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Fifty Years of Pear Breeding: An Overview of the Harrow (Ontario, Canada) Pear Breeding Program

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Abstract

The 'Harrow' (Ontario, Canada) pear breeding program was initiated in 1962 to develop fire blight resistant pear selections for the fresh and processing markets. Six cultivars have been introduced for commercial production in Canada, some of which have been protected and introduced in Europe. Several additional selections have been protected in Canada and will be introduced in the near future. Two cultivars have been protected, named and introduced to the European market. All selections and introductions have good to excellent resistance (but not immunity) to natural fire blight infections.

Keywords: Resistance breeding, fire blight, hybridization, *Pyrus communis*

Armut Islahının Elli Yılı: Harrow (Ontario, Canada) Armut Islah Programına Genel Bir Bakış

Özet

"Harrow" (Ontario, Canada) armut ıslah programı, taze ve işleme sanayi için ateş yanıklığına dayanıklı armut seleksiyonlarını geliştirmek için 1962'de başlatıldı. 6 çeşit Kanada'da ticari üretim için piyasaya girdi, bazıları koruma altına alındı ve Avrupa'da piyasaya sürüldü. İlave birkaç seleksiyon da Kanada'da koruma altına alınmıştır ve yakın gelecekte piyasaya sürülecektir. İki çeşit koruma altına alındı, isimlendirildi ve Avrupa pazarına girdi. Tüm seleksiyonlar ve introdüksiyonlar, doğal ateş yanıklığı enfeksiyonlarına iyiden mükemmele dayanıma (ancak bağışıklığa değil) sahiplerdir.

Anahtar Kelimeler: Dayanıklılık ıslahı, ateş yanıklığı, melezleme, *Pyrus communis*

1. Introduction

The North American continental climate is sufficiently moderated by the Great Lakes to allowing the commercial production of cold tender tree fruits (including peach, nectarine, apricot, and pear) in southern Ontario, Canada, and adjoining states of the USA.

In Ontario the major production area is the Niagara region, which extends ~50 km west from the Niagara River to the outskirts of Hamilton Ontario, and some 15-20 km south from Lake Ontario towards Lake Erie. In this area, the combination of soil types and climatic zones moderated by the interaction of Lake Ontario and the Niagara Escarpment provide conditions suitable for commercial tender fruit production. Growing conditions are less favourable elsewhere in Ontario, but a significant industry has developed along the north shore of Lake Erie in the southwestern part of the province, where climatic conditions are typically more extreme in both summer and winter. Pears can also be produced in limited areas around Georgian Bay, and along the St. Lawrence and Ottawa River valleys where conditions can be favourable.

Pear production in Ontario is concentrated in the Niagara region (~85% of provincial production) and southwestern Ontario (~12%) with limited production elsewhere in the province. Major cultivars are Bartlett

(syn. Williams) and Bosc (~60% and ~25%, respectively). Until 2008, ~60% of the Bartlett crop was processed, but this market was lost when the only processing plant in eastern North America was closed. Since 2008, pear production has declined. In 2010, Ontario produced 2928 T from 407 ha of bearing orchard, with a farm gate value of ~CAD 3.6 million (Statistics Canada, 2012).

Pear breeding activities were initiated by Dr. R.E.C. Layne in 1962 at the Agriculture and Agri-Food Canada (AAFC) Research Centre at Harrow Ontario, located in the south-westernmost part of the province (lat. 42° 02' N, long. 82° 54' W). Throughout the 1970s, Dr. H.A. Quamme made a large number of crosses, which were evaluated by Dr. F. Kappel (1982-1987) and Dr. D.M. Hunter (from 1988). Starting in 1988, crosses were made to incorporate resistance to both fire blight and pear psylla (*Cacopsylla pyricola*) into high quality fruiting selections. In the mid-1990s, the program was transferred to the AAFC Research Farm at Vineland Station in the Niagara Region (lat. 43° 11' N, long. 79° 24' W), the transition taking five years to complete (1996-2000). The Harrow/Vineland program was the only active pear breeding program in Canada in the 1990s and 2000s, and crosses were made each year during this period. AAFC funding for the program was discontinued in 2009, and an exit strategy was developed to accelerate seedling evaluation, with an emphasis on identifying potential introductions while at the same time removing seedlings which did not meet selection criteria. Final pollinations were conducted in 2011, primarily for pollen compatibility purposes. Under the terms of a commercialization contract completed in 2012 with the Vineland Research and Innovation Centre (VRIC), responsibility for pear introductions was transferred to VRIC, and currently (2016), VRIC is evaluating the remaining seedling populations for potential new advanced selections.

2. Breeding Objectives

The major pear breeding objective was the development of selections and cultivars with improved resistance to biotic stresses, especially resistance to fire blight. Fire blight (a bacterial disease caused by *Erwinia amylovora*) was, and still is, the major disease constraint for pear production in Ontario. The dominant cultivars, 'Bartlett' (syn. 'Williams') and 'Bosc', (approx. 60% and 25% of Ontario production, respectively), are both very susceptible to fire blight, and their continued production is dependent on timely applications of streptomycin for fire blight control. Breeding resistant or tolerant cultivars is the long-term alternative to dependency on chemical control.

Additional objectives included: (1) extending the harvest and marketing seasons, thus providing additional marketing opportunities; (2) improved fruit qualities such as fruit size, appearance, skin color, flesh firmness, flavor, texture, and processing and storage potential; (3) improved resistance to pear psylla (*Cacopsylla pyricola*); (4) improved tree longevity, good annual productivity with no biennial bearing habit, vigor, growth habit and precocity; and (5) improved resistance to other faults, such as pre-harvest drop, non-uniform fruit ripening, and short shelf life.

3. Breeding Strategy

Since it was initiated at AAFC-Harrow in 1962, the pear breeding program involved controlled hybridizations between selected parents, primarily *Pyrus communis* (European pear) cultivars. Crosses were made each spring from 1963-1968, 1972-1981 and 1988-2011. Typically, there was a minimum of 200 pollinated flowers per cross, and up to 80 parental combinations in any one pollinating season. Seedling populations were generated from which individual seedlings were selected (based on tree and fruit characteristics) for further evaluations prior to the introduction of new cultivars. Typically, this process takes at least 20 years.

A recurrent mass selection breeding strategy was followed to simultaneously improve disease resistance, cold hardiness, and tree and fruit characteristics. Modified back-crossing was also used to incorporate a greater range of desirable pomological characters while avoiding deleterious effects of inbreeding associated with repeated back-crossing to a single

parental cultivar. However, 'Bartlett' was used extensively in the program, as it was the industry standard, with many desirable characteristics. Interspecific hybridization was used only to a limited extent, the benefits of incorporating desirable characteristics found in other *Pyrus* species being offset by requirements for one to several generations of back-crossing in order to recover acceptable cultivar characteristics.

Many sources of resistance to fire blight were used, including fire blight-resistant selections from US breeding programs (e.g. Rutgers University, NJ; USDA, Beltsville, MD, and Kearneysville, WV; Purdue University, IN). The fire blight-resistance of advanced selections and introductions was derived from *P. communis* cultivars (e.g. 'Seckel', 'Waite', 'Maxine', 'Old Home', 'Farmingdale'), the interspecific hybrid 'Kieffer', or from species selections such as *P. ussuriensis* '76' and *P. pyrifolia* 'NJ-1'. Since the early 1970s, seedling selections from the Harrow program were also used as both pollen and seed parents. Several selections from the Cornell University (Geneva, NY, USA) program developed from a *P. communis* x *P. ussuriensis* cross back-crossed to *P. communis* had good resistance to both fire blight and pear psylla, and were used as pollen parents in the Harrow program during the 1988-1995 period.

4. Screening and Seedling Evaluations

Seedling populations were evaluated, primarily in the field, for characteristics of the major breeding objectives. Each objective forms part of a multiple trait selection protocol, and a serious deficiency in any of the major areas where cultivar improvement was being sought resulted in that individual seedling being discarded.

Fire blight screening techniques were developed to identify fire blight resistance in progeny and potential parents (Layne and Quamme, 1975). In the greenhouse, seedlings ~30-40 cm tall were inoculated near the actively growing shoot tip with 100 µL of a standardized suspension of six virulent strains of *E. amylovora* (10^8 cfu mL^{-1}). When evaluated two months later, seedlings were discarded if the lesion extended beyond ~25-30% of the shoot length, thus reducing the number of susceptible seedlings planted out for field evaluations. At Harrow, seedling trees were screened again when they started to fruit, usually 5-7 years after planting into seedling orchards. Actively growing shoot tips (minimum of 10 per tree) were inoculated in early June with the standardized mixture of six *E. amylovora* strains, and the lesion length as a percent of total shoot length was determined about six weeks later. In addition, all trees were assessed annually in the field for incidence and severity of natural fire blight infections, using a modification of the USDA scale (van der Zwet et al., 1970). 'Kieffer' was used as the standard reference for this assessment, and the rating had to be equal to or better than 'Kieffer' for continued evaluations. At Harrow, 'Bartlett' had an average rating of 3.9 on this scale.

Seedling trees were evaluated for horticultural and fruit characteristics. In order to determine optimum harvest time (based primarily on appearance and fruit firmness), fruits were harvested on 2-3 dates each harvest season, and evaluated after one to several weeks of cold storage. For seedling screening, fruits were rated for appearance, flavor and texture, while advanced selections were subject to more extensive fruit analysis (including Brix, pH, titratable acidity, fruit firmness, skin and flesh colour). In addition, other descriptive data were collected and used for filing Plant Breeder's Rights applications. Fruit samples were also processed as pear halves or puree, and evaluated by a semi-trained taste panel to assess the processing potential of these selections; Bartlett samples were also processed and used as the reference cultivar.

5. Virus Testing of Selections

When a seedling selection was advanced for further testing, trees were propagated for planting in replicated second test orchards and in grower trials. When propagation was initiated, budwood samples from the original seedling tree were sent to the Agriculture Canada Plant Quarantine Station [now known as the Canadian Food Inspection Agency (CFIA) Sidney Laboratory] in Saanichton, BC, for virus-testing. Woody-

host and herbaceous-host biological indicators, together with serological and molecular methods, were used to test for the presence or absence "of all known viruses, virus-like agents, viroids, and phytoplasmas" (D. Thompson, pers. comm). This process typically took about three years to complete, though preliminary results were usually available within two years of sample submission. With the development of new diagnostic methodologies, especially PCR, testing can now be completed within one year. If test results were positive, distribution of propagated trees in the nursery was cancelled to prevent spread of infected material. Virus-free trees have been maintained in a repository at the CFIA Sidney Laboratory, and limited quantities of virus-free budwood can be made available for propagation.

6. Second Test and Grower Trials

Trees of advanced selections and standard cultivars (as reference cultivars) were propagated on either Bartlett seedling rootstock or on clonally-propagated rootstocks, usually Old Home x Farmingdale 87 (OHF87), and planted into replicated trials at AAFC-Harrow (to 1994) or at AAFC-Vineland (starting in 1998), as well as at other research stations across Canada. In some years, trees were also propagated on quince rootstocks (Quince A or Quince C). Replicated trials at Harrow typically consisted of 3-5 selections and 1-3 reference cultivars, all on the same rootstock, and planted as single-tree plots in a completely randomized design with 4-6 replicates. Grower members of testing organizations [from 1964 to 1997: the Western Ontario Fruit Testing Association (WOFTA); after 1997: the Ontario Fruit Testing Association (OFTA)] could obtain limited numbers of trees of advanced selections, subject to non-propagation agreements, for testing in commercial orchards. By conducting replicated trials and grower evaluations concurrently, the time required for evaluation and introduction of a new cultivar was reduced. Data from replicated trials, evaluations of both fresh and processed fruit, and annual tree performance cards returned to WOFTA/OFTA were all used to determine the commercial potential of advanced selections.

The replicated trial orchards at Harrow and Vineland were also used to collect detailed objective descriptive data required for the Plant Breeder's Rights (PBR) applications under the Canadian Plant Breeder's Rights Act of 1990.

Advanced test selections were also evaluated by cooperating researchers in other countries. Commercialization contracts for introductions were developed, and, where possible, these introductions were protected under appropriate legislation (e.g. COV, EU PVR, USPP). In some cases, selections were discarded in Ontario as they did not meet criteria for introduction, but evaluations at other locations with less severe conditions [both abiotic (especially climatic) and biotic (especially disease pressure)] led to naming, protection and introduction outside of Canada.

7. Cultivar Introductions

To date, 25 selections have been placed in advanced trials. Of these, six have been named and introduced for commercial production in Canada. Other selections (i) are in the final stages of testing prior to naming; OR (ii) require some further evaluation; OR (iii) have been discarded from further evaluations in Ontario. All these selections have good to excellent resistance (but not immunity) to natural fire blight infections, with ratings greater than 8.5 on the USDA scale; on this scale, Bartlett (a susceptible standard cultivar) has a rating of 3.9, while Kieffer (a resistant standard cultivar) is rated at 9.0. Harvest dates for these cultivars and selections range from about 2 weeks before Bartlett to 4 weeks after Bartlett.

'Harrow Delight' and 'Harvest Queen' (Quamme and Spearman, 1983) were introduced into the public domain in 1981. 'Harrow Sweet' (Hunter *et al*., 1992), 'AC Harrow Gold' (Hunter *et al*., 2002a), 'AC Harrow Crisp' (Hunter *et al*., 2002b), and 'Harovin Sundown' (Hunter *et al*., 2009)] were introduced after the granting of Plant Breeder's Rights and are subject to commercialization contracts. Three additional selections (HW620, HW623 and HW624) are to be introduced in the near future. HW624 will be the first introduction combining fire blight resistance and psylla

resistance.

In addition, two cultivars [AC Harrow Delicious (HW608) and 'Harrow Bliss' (HW606)] were named, protected and introduced in Europe.

7.1. Brief Notes On Cultivars

The following are brief notes on introductions and selections, presented in approximate order of harvesting. Harvest dates were determined on trees grown at Harrow, Ontario, Canada. All these selections have good to excellent resistance (but not immunity) to natural fire blight infections.

7.1.1. Harrow Delight (HW603)

Harvested about August 10 at Harrow, ~2 weeks before Bartlett. Fruit colour is greenish-yellow with a red blush. Because it tends to drop heavily as it matures, fruit should be picked while still green. If left on the tree until the background colour changes to yellow, shelf life is also greatly reduced. The tree consistently produces good crops. Fruit size which is similar to Bartlett on unthinned trees is improved by thinning. Even when the skin colour is greener than yellow, flesh texture is very good, very juicy and free of stone cells. Fruit flavour is rated as high as Bartlett. When processed as halves or puree, Harrow Delight has had better-than-average ratings, but not as high as for Bartlett. Mature trees have excellent resistance to fire blight (9.5 rating on the USDA scale), but this cultivar is susceptible to pear psylla. Harrow Delight is pollen compatible with Harvest Queen, Bartlett, Bosc and Anjou. This cultivar was released in 1981 and therefore there are no propagation restrictions.

7.1.2. AC Harrow Gold (HW616)

Fruit are picked ~10 days before Bartlett, between Harrow Delight and Harvest Queen. An attractive yellow fruit, with good size (larger than Harvest Queen, similar to Bartlett), smooth skin, fine texture, very good flavour, and exceptionally juicy. The fresh fruit quality of AC Harrow Gold is rated similar to Bartlett. As with many other early season pears, the fruit will not store for very long (probably no more than 4-6 weeks), but it is excellent for roadside stands. The tree is fire blight resistant (9.5 rating). Pollination of Bartlett by AC Harrow Gold has been variable: in some years, it does not appear to pollinate Bartlett, while in other years, good fruit set has been obtained with AC Harrow Gold pollen. Bartlett does appear to consistently pollinate AC Harrow Gold. Precocity in a second test planting appears to be similar to that of Bartlett. AC Harrow Gold was introduced in 2000, and protection under the Plant Breeders Rights Act was granted in 2003.

7.1.3. Harvest Queen (HW602)

Picked the third week of August, ~1week before Bartlett. Fruit keeps on the tree very well and will increase in size with later picking. Fruit size is usually smaller than Bartlett, even with thinning which improves fruit size and reduces the tendency for biennial bearing. When grown on OHxF-333 rootstock, fruit size is further reduced, so that a higher proportion of fruit are unmarketable. Fruit quality, texture and flavour are as good as or better than Bartlett, both fresh and processed as pear halves. The tree has very good fire blight resistance (9.1 rating). Harvest Queen is pollen compatible with Harrow Delight, Bosc and Anjou, but not with Bartlett. This cultivar was released in 1981 and therefore there are no propagation restrictions.

7.1.4. AC Harrow Crisp (HW610)

A very attractive pear with red blush on smooth yellow skin. The cream-white flesh is smooth, grit-free, firm even when fully ripe, with a mild sweet flavour. The fruit matures at the end of August or early September, about the same time as Bartlett. It can be picked over a 2-week period. Early picked fruit can be stored for about 2 months, but storage life is reduced with later picking. If kept too long or picked too late, it will deteriorate internally without external signs. Fruit size on unthinned trees is slightly larger than Bartlett. It has a good to very good rating for quality of both fresh and processed fruit. Tree is medium in size, conical and upright, annually productive and hardy. It is a poor pollinator and will not pollinate

Bartlett, but Bartlett will pollinate AC Harrow Crisp to a limited extent. The tree has very good fire blight resistance (9.4 rating), similar to Harrow Sweet and Harvest Queen. Precocity of AC Harrow Crisp is similar to Bartlett, trees coming into production about 4 years after planting. AC Harrow Crisp was introduced in 2000, and protection under the Plant Breeders Rights Act was granted in 2003.

7.1.5. HW624

The fruit, which ripens about 7-14 days after Bartlett, have a light yellow background colour when ripe, with a very attractive bright red blush on the exposed side. Flavour and texture are very good. The original seedling had a good first crop in 1997, and yield was also good in 1998. This selection was advanced in 1998, and propagated for testing through OFTA in 2000. HW624 also has field resistance to pear psylla. It is not directly graft-compatible with Quince rootstocks. Protection under the Plant Breeders Rights Act was granted in 2012, and this selection will be introduced in the near future.

7.1.6. HW623

A late season pear harvested ~3 weeks after Bartlett. Fruits are yellow-green with a light blush, and a creamy-white flesh with smooth texture. Fruits have a long narrow neck, similar to Bosc. Yields have been moderate, and fruit size is medium-large. Protection under the Plant Breeders Rights Act was granted in 2010, and this selection will be introduced in the near future.

7.1.7. Harovin Sundown (HW614)

The fruit ripens about 3 weeks after Bartlett. The original seedling tree has been a good perennial yielder since being selected in 1982. Fruit shape is ovate to ovate-pyriform, with good size (similar to Bartlett). The fruit has a smooth yellow-green skin with a light russet in some years. The flesh is cream-white with good texture. While flavour is generally good, there can be some astringency in the skin which is reduced by storage. Poor fruit flavour due to astringency, even after storage, has been reported for fruit produced in cooler-than-normal seasons at Harrow, so this selection will probably not be adapted to the cooler growing season conditions in the Atlantic Provinces. This pear will store very well at -0.5 C for about 10 to 12 weeks (until late December). The tree is fire blight resistant (9.6 rating). It tends to produce secondary flower clusters which can lead to the development of late-ripening second crop. Secondary flowering has not resulted in increased fire blight infections. It does not appear to pollinate Bartlett well, but HW614 is pollinated by Bartlett. In second test plantings, precocity and productivity have been similar to Bartlett. Harovin Sundown was introduced in 2008 and protection under the Plant Breeders Rights Act was granted in 2010.

7.1.8. Harrow Sweet (HW609)

Harrow Sweet produces annual heavy yields of fruit ripening about 23-25 days after Bartlett. Fruit has yellow ground colour with red blush, and fruit size is comparable to Bartlett. Because it yields heavy crops, Harrow Sweet should be thinned to maintain fruit size and productivity. The fruit is very sweet and juicy, with excellent taste, and keeps well in cold storage for about 10 weeks (into December) - longer than Bartlett. It can be gritty around the core but this does not detract from overall quality. It has received acceptable ratings in processing trials at Harrow. The tree is medium in size, pyriform, upright spreading, hardy and consistently very productive. It has good fire blight resistance (9.3 rating), similar to Harvest Queen and Harrow Delight. Harrow Sweet is more precocious than Bartlett, producing fruit from lateral buds on one-year wood as well as on spurs, thus coming into production in the second or third year after planting; however, fruit size may be a problem on very young trees. Named in 1990, Harrow Sweet was the first release from the Harrow pear breeding program to be protected under Plant Breeders Rights legislation in Canada and Europe, and a US Plant Patent has been issued. This cultivar has been commercially available through our agent since 1996.

7.1.9. HW620

Attractive greenish-yellow fruit with no blush, ripening about 4 weeks after Bartlett. Fruit shape is similar to Bartlett. The original seedling, which is not thinned, may have a tendency to biennial bearing: in the lighter crop years, fruit size is larger than Bartlett, while in heavier crop years, fruit size is similar to or slightly smaller than Bartlett. Appropriate orchard management practices, especially pruning and thinning, have reduced this tendency in the early years of a second test orchard. Fruit texture is smooth and buttery with a mild pleasant flavour. Fruit will store well for about 12 weeks. The tree has very good fire blight resistance (9.3 rating) but pear scab has been a problem in some years. Protection under the Plant Breeders Rights Act was granted in 2012, and this selection will be introduced in the near future.

8. Commercialization

For information on commercial availability of introductions, please contact Agriculture and Agri-Food Canada, Office of Intellectual Property and Commercialization by email at OIPC-BPIC@agr.gc.ca.

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