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).

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.

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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* ssp. *glauca* (Bringhurst and Voth, 1978). The first commercially important day-neutral cultivar, 'Selva', gave the California industry an opportunity to increase overall volume without creating peak periods of heavy volume. 'Selva' and other day-neutral cultivars, when grown along California' central coast in a winter-planted system, increased overall production and lengthened the harvest season by shifting the harvest from a concentrated April through June period to a 7-month season from early April to early November.

A second, lesser-known system developed by DSA over the past 15 years is the planting of frigo plants of everbearing or day-neutral cultivars in southern California in midsummer. These plants begin producing fruit in late September and continue to fruit until mid-December to early January, depending on the season. This system is now used on about 700 ha in southern California, and has greatly increased the supply of fresh strawberries from California in the autumn–early winter period. Other private breeding programs are now developing cultivars for this system (Crandall et al., 2002), and the area planted in this system could increase rapidly.

The two systems described above, plus the development of earlier fruiting short-day cultivars for southern California winter-spring production, have changed the nature of the strawberry supply curve in California. Total fresh shipments of strawberries from California have increased more than 3-fold in the past 25 years (California Strawberry Advisory Board, 1979; California Strawberry Commission, 2003). The volume shipped during peak weeks has declined from 10% of season total volumes in the 1977–79 seasons to 6% in the 2000–02 seasons as shown in Fig. 1. The proportion of fruit shipped outside of April to June, the three highest volume months, has increased during this same period from 26% to 43% of season total volumes (California Strawberry Advisory Board, 1979; California Strawberry Commission, 2002a; California Strawberry Commission, 2003). Growers receive better average prices for fruit produced outside of weeks with heaviest volumes, which has helped profitability in the presence of declining real (inflation-adjusted) prices and increasing spreads between retail prices and grower prices (Bertelsen 1995; Evans, 2002).

The Florida strawberry industry has benefited from active breeding and cultural research programs in the past 25 years. A series of improved cultivars from the University of Florida breeding program led by Craig Chandler and, to a lesser extent, cultivars from Florida-based private breeding programs have replaced most of the University of California cultivars that were previously grown. Yields have improved markedly in the past 25 years, but can vary considerably from year to year due to adverse weather (Bertelsen, 1995). A major industry objective is control of anthracnose fruit and crown rot caused by *Colletotrichum* spp. The strategies for control include resistance breeding, chemical control and production of pathogen-free nursery stock in areas isolated from inoculum sources.

A present industry concern is the impending phase-out of methyl bromide (MB) soil fumigation, a nearly universal practice in California and Florida in the past 25 or more years (Albregts and Howard, 1984; Wilhelm and Paulus, 1980). However, the USDA has invested heavily in MB alternatives, and prospects for a chemical alternative are promising (Obenauf, 2002). In addition, the U.S. government has nominated MB for a critical use exemption that includes strawberry production and strawberry nursery use as separate categories. Those of us in the industry hope that a critical use exemption can be retained at least for selected uses, such as postharvest fumigation or strawberry nursery use, where alternative fumigants have not been as effective.

A complete loss of soil fumigants would have a major impact on the strawberry industry, with an estimated 35% to 40% yield loss in the first year, potentially increasing to 50% or more with subsequent cycles of nonfumigation (Shaw and Larson, 1999). Additional threats would be the increased incidence of fungal and nematode diseases, and higher weed control costs. Verticillium wilt was a major pathogen in California before soil fumigation (Wilhelm and Paulus, 1980), and the general level of resistance in current California cultivars is poor. Shaw et al. (1996) have found an effective level of variability in resistance to *Verticillium dahliae* in the Univ. of California strawberry germplasm, and believe that resistant cultivars could be developed. Plant manipulation is another technique that can lessen the impact of verticillium infection for some cultivars (Shaw et al., 2002).

Despite the impact of soil fumigation noted above, the success of the industry over the past 25 years is not based solely on high inputs of pesticides, water and plastic, as has been implied by others (Pritts, 2002). Neither is it the goal of strawberry producers to produce poor-tasting product that has limited affordability. For example, the California industry universally adopted methyl bromide-chloropicrin soil fumigation in the mid-1960s (Wilhelm and Paulus, 1980), yet yields have improved markedly since. Yields in California averaged 44.4 $t\cdot ha^{-1}$ from 1972 to 1974 (Seelig, 1975), while they averaged 62.9 $t\cdot ha^{-1}$ from 2000 to 2002 (California Strawberry Commission, 2003). This yield improvement has come largely through introduction of day-neutral germplasm, widespread adoption of an annual planting system, improvements in production technology and the health of nursery stock, and several cycles of complete replacement of cultivars with improved versions. In the past 25 years, both the public and private breeding programs in California have completed four to five generations of selection and improvement in the current group of most widely planted cultivars ('Camarosa', 'San Miguel', 'Diamante' and 'San Juan'). Water use has been reduced, and yields have improved, through improvements in drip irrigation technology. Release of predators and mechanical removal of insect pests (e.g., vacuuming) have reduced the number of insecticide and miticide applications made directly to the crop. These improvements in genetics, production systems, planting stock and non-chemical pest and disease control have supported the rapid growth of

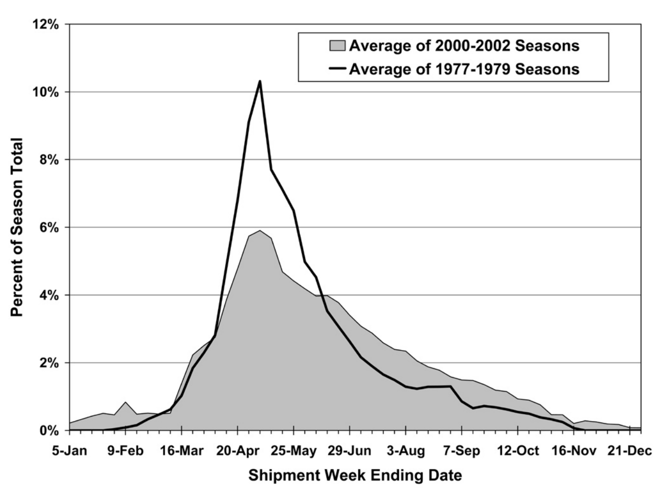

Fig. 1. Weekly fresh market shipments of strawberries from California expressed as a percentage of total shipments for each season. Data adapted from the California Strawberry Advisory Board (1979) and the California Strawberry Commission (2002a, 2003).

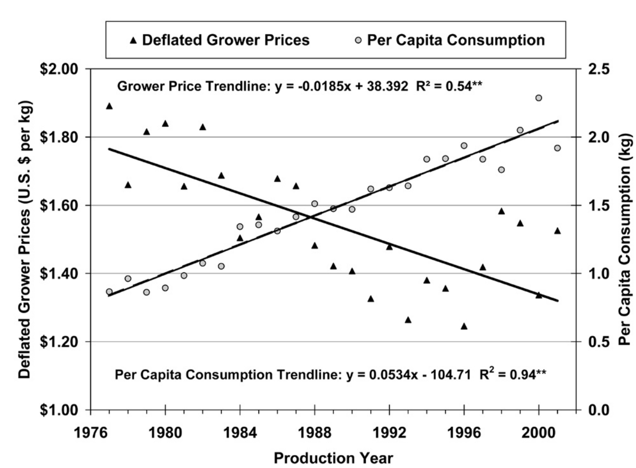

Fig. 2. Inflation-adjusted (deflated) price received by U.S. strawberry growers and per capita consumption of fresh strawberries in the United States from 1977 to 2001 (Bertelsen, 1995; Evens, 2002).

an organic strawberry industry in California (California Strawberry Commission, 2002b).

The concern that strawberries are unaffordable to poorer people is counter to industry price and consumption trends. The inflation-adjusted prices received by growers has declined by about one-fourth in the past 25 years while per capita consumption of fresh strawberries has more than doubled (Fig. 2) (Bertelsen, 1995; Evans, 2002). Finally, the perception that the industry cannot develop large, attractive fruit that taste good is too often based on older cultivars with poor flavor such as 'Selva' that have now been nearly replaced (California Strawberry Commission, 2002b). Recent releases from private breeding programs such as the 'San Miguel' and 'San Juan' cultivars mentioned above have combined very large fruit size with high flavor.

Raspberry (*Rubus*, subgenus *Idaeobatus*) and blackberry (*Rubus*, subgenus *Eubatus*). The Pacific Northwest region continues to dominant North American production of these crops. Red raspberry (*R. idaeus* L.) production from Oregon and Washington has increased more than three-fold in the past 25 years to 41,000 t annually. About 95% of the harvest is processed (Evans, 2002). Canadian production, primarily in British Columbia, has increased 75% in the past 25 years to 13,000 t (Food and Agriculture Organization United Nations, 2003). Demand for processed products such as juice, yogurt base and individually quick-frozen berries has stimulated new plantings, especially in Whatcom County, Washington and in the Fraser River Valley of British Columbia. The 'Meeker' cultivar released in 1967 is planted on about 70% of the production area in the Pacific Northwest (Washington Red Raspberry Commission, 2003). Oregon produces most of the North American black raspberry (*R. occidentalis* L.) crop, with a reported 1,700 t harvested from about 500 ha, virtually all of which is processed. This production has increased slightly in the past 25 years, but year-to-year volumes vary considerably (Evans, 2002).

California has emerged in the past 25 years as a major shipper of fresh market red raspberries. The primocane-fruiting 'Heritage' (Daubeny et al., 1992) and the 'Willamette' (Daubeny et al., 1989), which double-cropped along California's central coast area, were important cultivar early in this period. Today, growers licensed by DSA produce a majority of this production, using proprietary cultivars developed by Sweetbriar Development Co. (now part of DSA). Other private California breeding programs are introducing patented varieties, but there is no public research activity. The total volume of fresh red raspberries shipped from California in 2001 was reported as 12,900 t, which was 98% of the U.S. total. Imports from Chile and Mexico that year were 1,400 t and 1,500 t, respectively (Long and Marando, 2002). Most of this North American fresh market production is now grown under plastic-covered tunnels adopted from Spanish and U.K. strawberry tunnels.

Oregon produces most of the reported blackberry production in the United States, and production has increased in the past 25 years to a range of 16,000 to 20,000 t. Nearly all of the production is processed, and is produced from about 2,500 ha of trailing types such as 'Marion' and 'Evergreen Thornless', plus some hectares of new releases from the USDA breeding program at Corvallis, Ore. (Evans, 2002; Finn, 2001).

Growers across the United States produce a significant volume of fresh market blackberries from plantings of trailing, erect and semi-erect types (Finn, 2001). Pittman et al. (1998) reported nearly 1,000 ha of erect and semi-erect blackberries in a 1998 survey, much of which is in the southern United States. Unfortunately production from this region is not reported by USDA market statistics. Plantings in the southern United States have increased markedly in recent years, and production is based predominantly on a series of successful cultivars released by the University of Arkansas breeding program (Moore, 1997). In California, production is based on the 'Olallie' trailing blackberry and semi-erect cultivars, especially 'Chester Thornless' (Galletta et al., 1998). Reported fresh blackberry shipments in 2001 were 1,500 t from California and 500 t from Oregon. Imports of fresh blackberries were 4,200 t, with 85% of the shipments from Mexico, the remainder split evenly between Costa Rica and Guatemala (Long and Marando, 2002).

Blueberry (*Vaccinium* spp.). The North American blueberry industry has change tremendously in the past 25 years in terms of total production, geographic distribution and types of blueberries grown. Driving the change have been northern highbush cultivars developed by Arlen Draper that were introduced by the USDA blueberry breeding program in New Jersey (Vorsa, 1997), as well as southern highbush cultivars from breeding programs in Arkansas, Mississippi, North Carolina, and Florida. The contributions of these cultivars to the North American and world blueberry industry have yet to be determined, but many are complex hybrids involving several *Vaccinium* species from a diverse ecological range (Hancock et al., 1995). These cultivars have already expanded fresh market opportunities, lengthened harvest seasons and opened up new areas for production, both in North America and in other parts of the world, especially Chile (Lyrene and Muñoz, 1997).

The North American Blueberry Council estimates total North American production at 175,500 t in 2002 (North American Blueberry Council, 2003), which is four times greater than the production reported by the Food and Agriculture Organization of the United Nations (FAO) 25 years ago (FAO, 2003). About 60% of the production was from highbush types (including rabbiteye types) and 40% was from wild lowbush fields. Somewhat more than half of the highbush production in 2002 was marketed fresh, while 98% of lowbush production was processed. The percent of the total crop used fresh has remained fairly constant over the past 25 years, ranging from 30 to 40% (Evans, 1997, 2002).

Production area increased rapidly between 1978 and 1990 in Michigan, the leading North American highbush production area, but has now leveled off at 6,800 ha. Yields changed little during this time but tended to fluctuate widely between 3 and 6 $t \cdot ha^{-1}$ (Agricultural Statistics Board, 2003). Most of the Michigan area is planted to older cultivars such as 'Jersey' that are poorly adapted to fresh market production, and about 70% of the harvest is processed. New plantings of improved cultivars such as 'Duke' should offer greater opportunity for fresh market sales (Trinka, 1997).

Blueberry area in New Jersey has remained constant at about 3,000 ha while yields have improved significantly, stabilizing between 5 and 6 $t \cdot ha^{-1}$. The industry has moved rapidly in the past few years to replace older cultivars with larger-fruited cultivars better suited for fresh markets. The 'Duke' cultivar, developed by the USDA in New Jersey in cooperation with Duke Galletta's Atlantic Blueberry Company, seems particularly well adapted to New Jersey conditions. It is slow to de-harden in late winter and has a later blossoming period than older cultivars, thus avoiding frost and freeze injury (A. Draper, personal communication). The New Jersey industry markets more fresh fruit than any other state, about 14,000 t, nearly 80% of the entire crop (Agricultural Statistics Board, 2003).

The highbush blueberry industry in the Pacific Northwest region of North America has expended much faster than any other region. The British Columbia highbush industry now rivals New Jersey in annual volume, about 18,000 t (B.C. Blueberry Council, 2003). Oregon production has increased 12-fold in the past 25 years to 13,000 t annually, while yields have doubled to about 11 $t \cdot ha^{-1}$, highest in the United States. Production in Washington has nearly tripled in the past 25 years to 6,000 t through a combination of a modest yield increase and a more than doubling of production area (Agricultural Statistics Board, 2003). A majority of the production in the Pacific Northwest is based on older cultivars such as 'Bluecrop' that are mainly machine-harvested in Oregon or Washington, but mostly hand-harvested in British Columbia (B.C. Blueberry Council, 2003; Trinka, 1997). Newer plantings are mostly improved cultivars such as 'Duke' or 'Toro' that are suited for either fresh market or processed use.

Many cultivars developed in the eastern United States perform as well or better in the Pacific Northwest than in their original area of selection, due to fairly mild winters and mostly dry harvest periods. For example, the 'Chandler' cultivar selected in New Jersey and the 'Ozarkblue' cultivar from Arkansas seem better adapted to Oregon (Finn et al., 2000). Production in the region as a whole is split evenly between fresh markets and processing (North American Blueberry Council, 2003). A range of climatic zones and cultivars, combined with improved storage technology, gives the area the potential to ship fresh blueberries from June to November (Long and Marando, 2002). Some Oregon growers are also experimenting with rabbiteye cultivars to increase late-season volume. To improve access to eastern U.S. markets throughout this long fresh-market season, growers in this region sometimes consolidate their blueberry fruit with shipments of other fruit and vegetables at California shipping points.

North Carolina and Florida deserve mention as producers of highbush blueberries. Production in North Carolina has doubled to 7,000 t in the past 25 years as yields have doubled while the production area has remained around 1,500 ha. New southern highbush cultivars introduced by the North Carolina State University breeding program led by James Ballington have built upon the earlier work of Ralph Sharpe in Florida and the USDA program led by Arlen Draper. These cultivars have complex pedigrees that contain *V. darrowi*, *V. ashei,* and *V. tenellum* in their background along with *V. corymbosum*. Best known of these cultivars is 'O'Neal', which has exceptional flavor and is cultivated around the world in low-chill regions. Adoption of these cultivars by the North Carolina growers has improved the level and consistency of production (Agricultural Statistics Board, 2003; Ballington et al., 1997).

The Florida highbush blueberry industry is quite small and annual production is variable, ranging from 700 t to 1,400 t annually over the past 4 years (Agricultural Statistics Board, 2003; Evans, 2002). Yields are the lowest in North America, yet the Florida industry generates strong interest for two reasons. First, it is the earliest North American production region, and growers in Florida often receive very high prices for their production which is all marketed fresh, mainly in April and May (Fig. 3). Second, Florida is home to a very successful southern highbush breeding program now led by Paul Lyrene. Lyrene's cultivars and those developed by his predecessor Ralph Sharpe have been successfully used both in Florida and throughout the world in low-chill environments. Lyrene has released ten southern highbush cultivars in the past 10 years, and these are undergoing thorough evaluation in many areas (Lyrene, 2003).

The California blueberry industry is a rapidly emerging industry to watch in the future. Many hectares of fertile, sandy soils in the Central Valley of that state are, subject to pH modification of soil and water, well suited for the crop. Harvest in the Central Valley begins in May and continues through June. Production sites along the south coast of California show promise as well, and plants in those sites typically bear fruit over a much longer period, from April to July (Gaskell, 2001, 2002). The production area has not been surveyed, but may be in excess of 400 ha. The most promising cultivars are southern highbush types, and 'O'Neal' is the most widely planted. New releases from the University of Florida program are being widely tested.

The rabbiteye blueberry industry is heavily concentrated in Georgia, where late frosts have limited plantings of most southern highbush cultivars. The Georgia rabbiteye industry has grown rapidly in the past 25 years from a minor production state to an annual production level of 7,700 t on 1,800 ha (Agricultural Statistics Board, 2003; Krewer and NeSmith, 2002). The majority of the fruit is processed, but improved rabbiteye cultivars have helped develop a growing fresh market. One drawback of the rabbiteye types is their long bloom to ripe fruit period, which means growers miss higher early season prices. The USDA breeding program in Mississippi led by Jim Spiers has recently released

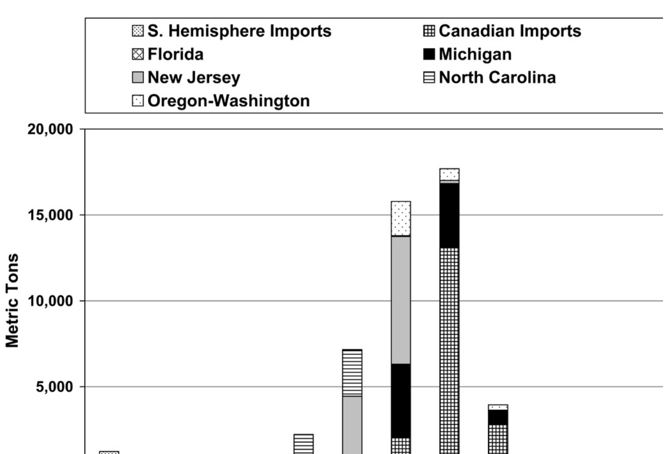

Fig. 3. Monthly fresh market blueberry shipments in the United States in 2001 reported from domestic and imported sources by Long and Marando (2002).

four southern highbush cultivars that bloom late but ripen earlier than rabbiteye types. Some of these, such as 'Magnolia', have performed well in initial southeastern U.S. regional trials (Gupton and Clark, 1998), but area of southern highbush cultivars is currently small (Krewer and NeSmith, 2002).

Wild lowbush blueberry production has trended higher in the past 25 years. Total production area is estimated to be nearly 53,000 ha, but the area harvested each year is influenced by expected price (Yarborough, 1997). Maine is the largest producing area with 35 to 45% of the total crop. The remainder of the crop is harvested from the Canadian provinces (in order of importance) of Quebec, Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland. About 98% of the crop is processed. Better management of these native stands has markedly improved yields, due to improved weed control, introduction of pollinating bees, irrigation and better understanding of fertilizer practices (Smagula and Yarborough, 1990; Yarborough, 1997).

Cranberry (*Vaccinium macrocarpon* Ait.). I do not profess any special wisdom or insight on the cranberry industry, so my comments will be brief. Reported production has more than doubled in the United States in the past 25 years, through the combination of a 50% increase in harvested area and a 50% increase in yield. During this period, Wisconsin has increased its share of U.S. production to about 50%, up from 33% in 1978. Demand for processed cranberries was very strong through most of this period, especially for juice products. However, in the past 5 years prices received by growers have fallen precipitously, from a high of nearly $66 U.S. dollars per 45-kg barrel in 1996 to $17 to $21 per barrel during the 1999 to 2001 seasons. Total industry crop value has fallen to early 1980s levels (Evans, 2002). Use has improved in 2002 from the 2 prior years, which may indicate that the worst of the price decline is behind the industry. However, since 90 to 95% of the crop is processed, the industry will be vulnerable to offshore production. The U.S. share of total world production has fallen from 94% in 1978 (the remaining 6% was from Canada) to 84% (Food and Agriculture Organization United Nations, 2003). In addition to Canada's current 12% share of world production, the FAO now reports significant production from Azerbaijan, Belarus, and Latvia. European production is believed to be *V. oxycoccus* L. harvested from the wild, which is mainly marketed as juice concentrate (Calvin, 1997). Chile is also developing a significant cranberry industry based on *V. macrocarpon* (Stang, 1997). For a review of other recent cranberry production trends in the United States, consult Caruso (1997).

THE FUTURE

James N. Moore was uncannily accurate in his vision of small fruit research and industry developments at an address given to this society 25 years ago (Moore, 1979). He predicted the role of germplasm collecting and molecular biology in making new gene sources and gene combinations available. He correctly forecast the greater emphasis placed on breeding for fruit quality and nutritional value. He understood the significant contributions that day-neutral strawberry cultivars, primocane-fruiting raspberry cultivars and blueberry cultivars adapted to wider climates would make to their respective industries. He also foresaw the role that tissue culture would play in speeding introduction of new cultivars and in germplasm preservation, even though the path to the first application has been bumpy.

I cannot hope to be as prescient as Moore was, but I do see several important trends over the next quarter-century. Overall, I believe that the North American small fruit industry is in a strong position at the start of our society's next century. We have a great opportunity, as the North American consumer has become more aware of the positive benefits of increased fruit and vegetable consumption. The small fruit industry, through increased research and marketing efforts, can be a major contributor to an improved diet while gaining economic benefit.

The fresh-market segment of the small fruit industry is in a particularly strong position. The relatively short shelf life of strawberries, raspberries and blackberries limits their production to areas that are within 5 days transport of the North American markets. The additional cost of airfreight will tip the balance in favor of producers that are within truck transport distance. This means that areas with low costs per delivered unit of fruit will be in the strongest position. The coastal regions of California, with cool, dry summers, long production cycles and high yields, will continue to supply the majority of North American spring, summer and autumn fresh market production in the next 25 years for these three crops. Primocane-fruiting germplasm developed at the University of Arkansas and North Carolina State University (Clark, 1999) will revolutionize the blackberry industry in much the same way as primocane-fruiting raspberries, by dramatically extending the fresh market season. Mexico will emerge as the major supplier of winter production of these crops. The North American Free Trade Agreement, improved highways, and proximity to an increasing proportion of North American population all favor direct truck shipments of these crops from production regions in Baja California and high elevation areas of the Central Mexico states of Jalisco, Michoacan, and Guanajuato.

Land, water and labor issues will plague the fresh market industries of these same three crops. I do not believe that machine-harvest of these crops for fresh markets will be widespread during the next quarter-century, so the supply of harvest labor will impact the growth of these industries. Picking aids that eliminate stoop labor in strawberry fields are being tested today in California and Florida, and will be widely adopted in the future. Conversion of land to nonagricultural uses and competition for water will result in a shift of production of these crops away from the south coast of California, replaced by increased production in Mexico and along the central coast of California.

The fresh market blueberry industry will continue to grow rapidly, and the increased supply of fruit from South America will be complementary to the increased supply from North America. Demand should grow as supplies grow, and more consumers will purchase blueberries any week of the year, following the pattern seen in strawberries. Regions such as Florida that have depended on high prices during low supply periods will be vulnerable to lower-cost producers from both North and South America. The recent cultivar releases from Paul Lyrene's program along with better cultural practices will hopefully improve Florida blueberry yields. Improved late-season cultivars and better post-harvest storage technology (Ehlenfeldt, 2002) will increase supply from South America in March and April and from North America during October and November. Improved early-season cultivars and expansion of production in Argentina, Chile and California will also increase supply in the October–November and April–May periods. Once the remaining gaps in supply are filled and seasonal price fluctuations diminish, the growth of blueberry production will be based on efficient production. Mechanical harvesters will continue to improve, and fresh marketing of mechanically harvested fruit will be commonplace. All fresh market cultivars of the future will have to suitable for mechanical harvest, as producers seek to lower harvest costs.

One impediment to future progress in the blueberry industry will be grower reluctance to plant new cultivars. Breeding programs have recently released a large number of northern and southern highbush cultivars, and growers will not be interested in replacing plantings of these new cultivars for some time to come, as they will need to recoup high initial investment costs. Time will be needed to sort through this batch of new material.

The processing segment of the small fruit industry will be increasingly vulnerable to low-cost producers in various countries around the world that have greater sources of low-wage harvest labor. Expansion of strawberry production in China, Mexico, Poland, and Turkey, blueberry production in China, Poland, and South America, cranberry production in Chile, and raspberry and blackberry production in Mexico will all increase pressure on traditional North American sources of processed supply. California will adopt strawberry cultivars with improved processing characteristics, which will place further pressure on the Pacific Northwest strawberry industry due to the lower per unit production cost in California.

My greatest area of concern for the future is the lack of strong programs to turn basic research findings into applications. A wealth of scientific discovery in the genetics, germplasm resources, molecular biology and dietary contribution of small fruit in the past 25 years is waiting to be applied. Future research will yield even greater potential applications, as the level of publicly funded research is strong. A survey of the USDA Current Research Information System (CRIS) in early 2003 found over 200 active small fruit research projects on a wide range of topics. Many of these scientists no longer have the development funds to turn these results into commercial applications, and the performance evaluation system in the public research sector may not adequately recognize and reward developmental research. Universities have allowed scientists to share in the financial rewards of commercial applications of patented research, but this incentive has been effective only where there is already an established application, such as chemicals or cultivars applied to large areas of production. Also, the increased complexity of the basic research, especially in molecular genetics and nutrition research, increases the difficulty of developing commercial applications.

The small fruit industry as it exists today has been closely tied to the genetic improvement of each crop over the past century. Major advances in each crop have often been linked to the development of a specific genotype that created new opportunities for the industry. For example, the mix of germplasm used as a base for the Univ. of California strawberry breeding program contained 'Nich Ohmer', a cultivar with extended floral initiation in cool coastal areas. This character contributed to the yield advantage and extended fresh market period of the initial releases from the Univ. of California program (Darrow, 1966). The development of 'Tufts' by the Univ. of California program and 'Heidi' by the DSA program made annual winter planted strawberry systems feasible, which in turn led to lower production costs, longer harvest periods and improved fruit quality (Welch et al., 1982). More recently, the development of day-neutral cultivars by the Univ. of California program and everbearers by the DSA program has dramatically changed the California fresh market supply curve, resulting in year-round shipments from a single state (Fig. 1).

Similar advances have occurred in other small fruit crops following introduction of specific cultivars. The introduction of the 'Cuthbert' red raspberry in the 1880s spurred the development of a fresh market shipping industry in western Washington (Hedrick, 1925; Ramsey, 1924). Improved cultivars released from Pacific Northwest breeding programs in the past 75 years, most notably the 'Chilliwack' and 'Tulameen' cultivars, have expanded fresh market opportunities in many parts of the world (Kempler and Daubeny, 1999). Development of primocane-fruiting raspberries, especially the 'Heritage' cultivar, extended the fresh market season, allowing raspberries to be on the produce shelf all year when combined with Northern and Southern Hemisphere production (Daubeny et al., 1992). Likewise, the development of certain raspberry cultivars such as 'Willamette' and 'Meeker' stimulated the development of machine-harvested raspberries (Daubeny et al., 1989; Moore and Daubeny, 1993). Blackberry fresh marketing has expanded much more quickly with the development of firmer, thornless cultivars (Moore, 1997), some of which have also extended the length of the fresh market season in California (Long and Marando, 2002). Primocane-fruiting blackberries (Clark, 1999) and lower-acidity cultivars will stimulate future fresh market sales. Blueberry cultivars adapted to lower-chill environments such as 'O'Neal' and 'Sharpblue' (Lyrene and Sherman, 1992), and extremely late-ripening cultivars like 'Elliott' (Ehlenfeldt, 2003), in combination with Northern and Southern Hemisphere production zones have put blueberries on the fresh market all year (Fig. 3). Newer firm-fruited cultivars such as 'Duke' have enabled machine harvesting for fresh markets (B. Caster, personal communication).

I fully expect future advances in the small fruit industry to be closely linked to cultivar development. I am, of course, speaking from the bias of a classical plant breeder, but I have a century of history to back up this statement. We must continue to develop cultivars in order to stimulate progress. Many of the industry advances listed above resulted from observations and discussions made following the release of specific cultivars.

I am particularly concerned about the level of strawberry cultivar development outside of California and Florida. A combination of strong public and private research programs have continued to advance production technology in those two states, creating a large gap in production economics relative to the remaining regions. Although day-neutral strawberry germplasm has been widely available since the early 1980s, little progress has been made in development of improved day-neutral cultivars for most areas of North America. In contrast, improvement of day-neutral cultivars and associated cultural systems has progressed rapidly in the United Kingdom (The Fruit Grower, 2003;

Vinson, 1998), using both public and private industry funds. Productivity of commercial day-neutral strawberry fields in the United Kingdom far exceeds those reported in comparable climatic zones in the United States. States such as North Carolina that have adopted a strawberry plasticulture system (Poling, 1993) have improved yields dramatically in the past 20 years (Bertelsen, 1995), but these states are still using older cultivars developed in California (Butler et al., 2002). Lack of suitable cultivars is also a major limitation to adoption of improved cultural systems in colder regions of the United States (O'Dell et al., 1999). Given the strong regional differentiation of strawberry germplasm (Gálvez et al., 2002; Sjulin and Dale, 1987), cultivars tailored to these regions and to specific cultural systems are urgently needed.

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