FACTORS ASSOCIATED WITH APPLE LENTICEL BREAKDOWN

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INTRODUCTION

Many physiological disorders affect the surface of the fruit: stain, scald, pitting, russet, sunburn, discoloration, cracking and lenticel breakdown. My research deals with the fruit epidermis (that is, the cuticle and underlying 2 to 3 layers of non-storage cells), and how changes in both pre- and postharvest environment may alter this important tissue system.

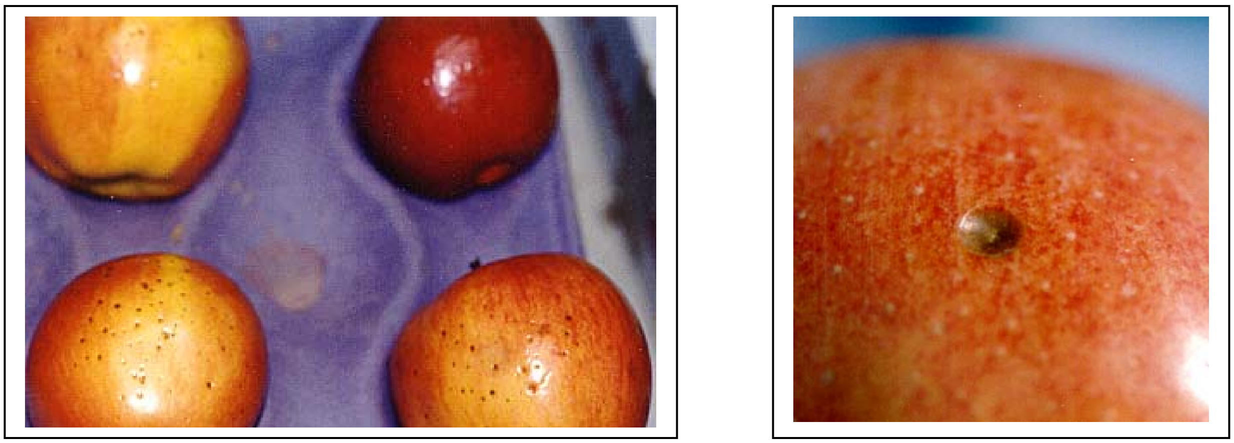

Figure 1. Lenticel Breakdown on Gala apples.

Although lenticel breakdown may occur on practically any apple variety, in the past 5 years it has been most prevalent on Fuji and Gala apples. The lenticels initially appear only slightly darkened, however, usually after packing, the cells underlying the lenticel itself begin to deteriorate and depressions appear. This disorder tends to increase the longer the fruit remain in storage. In the last year, a number of our research studies have shown certain factors are associated with increased lenticel breakdown in Gala and Fuji apples; other experiments are in progress. This report presents preliminary findings related to the occurrence of this disorder in order to formulate and test hypotheses as to why some orchard sites are more susceptible than others.

FRUIT GROWTH

The apple cuticle is a dynamic, growing tissue system. As long as the fruit is enlarging, the cuticle is in a constant state of growth. Consider the model (Figure 2) of how the surface of a sphere (representing fruit) increases with increasing diameter. The red arrows indicate how often the surface doubles in area. For example, if the fruit diameter is 2.5 inches one month before harvest, a 40% increase in diameter, from 2.5 to 3.5 inches, will result in a 100% increase in surface area. Not only does the cuticle grow, but cells embedded within the cuticle matrix continue to divide. These cells and, to a lesser extent, the layer of cells directly beneath the epidermal cells are the only cells which continue to divide as long as the fruit enlarges. The remainder merely enlarge and accumulate sugar in the form of starch, water, and other metabolites such as amino acids and organic acids. The doubling in fruit surface area and, thus, fruit cuticle represents an enormous amount of metabolic energy. Clearly, any disruption or dysfunction in these metabolic processes could have serious consequences to the integrity of this important tissue.

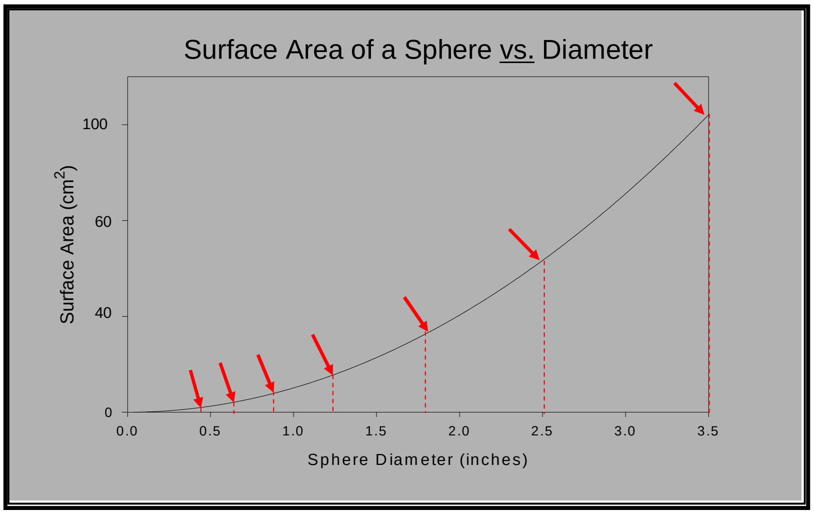

Figure 2. Graph of the surface area of a sphere as a function of its diameter. Arrows indicate doubling of surface area.

LENTICEL ENLARGEMENT

As cells within the fruit enlarge, the cuticle must expand to accommodate the enlargement. The cuticle, which is formed by the polymerization of compounds among the sandwiched waxy platelets (somewhat like loosely shuffled cards; Figure 3), begins stretching and thus, the platelets begin to shear. Under non-extreme environmental conditions, this process occurs gradually so that before they shear completely, thereby exposing the underlying cells, a repair process begins to fill in the “cracks” that have formed from the stretching cuticle (Figure 4).

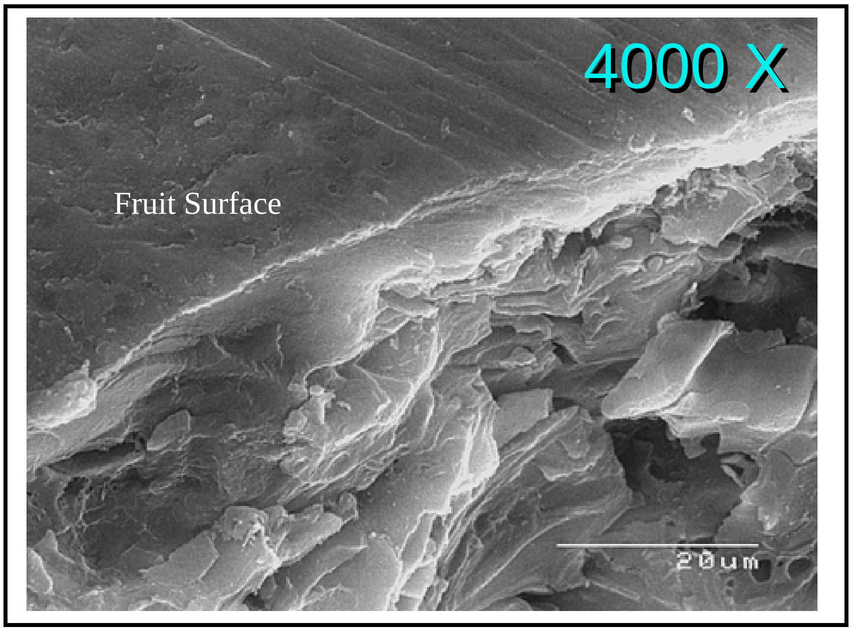

Figure 3. Fuji apple cuticle cross-section showing the layers of wax platelets similar to loosely stacked cards.

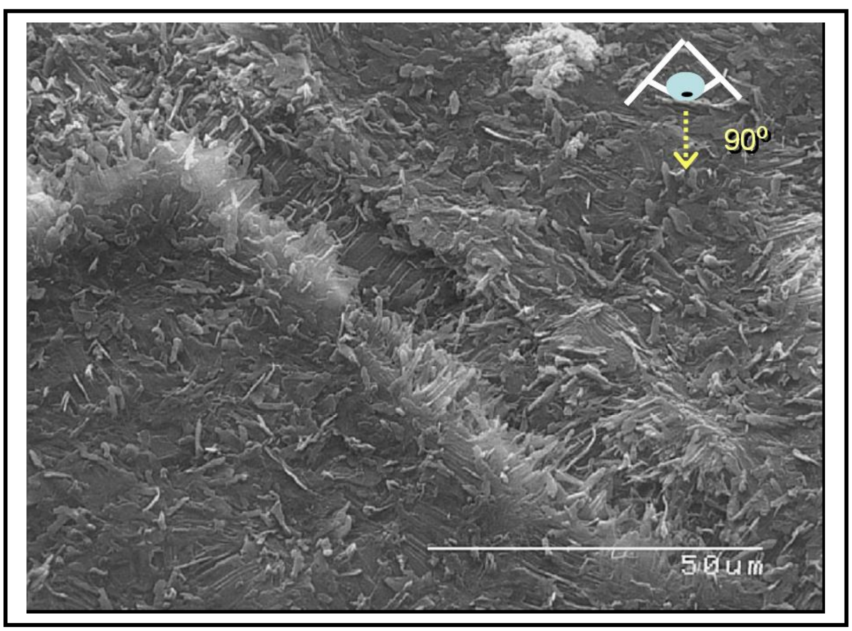

Figure 4. Surface of Fuji apple showing cuticle in the process of "tear and repair" during fruit enlargement.

If, on the other hand, the expansion occurs too rapidly, such as may occur when the microclimate changes from cool, cloudy conditions to hot, dry, sunny conditions, wax development may lag because of either 1) the influence of excessive incident radiation-induced heat stress (wax melts under high heat); or 2) inability of the fruit to supply sufficient substrate for wax development. In this event, the underlying cells may become exposed to the desiccation pressure of the environment and begin producing suberin (a cork-like substance) along the exposed cell surfaces. Within a day or two of these conditions, cracks in the surface may appear as fine white cracks. The lenticel is not immune to this process either. As the lenticel is forced to expand, the cuticle comprising the lenticel annulus may also crack and expose the unprotected cells beneath the cuticle (Figure 5). With the cells now exposed, they are subject to injury from both pathogens and abiotic influences such as surfactants, salts (e.g., from overhead cooling, or application of foliar minerals such as calcium or potassium preparations), or possibly, particulate matter.

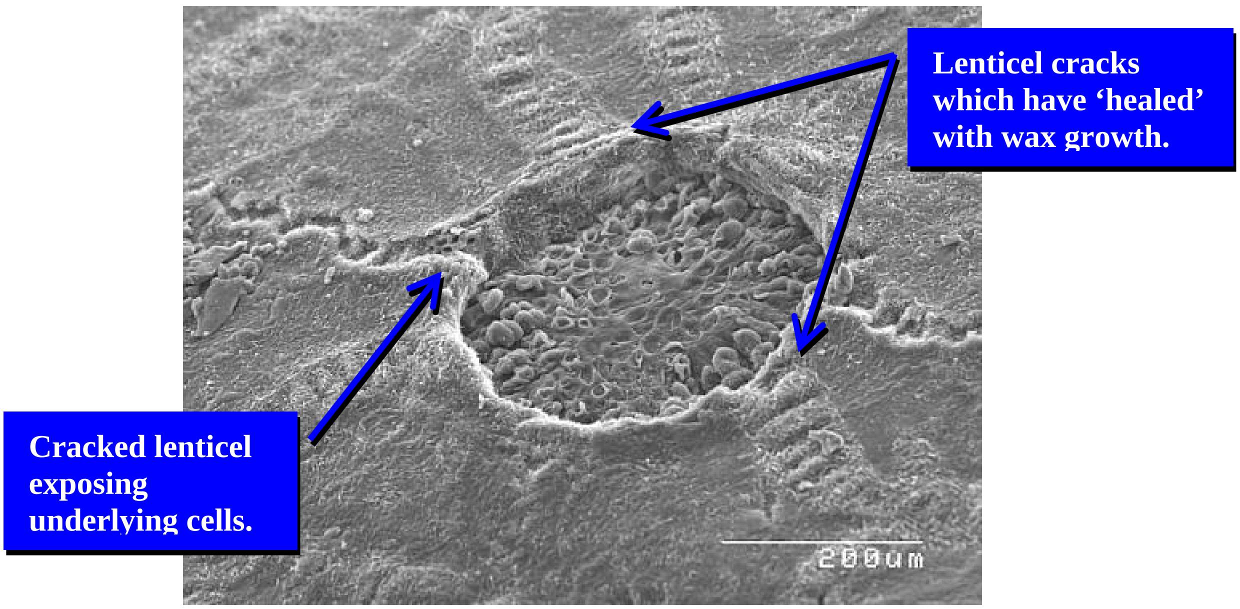

Figure 5. Fruit lenticel with cracks in the cuticle annulus at various stages of 'healing' or 'curing'.

Figure 5 is an electron micrograph of a fruit lenticel part of which has "cracked" and has not yet healed over with wax growth and subsequent cuticle development. The base of the lenticel, or what appears to be the "floor of the crater," also has a cuticle over its surface, however it is thinner than that over the surrounding tissue. Most lenticels develop from stomates on the young fruitlet, which cease to function when the cuticle rigidifies what would ordinarily be guard cells on normal leaves (anatomically, fruit are modified leaves). At harvest, if wax growth and cuticle development keep pace with fruit enlargement, some stomates may be as small as 20 to 30 microns. The lenticel in the figure above is approximately 10 times this.

This "tear and repair" mechanism of cuticle growth and development has as its basis the synthesis of wax and wax platelets on the fruit surface. Anything that alters wax growth and development has the potential to change the nature of the cuticle. These factors might include humidity, temperature, tree health and vigor, as well as substances either applied to the fruit and foliage (e.g., chemicals, fertilizers, surfactants, etc.) or which accumulate thereon (e.g., dust and particulate matter, salts from overhead cooling, etc.). Importantly, depending on the nature of these substances, cuticle development may be favored or adversely affected.

COMBINED FACTORS

Among the factors influencing cuticle development are: genetic predisposition, microclimate, fruit size and cropping, tree and fruit nutrition, irrigation and water quality, fruit growth rate, fruit maturity at harvest, topically applied chemicals, and storage conditions including temperature, humidity and atmosphere composition. For example, certain Fuji cultivars are genetically predisposed to fruit cracking and flecking, whereas some Golden Delicious cultivars are susceptible to russet associated with climate. Braeburn is more predisposed to calcium disorders related to cropping, whereas Delicious is prone to scald in relation to high nitrogen and fruit immaturity. In some seasons, several of the above factors combine to complicate the situation. Consider a season in which the crop is in the "off" flowering cycle and, thus, the number of fruit on the tree is low. If the weather in the first 4 weeks after blossoming is cool and moist, the cuticle composition will be that of an organism sensing little desiccation pressure—perhaps thinner and of different chemical composition, in contrast to fruit developing under warm, dry conditions where increased desiccation pressure might result in more wax production and thicker cuticle. If, when the fruit is in its rapid growth phase, a sudden and extreme change in ambient temperature occurs, the fruit is unprepared for the ensuing desiccation pressure. (In Golden Delicious, this is often when physiological russetting can first be seen as tiny, white, micro-cracks throughout the fruit surface.) If these hot, dry conditions persist as the fruit enlarges, the fruit will attempt to compensate and protect the exposed cells by building up suberin on the exposed cell surfaces as described above. The resulting pale whitish-yellow cork can be seen shortly thereafter. In addition, if water availability is inadequate for the increase in evapotranspiration (because leaves grown under cool, moist conditions will also have a cuticle less adapted to desiccation) the long, leafy shoots, also the result of a lighter than normal crop, will draw moisture, along with certain mobile cations, away from the fruit. This may result in localized calcium shortages within the flesh which may weaken cell walls and membranes or other calcium-strengthened anatomical structures within the fruit flesh, and become the basis of internal pitting later in the season or during storage. Compound the aforementioned factors with heavy irrigation before harvest and the resulting rapid growth rate through the harvest period, during which there is much cuticle expansion in progress and hence much lenticel cracking, and one has fruit which is predisposed to lenticel breakdown. In addition, it is also possible, rapid fruit expansion before harvest resulting in cracked lenticels coupled with hot, dry daytime weather conditions may permanently injure the cells directly beneath the lenticel creating a cavity which then becomes the forerunner of lenticel breakdown. The conditions just described were those of many locations in Washington State during the 2001 growing season in which Gala and Fuji apples showed a high incidence of lenticel breakdown.

RESEARCH 2001

Studies were conducted this past year on both Gala and Fuji apples in orchards from Okanogan to Patterson. At least six cooperators with Gala blocks and six with Fuji blocks participated. Each cooperator contributed three bins of fruit directly from the orchard. One bin was labeled and set aside in the respective commercial CA facility; one bin was stored in RA and one in CA—both in the Stemilt research storage facility to minimize any variation in storage facility conditions. At harvest, and at 4 and 8 months for Gala, and 5 and 10 months for Fuji, samples of 40 fruit from all cooperators were evaluated. Evaluation consisted of firmness and color measurements, as well as the soap/wax test to induce lenticel disorder. For the soap/wax test, cold fruit was placed in deionized water at 90 ºF for 10 minutes to simulate the dump tank, then placed in a 1X soap solution (neutral pH) for 1 minute, then allowed to dry briefly followed by hand-waxing. This fruit was set aside for 7 days at room temperature to allow maximum surface pitting (although most of the disorder was apparent after 48 hours). Treated fruit was compared with an untreated sample which usually showed little pitting. The number of pitted lenticels was counted within a 2 cm diameter ring on the most severely affected side of the fruit, as well as on the side opposite this. These numbers were averaged to give the relative average per fruit for comparisons. In some cases, surface pitting was present but minor and therefore, the percentage of marketable fruit was estimated.

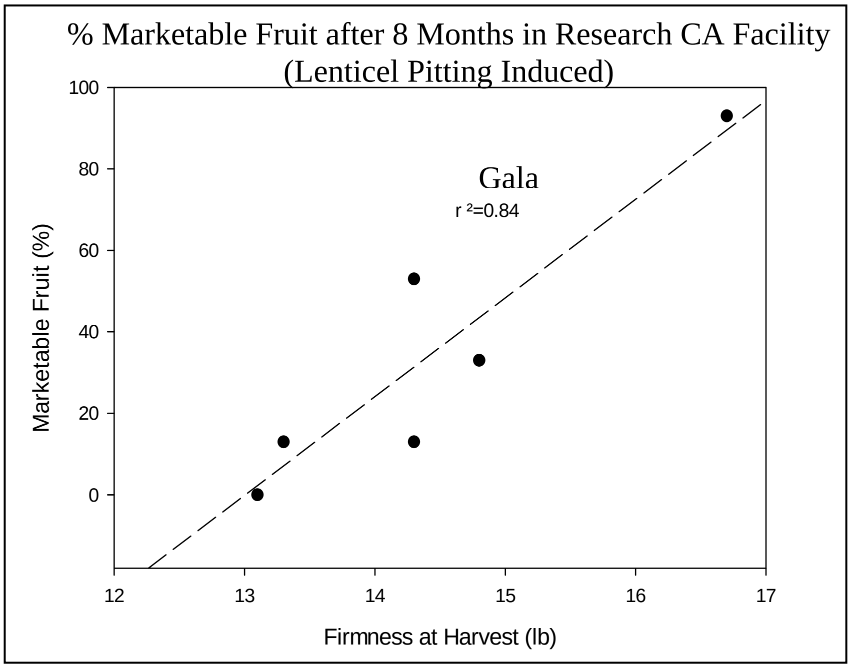

Figure 6. Percent marketable fruit (fruit treated with the soap/wax test) as a function of firmness at harvest in Royal Gala apples.

Figure 6 show the relationship between the firmness of Royal Gala apples sampled at commercial harvest date with the percent marketable fruit after 8 months CA storage and treated with the soap/wax test described above. Fruit with greater firmness at harvest developed less pitting (higher marketable yield) than fruit with lesser firmness values.

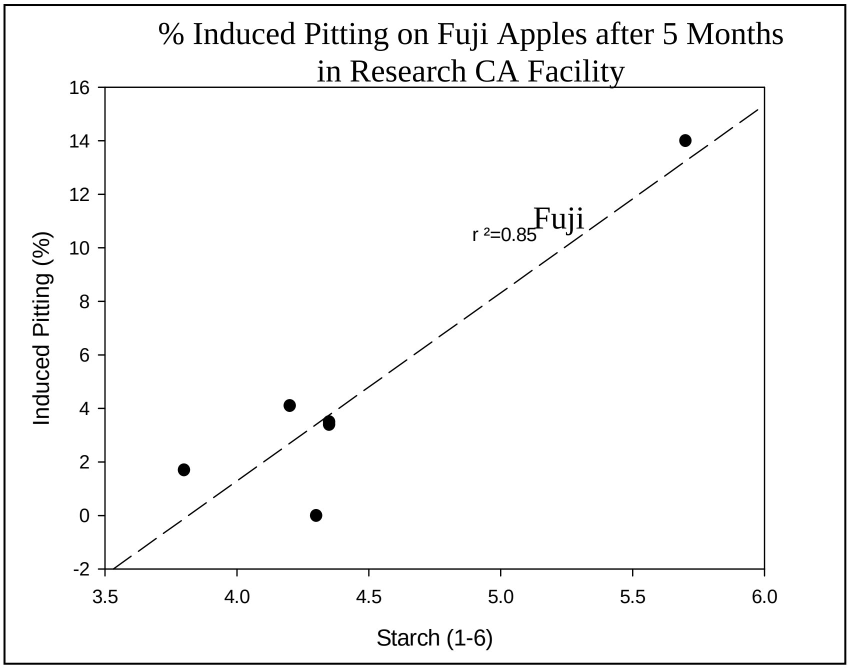

Figure 7. Percent induced pitting (fruit treated with the soap/wax test) as a function of starch rating at harvest in Fuji apples.

Similar to the graph for Royal Gala, Figure 7 shows the relationship between Fuji maturity at harvest and the % induced pitting (soap/wax test). Of the Fuji orchards sampled at commercial harvest, those having the highest starch rating (starch/iodine test based on the Delicious scale of 1 to 6) showed the greatest amount of induced pitting after 5 months CA storage.

Generally, the appearance of lenticel breakdown during packing of the 2001 crop occurred in two waves. The first was on fruit destined for immediate sale, which would likely have been large fruit of high dessert quality and, therefore, advanced maturity. Because lenticel breakdown appears to be inversely related to relative fruit firmness, fruit that would have been picked "ready to eat" and stored for several weeks would have undergone further firmness loss before packing. If the fruit was harvested during rapid fruit enlargement and advanced maturity, there would likely have been a number of lenticels which would have not "healed". When fruit enlarge quickly, as occurred in a number of orchards in 2001, the cuticle surrounding lenticels may crack, thereby exposing the underlying cells. Under normal conditions and less rapid fruit growth, the cuticle may be able to "keep pace" with cell expansion and thus the number of "open" lenticels would be fewer. The term "open" used here refers to lenticels whose cuticle has, during the course of fruit enlargement, cracked thereby exposing sub-epidermal cells to the environment. The second wave of lenticel breakdown began around February. This was likely mid-term fruit that was not immature, but still had a measure of firmness at harvest. After storage for 5 months, fruit had softened sufficiently to allow expression of the symptoms after packing.

Clearly, there is a relationship between the amount of induced pitting after storage and the condition of the fruit at harvest. Susceptible fruit with advanced maturity at harvest, whether assessed by firmness or starch level, developed more severe pitting after storage. There remains, however, a field component to this disorder that we are still investigating.

FRUIT NUTRITION

In 2001, we examined the elemental composition of fruit from each orchard in the trial in an effort to correlate the severity of symptoms with nitrogen (N), calcium (Ca), magnesium (Mg), and potassium (K) levels.

Table 1. Elemental analysis of Royal Gala and BC2 Fuji apple peel (based on dry weight) showing percent nitrogen (N), potassium (K), calcium (Ca) and magnesium (Mg) as well as ratios of (K+Mg)/Ca, N/Ca, and ((K+Mg)/Ca)+(N/Ca) and severity of symptoms in each of six orchards.

Orchard	Severity	N (%)	K (%)	Ca (%)	Mg (%)	K+Mg/Ca	N/Ca	K+Mg/Ca + N/Ca
Gala 1	Low	0.47	0.51	1230	627	4.7	3.8	8.5
Gala 2	Low	0.32	0.53	1030	599	5.7	3.1	8.8
Gala 3	Med	0.56	0.46	1180	722	4.5	4.7	9.2
Gala 4	Med	0.46	0.57	1090	765	5.9	4.2	10.1
Gala 5	Med	0.48	0.59	1120	1000	6.2	4.3	10.5
Gala 6	High	0.53	0.57	840	665	7.6	6.3	13.9
Fuji 1	Low	0.41	0.65	880	475	7.9	4.7	12.6
Fuji 2	Low	0.44	0.74	951	662	8.5	4.6	13.1
Fuji 3	Med	0.48	0.56	770	646	8.1	6.2	14.3
Fuji 4	High	0.52	0.67	612	529	12.0	8.0	20.0
Fuji 5	High	0.54	0.73	612	593	13.0	8.8	21.0
Fuji 6	High	0.56	0.84	488	577	18.0	12.0	30.0

Examination of the data in Table 1 indicates severity of lenticel breakdown appears to be related to the combined ratio [((K+Mg)/Ca) + (N/Ca)]. Generally, where symptom expression is low, relative calcium content in the peel is high and potassium content is low resulting in lower combined rations of [((K+Mg)/Ca) + (N/Ca)]. In contrast, where symptom expression is high, relative calcium content is generally lower and potassium higher. Adding nitrogen and magnesium content, and giving calcium twice the weight (because it is used in each of the separate ratios) strengthens the combined ratio. Although this is a small sampling of orchards experiencing lenticel breakdown, nutrition appears to have a role in development of the disorder. Importantly, proper nutrition is not merely a function of what is applied foliarly but rather a complex interrelationship between soil, fertilization, irrigation, rootstock, fruit/leaf ratio, vigor, and weather. Currently, I am gathering weather data for analysis to ascertain whether certain conditions predispose fruit to lenticel breakdown.

LAST BUT NOT LEAST

Throughout the course of these experiments I have seen symptoms of lenticel breakdown on numerous varieties, including Granny Smith, Delicious, Golden Delicious, Pink Lady® brand, Gala and Fuji. By far, the most widespread occurrence was on Gala and Fuji—specifically, Royal Gala and BC2 Fuji. It is possible that these cultivars have genetic differences in wax or cuticle composition that predispose fruit to symptom development. However, since the symptoms have increased in the last 5 years, my inclination is that management practices have changed somewhat, leading to increased incidence. Royal Gala and BC2 Fuji are not the most highly colored strains of these cultivars. Under certain conditions in certain years, color can be excellent; however, warm weather before harvest can reduce red color development. Because the market pays more as red color increases, and because the market has been down in the last several years, growers, almost out of necessity, have had to allow fruit to remain on the tree longer to develop more red color. The result is that fruit have been harvested at a physiological stage which is too advanced for the length of time they are being stored. Whereas other Gala and Fuji cultivars develop excellent color before ripening is auto-initiated, Royal Gala and BC2 Fuji, especially, do not have this characteristic. Therefore, where environmental conditions predispose fruit to develop lenticel breakdown, delaying harvest of these cultivars for improved color may result in losses that will more than offset the potential gain in grade. A 'forced march' might get you where you want to go, but you can bet that some of the troops will have tired legs.

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