Northern NY Agricultural Development Program
2019 Project Report

Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage

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- Everett Orchards, Peru, NY
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Background:

'Honeycrisp' is a popular apple variety that is very suitable for growing in cold climate regions such as northern New York. This variety has been very profitable for northern New York fruit growers, but is proving challenging to grow for many reasons.

One major obstacle for growing and marketing 'Honeycrisp' is the variety's susceptibility to bitter pit. Bitter pit is a physiological disorder of the fruit that manifests as sunken pits on or just beneath the fruit surface. The affected tissues are dry, spongy, and give the fruit a bitter taste, making the fruit unmarketable. Fruit can go into storage showing no signs of the disorder, but symptoms will then develop in storage, which can cause major reductions in the percentage of marketable fruit. This can cause great economic losses to apple growers.

There are currently few tools available to the grower to predict this loss prior to storage, since most fruit going into storage show no symptoms. The prediction tools currently available require analyzing the fruits' mineral nutrient contents prior to harvest, as there has been good correlation between ratios of fruit peel minerals and the development of bitter pit in storage (Baugher et al., 2017). However, these methods require growers to peel fruit and send samples to a lab, where results may take too long to be reported back to the grower. These mineral analysis results may be difficult to interpret.

The inability to easily assess the potential for bitter pit on the fruit prior to long-term storage necessitates a method that will allow apple growers to easily predict which fruit are most at risk of developing bitter pit. An easy-to-use, low-cost prediction method would enable growers to market fruit with high risk of bitter pit shortly after harvest before symptoms develop, and select blocks of fruit with low risk of bitter pit for storage long term for marketing later.

While fruit prone to bitter pit can be marketed more quickly to avoid economic loss, there could be an economic benefit to storing apples for longer durations if storage disorders could be minimized and acceptable pack-out levels could be maintained.

'Honeycrisp' are sometimes conditioned (held at 50˚F for one week) prior to being stored at 38˚. This conditioning is done to minimize soft scald and soggy breakdown. Soft scald and soggy breakdown are two other common 'Honeycrisp' storage disorders, which are likely to occur when fruit are exposed to low storage temperatures. Unfortunately, conditioning to reduce soft scald and soggy breakdown also tends to increase bitter pit development. In order to minimize overall storage disorder development, it would be beneficial to predict bitter pit risk to determine if fruit should be conditioned prior to long-term storage to minimize soft scald development. Additionally, even lower storage temperatures (33˚) could potentially be used on severe-risk bitter pit blocks to minimize bitter pit incidence on stored fruit, though this comes with even more risk for the development of soft scald. A tool to predict bitter pit ahead of harvest gives growers an opportunity to evaluate their bitter pit risk ahead of each harvest season, and would allow them to adjust their marketing and storage plans accordingly to get the most value out of their fruit.

In this Northern New York Agricultural Development Program (NNYADP)-funded project, we assessed a passive, low-cost, non-mineral method to predict bitter pit in 'Honeycrisp' to help northern NY growers better predict the incidence of the bitter pit disorder. We also trialed three storage treatments for blocks of apples predicted to be at low, moderate, and high risk of bitter pit development to determine if overall losses from storage disorders could be reduced when storing this challenging variety of apple.

Methods:

We collected fruit from 21 commercial apple orchard sites in northern New York to evaluate the passive method of bitter pit prediction at a commercial level. Study blocks represented a range of tree ages, rootstocks, and orchard management practices. One hundred (100) apples per orchard block were picked from 10-12 trees on September 4, 2019, three weeks before the anticipated commercial harvest date. These fruit were stored in a commercial storage room in Peru, NY, at 68˚F for three weeks to induce bitter pit symptom development. After three weeks, fruit were rated for the presence of bitter pit. In addition to these fruit, 20 apples per orchard (two fruit per tree) were collected, peeled, and sent to the Cornell Nutrient Analysis Laboratory in Ithaca, NY, for mineral nutrient analyses.

Another set of 100 fruit per orchard from the same orchard blocks was collected on September 25, at commercial harvest (Figure 1). These fruit were stored for four months under different storage treatments based on the percentage of bitter pit incidence predicted by the passive method (Figure 2).

The three storage treatments were selected based on the following conditions: (Al Shoffe and Watkins, unpublished work):

1. If bitter pit development on fruit collected 3 weeks before harvest (3WBH) was less than 5%, harvested fruit were conditioned for one week at 50˚F, then moved to 38˚ for four months plus 4 days (+4d) at 68°F.
2. If bitter pit development on fruit collected 3WBH was between 5-10%, the fruit were stored directly at 38˚ without conditioning for four months+ 4d at 68°F.
3. If bitter pit development on fruit collected 3WBH was between 10- 20%, fruit were stored at 33˚ for four weeks, and then moved to 38˚ for four months+ 4d at 68°F.

Fruit were rated on January 21, 2020, for the incidence of bitter pit, along with the following additional storage disorders: soft scald, rough skin, blotch, soggy breakdown, internal CO_2 injury, senescent breakdown, flesh browning, core browning, and vascular browning (Figure 3).

To assess the effectiveness of the passive method, we compared the predicted bitter pit incidence rates to the actual incidence rates of fruit for bitter pit following storage using bivariate regression analysis. We also compared the results of the passive method to the peel mineral analyses. We also summarized the total disorder development levels following storage for each block.

Results and Discussion:

Predicted bitter pit incidence of the 21 blocks of apples ranged from 0 to 18% (Figure 4A). The incidence of actual bitter pit on fruit after four months of storage+ 4d at 68°F ranged from 0 to 33% (Figure 4B).

Passive Method Prediction and Bitter Pit Percentages Following Storage in Conditioned Fruit

The predicted bitter pit incidence of fruit picked 3WBH was less than 5% in 14 of the 21 blocks surveyed. Fruit from these blocks were then picked at commercial harvest, conditioned for one week at 50°F, and then stored at 38°F for four months.

In 11 of these 14 blocks, the actual bitter pit incidence following storage was no more than 5% higher than we predicted using the passive method. Al Shoffe et al. (2019) found the average incidence of fruit coming out of 38°F storage after conditioning was 6% higher than the incidence in fruit picked 3WBH and stored at 68°F under the passive method. The final passive prediction formula they developed was:

$$\text{Actual bitter pit (\%)} = 6 + \text{predicted bitter pit (\%)}$$

Our findings for 11 of the 14 apples blocks stored under this treatment are in general agreement with this previously developed model.

The passive method under-predicted the actual amount of bitter pit in three of the 14 blocks by 13%, 10%, and 30%. The site with 13% greater actual incidence had a light crop load, while the site with 10% greater incidence was planted on a vigorous rootstock (Budagovsky 118) with relatively high levels of annual shoot growth. The site with 30% greater incidence was a young block, heavily pruned the previous winter, and had large fruit. These horticultural parameters can often lead to increased bitter pit development (Baugher et al., 2017; Cline, 2009). These additional horticultural factors may not have affected the fruit as severely at 3WBH. This illustrates the importance in evaluating block history when using the passive method.

Passive Method Prediction and Bitter Pit Percentages in Fruit Stored at 38°F Without Conditioning

The passive method predicted four of the 21 blocks to have 10%, 7%, 5%, and 8% bitter pit, and were therefore stored directly at 38°F for the entire four months of storage. The actual incidence of bitter pit of fruit from these blocks following storage was 10%, 1%, 16%, and 16%.

For this storage treatment, the actual incidence was the same in one block, was 6% lower in one block, and was 11% and 8% higher in two blocks. These results suggest choosing not to condition fruit based on the passive method predictions may have helped to maintain bitter pit incidence at relatively low levels in the stored fruit that were prone to bitter pit development.

Passive Method Prediction and Bitter Pit Percentages in Fruit Stored at 33°F for One Month Followed by Three Months at 38°F
The passive model predicted three blocks to have 17%, 18%, and 12% bitter pit. Fruit from these blocks were stored at 33°F for one month, followed by 38°F for the remaining three. The actual incidence rates following storage were 20%, 9%, and 2%, respectively.

Under this storage treatment, the actual bitter pit incidence was 3% higher in one block, and 9% and 10% lower in the other two. These data suggest storing fruit for one month at 33°F based on the passive method predictions can be effective at maintaining or reducing the incidence of bitter pit over a four-month storage period.

Bivariate Regression Analysis
Regression analyses were performed to assess the relationship of bitter pit incidence from the passive prediction model to actual bitter pit incidence of fruit stored under the storage treatments (Figure 5). Each storage treatment was analyzed separately. Predicted values had only moderate levels of correlation (R-square = .4) with incidence values in fruit conditioned at 50°F prior to storage at 38°F. This correlation is lower than has previously been found (Al Shoffe et. al, 2019), likely due to the high actual incidences observed in three of the 14 blocks stored under this treatment.

The passive method-predicted values had moderate correlations with actual bitter pit incidence values of fruit from the 33°F treatment (R-square = .5), and a very low correlation with fruit stored at 38°F (R-square = .03). The low correlations likely came from the effect of our decisions in storage management, based on the range of bitter pit from the passive method. **This indicates the ability to maintain or lower pitter bit incidence based on the prediction model. Since we were unable to completely eliminate bitter pit in storage, additional research is needed to develop optimal storage treatments.**

Development of Other Disorders in Stored Fruit
In addition to bitter pit, fruit were rated for the development of soft scald, blotch, shrivel, wrinkly skin, rot, soggy breakdown, senescent breakdown, CO_2 injury, and flesh, core, and vascular browning (Figure 6).

Soft scald and soggy breakdown are common postharvest disorders of 'Honeycrisp' that can be exacerbated if the apples are stored at low temperatures. The highest incidences of soft scald and soggy breakdown occurred in blocks stored at the lower storage temperature treatments to mitigate the risk of bitter pit development. Soft scald incidence ranged from 0 to 8%. The highest incidences of soft scald were observed in blocks 3, 5, and 8, (8%, 7%, and 6%). Fruit from these blocks were initially stored at 38°F, 33°F, and 33°F, respectively.

Soggy breakdown incidence ranged from 0 to 18%. The highest incidence was in block 8, which was stored at 33°F before being moved to 38°F.

The inverse relationship of bitter pit to soft scald development has been previously documented (Watkins et al, 2004), and should be heavily weighed when determining if 'Honeycrisp' should not be conditioned, or stored at lower temperatures, to minimize bitter pit. These findings reinforce that additional research is needed to optimize storage temperatures to reduce bitter pit while also reducing the risk of soft scald and soggy breakdown development.

Rot incidence ranged from 0 to 15%, and was commonly observed on fruit with soft scald, or in fruit that had been damaged by the stems of other fruit in the storage bin.

Blotch incidence ranged from 0 to 6%, and was also highest in a block of fruit stored at 33°F.

Senescent breakdown was observed at low levels (0 to 8%) across storage treatments.

Flesh, core, and vascular browning were observed at low levels (under 5%) in four, three, and five blocks, respectively.

We did not detect any wrinkly skin or CO_2 injury in any of the fruit we rated.

Combined Storage Disorder Percentages
Block 8 had the most combined storage disorders (48%) (Table 1). This block had been predicted to have 18% bitter pit development, and was therefore stored at 33°F before being moved to 38°F. While the low temperature treatment led to more moderate levels of bitter pit incidence (9%), the low temperatures likely exacerbated soft scald (6%) and soggy breakdown (18%) development. The block also had moderate levels of blotch (4%), rot (9%), and small amounts of senescent breakdown (2%). Block 5 had the second most combined disorders (45%) and was similarly stored at 33°F.

Passive Method and Mineral Analysis
Prediction results were compared to various peel mineral levels within the fruits (Table 2). Bitter pit is partially related to low levels of calcium within the fruits' peels. Mineral prediction models often use ratios of calcium to additional minerals within the fruit peel, such as phosphorous and magnesium (Al Shoffe et al., 2019). Our passive method was most closely correlated to the ratio of peel phosphorous plus magnesium to calcium (P+Mg)/Ca (R =.79), followed by the individual ratios of P/Ca (R=.77) and Mg/Ca (R=.75). A recent study (Baugher et al. 2017) recommended growers assess the peel mineral ratio of nitrogen to calcium, along with shoot length measurements for mineral bitter pit prediction, but also found the ratios of Mg/Ca and K/Ca were well correlated with bitter pit development. The results of this study show the passive method correlates well with mineral ratios, while being potentially less time consuming and expensive for growers to implement in an orchard setting.

Conclusions
This research study confirms previous reports (Watkins et al., 2004; Al Shoffe et al, 2019, Al Shoffe et al., 2020) of the effects low temperatures can have on storage disorder development in 'Honeycrisp' apples. While bitter pit can be somewhat mitigated by low temperature storage, the risk of developing other storage disorders needs to be considered. Since fruit in one of our treatments were stored at 33°F for four months, future studies should investigate shorter time intervals at 33°F. In the meantime, northern New York 'Honeycrisp' growers might instead

consider quickly marketing blocks that are at high risk of developing bitter pit, skipping conditioning prior to storing blocks with high bitter pit risk, or conditioning and storing only fruit from low bitter pit risk blocks based on the passive prediction method.

The passive method of bitter pit prediction has previously been confirmed as an efficient, cost-effective method for predicting bitter pit prior to commercial 'Honeycrisp' harvest across New York. Our findings from 21 NNY orchard blocks support these findings, as the predicted incidence rates were within 6 percent of the actual rates in 10 of the 14 blocks that were conditioned for one week at 50°F prior to being stored at 38°F. However, three of these 14 blocks under-predicted bitter pit development by 10% or more. Since these blocks had a history of bitter pit, or had management features making them more prone to bitter pit development, our findings highlight the importance of growers strongly taking into account their management practices and block history when interpreting the results of the passive method.

While low storage temperatures can help mitigate bitter pit development in some cases, the lack of conditioning and/or prolonged storage at 33°F can exacerbate soft scald and soggy breakdown, which can contribute to having less marketable fruit following storage. Therefore, our recommendation would be to condition fruit that have low predicted bitter pit values and a history of low rates of bitter pit prior to storage. Fruit with high bitter pit predictions should be marketed quickly rather than being put into long-term storage. If susceptible fruit must be stored, fruit should not be conditioned and should instead be stored directly at 38°F.

Education and Outreach:

2019 Eastern NY Commercial Fruit and Vegetable Conference

The Eastern NY Commercial Fruit and Vegetable Conference was held in Albany, NY, on February 19-20, 2019. On February 20, Dr. Chris Watkins spoke on storage recommendations for 'Honeycrisp' and discussed the passive prediction method. More than 100 attendees were present at this meeting, including many representing orchards from the northern NY region.

2019 Cornell Storage Workshop

An apple storage and postharvest management workshop was held in Ithaca, NY, on August 8, 2019, with invited speakers from across the United States and Canada, representing leading universities and industry leaders working on bitter pit management. This meeting was attended by more than 80 fruit growers from across the state of New York.

Newsletter Article

Following the 2019 Cornell Storage Workshop, we wrote an extension article reviewing key storage recommendations for the Eastern NY Commercial Horticulture Program (ENYCHP) Tree Fruit News. This newsletter is distributed online and through paper copies, reaching more than 150 fruit growers.

Tree Fruit E-Alerts

In addition to the newsletter article, additional information on harvest management and storage practices was regularly sent to the northern NY orchard community in weekly email alerts.

One-on-One Outreach

Growers participating in the storage project received frequent personalized emails, text messages, phone calls, and farm visits to discuss the results of their bitter pit predictions from both the passive and the mineral analysis methods.

Next Steps:

Grower outreach events were well received and will continue through 2020, including a presentation of these NNYADP project results at the 2020 Eastern NY Fruit and Vegetable Conference in Albany, NY, on February 25-26, 2020. This event is regularly attended by more than 150 fruit growers.

We will continue aiding growers in the adoption of the passive bitter pit prediction method. We plan to hold a bitter pit meeting in northern New York prior to harvest in 2020 to help growers understand how they can conduct the tests themselves on their farms.

While the passive method can be a helpful tool for predicting bitter pit development in fruit after storage, further work is necessary to increase its precision for use in northern New York to help the region's apple growers adjust for block history and management practices. Future work should also continue to identify storage treatments that can best reduce disorder development in bitter pit susceptible fruit in northern New York.

Acknowledgments:

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For More Information:

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References:

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Al Shoffe, Y.A., Nock, J.F., Baugher, T.A., Marini, R.P. and Watkins, C.B., 2020. Bitter pit and soft scald development during storage of unconditioned and conditioned 'Honeycrisp' apples in relation to mineral contents and harvest indices. Postharvest Biology and Technology, 160, p.111044.

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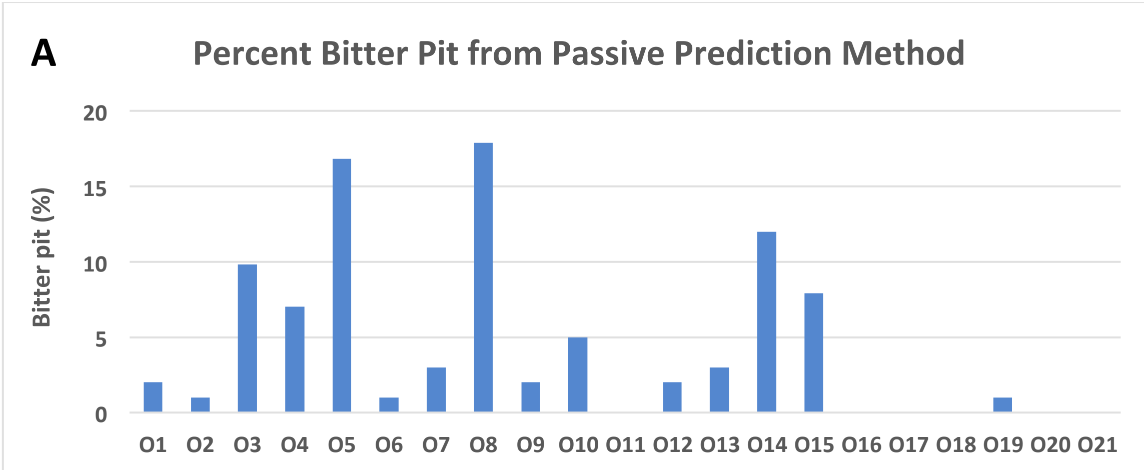
Watkins, C.B., Nock, J.F., Weis, S.A., Jayanty, S., Beaudry, R.M., 2004. Storage temperature, diphenylamine, and pre-storage delay effects on soft scald, soggy breakdown and bitter pit of 'Honeycrisp' apples. Postharvest Biol. Technol. 32: 213–221.

Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage Project Appendix

Left: Figure 1. Collecting fruit for storage treatments at one of the participating NNY commercial orchards field sites in the Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP. Photo by: Michael Basedow

Right: Figure 2. Stacking the 100 fruit samples from different commercial blocks for the harvest storage treatments in the storage facility at Forrence Orchards, Peru, NY. Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP. Photo by: Andrew Galimberti

Figure 3. Evaluating fruit for bitter pit and other storage disorders after storage for 4 months +4 days at 68°F, Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP. Photo by Michael Basedow.



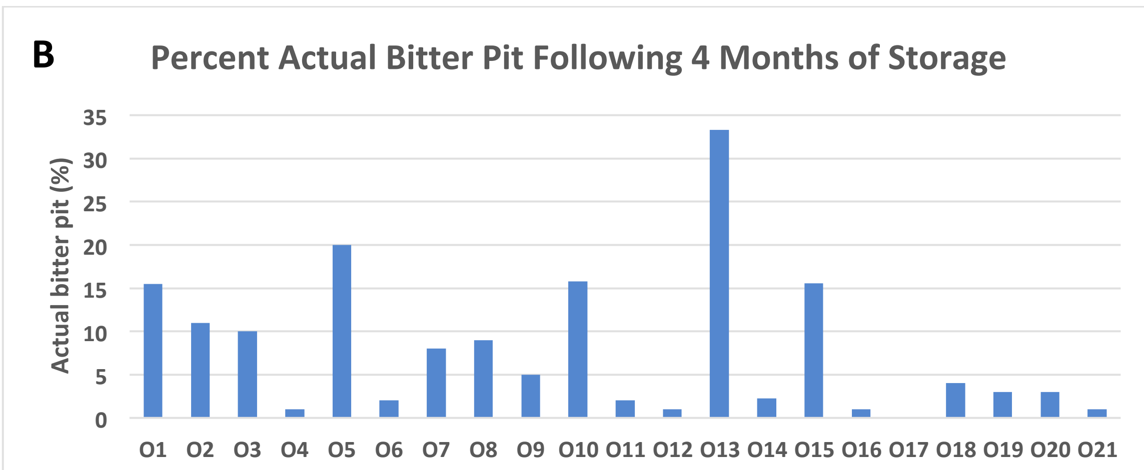


Figure 4. (A) Bitter pit (%) in 'Honeycrisp' apples from fruit harvested at 3 weeks before anticipated harvest from different orchard blocks in NNY Champlain region and kept for 3 weeks at 68°F or (B) harvested at commercial harvest and stored for 4 months+ 4 days at 68°F. Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP.

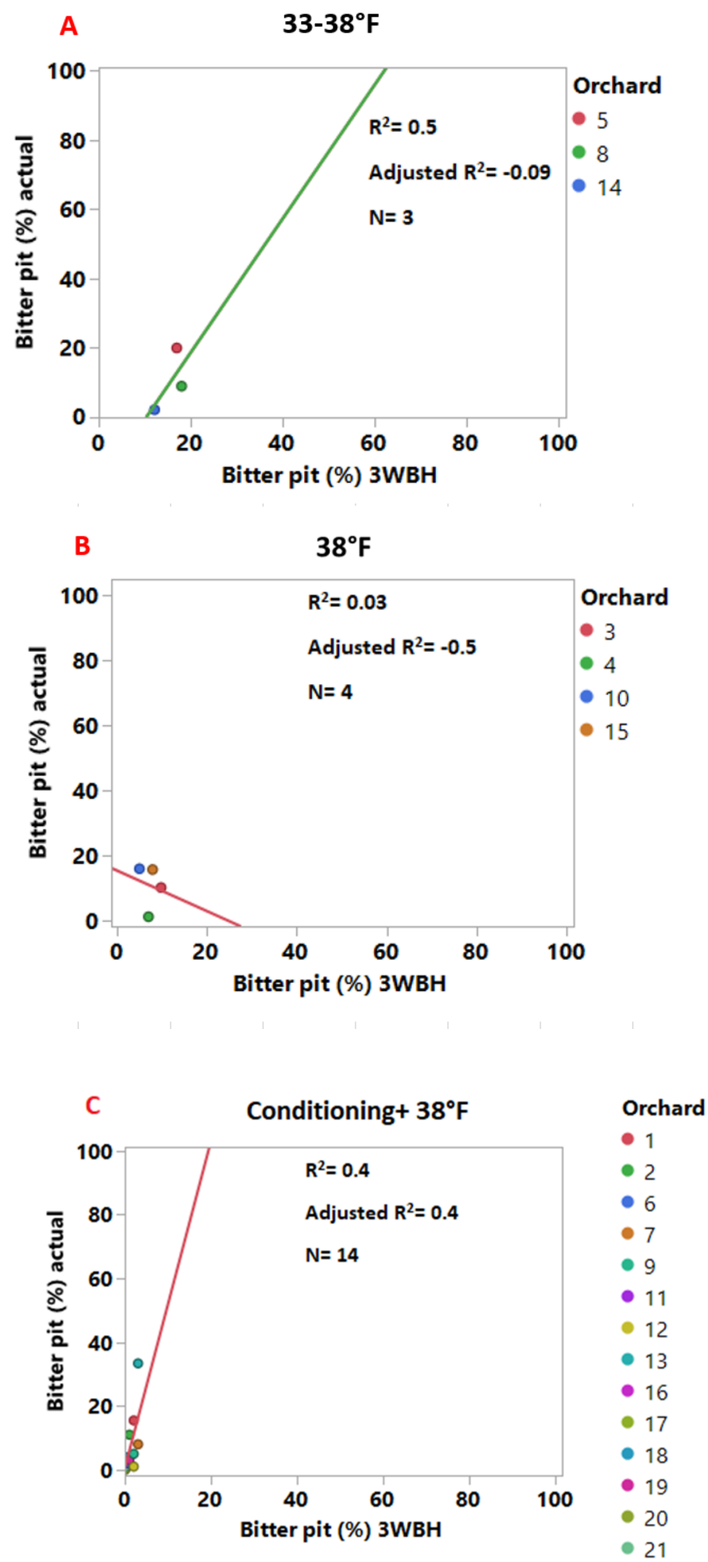
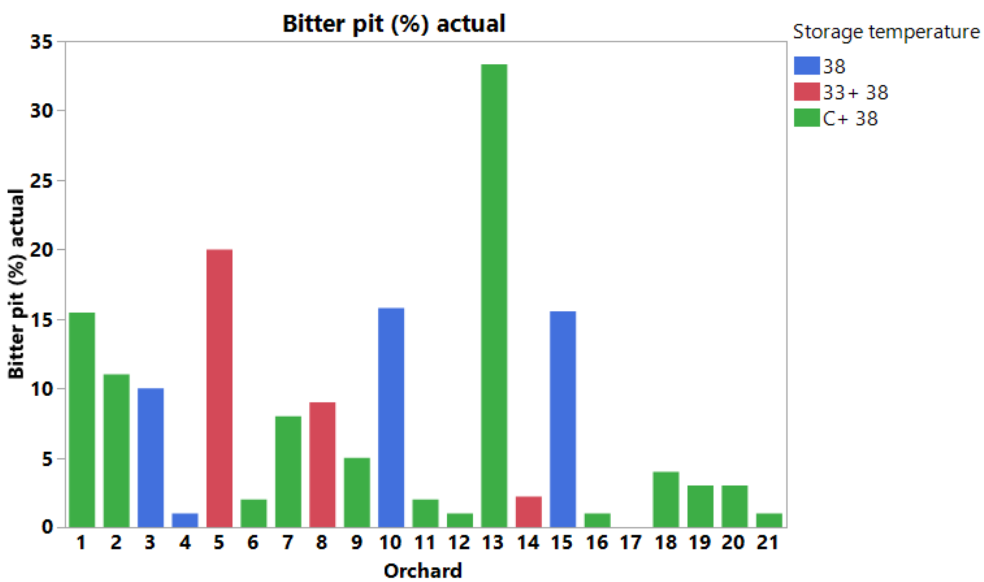


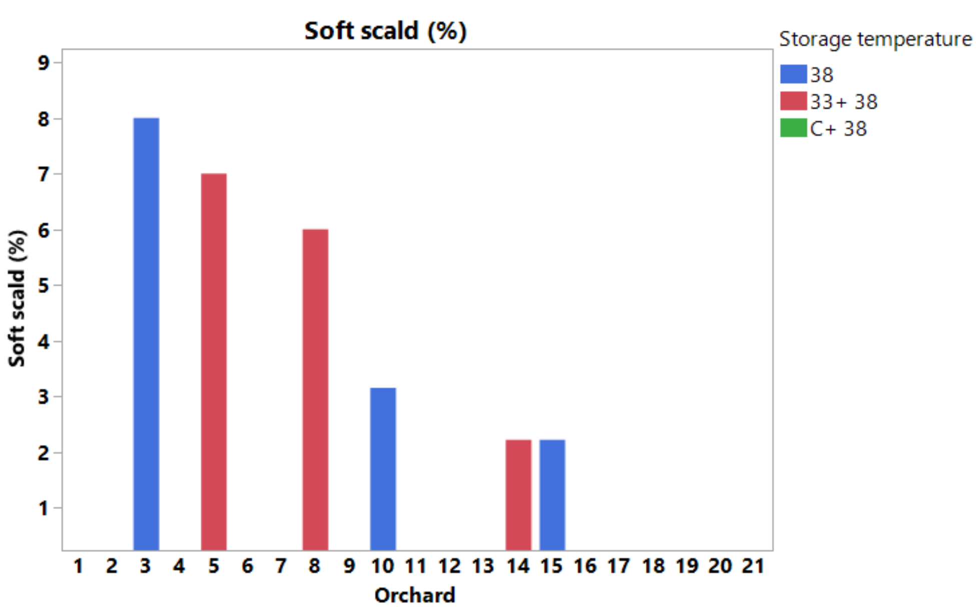
Figure 5 A-C. Bivariate analysis for bitter pit from 3WBH against bitter pit from (A) 33°-38°F, (B) 38°F, and (C) conditioning+ 38°F. Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP.

The next 10 graphs represent the incidence of physiological disorders in 'Honeycrisp' apples after storage for 4 months +4 days at 68°F:

- **(A): Bitter pit**
- **(B): Soft scald**
- **(C): Soggy breakdown**
- **(D): Blotch**
- **(E): Rot**
- **(F): Senescent breakdown**
- **(G): Flesh browning**
- **(H): Core browning**
- **(I): Vascular browning**
- **(J): Total disorders.**



A



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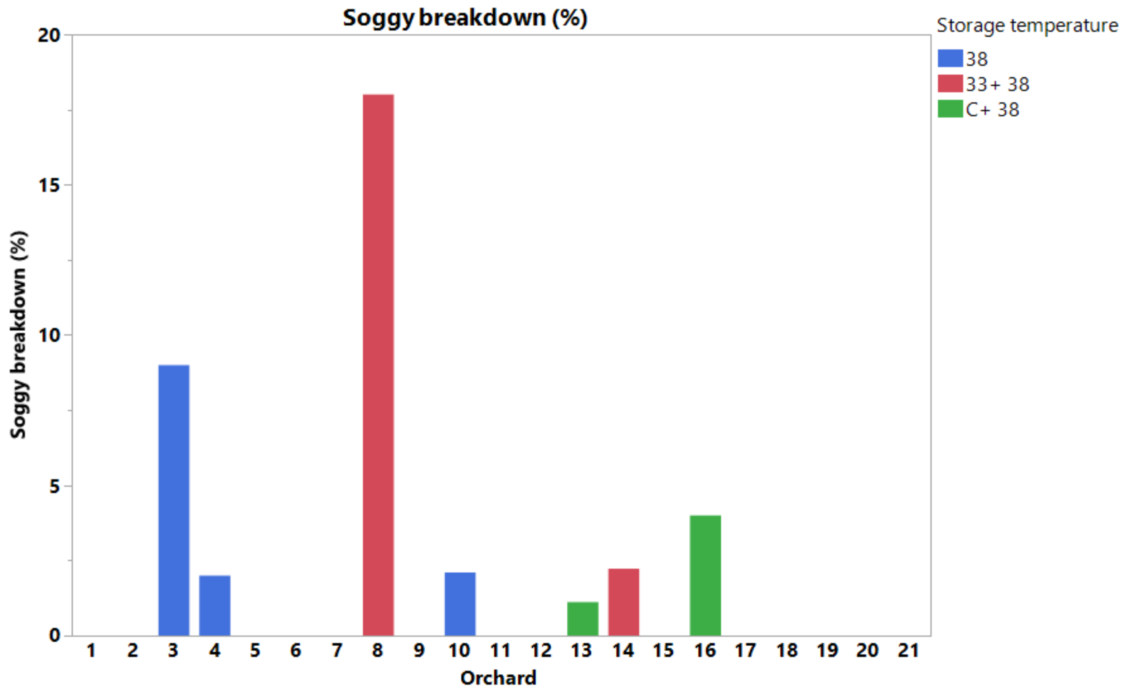
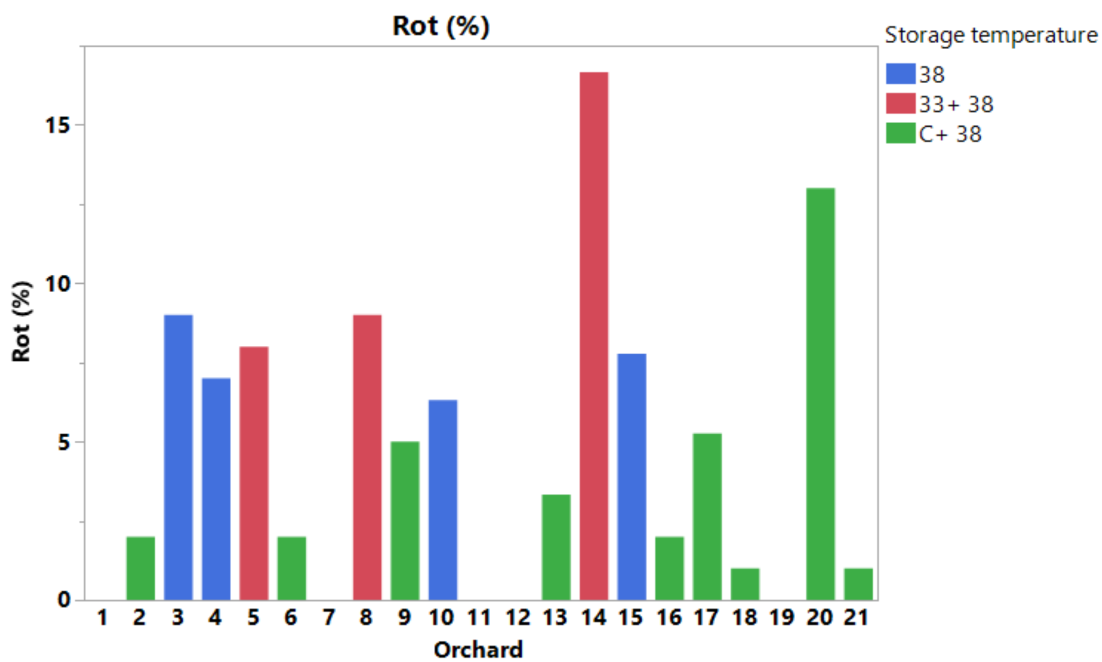
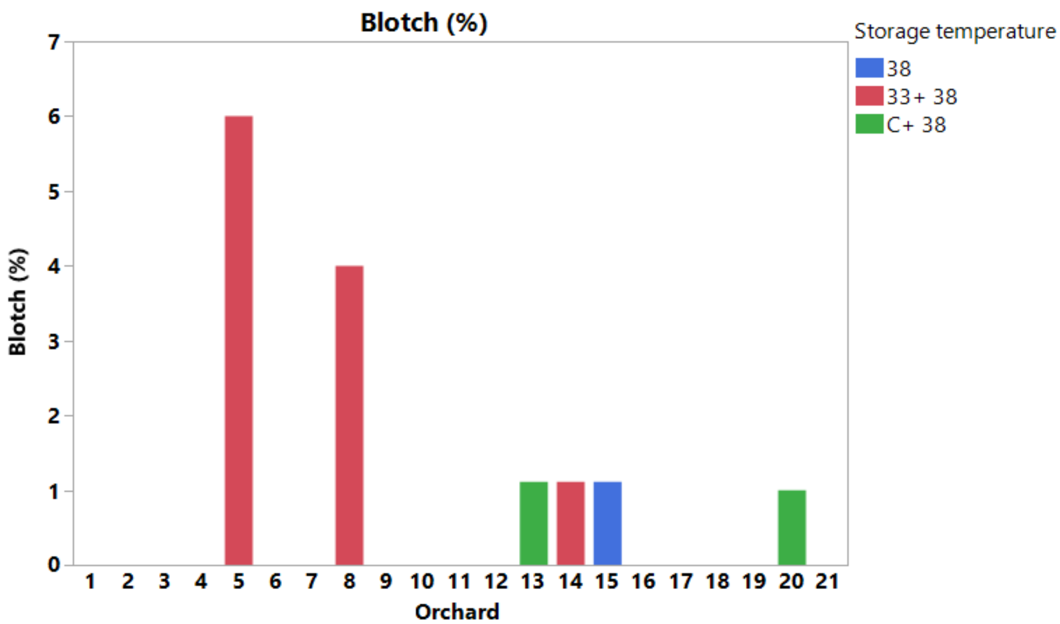
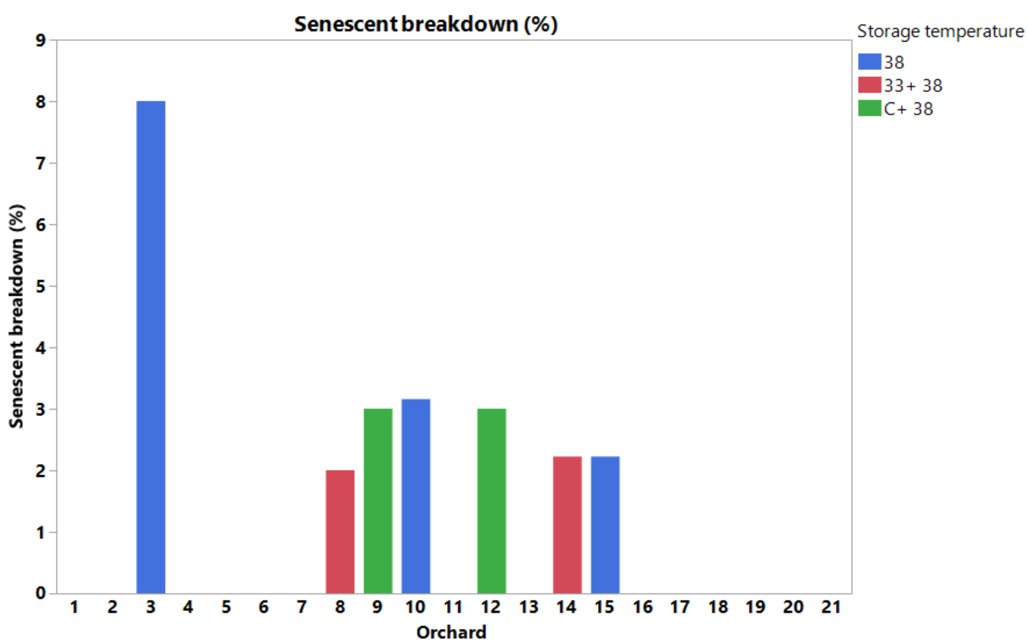

Soggy breakdown (%)
Storage temperature
38
33+ 38
C+ 38
Soggy breakdown (%)
0
5
10
15
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard

D


Rot (%)
Storage temperature
38
33+ 38
C+ 38
Rot (%)
0
5
10
15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard


Blotch (%)
Storage temperature
38
33+ 38
C+ 38
Blotch (%)
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard

E


Senescent breakdown (%)
Storage temperature
38
33+ 38
C+ 38
Senescent breakdown (%)
9
8
7
6
5
4
3
2
1
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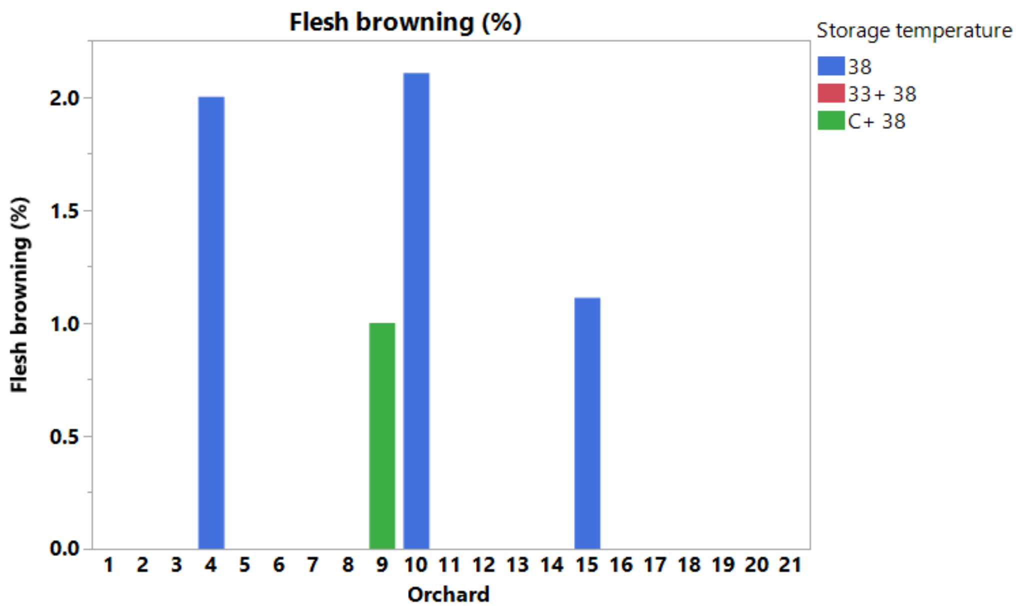
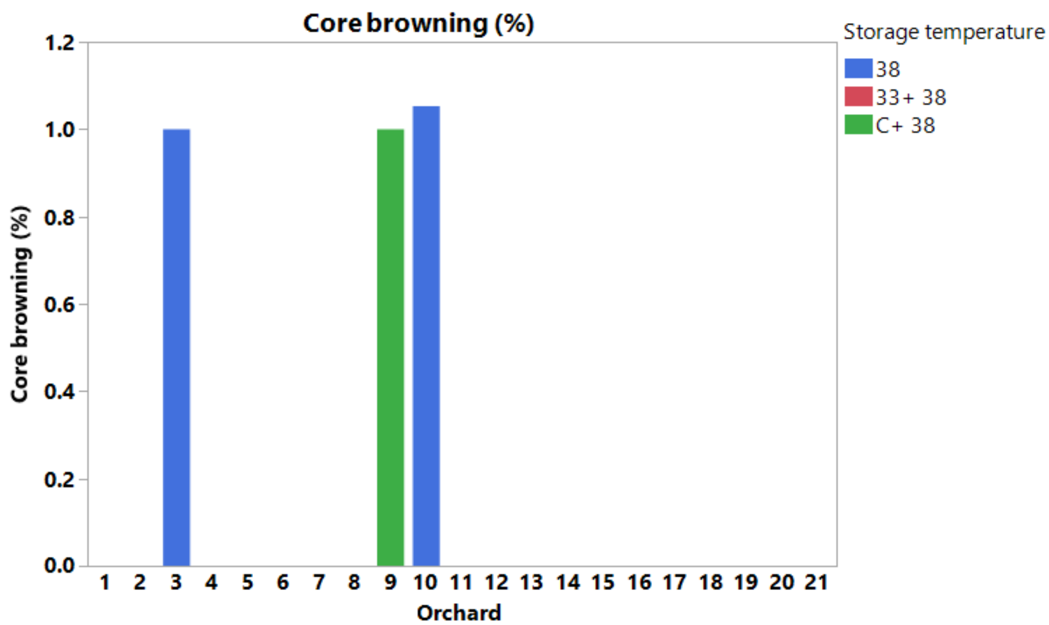
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard

F

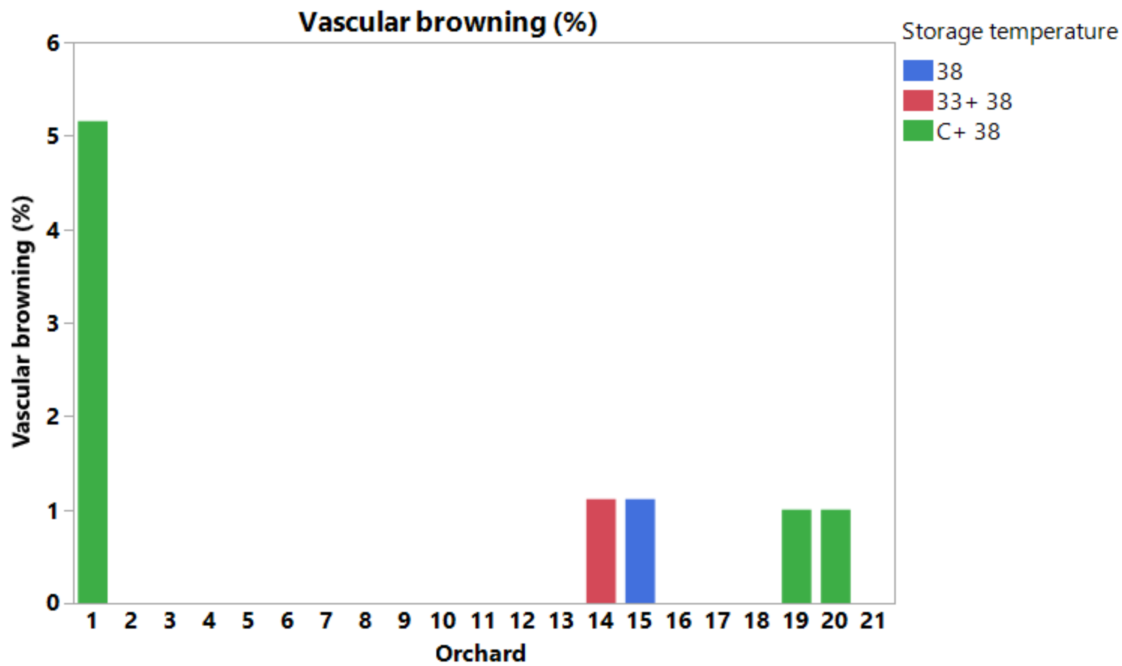

Flesh browning (%)
Storage temperature
38
33+ 38
C+ 38
Flesh browning (%)
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard

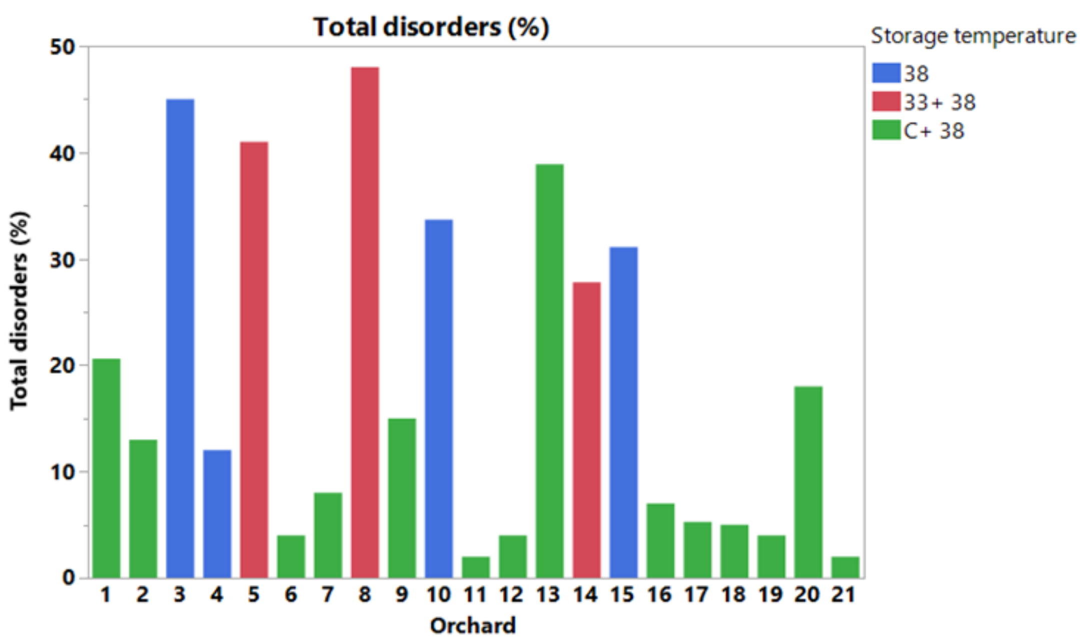
G


Core browning (%)
Storage temperature
38
33+ 38
C+ 38
Core browning (%)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Orchard

H

I





J

Figure 6 A-J. Physiological disorders in ‘Honeycrisp’ apples after storage for 4 months +4 days at 68°F. Prediction of Bitter Pit in ‘Honeycrisp’ Apples Before Storage project, NNYADP.

Table 1. Total disorder development of the 21 study blocks following four months of storage. Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP.

Orchard Block	Initial Storage Temperature (°F)	Predicted Fruit with Bitter Pit (%)	Actual Fruit with Bitter Pit (%)	Difference Between Predicted and Actual (%)	Soft Scald (%)	Soggy Breakdown (%)	Blotch (%)	Wrinkly Skin (%)	Shrivel (%)	Rot (%)	Senescent Breakdown (%)	Flesh Browning (%)	Core Browning (%)	Vascular Browning (%)	Internal CO2 Injury (%)
1	50	2	15	13	0	0	0	0	0	0	0	0	0	5	0
2	50	1	11	10	0	0	0	0	0	2	0	0	0	0	0
3	38	10	10	0	8	9	0	0	0	9	8	0	1	0	0
4	38	7	1	-6	0	2	0	0	0	7	0	2	0	0	0
5	33	17	20	3	7	0	6	0	0	8	0	0	0	0	0
6	50	1	2	1	0	0	0	0	0	2	0	0	0	0	0
7	50	3	8	5	0	0	0	0	0	0	0	0	0	0	0
8	33	18	9	-9	6	18	4	0	0	9	2	0	0	0	0
9	50	2	5	3	0	0	0	0	0	5	3	1	1	0	0
10	38	5	16	11	3	2	0	0	0	6	3	2	1	0	0
11	50	0	2	2	0	0	0	0	0	0	0	0	0	0	0
12	50	2	1	-1	0	0	0	0	0	0	3	0	0	0	0
13	50	3	33	30	0	1	1	0	0	3	0	0	0	0	0
14	33	12	2	-10	2	2	1	0	0	17	2	0	0	1	0
15	38	8	16	8	2	0	1	0	0	8	2	1	0	1	0
16	50	0	1	1	0	4	0	0	0	2	0	0	0	0	0
17	50	0	0	0	0	0	0	0	0	5	0	0	0	0	0
18	50	0	4	4	0	0	0	0	0	1	0	0	0	0	0
19	50	1	3	2	0	0	0	0	0	0	0	0	0	1	0
20	50	0	3	3	0	0	1	0	0	13	0	0	0	1	0
21	50	0	1	1	0	0	0	0	0	1	0	0	0	0	0

Table 2. Multivariate analysis for bitter pit against minerals from fruit harvested at three weeks before anticipated harvest. Prediction of Bitter Pit in 'Honeycrisp' Apples Before Storage project, NNYADP.

Peel Element or Ratio Predictor	R	P value
P	0.6406	0.0018
K	0.3715	0.0973
Mg	-0.0081	0.9722
Ca	-0.5487	0.01
P/Ca	0.7743	<.0001
K/Ca	0.6691	0.0009
Mg/Ca	0.7466	0.0001
(P+K)/Ca	0.6856	0.0006
(P+Mg)/Ca	0.7894	<.0001
(K+Mg)/Ca	0.6786	0.0007
(P+K+Mg)/Ca	0.6932	0.0005

The correlation is significant when P value ≤0.05.