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Controlling Bitter Pit in Apples: Best Practices for Growers

Consumer enthusiasm for Honeycrisp apples' distinctly crispy flesh and fresh flavor allows growers to sell them for a higher price per bin than nearly any other variety. However, growers may discover high portions of a healthy-appearing harvest can become unmarketable when symptoms of the disorder bitter pit emerge during storage, making bitter pit one of the greatest threats to the profitability of Honeycrisp and other varieties. The disorder was once thought to result from a simple deficiency in calcium, but more recent research has revealed that bitter pit is a complex issue exacerbated by multiple variables. Effectively controlling the disorder requires balancing multiple strategies and incorporating the use of existing prediction models to individual orchard blocks.

Figure 1. *Bitter Pit developing on Honeycrisp apples in the orchard. Photo: Dr. Macarena Farcuh*

What is a bitter pit?

Bitter pit is a physiological disorder, an abnormality that can occur within fruit tissue that is not caused by pests or mechanical damage. Rather, it is caused by several factors such as environmental conditions, genetic background, maturity at harvest, preharvest, and postharvest practices. The disorder is characterized by small, dark brown, sunken spots on the apple's skin (Figs. 1, 2). The pits typically form towards the calyx end of the fruit. The flesh is brown, and the pit is slightly water-soaked. Bitter pit results from an internal imbalance, rather than a deficiency, of calcium (Ca) on the calyx end of the fruit. Calcium is an essential element for cell membrane and cell wall development and stability. Low amounts of available Ca in the cell causes the cell membrane to leak. If the cell membrane leaks, the cells die. Pockets of dead cells form bitter pits on apples.

Calcium is taken up by roots along with other nutrients (such as potassium, magnesium, and nitrogen) and transported up the tree through transpiration via the xylem. Then it is divided between transpiring organs, such as the shoots and the fruits. Calcium then moves from the stem to the calyx end of the fruit. Finally, it is partitioned to the cell membrane and other parts of the cells. Particularly in Honeycrisp, the xylem tissue has a lower functionality, and thus is less effective in transporting Ca, compared to other varieties less prone to bitter pit development. For example, researchers at Michigan State University demonstrated that there is a seasonal progression of xylem breakdown occurring earlier in Honeycrisp than in other varieties, such as Gala. The calcium distribution cannot keep pace with the expansion of the fruit, resulting in the development of bitter pit.

Bitter pit begins to develop after petal fall. Early signs of slight indentations surrounded by darker green may be visible on the tree (Fig. 1). However, the true quantity of fruits with bitter pit cannot be visually detected until the first 60 days of storage have elapsed (Fig. 2).

Figure 2. Bitter pit on Honeycrisp apple after harvest. Photo: Yosef Al Shoffe, Cornell University

What factors cause or contribute to bitter pit?

There are several factors that can cause or contribute to the development of bitter pit, including *preharvest management factors, environmental factors, genetic background, and maturity at harvest,* as well as *postharvest practices.*

Within *preharvest management factors*, tree nutrition plays an important role. The nutrients potassium (K) and nitrogen (N) compete with calcium for uptake by the tree. When the internal ratio of K/Ca or N/Ca is too high, the amount of available Ca is restricted. To maintain healthy Ca levels in the fruit, the uptake of other nutrients must be limited. Excessive N can not only reduce the Honeycrisp tree's capacity to take in Ca, it can also encourage unnecessary vegetative growth and lower yield. If an orchard has a history of bitter pit, nitrogen application should be significantly reduced. Nitrogen should only be applied at bud break and right before petal fall when the shoots are still growing. Applying N after petal fall risks increasing N levels in the fruit, lowering the proportion of calcium. Boron (B) helps the movement of Ca, so if B is low then Ca levels will also be low. Consequently, B levels should be monitored constantly.

Rootstocks also play an important role as *preharvest management factors* as high rootstock vigor leads to increased bitter pit incidence, because nutrients are diverted to shoots and leaves rather than fruit. However, in Honeycrisp, which is known for its weak growth, the vigor should remain high enough to produce adequate yields. Rootstocks that grow to a larger size may take up more water, K, and N, lowering the K/Ca and N/Ca ratio. The optimal choice of rootstock depends on the specifications of the planting site. In studies under New York environmental conditions, rootstocks producing the highest bitter pit-free fruit were G.11, G.30, G.214, and G.935, which translated to a higher crop value.

Crop load, another important *preharvest management factor*, plays a critical role as large fruits are more prone to bitter pit because low crop loads have an elevated K/ Ca ratio.

Environmental factors play a key role in bitter pit development. A drought during bloom or in July after petal fall can stress the xylem and inhibit the movement of calcium into developing fruits. Conversely, high rainfall can lead to increased vegetative growth, limiting Ca partitioning to fruits and causing excessive fruit size.

Genetic background also plays a critical role as Honeycrisp has a particularly high susceptibility to bitter pit compared to other varieties such as Gala. This heightened susceptibility can be attributed to Honeycrisp's limited genetic capacity to utilize calcium at various stages of the uptake process. Other varieties at high risk of bitter pit development include Cortland, Cox Orange Pippin, Braeburn, and Golden Delicious.

Maturity at harvest is also of key importance as fruit that is harvested before reaching optimal maturity is more susceptible to bitter pit. Researchers at Cornell University have demonstrated that the plant growth regulators ReTain® (active ingredient: Aminoethoxyvinylglycine (AVG), Valent USA) and HarvistaTM (active ingredient: 1-Methylcyclopropene (1 -MCP), AgroFresh) ncrease the incidence of bitter pit.

Postharvest practices such as the use of a conditioning period at 50°F before cold storage (38°F) an reduce the risk of chilling injuries soft scald and soggy breakdown in Honeycrisp. Conversely, these practice may also increase the risk of bitter pit.

What are the practices that can be implemented to manage or avoid bitter pit incidence?

Growers can implement effective *preharvest management practices* to manage or avoid the incidence of bitter pit in their crops. These include choosing the appropriate rootstock under the specific growing environmental conditions as well as focusing on nutritional management and crop load. Avoid over-thinning to maintain a moderate fruit load and size. Thin apple trees to 4 fruits/cm² trunk cross sectional area (TCA) for young trees (year 2 to year 4) and 5–7 fruits/cm² TCA for older trees to prevent growth of large fruits with high internal K/Ca ratios. Prune excess shoots and leaves to promote Ca partitioning into fruits. Additionally, maintain soil moisture and the availability of micronutrients B and Zn to help improve Ca uptake from the soil. Furthermore, pre harvest foliar calcium sprays can be applied during the season to maintain higher Ca levels. Nevertheless, the effectiveness of calcium sprays intended to improve the internal calcium content of fruits varies significantly by the orchard site and by the growing season. As little as 1% of the treatment enters the fruits; this is an insufficient change that cannot prevent bitter pit on its own. Spray treatments can mitigate but not completely prevent bitter pit and should be considered a complement to other management practices.

Another important strategy is managing the stage of *maturity at harvest*. Avoid early harvests as these will enhance bitter pit development. If this is not possible due to operational constraints, consider marketing these fruits soon after harvest before they develop bitter pit. It is critical to monitor the maturity of your fruits weekly to determine optimal harvest dates.

Implementing adequate *postharvest practices* is also crucial to managing bitter pit development. Avoid conditioning fruit at 50°F and instead directly store fruit at 38°F, as this practice decreases bitter pit incidence and/or limits its appearance. However, skipping conditioning may enhance the risk of less destructive disorders such as soft scald and soggy breakdown. Application of the ripening inhibitor 1-Methylcyclopropene (1-MCP) decreases bitter pit risk, together with the use of controlled atmosphere during long term storage. Drenching immediately harvested apples in a calcium solution before storage may work as a complementary practice.

How can bitter pit incidence be predicted?

Peel Sap Analysis

Researchers at Cornell University developed the peel sap analysis method under New York growing conditions. The analysis is also applicable for fruit grown under Maryland environmental conditions.

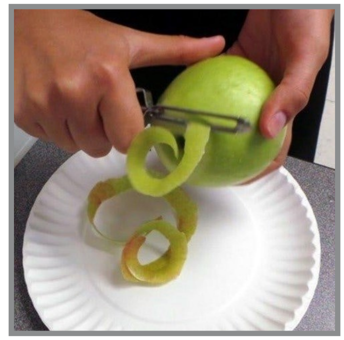

Figure 3. *Peel sap analysis using two peels from 30 golf ball-sized apples can assess the bitter pit risk in the developing fruit. Photo: Mario Miranda Sazo, Cornell University*

In July, collect 30 fruitlets when they reach a size of 50-55g/fruit. Remove the stems and clean the fruitlets using a paper towel dampened with purified water. Allow the fruitlets to dry completely after cleaning. Peel from the stem end to the calyx end, on two opposite sides, to collect two peels per fruitlet (Fig. 3). Place the peel samples in a freezer bag labeled with the farm name, grower name, contact information, and sampling date. Press air out of the bag and freeze immediately. The samples are then ready to be sent to the Cornell Nutrient Analysis Lab in Ithaca, NY, where the concentration (ppm) of Ca, K, N, and Mg in the juice of the peel is measured using spectrometry. There is a $5 charge for each sample submitted. A peel sap K/Ca ratio of over 25 is correlated with a high risk of bitter pit arising at harvest or storage.

Average Shoot Length

Increased shoot length is correlated with high bitter pit because fruits compete with shoots for calcium. Researchers at Penn State developed a system of relating the average length of shoots to the N/Ca ratio in the fruit peel. Three weeks before harvest, select 20 typical trees per block to measure. Record in inches the length of five current season terminal shoots with moderate branch angles. Add the lengths of the five shoots from the 20 trees; divide that number by 100 to find the average shoot length for the block. Collect three typical fruits

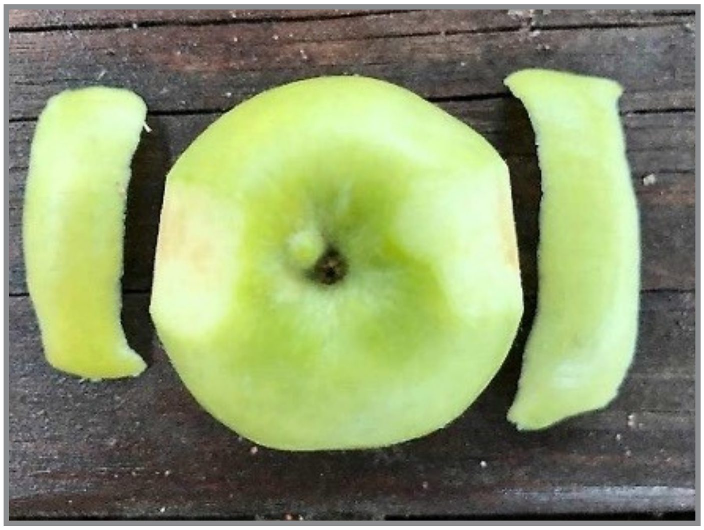

Figure 4. *To collect a sample for nutrient analysis using the method developed by Penn State, peel from the calyx end of the fruit without removing flesh. The sample from one apple should be the size of the peel already on the plate. Photo: Dr. Rich Marini, Penn State University*

from the same 20 trees per block. Remove stripes of peel about 1 cm wide around the circumference of the calyx end of the fruit (Fig. 4). Combine the 60 peel samples and dry thoroughly in an oven at 180°F overnight (at least 8 hours).

Send the peel samples to the Penn State Analytical Services lab with a standard plant analysis kit for $24. Include the average shoot length on the information form of your sample submission. The N/Ca ratio and average shoot length predict the percent bitter pit incidence according to the following table:

Table 1. *Estimated percent of apples on Honeycrisp trees developing bitter pit after cold storage as affected by shoot length and N/Ca.*

N/Ca ratio	Average shoot length < 5 inches	Average shoot length 15 inches	Average shoot length < 25 inches
2	0	20	59
6	0	28	67
10	0	36	75
14	5	44	83
18	13	52	91
22	21	60	99

Source: Dr. Rich Marini (2023) Penn State University Extension

Passive Prediction Model

The passive prediction model was developed under several different growing conditions in the United States to accompany other bitter pit prediction methods. Three weeks before harvest, sample 100 average-sized fruits from at least 10 trees in the orchard block that is being assessed. Store the fruits at room temperature. Two days before harvest, assess internal and external bitter pit incidence of the collected and stored fruit. If less than 10% of the fruits have bitter pit, the apples are suitable for conditioning at 50°F. If greater than 30%, skip conditioning and immediately store at 38°F and sell the apples within three weeks. Cornell researchers revealed a strong relationship between predicted and actual bitter pit risk using this method on apples grown in Pennsylvania/ Maryland, whereas the passive prediction model underestimated bitter pit incidence in New York orchards in the second year of a three-year trial. In a review of bitter pit prediction methods, the Washington Tree Fruit Research Commission concluded that the passive prediction model was not sufficiently accurate for fruit grown in Washington state due to the high variability.

Figure 5. *To approximate the incidence of bitter pit in an orchard block, gather 100 apples three weeks before harvest and keep them at room temperature. The number of apples with bitter pit in the sample will help determine whether to store the apples or market immediately for the corresponding orchard block. Photo: Yosef Al Shoffe, Cornell University*

Conclusions

Although bitter pit is linked to an imbalance of calcium within the fruit cells, the disorder is also influenced by competing nutrients and various other factors. Foliar calcium sprays have a low uptake and are best used as a complement to other practices but are still essential to perform as they can reduce bitter pit development. To manage nutrient imbalances as fruits develop, prioritize rootstock selection, pruning, and thinning. Plant growth regulators and early harvests can increase bitter pit incidence. Multiple preharvest prediction models can be employed to estimate the appearance of bitter pit during storage. The accuracy of such tests varies by site, but they are important to consider, especially regarding avoiding a conditioning period on blocks with a significant risk of bitter pit. Nevertheless, skipping the conditioning period will put Honeycrisp fruits at a high risk of developing chilling injury disorders. In summary, a multifaceted approach—monitoring and balancing factors like plant nutrition, vigor, and chilling injury susceptibility—is key. Layering best practices, including rootstock selection, thinning, proper harvest timing, and storage conditions can reduce bitter pit incidence, benefiting both growers and consumers.

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