Bitter Pit in Honeycrisp on G-41 vs M9-337: Observations from an Orchard Visit

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Bitter Pit is a physiological disorder that is associated with low calcium levels in apple fruit (Ferguson and Watkins 1989). In Honeycrisp, bitter pit is expressed as discolored, generally brown, sunken necrotic lesions on the skin, commonly at the calyx or blossom end of the apple (Figure 1), but can be found in the stem half of the fruit as well when incidence is severe. The lesions will vary in shape and shade of brown, and are defined by irregular, faceted borders, with the affected tissue remaining firm to the touch. Over time, small lesions can coalesce into larger lesions of irregular shapes. In other cases, larger, more rounded lesions are observed, but still with faceted borders and firm texture, helping to distinguish them from cases of lenticel breakdown and secondary attacks by opportunistic fungal pathogens. Under the peel, cortex tissue can become "corky" in texture and brown in color (Figure 2). Bitter pit can occur without peel symptoms, although this appears uncommon in Honeycrisp.

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While bitter pit can often be seen on Honeycrisp fruit at harvest, the disorder can also occur within the first month of refrigerated storage (Al Shoffe et al. 2016), or while transiting in the retail supply chain. Conditioning of fruit for 7 days at 50°F prior to 38°F storage for soft scald mitigation is known to increase bitter pit expression. Growers can face the Faustian dilemma of choosing between storage regimes that favor one problem over the other. The economic loss to the grower can be severe, since a single bitter pit lesion is enough to downgrade an apple from fresh market grade to juice, with a loss in value of 75% or more.

The incidence and severity of bitter pit will vary by variety, orchard block, farm, region, season, and storage regime, but continues to defy prediction. While calcium deficiency of some form is generally considered to be the cause of bitter pit, the exact biological process(es) is not known. Calcium ions (Ca^{+2}) are important structural components in cell membranes, also in cell walls, and they serve to help regulate water within cells, as well as playing a role in hormonal signaling (De Freitas and Mitcham 2012). The concentration of "free" calcium in an apple tree is very tightly regulated, and the ions are known to move around locally in the plant via the spaces between cells (the apoplast), through the cells themselves (the symplast), and from the roots to leaves and fruit via the xylem. The transpiration (water) stream serves as a sort of "engine" that moves calcium ions upward to the growing points of shoots and fruits. Excess calcium in the system is stored within cell organs called vacuoles. The amount of calcium stored in vacuoles can reach 40% (Bangerth 1979) of total plant calcium. It is commonly understood by growers that calcium ions do not move readily in the soil profile, hence the importance of adjusting soil calcium and pH levels through incorporation during the pre-plant phase of new orchard development. The case is similar in plant tissue, where calcium ions demonstrate only limited mobility. Calcium transport does not occur to any significant degree via the phloem, so calcium will not transfer from leaf tissue to growing fruit in the photosynthate stream. As the fruit increases in size during the cell expansion phase of development, xylem tissue in the fruit end begins to lose transport effectiveness (Lazar et al. 2001), especially in the calyx end.

Figure 1. Bitter Pit lesions on a Honeycrisp apple. In this severe example of the disorder, smaller pits have coalesced into larger blotches; photograph taken at harvest. (Photo by Dan Donahue).

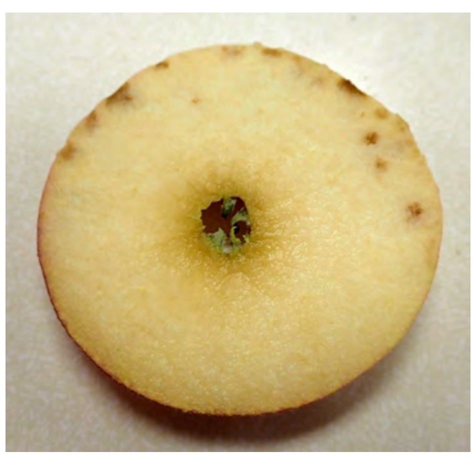

Figure 2. Bitter Pit expression in Honeycrisp cortex tissue. (Photo by Dan Donahue).

Research continues at Cornell University, and elsewhere around the world, focusing on bitter pit causation, prediction, and mitigation. One school of thought considers the expression of the disorder to be directly related to calcium status in the tree, as discussed above. An alternative hypothesis is to consider calcium status as an indirect factor, with some other factor(s) triggering the expression of the disorder, such as environmental conditions or plant hormones (Saure 1996). Apple rootstocks have been observed to influence elemental mineral status in leaves (Fallahi 2012; Fazio et al. 2013), with rootstock effects on the elemental mineral status of leaves and fruit being a focus of research being conducted by a team lead by Dr. Lailiang Cheng, Professor of Horticulture at Cornell University in Ithaca, New York. Dr. Cheng recently discussed his research on rootstocks and mineral nutrition at a stop on the 2016 International Fruit Tree Association Summer Tour of Western New York and the New York State Agricultural Experiment Station in Geneva. During Dr. Cheng's presentation, he stated that Budagovsky 9 (Bud 9) and some of the Geneva series rootstocks show less potassium uptake and lower bitter pit incidence. Dr. Cheng's presentation can be found on YouTube at http://fruitgrowersnews.com/video/rootstock-selection-impacts-bitter-pit-honeycrisp/ (or simply use the search terms "Rootstock Selection Bitter Pit" and you will see the link to the Fruit Grower News article.).

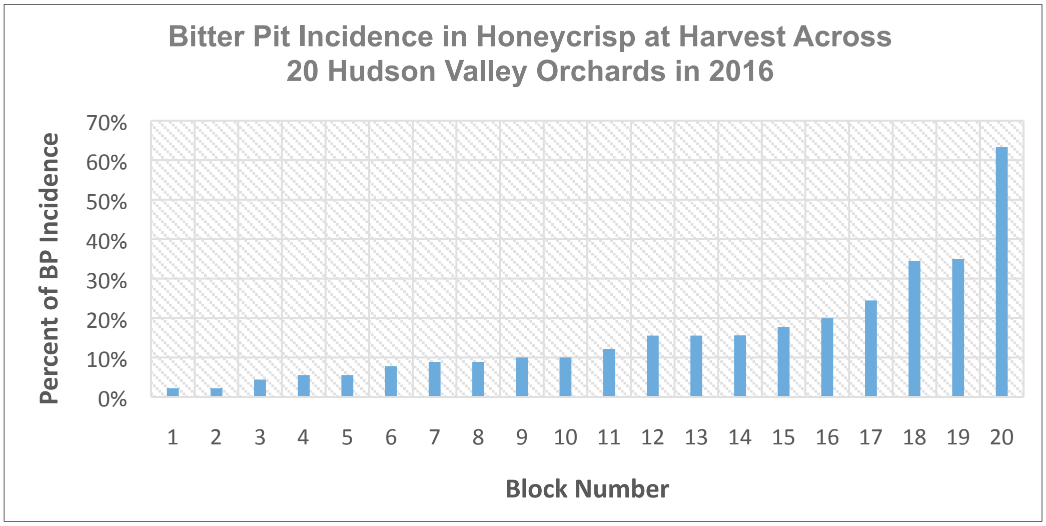

Figure 3. 2016 Bitter Pit incidence ranging from 2.2% up to 63.3% at harvest. (Source: D. Donahue and A. Wallis, unpublished).

It is interesting to note that Bud 9 has a good, if anecdotal, reputation in the Hudson Valley for producing Honeycrisp with less bitter pit incidence. Such claims are difficult to confirm scientifically in the commercial orchard, as growers are not in the habit of planting different rootstocks in what scientists describe as "randomized complete blocks" that allow for sophisticated statistical analysis. There exists a growing body of evidence that indicates rootstocks can play a role in improving the elemental nutrition status of the scion variety. As this body of knowledge develops, it may eventually become possible for growers to factor a particular rootstock's nutritional performance profile into their selection decision. For example, soil tests indicate a potential for calcium deficiency, so choose a rootstock known for its efficiency in calcium uptake. Such characteristics can be capitalized on in breeding programs to develop rootstocks more finely tuned to address issues such as susceptibility of fruit to bitter pit. However, actual field data from grower orchards documenting the relationship of the rootstock selection to incidence and severity of bitter pit is not well represented in the scientific literature. This should not be a surprise, as the overwhelming variability associated with bitter pit makes it difficult to design and site the long-term studies needed to accurately document this issue under commercial conditions.

As (bad) luck would have it, in addition to significant yield losses due to the early April freeze, the 2016 season proved to be a banner year for bitter pit in the Hudson Valley of New York State. Survey data from twenty Honeycrisp blocks located in Ulster, Dutchess, and Columbia Counties described a bleak picture of bitter pit incidence this past season (Figure 3).

With bitter pit incidence in the field reaching 63.3% on 9 September in an unrelated research trial, it was not surprising to get a call from a Columbia County apple grower the next day who had observed a serious case of bitter pit in his 3rd leaf Honeycrisp orchard. The grower was concerned that while it was all bad, one Honeycrisp/rootstock combination appeared to be worse than the other. The orchard was planted as two adjacent blocks, but seamless in appearance, on a consistent soil type, trickle-irrigated, trees sourced from the same nursery, and of comparable (high) quality, planted at the same time, and trained per the tall spindle system at 4' x 13'. The only difference was that half of the planting was G-41, and the other half was M.9 NAKBT337 (M9-337). Upon visual inspection, the fruit on the G-41 side was more severely afflicted with bitter pit. While not absolutely ideal for statistical analysis, it was clear that this was still an opportunity to compare the performance of two popular rootstock choices under commercial conditions. An experiment was immediately set up to document horticultural and environmental factors that might explain through data analysis what the eye could see in practice.

Materials & Methods

The experiment was initiated on 10 September, with the grower planning for harvest two days later. Six trees were selected in each block, with the only selection criteria being the presence of a nursery tag confirming the identity of the rootstock. Each tree was strip-picked, the number of drops recorded, and the trunk circumference was measured at 30 cm above the soil line. Harvested fruit were returned to the Cornell Hudson Valley Research Laboratory for bitter pit evaluation. Two separate 15-apple samples, from trees adjacent to the test trees, one sample from each rootstock/block, were taken for destructive evaluation of fruit firmness, soluble solids, and starch pattern index. Several days later, following harvest, 10 randomly selected terminal shoots were measured on each tree, a foliar sample was taken from each block (10 leaves/tree, one per terminal shoot taken 1/3 down from the shoot tip, from each tagged tree), along with a soil sample from each block, one core per tagged tree. Foliar and soil samples were sent to a commercial laboratory for analysis. Individual apples were rated for bitter pit lesion quantity and incidence, the peel surface area affected by bitter pit was visually estimated in 10% increments, and fruit diameter (mm) and fruit weight (grams) was measured. Data were analyzed using JMP statistical analysis software.

Results

Observations of orchard condition and fruit quality. Tree vigor throughout the block was very uniform, with trees appear-

Figure 4. Honeycrisp on G-41, 3rd leaf. (Photo by Dan Donahue).

Figure 5. Honeycrisp on M9-337, 3rd leaf. (Photo by Dan Donahue).

ing to be in good health (Figures 4 and 5). Irrigation water was applied generously through the growing season, compensating for the relatively dry summer and fall. The crop load appeared to be reasonable for a 3rd leaf Honeycrisp orchard, especially considering the early season freeze losses. Fruit flesh firmness and soluble solids content were identical between the two blocks (Table 1), while the starch pattern index (SPI) differed only slightly.

Incidence and severity of Bitter Pit. The total numbers of apples evaluated were 144 (average 24 apples/tree-rep) in the M9-337 block, and 171 (average 28.5 apples/tree-rep) in the G-41 block (Table 2). Differing lower case letters following the numbers indicate statistical significance was found. The first rating is the most common technique – incidence, or does the apple express symptoms of the disorder, yes or no? The G-41 side of the block showed 81.9% BP incidence compared with 59.7% for the M9-337 side.

The second technique involved counting bitter pit lesions on the surface of each apple. Again, the G-41 block was found to have more bitter pit, with an average of 49 lesions per sampled apple compared with 18 lesions per sampled apple in the M9-337 side. The third method involved relating the spot counts to the actual size of the apple. Surface area (SA) was estimated by a calculation based on the geometric formula for a sphere. Honeycrisp apples are not actually spherical in shape, but are most often flattened vertically, and can have an irregular form. Cursory measurement checks on other Honeycrisp fruit indicated that the formula for a sphere would likely overestimate the actual surface area of the apple by approximately 5%. For the purposes of this field study, it would be reasonable to expect this error to remain a constant across all the sampled apples, and therefore would not adversely impact the comparative results presented in Table 2. In terms of lesion density, Honeycrisp on G-41 at 2.3 lesions/cm^2 SA in this orchard was more severely afflicted with bitter pit than the fruit grown on M9-337 at 0.8 lesions/cm^2 SA.

Soil and foliar nutrient status. The orchard soil is classified as a Knickerbocker Fine Sandy Loam 3-8% slope, with a deep profile. The actual slope of the site was mild, closer to the 3% side of the range. I would expect this site to be droughty in the absence of irrigation. Soil test parameters (Table 3) indicated a pH above 6.5, optimum availability of magnesium (Mg), near-optimum availability of phosphorus (P), near-optimum availability of potassium (K), and low availability of calcium (Ca). Percent organic matter (OM) in the bottom 2% range is rather low, and the capacity of this soil to provide nitrogen (N, as nitrate) is also low. Considering the excellent soil water drainage, low water holding capacity, and low capability to supply nitrate nitrogen, this orchard would likely benefit from split calcium nitrate applications in the spring. The levels of nutritional elements present in the foliage generally reflects the soil weaknesses (Table 3). Foliar calcium levels are well below optimum overall, with G-41 at 1.10%

Table 1. Harvest indices in Honeycrisp apples from two rootstocks.

Rootstock	Firmness (lbs./in.2)	Soluble Solids (%)	Starch Pattern Index *
M9-337	17.1	14.2	6.9
G-41	17.1	14.2	6.5

* Cornell 1-8 step rating scale

Table 2. Incidence, Severity, and Density of Bitter Pit: Honeycrisp on G-41 vs. M9-337

	Incidence of Bitter Pit *	Average Number of Bitter Pit Lesions per Apple **	Average # BP Lesions per CM2 of Apple Surface **
HC/M9-337	59.7% a	18 a	0.8 a
HC/G-41	81.9% b	49 b	2.3 b

** JMP LSM/Student's t-Test $p \leq 0.05$
* JMP Contingency Analysis of Means by Treatment, w/Chi-Square and Analysis of Means by Proportion

Table 3. Elemental Nutrient Analysis: Foliar vs. Soil at Harvest

Nutrient	G-41	M9-337	Acceptible Range
Foliar Nitrogen (%)	2.42	2.19	2.4-2.6
Soil Nitrogen (ppm)	23.5	7.2	Low
Foliar Potassium (%)	1.54	1.47	1.35-1.80
Soil Potassium (lbs./A)	202	158	Near Optimum
Foliar Phosphorous (%)	0.15	0.14	0.13-0.33
Soil Phosphorous (lbs./A)	4.0	2.0	Low - Good
Foliar Calcium (%)	1.10	0.95	1.3-2.0
Soil Calcium (lbs./A)	1,563	1,455	Low
Foliar Magnesium (%)	0.21	0.27	0.35-0.50
Soil Magnesium (lbs./A)	219	219	Optimum
Soil Organic Matter (%)	2.4	2.1	Low
Soil pH	6.5	6.8	Good

Table 4. Measurements of Horticultural Parameters

	Average Terminal Shoot Length (mm) **	Average Trunk Cross-Sectional Area (TCSA) (cm2) *	Fruit Diameter (mm) **	Fruit Weight (gm) **	Fruit Load (# fruit/cm2 TCSA) **	Calculated Yield per Acre (Bu.) **
HC on M9-337	306 a	7.84 a	82.9 a	243 a	3.5 a	294 a
HC on G-41	279 a	7.37 b	83.1 a	237 a	4.4 a	364 a

* JMP LSM/Student's t-Test $p \leq 0.05$
** JMP LSM/Student's t-Test No significant diference at $p \leq 0.05$

besting M9-337 at 0.95%, but the statistical significance, if any at all, is unknown. Overall, albeit below optimal levels and with the exception of Mg, elemental nutrient levels in Honeycrisp foliage on G-41 were higher than those measured on M9-337. While observable tree vigor was adequate, it was not outstanding, and it looks unlikely that these trees will reach the top wire of the trellis (8') by the end of 4th leaf in 2017.

Measurements of horticultural parameters. Data on terminal shoot growth along with other common horticultural parameters are presented in Table 4. Terminal shoot growth was not found to be significantly different between the two rootstocks. Trunk cross-sectional area of the Honeycrisp scion was found to be significantly different between the two rootstocks, with M9-337 producing a tree with a slightly more robust trunk. Table 4 includes additional data on four common parameters, which were not found to be statistically significantly different between the two rootstocks: fruit diameter, fruit weight, fruit load, and calculated yield per acre. In addition, fruit size and weight were not found to be significantly correlated with bitter pit severity.

Discussion

The seriousness of the bitter pit problem in this orchard was striking. The grower had no option but to "juice" the entire block, incurring thousands of dollars in losses. Low soil and leaf calcium, in the context of adequate potassium, was consistent between the two rootstocks and may help explain the severe bitter pit overall, but not the statistically significant difference between performance of the two rootstocks. The results of horticultural parameter measurements were not always statistically significant, but the trends were consistent. The data collected from this site consistently suggested that Honeycrisp on G-41 are slightly less vigorous, and represented a more productive rootstock/scion combination than M9-337. Even so, with a slightly higher crop load, less apparent tree vigor and being grown under similar conditions, plus seemingly better foliar nutrient status, the Honeycrisp/G-41 combination still produced fruit with significantly more bitter pit expression. Fruit workers often equate higher vigor, and lower crop load, as factors contributing to a higher potential for bitter pit, not vice-versa, as was observed here.

In summary, the numbers supported what the eyes could see. Causation of, and a solution for the bitter pit issue is not at all clear. Topdressing with high-calcium lime may help in this particular example, but not in the short term. Foliar calcium applications have been known to produce inconsistent results. One takeaway from this modest field exercise is that rootstock selection can have serious consequences beyond our usual concerns about tree size, burr knots, woolly apple aphid and fire blight resistance, replant issues, and *Phytophthora* tolerance. On paper, it would have been reasonable to expect G-41 to perform better than M9-337, but the reality was not so, and it is difficult to explain why. In the case of Honeycrisp, as a grower, it would be prudent to factor in your experience with bitter pit in your own orchards when deciding on what rootstock to select for new plantings. In recent years, the supply of size-controlling rootstocks has been tight, and planting decisions are too often driven by availability, not necessarily by the best horticultural match to the situation at hand. Please review pack out data carefully and look closely at the performance of your own orchards and others in your region when making rootstock decisions.

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