Captan 80 WDG 2.5 lb</td>
<td>2 – 5C</td>
</tr>
<tr>
<td>12 Imdari 6 fl oz + Manncozeb 75 WG 3 lb</td>
<td>HIG, TC</td>
</tr>
<tr>
<td>Rally 5 oz + Manncozeb 75 WG 3 lb</td>
<td>PK</td>
</tr>
<tr>
<td>Luna Sensation 5 oz + Manncozeb 75 WG 3 lb</td>
<td>MB, PF</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb/ba (1-5C)</td>
<td>1C-5C</td>
</tr>
<tr>
<td>13 Fontetil 16 fl oz + Imdari 8 fl oz</td>
<td>TC, PK</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb/ba (1-5C)</td>
<td>TC, MB, PF</td>
</tr>
</tbody>
</table>

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
new SDHI-s Miravis (pydiflumetofen), labeled in this report as two formulations A19649[B] and A19649[H], and pyrazifluim, as well as a triazole fungicide Cevya 3.34 SC (35.93% W/W mefentrifluconazole; FRAC 3). We used 24-year-old apple trees on M.9 rootstock planted in discrete three-cultivar replicated plots at 25 ft between trees, 10 ft between trees withing 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 Turboton 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 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 (α = 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.

**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.

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<tbody>
<tr>
<td>1 Untreated control</td>
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<tr>
<td>Vangard 5 oz + Manzate Pro-Stick 75 WG 3 lb</td>
<td>GT</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz + Manzate Pro-Stick 75 WG 3 lb</td>
<td>HIG</td>
</tr>
<tr>
<td>Merivon 5.5 fl oz + Manzate Pro-Stick 75 WG @ 3 lb</td>
<td>LTC</td>
</tr>
<tr>
<td>Excalia 3 fl oz + Syl-Coat 0.062% v/v (8 fl oz/100 gal)</td>
<td>PK</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>BL</td>
</tr>
<tr>
<td>Excalia 3 fl oz + Syl-Coat 0.062% v/v (8 fl oz/100 gal)</td>
<td>PF</td>
</tr>
<tr>
<td>Captan 80 WG 3 lb</td>
<td>1C – 4C</td>
</tr>
</tbody>
</table>

**Table 3.** spray programs with insecticides 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.

**Table 4.** spray programs with insecticides 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.
Unigreen Turboteuton Mistblower air-blast sprayer (Unigreen 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 calculated 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

### Treatment program with amount per Acre

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<tr>
<td>2 Manzate Pro-stick 75 WG 3lb</td>
<td>GT</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TC</td>
</tr>
<tr>
<td>Cenvia 3.34SC 4 fl oz + Manzate Pro-stick 75 WG 3lb</td>
<td>TC</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TC</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>TK</td>
</tr>
<tr>
<td>3 Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Cenvia 3.34SC 5 fl oz + Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>TK</td>
</tr>
<tr>
<td>4 Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz + Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>TK</td>
</tr>
<tr>
<td>5 Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Escalia 4 fl oz</td>
<td>TK</td>
</tr>
<tr>
<td>Inspire Super 12 fl oz</td>
<td>TK</td>
</tr>
<tr>
<td>Escalia 4 fl oz</td>
<td>TK</td>
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</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>TK</td>
</tr>
<tr>
<td>6 Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
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<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
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<tr>
<td>Miravis 3.42 fl oz</td>
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</tr>
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<td>Inspire Super 12 fl oz</td>
<td>TK</td>
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<tr>
<td>Miravis 3.42 fl oz</td>
<td>TK</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Captan 80 WDG 3 lb</td>
<td>TK</td>
</tr>
<tr>
<td>7 Stargus 3 qts + Microthiol Dispers 20 lbs</td>
<td>TK, TC, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>Stargus 3 qts + Microthiol Dispers 20 lbs + NuFilm P 32 fl oz/100 gal</td>
<td>HIG</td>
</tr>
<tr>
<td>8 Stargus 2 qts + Manzate Pro-stick 75 WG 3lb</td>
<td>TK, TC, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>Stargus 2 qts + Manzate Pro-stick 75 WG 3lb</td>
<td>HIG, TC, TK, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>9 Stargus 3 qts</td>
<td>TK</td>
</tr>
<tr>
<td>Stargus 3 qts + NuFilm P 32 fl oz/100 gal</td>
<td>HIG</td>
</tr>
<tr>
<td>10 Microthiol Dispers 20 lbs</td>
<td>TK</td>
</tr>
<tr>
<td>Microthiol Dispers 20 lbs + NuFilm P 32 fl oz/100 gal</td>
<td>HIG</td>
</tr>
<tr>
<td>11 Indar 8 fl oz + Manzate Pro-stick 75 WG 3lb</td>
<td>TK, PK, MB, PF, 1C</td>
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<tr>
<td>Rally 8 oz + Manzate Pro-stick 75 WG 3lb</td>
<td>TK, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>Luna Sensation 4,175SC 5 fl oz + Manzate Pro-stick 75 WG 3lb PF</td>
<td>TK, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>Manzate Pro-stick 75 WG 3lb</td>
<td>TK</td>
</tr>
<tr>
<td>Captan 80 WDG 2.5 lb</td>
<td>TK</td>
</tr>
<tr>
<td>12 Vaciplant 14 oz</td>
<td>TK, TC, PK, MB, PF, 1C</td>
</tr>
<tr>
<td>13 Untreated control</td>
<td>TK</td>
</tr>
</tbody>
</table>

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.
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

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**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, TC2 - 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. Please refer to the caption of Fig. 1B 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 Highland NY, recorded by a weather station. Please refer to the caption of Fig. 1B for specific graph visual parts explanations.

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**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. GT - green tip, HIG - half-inch green, TC - tight cluster, TC2 - tight cluster, PK - pink bud, BL - bloom, PF - petal fall, 1C - first cover.

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**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 of these two cultivars to <i>V. inaequalis</i>. 

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

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![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.](image_url)

![Figure 5. Apple scab incidence on spur leaves (A), fruit (B) and shoot leaves (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.](image_url)
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 Dispers, Microthiol Dispers 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 (81.1 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 Dispers, 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 Dispers (#2, 4, 6, 7), and Microthiol Dispers 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: (I) 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**


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Hard Cider Apple Cultivars for New York

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Keywords: Hard apple cider, tannins, titratable acidity, bitter sharp, juice quality

The cider industry has created opportunities for new business ventures and diversification of existing farm enterprises. Most of the more than 1,000 U.S. cider producers have been in business for only a few years and many do not grow their own fruit (Peck and Miles, 2015). In 2017, the U.S. cider industry required about 18.2 million bushels of apples, which is equivalent to 7% of the U.S. apple crop (Alcohol and Tobacco Tax and Trade Bureau, 2017). However, larger producers are importing apple juice concentrate, so a much smaller volume of cider is actually made from U.S.-grown apples. Additionally, many U.S. cideries are made from fresh-market cultivars that have lost their value, apples that didn’t make size or color grade, and processing apples. This offers opportunities for New York’s apple growers to sell apples from existing plantings, as well as to diversify into growing high-tannin cider apple cultivars.

Specialized bitter cider cultivars have up to ten times greater polyphenolic (specifically tannins, such as procyanidins) concentration than culinary apples (Thompson-Witrick et al., 2014). Tannins contribute desirable flavors to cider, such as bitterness and astringency which leads to a more robust sensory experience. While the U.S. is the second largest apple producer in the world, only a small percentage of the total acreage is planted with high-tannin cider apple cultivars. In fact, national surveys have reported that less than one-third of cider producers have cider apple plantings (Peck and Miles, 2015). A recent Harvest NY survey indicated that high-tannin cider apples are increasingly sought by producers of all scales, but supply is well below demand (Pashow, 2018). For example, New York is home to Angry Orchard’s Research and Development facility which is actively seeking New York-grown cider apples.

The Harvest NY survey also reported that cider producers placed an emphasis on the need to acquire these bitter cider apples and are willing to pay up to double the price of fresh-market cultivars for these fruit (Pashow, 2018). At an average of $0.35/lb, high-tannin cider apples are 2-4 times more valuable than most processing fruit (Miles et al., 2020; Peck and Knickerbocker, 2018). This price premium for bitter cider apples is primarily driven by a lack of supply for this specialized fruit. Additionally, cider apples can be mechanically harvested and may require lower pesticide inputs than culinary apples because cosmetic defects and even some superficial damage are acceptable for apples that will be processed soon after harvest (Merwin, 2015). However, many European cider cultivars are minimally responsive to chemical fruit thinning, have an extremely biennial bearing habit, tend to be overly vegetative, and/or are highly susceptible to economically important apple diseases, which makes cultivar selection extremely important in developing an economically viable cider apple supply chain.

The goal of this project was to generate research-based information on the horticultural and juice quality attributes of European cider apple cultivars.

Materials and Methods

In 2015, a replicated cultivar trial was established at the Cornell Orchards in Ithaca, NY. Cultivars in this trial included: ‘Binet Rouge’, ‘Brown Snout’, ‘Brown’s Apple’, ‘Dabinett’, ‘Ellis Bitter’, ‘Harry Masters Jersey’, ‘Porter’s Perfection’, “Geneva” Tremlett’s Bitter’ (note this cultivar is not the true-to-type ‘Tremlett’s Bitter’ and has thus been dubbed “Geneva” Tremlett’s Bitter’ by the cider industry in reference to the misidentification originating in the USDA’s Malus germplasm collection in Geneva, NY), and ‘Vilberie’. Each cultivar is replicated four times in two-tree sets in a completely randomized block design. The trees are planted 3’ apart and 12’ between rows, grafted onto G.935 rootstock, and trained as a tall spindle. ‘Chisel Jersey’ was intended to be included in this trial, but there were insufficient trees at planting to include in the replicated design, so it was only included as a buffer between blocks.

Tree growth, fruit yields, and fruit and juice quality were measured annually. In mid-summer, fruit was thinned to 5 fruit/TCSA to prevent branch breakage. At harvest, fruit was selected from upper, lower, exterior, and interior sectors of each tree to reduce within tree variation. Fruit was stored in standard atmosphere cold storage (1-3°C; >90% relative humidity) for no more than seven days prior to analyses. To evaluate maturity, fruit were sliced equatorially and the starch-iodine index was determined.

This work was supported by the NY Apple Research and Development Program

Hard cider is made richer and more complex with high tannin apple cultivars which are not widely grown in the US. Many European cider cultivars are extremely biennial and are highly susceptible to fire blight which makes cultivar selection extremely important. The goal of this project was to generate information on horticultural and juice quality attributes of European cider apple cultivars.
by dipping the exposed tissue into a potassium iodide solution (1 g potassium iodide plus 0.25 g iodine in 100 mL water), for comparison to staining patterns on published charts (Blanpied and Silsby, 1992). The harvest date was selected when the fruit had less than 20% of the flesh stained with the potassium iodide solution. Flesh firmness was measured, after removing part of the peel at two locations along the equator of each apple, with a penetrometer (Fruit Texture Analyzer, Güss Manufacturing Ltd., Strand, South Africa) fitted with a cylindrical 11.1 mm diameter tip.

Apples were milled and juiced using a Norwalk 280 Juicer (Bentonville, AR). The extraction efficiency was calculated using the pulp weight and extracted juice weight. Juice samples were stored at -80 °C and then thawed to 4 °C immediately prior to analysis. Soluble solids concentration was measured using a PAL-1 digital refractometer (Atago U.S.A., Inc., Bellevue, WA) and reported as percent Brix. Titratable acidity was measured by titrating a 5 mL juice aliquot against a 0.1 N NaOH solution to an end-point of pH 8.1 with an 809 Titrando autotitrator with the Folin–Ciocalteu assay (Thompson-Witrick et al., 2014) and reported as gallic acid equivalents.

All data was subjected to statistical analysis using analysis of variance and post-hoc mean separations determined by Tukey’s Honestly Significant Difference using RStudio version 1.1.442 (RStudio, Boston, MA).

Table 1. Fall 2020 measurements of trunk cross-sectional area (TCSA), total yield, crop load, yield efficiency, crop density, harvested fruit weight, and pre-harvest fruit drops of ten hard cider cultivars planted in 2015 in Ithaca, NY.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Fall 2020 TCSA (cm²)</th>
<th>2020 Average Total Yield (harvest + drop wt, kg)</th>
<th>2020 Average Crop Load (no. drops + no. harvested)</th>
<th>Yield Efficiency (total wt. · TCSA⁻¹)</th>
<th>Average Crop Density (Crop Load · TCSA⁻¹)</th>
<th>Average Fruit Weight (g)</th>
<th>Pre-harvest drops (%)</th>
<th>Cumulative Yield (kg/tree) 2016-2020</th>
<th>% Change TCSA Spring 2015-Fall 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binet Rouge</td>
<td>18.5 cdx</td>
<td>4.6 bc</td>
<td>67.9 ab</td>
<td>0.26 b</td>
<td>3.8</td>
<td>69.3 c</td>
<td>37.2 b</td>
<td>23.6 dac</td>
<td>796 cd</td>
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<tr>
<td>Brown’s Apple</td>
<td>22.4 bc</td>
<td>6.5 bc</td>
<td>58.0 ab</td>
<td>0.31 ab</td>
<td>2.7</td>
<td>116.0 a</td>
<td>43.6 bc</td>
<td>19.6 bc</td>
<td>1407 ab</td>
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<td>3.3 c</td>
<td>50.3 b</td>
<td>0.24 b</td>
<td>3.6</td>
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<td>65.6 ab</td>
<td>20.1 bc</td>
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<td>2.0 c</td>
<td>24.5 b</td>
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<td>252 d</td>
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<td>7.9 ab</td>
<td>73.8 ab</td>
<td>0.33 ab</td>
<td>3.1</td>
<td>109.8 a</td>
<td>37.1 bc</td>
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<td>19.7 bcd</td>
<td>11.6 a</td>
<td>101.7 a</td>
<td>0.59 a</td>
<td>5.2</td>
<td>114.4 a</td>
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<td>880 bcd</td>
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<td>61.6 ab</td>
<td>0.14 b</td>
<td>2.1</td>
<td>66.1 c</td>
<td>34.9 bc</td>
<td>20.1 bc</td>
<td>1510 a</td>
</tr>
<tr>
<td>Tremlett’s Bitter</td>
<td>8.2 e</td>
<td>2.4 c</td>
<td>35.1 b</td>
<td>0.32 ab</td>
<td>4.4</td>
<td>97.6 ab</td>
<td>25.6 c</td>
<td>11.4 cd</td>
<td>375 d</td>
</tr>
<tr>
<td>Vilbere</td>
<td>13.9 d</td>
<td>4.8 bc</td>
<td>43.3 b</td>
<td>0.32 ab</td>
<td>3.0</td>
<td>115.6 a</td>
<td>89.9 a</td>
<td>20.8 bc</td>
<td>809 bcd</td>
</tr>
<tr>
<td>Chisel Jersey</td>
<td>13.6 x</td>
<td>9.6</td>
<td>41.3</td>
<td>0.74</td>
<td>3.3</td>
<td>234.6</td>
<td>83.1</td>
<td>27.7</td>
<td>657</td>
</tr>
</tbody>
</table>

1 Different letters within each column indicate means separation at p ≤ 0.05 level of significance using Tukey's honest significantly difference test. | Tremlett’s Bitter is not true-to-type. This cultivar is often called, "Geneva"Tremlett’s Bitter. | Chisel Jersey trees were inter-block buffers; not part of replicated experimental design.

Results and Discussion

Trunk measurements taken in Fall 2020 were compared with measurements taken at the time of planting in Spring 2015 (Table 1). ‘Porter’s Perfection,’ ‘Brown’s Apple,’ and ‘Brown Snout’ grew the most during this period. The least amount of tree growth over the six years was found for ‘Dabinett’ and “Geneva” Tremlett’s Bitter, with the other cultivars being intermediate in growth and not statistically different from each other. “Geneva” Tremlett’s Bitter’ appears to be a low-vigor cultivar, while the slow growth of ‘Dabinett’ may be attributable to cold damage. In fact, half of the ‘Dabinett’ trees died by the fifth year of this experiment. Overall yields in 2020 were lower than expected, perhaps due to the biennial bearing habit for many of these cider cultivars.

Table 2. Starch pattern index (SPI), soluble solid content (SSC), pH, titratable acid (TA), Folin–Ciocalteu total polyphenols (FC), juice extraction efficiency, flesh firmness, peel color, change in absorbance (ΔA), and post-harvest average fruit weight of ten hard cider cultivars planted in 2015 and harvested in 2020 in Ithaca, NY. Subsets of ten randomly selected apples (or fewer if insufficient fruit) were assessed for maturity and subsequently pressed for juice analysis.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>SPI (1-8)</th>
<th>SSC (*°Brix)</th>
<th>pH</th>
<th>TA (g·L⁻¹)</th>
<th>FC</th>
<th>Juice extraction (%)</th>
<th>Firmness (%)</th>
<th>Red peel color (%)</th>
<th>ΔA</th>
<th>Post-harvest fruit wt. (g)</th>
<th>Fruit diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binet Rouge</td>
<td>4.4 dx</td>
<td>18.4 b</td>
<td>4.54 ab</td>
<td>2.3 d</td>
<td>1.8 de</td>
<td>51.2 bc</td>
<td>86.2 a</td>
<td>80.3 c</td>
<td>14.1 d</td>
<td>71.3 de</td>
<td>57.6 de</td>
</tr>
<tr>
<td>Brown’s Apple</td>
<td>6.4 bc</td>
<td>15.4 bca</td>
<td>3.19 e</td>
<td>12.9 a</td>
<td>1.3 e</td>
<td>71.9 a</td>
<td>53.0 de</td>
<td>96.0 a</td>
<td>0.23 cd</td>
<td>129.7 a</td>
<td>70.7 a</td>
</tr>
<tr>
<td>Brown Snout</td>
<td>5.9 c</td>
<td>21.6 a</td>
<td>4.06 c</td>
<td>4.6 c</td>
<td>1.9 de</td>
<td>—</td>
<td>67.2 c</td>
<td>—</td>
<td>0.11 d</td>
<td>68.1 a</td>
<td>56.4 e</td>
</tr>
<tr>
<td>Dabinett</td>
<td>7.3 ab</td>
<td>16.8 bcd</td>
<td>4.82 a</td>
<td>1.8 d</td>
<td>2.3 de</td>
<td>69.1 a</td>
<td>77.8 ab</td>
<td>87.5 a</td>
<td>0.60 a</td>
<td>89.1 cd</td>
<td>61.8 de</td>
</tr>
<tr>
<td>Ellis Bitter</td>
<td>7.9 a</td>
<td>14.8 d</td>
<td>4.52 ab</td>
<td>2.3 d</td>
<td>2.5 cd</td>
<td>69.7 a</td>
<td>46.2 e</td>
<td>90.4 a</td>
<td>0.12 d</td>
<td>113.6 b</td>
<td>68.2 ab</td>
</tr>
<tr>
<td>Harry Masters Jersey</td>
<td>6.6 bc</td>
<td>17.6 bc</td>
<td>4.42 b</td>
<td>2.4 d</td>
<td>3.0 bc</td>
<td>42.2 c</td>
<td>91.4 a</td>
<td>90.9 a</td>
<td>0.11 d</td>
<td>114.3 b</td>
<td>65.3 cd</td>
</tr>
<tr>
<td>Porter’s Perfection</td>
<td>7.8 a</td>
<td>16.7 bcd</td>
<td>3.63 d</td>
<td>9.7 b</td>
<td>3.4 b</td>
<td>72.3 a</td>
<td>83.5 ab</td>
<td>87.5 bc</td>
<td>0.37 b</td>
<td>64.7 e</td>
<td>56.8 e</td>
</tr>
<tr>
<td>Tremlett’s Bitter</td>
<td>7.6 a</td>
<td>12.6 e</td>
<td>3.22 e</td>
<td>13.4 a</td>
<td>1.9 de</td>
<td>72.1 a</td>
<td>73.2 bc</td>
<td>87.2 bc</td>
<td>0.69 a</td>
<td>106.4 b</td>
<td>66.8 b</td>
</tr>
<tr>
<td>Vilbere</td>
<td>7.8 a</td>
<td>18.1 b</td>
<td>4.34 b</td>
<td>2.6 d</td>
<td>5.9 a</td>
<td>69.7 a</td>
<td>63.0 cd</td>
<td>70.5 d</td>
<td>0.33 bc</td>
<td>104.7 bc</td>
<td>67.3 ab</td>
</tr>
<tr>
<td>Chisel Jersey</td>
<td>6.9</td>
<td>20.0</td>
<td>4.62</td>
<td>2.5</td>
<td>5.0</td>
<td>—</td>
<td>70.8</td>
<td>—</td>
<td>0.44</td>
<td>104.0</td>
<td>64.9</td>
</tr>
</tbody>
</table>

1 Different letters within each column indicate means separation at p ≤ 0.05 level of significance using Tukey’s honest significantly difference test. | Tremlett’s Bitter is not true-to-type. This cultivar is often called, "Geneva"Tremlett’s Bitter. | Chisel Jersey trees were inter-block buffers; not part of replicated experimental design.
Over the six years, cumulative yields were greatest for ‘Harry Masters Jersey’ and ‘Ellis Bitter’ which both had greater than 30 kg/tree (Table 1). ‘Binet Rouge’, ‘Brown Snout’, ‘Porter’s Perfection’, and ‘Vilberie’ had cumulative yields between 20-24 kg/tree, and ‘Brown’s Apple’, ‘Dabinett’, and “Geneva” Tremlett’s Bitter had less than 20 kg/tree. Pre-harvest drops were least for ‘Binet Rouge’, ‘Brown’s Apple’, ‘Ellis Bitter’, ‘Porter’s Perfection’, and “Geneva” Tremlett’s Bitter, and most for ‘Dabinett’, ‘Harry Masters Jersey’, and ‘Vilberie’.

Cider cultivars were allowed to tree-ripen to a starch pattern index of 6, which is greater than fresh market apples, so as to have the greatest sugar content for fermentation (Table 2). In this trial, ‘Brown Snout’ had the greatest soluble solid concentration, while ‘Ellis Bitter’, “Geneva” Tremlett’s Bitter, and ‘Vilberie’ had the lowest. ‘Brown’s Apple’ and “Geneva” Tremlett’s Bitter had exceptionally high titratable acidity and along with ‘Brown Snout’ and ‘Porter’s Perfection’ would be considered “sharp” apples (> 4.5 g/L TA) (Figure 1). All of the cultivars in this trial would be considered “bitter” with a polyphenol concentration of greater than 1.25 g/L as measured by the Folin-Ciocâlteu assay, though ‘Brown’s Apple’ is usually categorized as “sharp” rather than “bittersharp” due to its low (<1.25 g/L) phenolic content and lack of perceived bitterness (Copas, 2013). ‘Vilberie’ had an exceptionally high polyphenol concentration of 5.9 g/L. ‘Dabinett’, ‘Ellis Bitter’, ‘Harry Masters Jersey’, and ‘Porter’s Perfection’ had polyphenol concentrations between 2-4 g/L. ‘Brown’s Apple’, ‘Ellis Bitter’, ‘Porter’s Perfection’, ‘Tremlett’s Bitter’, and ‘Vilberie’ all had greater than 70% juice extraction efficiency suggesting that they would provide very high juice yields when milled and pressed. By contrast, the extreme viscosity of ‘Harry Masters Jersey’ (~40% extraction efficiency) makes it suitable for blending with fresh-market and processing apples to add “body”.

Overall, ‘Porter’s Perfection’ was one of the best performing cultivars in this trial in terms of tree growth and productivity, with minimal pre-harvest drop (Table 3). ‘Porter’s Perfection’ also had many of the juice quality attributes to make a single variety cider. The other cultivars could contribute sugar, acidity, and/or phenolics, but not necessarily all three attributes. ‘Vilberie’, in particular, should be considered as a cultivar to add in low volume to a blend of fresh-market or processing apples to provide polyphenols. Other cultivars that performed adequately included, ‘Binet Rouge’, ‘Brown’s Apple’, ‘Ellis Bitter’, and ‘Harry Masters Jersey’. ‘Dabinett’ did not perform well, most likely due to freeze damage that occurred in the nursery to the trunks. In other experiments, ‘Dabinett’ has shown itself to be a productive and regular bearer.

Observations on Growth Habit

Binet Rouge is moderate to low vigor, with a strong central leader and many small diameter branches that have a wide branch angle with moderate growth. ‘Brown’s Apple’ is vigorous and only produces a few branches that are large caliper and fairly upright (with a red hue to the leaves). ‘Brown Snout’ is vigorous, somewhat acrotonic, and not well feathered. ‘Chisel Jersey’ has moderate vigor and a slightly upright branch angle. In our trial, the ‘Dabinett’ trees were negatively affected by freeze damage; however, in other plantings, we found this cultivar to be of moderate vigor and fairly well feathered, with long, slightly upright branches, and somewhat tip-bearing. ‘Ellis Bitter’ is highly vigorous and acrotonic, with long, large caliper, upright branches, and a very dominant central leader (though it has a tendency to send up three or four co-dominant leaders that need to be thinned to one in high-density systems), long internodes and a tendency for producing blind wood. Aggressive stub pruning of ‘Ellis Bitter’ branches in the first few years after planting seems to help moderate the vigor and bring this cultivar into bearing. ‘Harry Masters Jersey’ is moderately vigorous, well-feathered, with wide branch angles. ‘Porter’s Perfection’ is highly vigorous, with thick, somewhat upright branches that have fairly long internodes. ‘Porter’s Perfection’ has a strong propensity to send up multiple leaders, which should be thinned to a single leader in high-density plantings, but it also produces many branches.

Table 3. Descriptive assessment of ten hard cider cultivars planted in 2015 in Ithaca, NY.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Juice quality</th>
<th>Bearing habit</th>
<th>Productivity</th>
<th>Harvest window</th>
<th>Pre-harvest fruit drop (average; range over five years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binet Rouge</td>
<td>Bittersweet, soft tannins</td>
<td>Biennial</td>
<td>Fairly productive</td>
<td>Last week of September/Early October</td>
<td>39; 22-65%</td>
</tr>
<tr>
<td>Brown’s Apple</td>
<td>Sharp, slightly red in hue</td>
<td>Annual</td>
<td>Less productive, precocious</td>
<td>2nd/3rd week of September</td>
<td>36; 21-62%</td>
</tr>
<tr>
<td>Brown Snout</td>
<td>Mild bittersharp, soft tannins</td>
<td>Annual</td>
<td>Fairly productive</td>
<td>2nd/3rd week of October</td>
<td>45; 22-66%</td>
</tr>
<tr>
<td>Dabinett</td>
<td>Bittersweet</td>
<td>Biennial</td>
<td>Productive</td>
<td>Last week of October</td>
<td>58; 42-72%</td>
</tr>
<tr>
<td>Ellis Bitter</td>
<td>Bittersweet, soft tannins</td>
<td>Fairly annual</td>
<td>Highly productive, precocious</td>
<td>First week of September</td>
<td>36; 23-46%</td>
</tr>
<tr>
<td>Harry Masters Jersey</td>
<td>Bittersweet, viscous</td>
<td>Fairly annual</td>
<td>Highly productive, precocious</td>
<td>Mid-September until 1st week of October</td>
<td>59; 24-86%</td>
</tr>
<tr>
<td>Porter’s Perfection</td>
<td>Bittersharp, juicy</td>
<td>Annual</td>
<td>Fairly productive</td>
<td>Last week of October</td>
<td>43; 26-57%</td>
</tr>
<tr>
<td>Tremlett’s Bitter</td>
<td>Bittersharp</td>
<td>Biennial</td>
<td>Precocious</td>
<td>2nd/3rd week of September</td>
<td>33; 18-71%</td>
</tr>
<tr>
<td>Vilberie</td>
<td>Bitter, strong tannins</td>
<td>Fairly annual</td>
<td>Precocious</td>
<td>Last week of September/1st of October</td>
<td>70; 33-90%</td>
</tr>
<tr>
<td>Chisel Jersey</td>
<td>Bittersweet</td>
<td>Fairly annual</td>
<td>Highly productive</td>
<td>2nd/3rd week of October</td>
<td>58; 40-83%</td>
</tr>
</tbody>
</table>

* Tremlett’s Bitter is not true-to-type. This cultivar is often called, “Geneva”Tremlett’s Bitter.
* Chisel Jersey trees were inter-block buffers; not part of replicated experimental design.
which can be renewed on a regular basis. Due to its late harvest
date, ‘Porter’s Perfection’ also has a tendency to drop leaves prior
to harvest. “Geneva” Tremlett’s Bitter’ is a low-vigor cultivar
with short branches, a propensity for blind wood, and tends to
develop multiple leaders which sometimes grow so strongly that
they outcompete the existing leader within a season. “Geneva”
Tremlett’s Bitter’ also has very brittle wood, which can lead to
many broken branches in their “on-year”.

Spanish cultivars

In 2018, we established a replicated trial of elite Asturian
Spanish cider cultivars which will allow NY producers to explore
Spanish cider styles. Spanish cider (or sidra) tends to be more
acidic and acetic than English and French ciders. Cultivars in this
study include, ‘Blanquina’, ‘Collaos’, ‘Coloradona’, ‘Maria Elena’ (syn:
and ‘Cristalina.’ Juice quality data were taken from the small
number of fruit available in 2020 and should be only considered
preliminary at this time. However, it is evident that ‘Piel do Sapo’
has exceptionally high titratable acidity (19 g/L). The other cul-
tivars ranged from 2 (‘Sangre de Toro’) to 11 g/L (‘Blanquina’).

‘Piel de Sapo’ would be considered “bitter” with a total polyphenol
content over 1.25 g/L.

Misnamed Cultivars

As a point of clarification, “Geneva” Tremlett’s Bitter’ is the
name we use for an unidentified cultivar that has been mistakenly
propagated as ‘Tremlett’s Bitter’. We have been unable to match
it with any known apple cultivars in our genetic fingerprinting
datasets, and its provenance is currently unknown. Fruit from
both cultivars are conical with a red peel, and superficially re-
semble each other. However, the true ‘Tremlett’s Bitter’ is a low-
acid bittersweet, while “Geneva” Tremlett’s Bitter’ is a high-acid
bittersharp.

In the U.S., ‘Binet Rouge’ has sometimes been mistakenly
propagated under the name ‘Yarlington Mill’, as has ‘Michelin’, a
widely-grown bittersweet cultivar in the United Kingdom. The
true-to-type ‘Binet Rouge’, which was included in this trial, has
fruit that is oblate and somewhat small, with a green/yellow back-
ground and red blush, ripe in late September or early October in
Ithaca. The true-to-type ‘Yarlington Mill’ (not included in this
trial) apple is rather large, long and conical, with a pinkish-red
color and orange-yellow background, ripe in mid-September in
the Finger Lakes region, and often exhibits black necrotic spots
due to heat stress damage. There is at least one other incorrectly
identified cultivar that has been traded and sold as ‘Yarlington Mill’ in the U.S. that may have been misidentified in USDA’s Malus germplasm collection.

Although not part of our Ithaca trials, ‘Foxwhelp’ is another very well-known cider cultivar that has been widely traded and sold in the U.S. as not true-to-type. Recently, John Bunker from Maine’s Fedco Seeds published a very thorough article about the many ‘Foxwhelps’ in Malus, an independent zine published out of California (Bunker, 2020). In order to rectify these misidentified cultivars, we have imported and genotyped true-to-type cider apple cultivars from the United Kingdom. In fact, this work is part of a larger project that genotyped over 100 cider cultivars with the goal to not only correctly identify cultivars, but also to better understand the relationships and genetic diversity of cider apple germplasm.

Additional Research

In addition to horticultural performance and juice quality, my lab is measuring polyphenol composition, yeast assimilable nitrogen, flavor volatile profiles, and fermentation characteristics of the cider apple cultivars in these trials. To gain a greater understanding of the diversity of cider apples available in the United States, we are also phenotyping, chemotyping, and genotyping more than 350 accessions in the USDA’s Malus germplasm collection (Peck et al., 2019). Through this work and the above-described cultivar trials, we hope to identify cider apple genotypes that have desirable and, perhaps, unique juice quality, but that are also productive in modern orchard systems. We also have on-going trials to develop best practices for managing crop load (Peck et al., 2016; Zakalik et al., 2020), minimizing pre-harvest fruit drop (Peck et al., 2020), increasing yeast assimilable nitrogen content (Karl et al., 2020a, 2020b), and mechanically harvesting cider apples in high-density orchards. Clearly, there is a lot of work to be done. We hope these efforts support the continued planting of cider apple orchards throughout the region.

Acknowledgments

We thank Heather Boocks, the Cornell Orchards Summer Interns, and the Cornell Orchards staff for their assistance and many hours of hard work during this project. Funding was provided by the New York Apple Research Development Program, the New York Farm Viability Institute, and the New York State Department of Agriculture and Markets. Additional funding was provided by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch under accession 1014042, the Angry Orchard Cider Company, LLC., and Cornell University’s College of Agriculture and Life Sciences and School of Integrative Plant Science—Horticulture Section.

Literature Cited


Dr. Gregory Peck is research and teaching professor of Horticulture located at Cornell’s Ithaca campus who leads Cornell’s program on cider apples. David Zakalik is a graduate student who works with Dr. Peck, and Michael Brown is a research support specialist who works with Dr. Peck.
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