

Recent Advances in Apple Breeding, Genetics and New Cultivars

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The genetic diversity that exists within apple is amazing. Diversity in appearance (color, shape, finish), texture (fine, crisp, hard) and flavor (complex, spicy, mild) offer breeders tremendous possibilities for improvements. The existence of several dominant genes for scab and powdery mildew resistance are also advantages.

The Cornell apple-breeding program continues to emphasize the development of new, distinctive cultivars with excellent and consistent quality. Distinctiveness may mean new colors, new striping patterns, different types of fruit finish (extremely glossy or finely russeted), and unusual shapes (uniformly conic, longer).

In trying to improve apples, we take advantage of the diversity that exists and cross parents to create new combinations of characteristics. Sometimes seedlings from a particular cross will be quite diverse, but the combination of characters expressed is not desirable. An example would be a progeny with seedlings bearing fruits of different colors and sizes but an undesirable finish such as russetting or scarfskin. Often we see uniformity of fruit shape in a cross but great diversity in the appearance and finish. Other crosses have a diversity of sizes but are skewed to smaller sized fruits presenting more of a challenge. With respect to fruit quality, we are seeing tremendous diversity for texture, firmness, flavor and other characteristics (Brix, acid, astringency) in our crosses. We are also seeing a range in flavors in crosses, with some seedlings very mild to bland and others strongly flavored and having a high Brix/acid ratio. Research

has indicated that there are consumers for both types. The more strongly flavored types sometimes decrease in acidity while in storage, and other times their acidity is maintained.

Use of some of Roger Way's advanced selections as parents has been very successful in producing high quality offspring. One hybrid that has 'Golden Delicious,' 'Monroe' and 'Melrose' in its pedigree imparts wonderful quality when used as a parent. Some seedlings have been selected that have anise flavor, which is a mild licorice-like taste. Ironically, we had greater success in producing non-russetting yellow apples when we used a russet-prone, yellow-fruited cultivar as a parent than when we used a russet-resistant clone. The yellow and green selections we have made have good resistance to russetting.

Quality assessment studies, funded by the Apple Research and Development Program and by Motts, have allowed us to assess initial performance of our advanced selections. The appearance of many of these selections has been documented photographically. With many selections, we are seeing good levels of soluble solids, acids, firmness and crispness that are maintained in storage. We are also finding parental defects in the progeny; for example, we must evaluate 'Gala' offspring for stem end cracking and 'Honeycrisp' offspring for susceptibility to soft scald and fruit rots.

This past November 2004 we held a variety showcase to offer growers an opportunity to see and sample many of our new selections and over 100 cultivars and strains that we also put on display.

The Cornell apple-breeding program continues its efforts to develop distinct and quality varieties as it explores the expansive genetic diversity of apple. Not only are flavor and appearance important considerations, but nutritional value is also a significant trait.

Many of our selections are registering 15 to 17 pounds firmness when removed from cold storage in January and are free of storage disorders. In 2005, we began collecting a list of growers interested in testing material and will be propagating advanced selections for grower trials under a non-distribution agreement. Any growers interested in test plantings should contact us.

Nutritional Value/Health Benefits

Our program and other apple breeding programs are studying vitamin C (ascorbic acid) and antioxidant content of potential parents and the transmission



A selection with 'Honeycrisp' as a parent. Fruits have wonderful texture and juiciness.

of these nutritional traits to progeny. While many apple cultivars average only 5 to 10 mg of ascorbic acid per 100 g of fresh weight, NY 674, 'Braeburn,' 'Goldrush,' and 'Topaz' have from 15 to 32 mg /100 g of fresh weight, approaching the 40 mg found in oranges. We have made crosses with the objective of increasing vitamin C content in new varieties, coupled with good quality, and have found significant increases in Vitamin C content in seedlings from these crosses.

Studies have demonstrated that vitamin C is just one of the many antioxidants found in apple, and ironically, a variety might have high vitamin C but low total antioxidants. Vitamin C only contributes 12.8% to total antioxidant capacity, with other phenolics such as quercetin are more important (Lee et al., 2003). Certain of our selections have been evaluated for total antioxidants and been found to have very high levels.

As we increase antioxidants we also increase flesh browning. Non-browning cultivars are also desired and can be developed by concentrating on lowering the browning enzymes and raising vitamin C content. Such cultivars are important in value-added products, and low browning cultivars are being developed in our program.

Molecular Markers

Molecular markers for many traits of interest to apple breeders and growers have been discovered by geneticists around the world. At Geneva, we have developed markers for fruit color, columnar and weeping plant form, and several markers for the different scab resistance genes, including V_r , V_m , V_r , V_x , V_a and V_b . Scab genes were found to cluster onto two linkage groups (chromosomes) which is an important finding for breeding and transformation. There are also markers available for several sources of powdery mildew resistance, woolly apple aphid resistance and rosy apple aphid resistance. Self and cross incompatibility genes have also been studied extensively, and markers and knowledge of the genes involved aid pollination plans.

Genes Identified and/or Sequenced in Apple

Genes influencing the time required for a tree to fruit, flowering, fruit

development, photosynthesis, stress and fruit maturation have been identified, and many have been sequenced. Genes for dwarfing and disease resistance have also been studied.

Recently, a major grant was funded at the University of Illinois to study expressed sequence tags (ESTs) in apple. Similar research has also been conducted in New Zealand. ESTs reflect genes being expressed at certain stages of development or from different treatments. This research promises to add greatly to our knowledge of genes in apple.

Cultivars Transformed

Many apple cultivars have been transformed by different research groups including (in alphabetic order): 'Delicious,' 'Elstar,' 'Florina' (a scab resistant variety), 'Fuji,' 'Gala' and its sports, 'Golden Delicious,' 'Jonagold,' 'McIntosh' (and its columnar sport 'Wijcik McIntosh'), 'Orin' and 'Pink Lady.'

Transgenes Used

Lytic peptides have been used to impart resistance to bacterial diseases such as fire blight (*Erwinia amylovora*), and chitinases have been used for resistance to fungal diseases in rootstocks and scion cultivars (Aldwinckle et al., 2003).

Anti-sense technology, where a gene for a trait of interest is inserted in the wrong direction, is an effective way to turn off or reduce the expression of that gene. The anti-sense approach is being used with the self-incompatibility gene to produce self-fertile cultivars and with reduced polyphenoloxidase (PPO) to reduce flesh browning (Barbier et al., 2003).

With the advances made in apple gene mapping, genes from apple were recently targeted as transgenes. In 2003, 'Gala' was transformed with what was believed to be the V_r scab resistance gene and the transgenic lines produced were resistant to scab.

Studies of transgenic apple trees and their fruits promise to add to our knowledge of transgene expression and transgene interaction with other genes and the environment. An example of this is presented in research that discusses the effect of silencing (turning off) ACS or ACO, enzymes responsible for ethylene production (Dandekar et al., 2004;



Another 'Honeycrisp' offspring with excellent crispness and long storage life.

Hrazdina et al., 2003). In fruits silenced for ethylene, there was no effect on sugar and acid composition but the synthesis of volatile esters (which contribute to flavor) was dramatically suppressed.

Club Marketing

In recent years there have been a greater number of restricted access cultivars since 'Pink Lady' was marketed under a club concept. The New Zealand program's Pacific series and 'Jazz' are examples of restriction and dual location (New Zealand and Washington State) production. Franchise fees and production-based royalties are also new developments. 'Delblush' ('Tentation') is another example of a restricted access variety from the Delbard program in France. In North America, we have seen 'Ambrosia' become restricted to Canada, even after trees had been planted and harvested in the US. 'Sonya,' from the NZ breeding program of John Nelson, is also a club variety in Washington. The most recent restriction is on 'Piñata,' trademarked by Stemilt in cooperation with Pepin Heights orchard in Minnesota. 'Piñata' will be exclusive to that partnership, which is unusual because 'Piñata' was originally introduced as a public variety to the US. This introduction from the Dresden/Pillnitz breeding program in Germany was available to all growers. Its name was first changed to 'Corail' and later to 'Sonata' for marketing purposes. The trademarked name, 'Piñata,' comes from a combination of the names 'Pinova' (Pin) and 'Sonata' (ata).

'Ariane,' a scab resistant apple from the INRA program in Angers, France, is the newest club release. Its pedigree is complex, involving a hybrid of the scab resistant cultivars 'Florina' and 'Prima,' crossed with a selection derived from



A non-russetting 'Golden Delicious' type seedling with texture similar to its 'Fuji' parent.

'Golden Delicious' open pollinated. This cultivar is the first release by a cooperative program between INRA and French nurseries. Seventeen French nurserymen, with an aim to produce high-quality, disease resistant cultivars, founded the company NOVADI in 1997. This group then partnered with producers and marketers to form POMALIA. The company selects among the best cultivars identified by NOVADI. These groups have already organized the planting of over 95,000 trees of 'Ariane' in France.

New Cultivars Released

Cultivars for which patent applications have been filed in the US include:

- 'Civni' ('Rubens'®): (USPP#14,177: 9/23/03). This hybrid of 'Gala' x 'Elstar' was developed by the CIV (Consorzio Italiano Vivaisti) in Italy and has been planted fairly extensively in the South Tyrol since 1999. 'Civni-Rubens' may become biennial, like its 'Elstar' parent. Fruits are prone to cracking at the calyx end at harvest, especially on trees with a lighter crop load (Thomann et al., 2004).
- 'Rebella': (USPP#15,134: 9/7/04). A scab resistant variety released from a German breeding program. This hybrid of 'Golden Delicious' by the scab resistant cultivar 'Remo' is noted to have good fruit quality and good resistance to powdery mildew and fire blight.
- 'Sundance'TM (Co-op 29): A yellow, scab-resistant variety from the Purdue/Rutgers/Illinois (PRI) cooperative breeding program. It has good quality but is prone to russetting in New York and can also be biennial in production. It was included in the NE183 regional trial evaluating apple cultivars.
- 'Crimson Crisp' (Co-op 39): Another scab-resistant release from the PRI

program that was also tested in the NE183 project. It has good storage characteristics.

'Stella Minnesota': (USPP#13,930: 7/1/03). A chance seedling that ripens in the early season and has good quality fruit with good resistance to flesh browning when cut.

Cultivars and sports with a plant patent application filed but not yet granted include:

- 'Rosy Glow': A limb sport of 'Cripps Pink' ('Pink Lady') discovered in Australia in 1996. Fruits are more highly colored even in shaded areas of the tree. The red color is said to extend into the calyx.
- 'Royal Beauty': A sport of 'Royal Gala' discovered in South Africa in 1996 that has intense red color on more of the fruit surface.

New sports of Gala:

- 'Dalitoga': (USPP#15,465: 1/4/05) A whole tree mutation of 'Imperial Gala' discovered in France.
- 'Star Gala'TM ('Weaver'): (USPP #14,752: 5/4/04). A limb sport of 'Fulford Gala' discovered in Pennsylvania that is reported to have larger fruits (~3-3.5" in diameter) with a less vigorous tree than 'Fulford Gala.'

New sports of Fuji:

- 'Brak' ('Kiku'®): (USPP#15,261: 10/26/04) A branch mutation of 'Fuji' that was discovered in Japan and selected by A. Braun of the South Tyrol along with seven other 'Fuji' sports to be part of the 'Kiku'® brand (www.kiku-apple.com).
- 'Daybreak Fuji' ('Rankin Red'): (USPP#12,551: 4/16/02). A limb sport of 'Yataka,' 'Daybreak Fuji' ripens five days before 'Yataka' (five weeks before standard 'Fuji'). 'Daybreak Fuji' is said to have better and more uniform coloring and a smoother finish.

Summary

New knowledge of apple genes and their interactions will aid apple breeding and transgenic approaches to improvement of existing varieties. Improvements in quality and nutritional content are evident in our seedling populations, and we are creating the needed diversity to produce cultivars that are distinctive in appearance and/or quality and have consistency in these attributes. Access to some new cultivars is being restricted, but our established collaborations with researchers and

nursery personnel continue to provide us access to new material from the US and abroad.

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