The North American Small Fruit Industry 1903–2003. II. Contributions of Public and Private Research in the Past 25 Years and a View to the Future

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The North American small fruit industry, and especially the research structure that supports it, has changed markedly since the American Society for Horticultural Science met in Boston in 1978 to celebrate its 75th anniversary (Moore, 1979). As a graduate student at Michigan State University, and then a small fruit breeder at a public institution at the start of this period, I saw, heard and experienced first-hand many of the changes in the research structure. Trained primarily as a plant pathologist and classical geneticist, I marveled at the emerging DNA technology that promised to revolutionize cultivar development. High inflation in the United States and elsewhere during the 1970s and 1980s forced administrators to cut state experiment station operating budgets to free up funds for needed salary increases. Small fruit research programs, especially breeding programs such as the one I managed from 1981 to 1986 at Washington State University, were hit especially hard. Administrators hoped that the emerging molecular techniques would supersede traditional breeding, and researchers could tap into national funding sources for molecular research. I saw the state funded portion of my operating budget dwindle as fast as I could find new funds from the Pacific Northwest regional commodity commissions. My administrators encouraged me to seek competitive grants from the USDA, which meant a redirection of my effort from cultivar development towards basic genetic research. Similar changes occurred throughout North America. Today, we find fewer publicly funded small fruit breeding programs in the United States (Pittman et al., 1998) compared to 25 years earlier (Moore, 1979), and several of the remaining programs have redirected some of the effort away from cultivar development. The number of Rubus breeding programs did increase during this period (Finn and Knight, 2002), due in part to a novel joint venture between public and private sources of funding in Maryland, New Jersey, Virginia, and Wisconsin, but this program is in the process of being privatized (Swartz, 2002).

Despite the shift in emphasis towards basic research, the contributions of publicly funded research programs to the small fruit industry during this period have been outstanding. We have learned much about genetics, germplasm resources, pests and diseases, crop physiology, cultural practices, micropropagation, and environmental effects, from papers published in this society's journals and elsewhere (see recent volumes of *Acta Horticulturae* such as Brennan et al. 2002; Hepp, 2002; Hietaranta et al., 2002). Jennings (1988) covered most of the Rubus research before 1988. Hancock (1999) has recently reviewed much of the significant research on the strawberry (*Fragaria ×ananassa* Duch.) since Darrow's publication (1966).

Great strides have been made in our understanding of pests and diseases of small fruit. The excellent compendia from The American Phytopathological Society summarize the research on etiology, epidemiology and control measures for pathogens of all major small fruit crops (Caruso and Ramsdell, 1995; Ellis et al., 1991; Maas, 1998). Promising new sources of disease and pest resistance have been identified (Galletta et al., 1993; Maas et al., 2002; Meyer and Ballington, 1990; Shanks and Moore, 1995; Stretch et al., 2001). Entomologists and pathologists have developed integrated pest management systems for small fruit crops (Cooley et al., 1993; Strand, 1994). Pathologists, especially virologists, have used molecular biology techniques to incorporate disease resistance and improve pathogen detection (Duncan and Cooke, 2002; Jones, 2002; Jones et al., 2001; Martin, 2002). A perusal of recommended detection procedures for small fruit viruses over the past 25 years demonstrates the major contribution of molecular biology to pathogen detection during this period (Frazier, 1970; Converse, 1987; Martin, 2001).

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Three areas of small fruit research that have received major attention during the past 10 years are molecular biology, germplasm resources and health benefits, and the results of those efforts will be discussed in more detail.

MOLECULAR BIOLOGY CONTRIBUTIONS TO SMALL FRUIT IMPROVEMENT

Molecular biology offers great promise for improvement of small fruit crops, both by genetic modification (Jiménez-Bermúdez et al., 2002; Martin, 2002; McNicol and Graham, 1999; Mezzitti et al., 2002a, 2002b; Morgan et al., 2002; Serres et al., 1997) and by use of markers. Polashock and Vorsa (2002b) used markers for separation and estimation of genetic similarity among American cranberry (*Vaccinium macrocarpon* Ait.) clones where years of encroachment by wild vines and seedlings has left the identity of propagation stock in question. Marker assisted selection (MAS) has been successfully applied to many crops (Staub et al., 1996), and may be a valuable tool for small fruit crops, especially for disease resistance breeding (Graham and Smith, 2002; Lerceteau-Köhler et al., 2002; Nourse et al., 2002). MAS is not a tool that will benefit all breeding programs (Luby and Shaw, 2001), but it has already found use. For example, the Driscoll Strawberry Associates, Inc. (DSA) strawberry-breeding program now routinely screens about one-fourth of its 80,000-plus annual seedling population for one or more selectable marker. We realize significant savings in time and expense by using this process for select populations.

Unfortunately, the acceptance of genetically modified (GM) foods in North America and Europe has been poor, especially for fresh produce. Consumers are wary of GM food, unless it is clearly safe and clearly of benefit to the consumer. Until recently, most of the work has focused on traits that would improve production, not those that clearly enhance the safety or nutritional value of the harvested crop (Aharoni and O'Connell, 2002; Jiménez-Bermúdez et al., 2002; Martin, 2002; Morgan, 2002; Owens et al., 2002; Zeldin et al., 2002). We still must wait to see the benefit of this area of research. Programs that can use a combination of traditional breeding, marker assisted selection when appropriate, and transformation will probably be in the strongest position in the future (Polashock and Vorsa, 2002a).

SMALL FRUIT GERMPLASM RESEARCH

Considerable research in the past 25 years focused on the genetic diversity of small fruit crops, acquisition of germplasm, and strategies for expansion of the germplasm base (Moore and Ballington, 1990). We began to understand the limitations of the gene pool with which we worked, at least of the crops (Dale et al., 1993; Dale and Sjulin, 1990; Hancock and Luby, 1995; Hancock and Krebs, 1986; Hancock and Siefker, 1982; Lyrene, 1984; Sjulin and Dale, 1987). Isozyme analysis supported prior estimates of genetic relatedness based on pedigree analysis in cultivated strawberry, and found a pattern of reduced polymorphism in recently released cultivars from California/Mediterranean programs (Gálvez et al., 2002). Strategies for broadening the genetic base included maintaining a larger effective parental size in each generation, introduction of unrelated material from other breeding programs, and introgression of wild material (Sjulin and Dale, 1987). The USDA and University of Florida highbush blueberry (*Vaccinium corymbosum* L.) breeding programs had previously incorporated several *Vaccinium* species (Hancock et al., 1995; Lyrene, 2002), but most of the potential diversification was lost in the process of back-crossing to a narrow group of recurrent parents.

Several important collecting expeditions throughout the world were completed in recent years to expand collections of *Fragaria*, *Ribes*, *Rubus,* and *Vaccinium* (Ballington, 2001; Hancock et al., 2001; Hummer and Finn, 1999). Geneticists are now using these collections to broaden the germplasm base (Ballington, 2001; Finn, 2001), introduce specific traits (Finn et al., 2002), and reconstruct a cultivated species (Hancock et al., 2001). This latter approach in *Fragaria* is an ongoing effort that will incorporate superior wild clones as they become available (Hancock et al., 2003).

DIETARY RESEARCH IN SMALL FRUIT

The most exciting small fruit research in recent years has been the validation of the healthy attributes of small fruit consumption. This work began with studies on ellagic acid content of small fruit (Maas et al., 1991), but now has broadened to include all plant phenolic compounds with antioxidant activity (AA) (Törrönen and Määttä, 2002). AA is high in a diverse group of small fruit (Liu et al., 2002; Moyer et al., 2002; Sun et al., 2002; Yan et al., 2002), the potential contribution to the North American diet is quite significant (Vinson et al., 2001), and the levels of antioxidants in human serum rises after ingestion of fruit with high AA (Mazza et al., 2002). The benefits of these high AA fruit include reduction of carcinogens in humans (Chung et al., 2002) protection against tumor development (Kresty et al., 2001) and reversal of age-related effects on memory (Bickford et al., 2000). The heritability of AA levels and total phenolic content was reasonably high in highbush blueberry (Conner et al., 2002b), but genotype by environment effects were present (Conner et al., 2002c). Cold storage at certain temperatures seems to improve AA levels in several small fruit (Conner et al., 2002a; Kalt et al., 1999; Wang and Stretch, 2001), creating potential opportunities to enhance AA. Strawberry AA levels are affected by both growing temperatures (Wang and Zheng, 2001) and cultural practices (Wang et al., 2002), which may also provide opportunities to enhance AA levels. The future is promising for development of improved cultivars with enhanced nutritional value, but much work remains. This is an area of research that will benefit from newer molecular genetic techniques (Aharoni and O'Connell, 2002).

THE REEMERGENCE OF PRIVATE BREEDING PROGRAMS

Moore (1979) described how the small fruit industry in the first 75 years of the 20th Century evolved from complete use of cultivars developed by private breeders in the 19th century to nearly complete use of cultivars developed by public programs. This trend has reversed in the past 25 years, and now several private breeding programs are actively developing small fruit cultivars, especially in California. Privately developed cultivars now constitute about 30% of the California strawberry area (California Strawberry Commission, 2002b). At least five California-based programs, one northeastern U.S.-based program and one Florida-based program are active in the strawberry area. The California red raspberry (*Rubus idaeus* L.) industry is dominated by cultivars developed by Sweetbriar Development Co., now part of DSA. Other private raspberry breeding programs include two based in California (Plant Sciences, Inc., and a program led by Beth Crandall) plus one based in the eastern United States (Swartz, 2002). DSA has also recently begun a private highbush blueberry-breeding program.

Private breeding programs in other parts of the world are also making significant contributions to both the strawberry and the red raspberry industry (Finn and Knight, 2002), and cultivars developed by these programs are being tested in North America. The strawberry-breeding program managed by Peter Vinson in the United Kingdom has released several day-neutral cultivars, including 'Everest', the most widely planted day-neutral cultivar in the U.K. today. Recently, Redeva, a subsidiary of AFI-Redbridge in the U.K., was formed under the direction of Ronnie McNicol, and includes the former Medway Fruit breeding program managed by Derek Jennings (Jennings, 2002), and the GIYO strawberry-breeding program from Israel. Other important private strawberry breeding programs are the joint Darbonne–PLANASA program in France and Spain, and the CIV program in Italy.

The level of patent activity is one measure of the activity of private small fruit breeding programs, as these programs do use patents as one means of controlling use of their germplasm. In the 10-year period from 1983 through 1992, the U.S. Patent and Trademark Office (USPTO) issued 18 strawberry plant patents to two public programs and 20 to eight different private programs. In the latest 10-year period ending in 2002, the USPTO issued 30 strawberry plant patents to eight different public breeding programs and 57 strawberry patents to 12 different private programs. Twenty of the patents issued to private programs were granted to DSA, while the Darbonne–PLANASA group from France and Spain, and the Plant Sciences, Inc.-Berry Genetics Inc. group of Watsonville, Calif., were each granted eleven.

SUMMARY OF RESEARCH CONTRIBUTIONS IN THE PAST 25 YEARS

The preceding review is not intended to be a comprehensive review of all significant research affecting the small fruit industry. Rather, I intend to provide a sample of the many important findings during this period. Ironically, much of the publicly funded work has yet to have its effect on the small fruit industry. We are now benefiting from public research started 25 or more years ago, especially in the area of genetic improvement and production technology. Private industry research, especially private breeding programs, is now having a more immediate impact on today's small fruit industry.

THE NORTH AMERICAN SMALL FRUIT INDUSTRY TODAY

Today, the North American small fruit industry is characterized by strong geographic concentration of production by specialized producers and shippers. The Pacific Northwest produces most of the processed red raspberries. California now dominates the production for fresh market of strawberries, blackberries and raspberries, and Mexico is as a major supplier of fresh fruit of these three crops in the winter months. Cranberry production has grown rapidly in the past 25 years, but continues to be localized in specialized areas in New England, Wisconsin and the Pacific Northwest. Blueberry production is more diversified both geographically and in terms of production systems. Commercial rabbiteye (*V. ashei* Reade) and southern highbush production has expanded rapidly in the southern tier of the United States while northern highbush and wild lowbush (*V. angustifolium* Ait. and *V. myrtilloides* Michx.) production in the northern United States and Canada have remained strong. Chile has become a major supplier of fresh blueberries to North America from December through March, and Argentina is emerging as a significant source from October through December. Commercial cultivation of *Ribes* is very small, but some individuals are attempting to revive that industry. I will discuss the factors that have shaped change for each small fruit type individually.

Strawberry (*Fragaria* ×*ananassa* Duch.). The North American strawberry industry is by far the largest small fruit industry in North America. Reported United States fresh shipments to grocery retailers and wholesale markets in 2002 were about 597,000 t, with a total estimated fresh market production, including direct sales and u-pick, of 677,000 t (Agricultural Statistics Board, 2003). California represented 85% of the reported fresh shipments, Florida 12%, and North Carolina 1.5%. Another 35,000 t were imported into the United States from Mexico, mainly from Baja California (California Strawberry Commission, 2003). Total U.S. processed production was about 217,000 t in 2002, with California contributing 90%, Oregon 6.6% and Washington 3% (Agricultural Statistics Board, 2003). An estimated 47,000 t of processed product was imported in 2002, mainly from Mexico (Processing Strawberry Advisory Board of California, 2003). Total value of U.S. used production, fresh plus processed, was $1.22 billion, placing strawberries third in value in the United States in the noncitrus fruit category behind grapes and apples (Agricultural Statistics Board, 2003).

California's dominance of the North American strawberry industry is due in large part to a unique climate that allows extended periods of plant growth, flower initiation and fruit production (Bringhurst, 1991). Public and private breeding programs have exploited this unique climate since the University of California began a breeding program in the late 1920s. A well-known example is the development of day-neutral strawberry cultivars derived from a wild clone of *F. virginiana*