Fruit Bruising: It's More than Skin Deep

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We are all aware of the financial consequences of rough handling of fruits. If care is not taken with harvest, with transport to the packer or the storage facility, or with unloading, we will have to deal with a load of bruised fruit. Dark patches or water-soaked areas will mean that the fruit are of reduced value or of no value at all because the consumer wants fruits that look good. Plant physiologists know a lot about the factors that contribute to the fruit cosmetic problems associated with bruising. **Note:** *The authors want to make certain that the readers get an impression of the linkage of specific effects of bruising on cell structure and biochemistry and, in turn, of the connection of these cellular effects to bruising damage. While the following brief review of plant cell structure may seem superficial to some, we feel that it contains the information necessary to understand the logic behind our study.*

Plant Cells and Bruises

The physical impacts that a fruit experiences have their primary consequences on the membrane systems of individual cells (Figure 1).

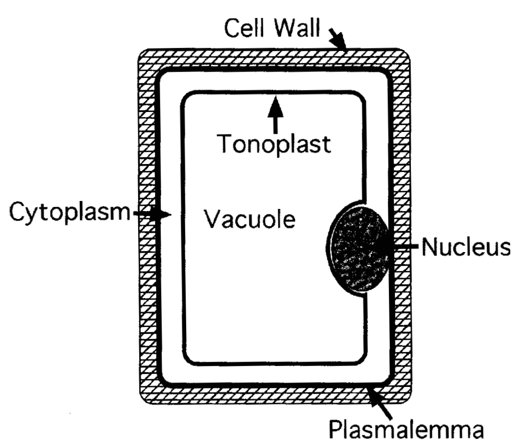
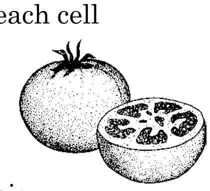


Figure 1. *A line drawing of a single plant cell. Around the outside is the relatively rigid cell wall. As you move toward the center from the cell wall you will cross (in order) the plasmalemma, the cytoplasm (in which the DNA-containing nucleus resides), and the tonoplast, finishing in the large central vacuole.*

One membrane, the plasma membrane or plasmalemma, surrounds the cell and regulates movement of molecules between the inside of each cell and the outside. Another important membrane, the vacuole membrane or tonoplast, surrounds the vacuole, a large fluid-filled structure found in the center of each cell. The tonoplast regulates movement of molecules between the vacuole and the cellular cytoplasm. The cytoplasm, the material between the plasmalemma and the tonoplast, is the area of the cell in which most, but not all, of the life processes of the cell and, hence, the plant (or fruit, leaf, flower, root or stem) which is made of these cells occur. An important role of the membranes is to keep things separate that "should be" kept separate. When a plant part experiences physical injury its membranes are damaged and are no longer able to "keep things separate". As a result, a bruise can allow the mixing of enzymes from the cytoplasm with molecules (called phenolics) from the vacuole and the resulting reaction creates the dark coloration associated with a bruise. Bruising may also lead to the leakage of cellular water across a damaged plasmalemma so that water-soaked areas develop.

Although the preceding description of the biology of bruise development may have been new to you, your understanding of why bruising is a postharvest problem has probably been with you for a long time. But bruising is not just a cosmetic problem. We have been working with tomato processors for several years, trying to understand the factors which contribute to the production of a high quality tomato paste. For tomato paste, high quality means thick and slow running (i.e., high viscosity). Viscosity of fruit purees is thought to be primarily influenced by the properties (e.g., solubility and size) of the complex sugar-containing molecules found in the cell walls of plant cells. The cell wall is a physically tough structure found to the outside of the plasmalemma of each plant cell. The cell wall gives a lot of strength to each cell and, thus, in the aggregate, to the fruits, stems, flowers etc. that are composed of these cells. When a fruit ripens it softens. An important factor contributing to this softening is the ripening-associated digestion



(breakdown) of the cell walls of the fruit cells. The digestion occurs because each fruit cell makes cell wall-digesting enzymes that are moved through the plasmalemma in a very controlled way. When these enzymes are outside of the plasmalemma they are free to digest the complex molecules of the cell wall. Thus the walls are weakened and the fruit softens. Tomato paste manufacturers know about this part of fruit developmental biology and heat the fruit very quickly (the so-called "hot break") after it is disrupted so that enzymes are inactivated (high temperature inactivates or "denatures" enzymes) before the enzymes have a chance to digest the tomato cell wall components extensively. If they are not broken down these cell wall components will contribute to a paste of high quality.

Bruising and product quality

We have been investigating the potential impact of bruising on the quality of tomato paste. Fruits are mechanically harvested and may be held in trucks for several hours before they are passed into the processing plant where heat treatment inactivates cell wall-digesting enzymes. Our concern was that bruising at harvest could lead to uncontrolled action of cell wall-digesting enzymes because of damage to cell membranes which, in turn, would lead to decreased paste viscosity.

Harvest study

We used an Instrumented Sphere to learn where along the path of a tomato from the field into the processing plant the largest physical insults were experienced. The Sphere, a ball about 3.5 inches in diameter, is filled with sensors to measure jolts, bounces, and other types of impacts and also contains a timer and storage chips for saving, and subsequently accessing information from the sensors. One of us (Mitcham) had already used the Sphere to determine where along a pear packing line the potentially damaging impacts occurred. We nested it in vines of ripe tomatoes so that it would be picked up by the harvester, passed through the harvester (up conveyors and along sorting stations), and subsequently dropped into a truck bed. We followed the Sphere as it traveled along with several tons of tomatoes from the field to the processing plant. We allowed it to be dumped from the truck, along with those tons of tomatoes and washed through the flumes and down waterfalls into the plant where it was rescued (several times) just before it plunged into the steaming bowels of the hot break unit.

Laboratory results

Our analysis of the data collected showed us that by far the greatest physical impacts felt by the fruit occurred during the mechanical harvest. Might this, therefore, have a detrimental effect (as discussed above) on the texture quality of the paste product? To determine this we resorted to some lab studies. We used ripe fruit that were hand-harvested and free of bruises for the tests. Some fruits were kept as controls. Others were dropped from different heights onto a metal roller. Once we had a series of fruits that had been bruised with small, medium or large drops, all fruits were placed in an incubator and held for one hour or five hours at about 95°F. After this incubation, which was intended to simulate the time a truckload of harvested tomatoes might be held before entry into the plant, the darkened, water-soaked bruising was apparent. We cut the bruised portions out and subjected them to a series of analyses that was designed to determine if cell walls had been broken down. Unbruised

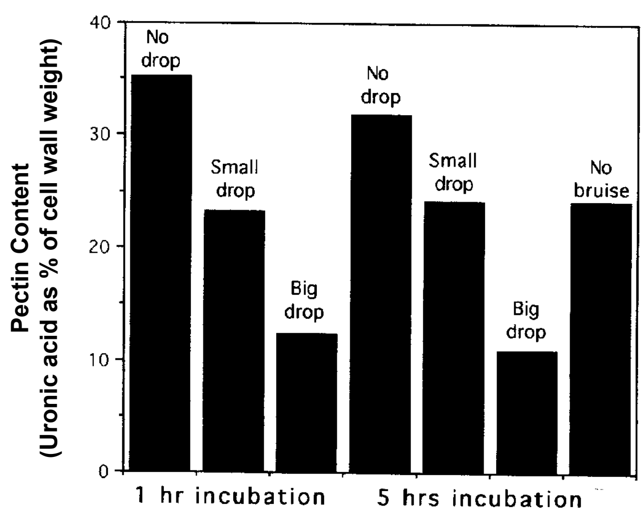


Figure 2. *Uronic acid (UA, shown on the Y axis) is the primary sugar building block of the cell wall components known as pectins. A cell wall with UA content that is lower than that isolated from unbruised fruit has lost pectins, presumably because enzymes that are "activated" because of bruising have digested the pectins away. The data, therefore, indicate that bruising leads to loss of pectin from tomato fruit cell walls. The right hand bar indicates the cell wall pectin content of a section of fruit removed from the unbruised part of a dropped fruit. Additional tests indicated that the pectins that remain in the cell walls of bruised fruit are smaller than the pectins of unbruised fruits.*

portions of some of the dropped fruits were also analyzed as further controls.

Conclusion
The study provided clear evidence that bruising of the fruit leads to the degradation of cell walls (Figure 2) and a strong possibility of decreased tomato paste quality and increased fruit costs. This may be inevitable. It is not likely that the industry will move away from mechanical harvest. On the other hand, it may be possible, through improved design of harvesting equipment or altered cultural practice to reduce the size of the physical impact on the fruit or the effects on cell wall digestion. Genetic engineering of the fruits might also help. Biotech companies have already released lines of tomatoes with greatly reduced presence of the cell wall-degrading enzyme polygalacturonase (PG; Calgene's 'FlavrSavr' tomato contains only 1% of the PG found in most tomatoes) and our study reveals that PG activity could be responsible for some of the bruising-related breakdown of tomato cell walls.

We will continue this line of research in the hope that what we find may pave the way to improved texture properties of processed tomato products. It should be clear that bruising is not just a cosmetic problem. Bruising alters the functioning of plant cells in very important ways. It is quite possible that additional research will indicate more ways that the quality of fruits can be affected by physical damage incurred at harvest.

Use of Retain on Apples and Pears

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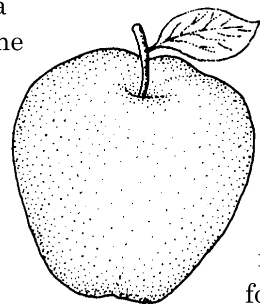
It has been known for many years that aminoethoxyvinylglycine (AVG) inhibited ethylene biosynthesis in plant tissue. After that discovery, numerous laboratory-based studies documented the effects on fruit ripening and other plant processes. However, the cost of AVG was prohibitive to field trials or commercial use of this compound. Recently, a fermentative process was developed to produce AVG less expensively, and a commercial formulation, called Retain™, was developed by Abbott Laboratories. Research has been conducted for several years and continues in many locations including California, Michigan, Washington, and Pennsylvania. The commercial use of Retain™ on apples and pears was approved for use in the US (except California) in 1997 and in California in 1998.

Apples
One of the main reasons for use of AVG on apples is to prevent premature fruit abscission (as a "Stop-Drop"); thus the name Retain™. (The "Stop Drop" benefits for pears may not be as good.) However, there appear to be other benefits to using Retain™. In general, use of Retain™ delays fruit maturation 7 to 14 days. Delays in the increase in ethylene production or internal ethylene concentrations, fruit softening, starch conversion to sugars, and change in background color from green to white to yellow are generally seen. Red color development can be delayed along with other ripening parameters. After storage, ethylene production often remains lower in Retain™ -treated fruit, and fruit usually have a greener background color and may be somewhat firmer. In the 1997 year of our study, Retain™ –treated California 'Gala' and 'Fuji' apples had 25 to 75% less bitter pit after air storage than control fruit. Additional work is needed to further study the effect of Retain™ on bitter pit, as this result has not been noted in other growing locations or in other seasons in California. The 1997 season was a year of high bitter pit incidence in apple fruit. The overall results of Retain™ are dependent on application rate and timing. The label allows for 50 grams of active ingredient per acre, applied 4 weeks prior to harvest. The results also appear to depend somewhat on variety and growing location.



Pears
There has been much less work on the effects of Retain™ on pears, and further work is needed to develop clear recommendations. In fact, for the 1998 season, Abbott Laboratories recommends that growers contact the company for additional information prior to use of Retain™