Chapter 1
Trends in Fruit Breeding

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Abstract Fruit breeding is a long-term process which takes a minimum of about a decade from the original cross to a finished cultivar. Thus, much thought needs to go into which objectives to be emphasized in the breeding. Although certain objectives, such as yield and basic quality, are always important, the overall lifestyle, environmental, marketing, and production trends affect the objectives that breeders emphasize in their programs as they strive to anticipate the future needs of the fruit industry. The importance of each trend varies with the crop and environment. The major trends are to develop cultivars which simplify orchard practices, have increased resistance to biotic and abiotic stress, extend the adaptation zones of the crop, create new fruit types, create fruit cultivars with enhanced health benefits, and provide consistently high quality.

Keywords Food marketing • Carbon foot print • Food for health • Fruit quality • Labor, food safety • Organic, sustainable production • Global warming • Environmental contamination • Host plant resistance

1 Introduction

Fruit breeders need to anticipate cultivar needs at least 10 years into the future, as this is the minimum time that most fruit cultivars take to develop from pollination to release. This chapter explores the larger trends in our lives, such as environmental issues, health consciousness, consumer trends in lifestyle, and the expectations and needs of producers to examine how these affect the objectives of our fruit breeding programs.

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2 Trends in the Business of Plant Breeding

Improved plant protection legislation in the USA, Europe, and throughout the world has stimulated substantial research and the development of new plants for commercial exploitation. This has also tended to shift the breeding into the private sector (Heisey et al. 2001; Frey 1996, 1998; Traxler 1999). This shift was quicker for the annual large acreage crops, such as corn, where public-generated commercial cultivars in the USA disappeared in the 1940s and the use of publically generated inbred lines ceased in the 1970s. Currently, public corn breeders concentrate more on basic research into corn breeding and genetics (Traxler 1999).

In fruit crops, this shift has been slower and dependent on the crop, with those crops with shorter life cycles and larger markets shifting to the private sector more rapidly. Throughout the world, the proportion of peach releases from public programs has decreased from 45% in the 1980s to 34% in the early 1990s (Della Strada et al. 1996; Della Strada and Fideghelli 2003; Fideghelli et al. 1998). During the last decade in the USA, only ~15% of the peach and nectarine cultivars were released by public institutions. Support for the development of apricots, cherries, and apples is still with public institutions, but this is eroding and the private sector is becoming more involved in the release and marketing of new cultivars (Kappel 2008; Fideghelli and Della Strada 2010; Lespinasse 2009). The initial development of many small fruits, such as strawberries, blueberries, blackberries, and raspberries, was done by public breeders, but currently the private breeders are expanding their efforts to develop proprietary cultivars with a marketing advantage (Clark and Finn 2008; Finn et al. 2008; Hancock and Clark 2009).

Another factor is decreased funding for public breeding programs. In the USA, the public funding dedicated to breeding activities has decreased dramatically since the 1970s as the government shifted from a philosophy of completely funding programs to assisting programs with partial funding (Moore 1993; Frey 1996; Heisey et al. 2001). Thus, those programs that were able to develop additional sources of funding were able to survive. Many did not. A similar trend is seen in Europe.

In the early 1980s, most public fruit breeding programs in the USA made public releases without protecting the intellectual property. The idea was to get the cultivar out to the producer without charging twice since tax dollars were used in the development of the new cultivars and to maximize germplasm exchange (Moore 1993). In the present environment, public breeding programs are raising money by patenting their releases and partnering with the private sector to test and market new cultivars. Although these arrangements are working, it has led to less germplasm exchange among the public breeding programs. There is a need to modify the paradigm to encourage germplasm exchange (Hancock and Clark 2009).

The other aspect of this trend is the amount of ongoing research into germplasm development, genetics, and new breeding techniques. In the USA, private fruit breeding programs devote more than 90% of their efforts to the development of new cultivars, whereas public breeding programs only devote 36% of their efforts to developing new cultivars (Table 1.1); the other 64% of their efforts are in germplasm

Table 1.1 Public versus private breeding programs in temperate fruit and nut crops in the USA (Frey 1996, 1998)

Activity	Public	Private
Cultivar development (%)	36	91
Germplasm enhancement (%)	36	6
Genetic research (%)	28	3
Total (scientist-years) effort	73	32

development, genetics, and breeding technology (Frey 1996, 1998). The funding for this type of research which also funds the training of new plant breeders comes mainly from federal grants. This is where private breeding programs need to get more involved because industry support strongly influences the governmental funding decisions (Sansavini 2009; Byrne 2005; Llacer 2009). This research is essential for the long-range success of the breeding programs in the world

3 Broad Trends Affecting Fruit Breeding

Fruit breeders need to be cognizant of the major issues of the day that influence the production, marketing, and consumption of fruit as they are, in part, a predictor of the future. The cultivars that they are developing currently will not be important in the marketplace for about a decade. There are several broad trends that influence the breeding objectives of breeders.

3.1 Environmental Issues

The most important issue is the preservation of our environment. This is a very broad issue that includes a wide range of discussions on environmental contamination, sustainable agricultural development, biodiversity, and global warming.

The environmental contamination discussion considers the use of pesticides, fungicides, fertilizers, and plastics, their role in the contamination of the ground water, soil, and the general environment, their effect on the flora and fauna and on human health, and the ability to recycle. These concerns have launched innumerable studies into integrated pest control, organic farming techniques, recycling, optimization of resource use, biodegradability of agricultural chemicals and other inputs, and the effects of agricultural chemical accumulation on the ecology and biodiversity of the agroecosystem. These studies have led to more restrictions of the use of agricultural chemicals and the development of more environment-friendly and sustainable fruit production and marketing systems.

Global warming relates to agriculture mainly as agriculture replaces the forests and the carbon footprint generated in the production and marketing of fruit. Some have argued that a long-term fruit production system is more sustainable than an

Table 1.2 Relative energy cost of moving freight according to the mode of transportation (Heyes and Smith 2008)

Mode of transportation	Description	Energy (MJ/ton km)
Air	Short haul	23.7
Air	Long haul	8.5
Road	Small van	1.7
Road	Large truck	1.1
Sea	Roll on/roll off	0.55
Sea	Bulk carrier	0.15

annual crop production system which may be true, but in both cases the natural vegetation is replaced by an introduced crop reducing biodiversity tremendously. Although this discussion is important, more pertinent to this article would be the carbon footprint of production and marketing of fruit. In the mid 1990s, the concept of "food miles" was popularized as a tool to measure the environmental consequences of our globalized food system. This approach did not take into account how food was transported or any of the production and postharvest aspects of production and thus was not very accurate in its conclusions (Coley et al. 2009). Since then, there has been a shift toward measuring the "carbon footprint" using a more comprehensive approach, the Life Cycle Assessment, which attempts to calculate the carbon cost of the product from production through harvesting, processing, marketing, consumption, and the disposal of any waste (Brenton et al. 2009; Sim et al. 2007). This type of analysis has indicated that even though a fresh product is produced several thousand miles away it does not mean that its carbon footprint is greater than locally produced product, especially if the production costs are high, the product is not in season, or it needs to be stored for an extended period. Good examples of this would be comparisons of the carbon footprints of apples consumed in Europe and produced in either Europe or the southern hemisphere (Blanke and Burdick 2005; Milà i Canals et al. 2007) and cut flowers for Europe and produced in either the greenhouse in Holland or Kenya (Brenton et al. 2009).

In most cases, it would seem that the carbon footprint of locally produced fruit in season is less than that of imported fruit. Given that the market wants a year-round supply of fresh fruit, the issue becomes how to reduce the carbon footprint of out-of-season fruit. The cost of transportation varies widely depending on the mode of transportation, with air freight being 15 to over 100 times more energy intensive than sea freight (Table 1.2). Among the modes of land transportation, larger trucks are less energy intensive than smaller trucks and freight by train is about 50% more energy efficient than truck transportation (Canning et al. 2010). This cost to transport fresh produce is a critical component of the carbon cost of supplying product in the off season, especially for fruit that is highly perishable.

As global marketers go "green" and reduce their carbon footprint, there is a trend to transport fruit more via boat versus airplane, as this reduces the carbon footprint tremendously. Although this is routinely done with such crops as apples, grapes, nuts, bananas, and citrus, many other crops, such as berries and stone fruit, have short postharvest durability which limits their ability to be shipped consistently via sea freight. This requires improved postharvest characteristics of the fruit cultivars. In addition, there is greater emphasis to produce fruit locally wherever possible which creates a need for more locally adapted cultivars.

The other footprint which needs to be reduced in the future is the water footprint of production. Water quantity and quality are becoming major challenges in many growing regions. Currently, 70% of the world's fresh water supply is used in agriculture (Sansavini 2009). This reality has spurred much research in better delivery (i.e., drip irrigation) and more efficient management techniques (real-time weather monitoring linked to irrigation control). More needs to be done to develop the genetics that perform well under less or with poorer quality water.

3.2 Health Consciousness

As we learn more about the benefits of fruit consumption in human health (Prior and Cao 2000; Wargovich 2000), the demand for healthier foods is increasing. These foods could take the form of fresh fruit with high levels of health-promoting substances or other natural products, such as fruit extracts for natural sources of antioxidants, antimicrobials, or food colorants for the health and food industries (Cevallos-Casals et al. 2002, 2006).

Currently, it seems that no matter where you look there is information on the health benefits (or hazards) of everything. Health concern is one of the major driving forces of the world food market and globally, although it varies by region, is the first or second most important concern of consumers. Consumers see the connection between diet and health and associate their diets with the prevention of cardiovascular disease, vision problems, lack of energy, obesity, arthritis/joint pain, and high cholesterol (Sloan 2006; Dillard and German 2000). Since the early 1990s, the US Government has been promoting the consumption of three to five servings of fruits and vegetables for good health, and recently raised this suggested level to five to nine servings of fruits and vegetables per day which would include three to four fruits or two cups of fruit per day (Wells and Buzby 2008; USDA 2005). Unfortunately, the average per capita consumption of fruits (both fresh and processed) in the USA is only about 1/2 of this with only a 5–6% increase since the mid 1970s (Fig. 1.1). This increase is primarily due to the per capita increase in fresh fruit consumption (~20%) as the consumption of processed (canned, frozen, juice, dried) fruit has decreased about 6% over this same period (Pollack and Perez 2008; Wells and Buzby 2008).

Fruit has been in the forefront of the food for health movement with a proliferation of superfruits which are touted to have exceptional health benefits. Although the best known are blueberries, pomegranate, and several exotics like acai, noni fruit, and mangosteen, many of our temperate fruits have also been claimed to be super fruits as can be easily seen in a quick Internet search for the terms 'superfruit' and your favorite fruit. Such a search quickly determines that someone promotes fruits, such as the apple, plum, prune, blackberry, raspberry, strawberry, grape, black currants,

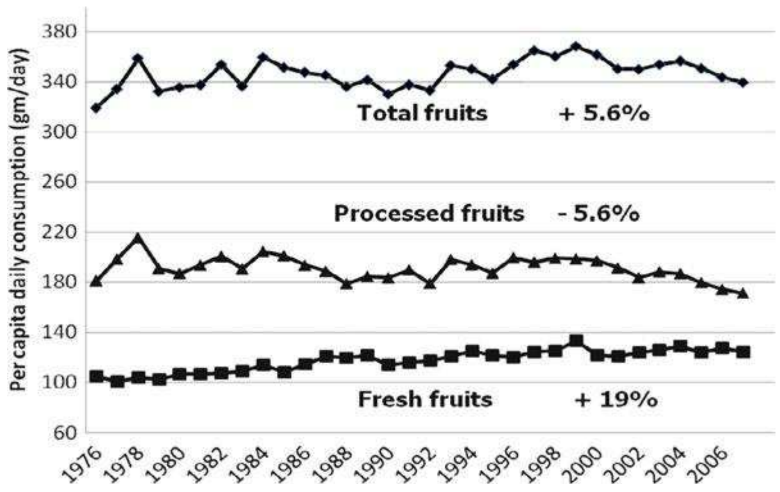

Fig. 1.1 Per capita fruit consumption in the USA (data from Pollack and Perez 2008)

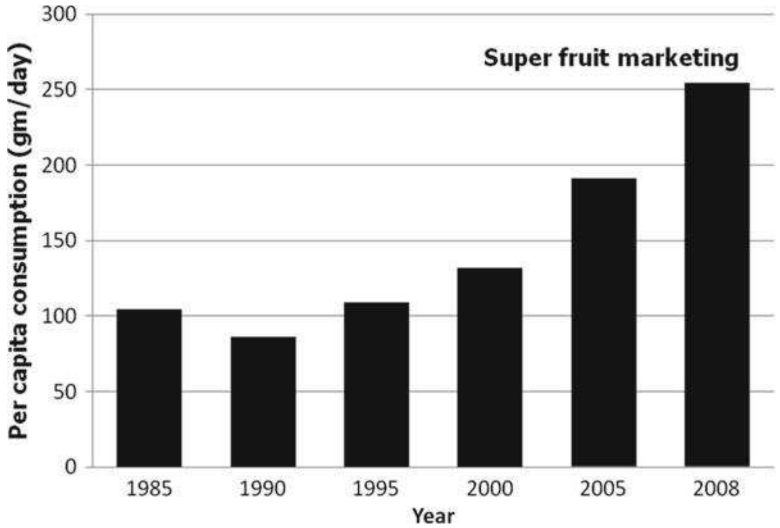

Fig. 1.2 Per capita blueberry consumption in the USA (data from Pollack and Perez 2008)

persimmons, orange, and cherry, and others as superfruits. The term is not well-defined, so it only denotes that a particular fruit is perceived to be particularly beneficial from a health perspective. Thus, it is mainly a marketing term. Nevertheless, the blueberry has seen a distinct increase in per capita consumption in the USA since it was promoted as a superfruit in the late 1990s (Fig. 1.2). This type of marketing has shifted and promoted the consumption of more fruits.

The other side of this health consciousness is the consumer concern over the safety of the food supply and the possible contamination of our fresh fruits with pathogenic agents, pesticides, and fungicides (Johnston and Carter 2000; Batt and Noonan 2009; Sloan 2006; Wei 2001). These concerns have led to stricter regulations and more testing for residues in our produce along with improved systems to trace the source of the produce. This allows excellent enforcement if residues are found, so the potentially tainted produce can be removed from the market and any problems can be corrected (Golan et al. 2004; van Rijswijk et al. 2008).

This food safety concern has led to the greater interest in growing fruit using sustainable or organic production systems which use few or no agrochemicals. This market, although still small, is rapidly growing (20–35% annually) (Delate et al. 2008) with the USA and the EU being the largest consumers of organic produce (Dimitri and Oberholtzer 2005). About 3% of the apples worldwide are being grown organically (Granatstein and Kirby 2007) and 1–5% of the fruit in the EU is certified organic. This is low compared to the 10% market share that organic vegetables have in the EU (Weibel et al. 2007; Sansavini 2009). The rapid growth is also reflected in the mainstreaming of organic produce from a specialty produce category mainly carried by natural food stores to a produce item found in most conventional grocery stores (Dimitri and Greene 2002; Dimitri and Oberholtzer 2005; Granatstein and Kirby 2007; Martinez 2007).

Currently, much of the organic tree fruit production is in semiarid climates with traditional cultivars, where disease control is not the major issue as the disease and pest control procedures are still not reliable. In spite of higher prices (20–40%), the higher risk and lower yields (15–40% less), especially for more humid zones, have discouraged growers from switching from conventional to organic production. In apple production, although the scab-resistant cultivars facilitate organic production, the apple market is cultivar specific and the acceptance of these cultivars in the mainstream market is limited. The potential benefits, both economically and environmentally, have encouraged increased private and public investment to develop better management approaches and disease-resistant cultivars for sustainable and organic agricultural systems throughout the world (Delate et al. 2008; Granatstein and Kirby 2007; Weibel et al. 2007; Sansavini 2009). Whereas public policy in the USA has relied on the free market approach to encourage organic production, in the EU "green payments" are used to subsidize the transition costs from conventional to organic production (Dimitri and Oberholtzer 2005). More common (60–90% fruit sales) in Europe are Integrated Fruit Production systems which are designed to minimize the use of agricultural chemicals.

3.3 Consumer Expectations and Habits

Consumer expectations drive the marketing trends. Thus, beyond the search for products that are "green," healthy and safe as previously discussed, consumers now expect to have produce that is convenient to eat, of consistent quality, good flavor,

Table 1.3 Fresh fruit production of major Southern Hemisphere temperate fruit exporters (http://FAOstat.fao.org, accessed 10 Nov 2010)

Fruit	1970	1975	1980	1985	1990	1995	2000	2005
Strawberry	11	15	19	23	37	46	70	86
Plum	13	13	14	14	19	24	31	45
Cherry	15	18	16	18	22	31	39	48
Pear	447	470	497	547	699	1,019	1,296	1,353
Peach	697	811	798	756	786	881	986	1,139
Apple	1,400	1,560	1,980	2,500	3,190	3,940	4,500	4,990

Figures are 5-year averages in 1,000 mt
Argentina, Australia, Brazil, Chile, New Zealand, Peru, South Africa

and of a wide variety all year round (Byrne 2005; Sloan 2006, 2007, 2008; Lucier et al. 2005; Jaeger 2006; Jaeger et al. 2003; Jaeger and Harker 2005; Blisard et al. 2002).

Globally, there is a shift toward a supermarket distribution system which requires fruit with good storability (Frazão et al. 2008). Furthermore, with the advent of technological advances in transportation, storage, remote monitoring of refrigerated systems, and communications, the global trade of all agricultural products and particularly fresh fruits and vegetables has blossomed. In 1961, the value of the global trade in fruits and vegetables was $360 million, and by 2001 it had grown to a value of $11.8 billion. Since the 1980s, the global trade of fruits and vegetables has increased more rapidly than any other agricultural commodity (Huang 2004; Huang and Huang 2007). This has allowed the long-distance shipment of fruits to the markets, allowing exotic tropical fruits as well as off-season temperate fruits to arrive to a market destination thousands of miles away from the production site in excellent condition. An example of this would be the growth of fruit production in the Southern Hemisphere (Argentina, Australia, Brazil, Chile, New Zealand, Peru, South Africa) to supply the off-season markets in the Northern Hemisphere. The production of these countries increased rapidly beginning in the 1980s (Table 1.3).

Beyond the year-round availability, the diversity of produce items available in supermarkets has increased over the last several decades (Calvin and Cook 2001). This reflects not just an expanded array of cultivars or fruit types available for temperate fruits, but more exotic fruits and a new class of convenience food: the minimally processed products (Handy et al. 2000).

The minimally processed product reflects our ever-increasing tendency to fix meals in less time and to eat out more often (Stewart et al. 2006). The time spent preparing food in the USA has decreased from 65 to 31 min a day from 1965 to 1995 partially due to the use of minimally processed and other prepared foods as well as the increase of food preparation and cleaning appliances in the home. The percent of calories eaten away from home in the USA has increased from 18 to 32% from the mid 1970s until the mid 1990s (Canning et al. 2010). This trend to use minimally processed foods has extended to the food service industry as they strive to cut preparation costs. This is reflected by the decrease of jobs available in the food service industry and the increase of jobs available in the food processing industry in preparing these minimally processed products from 1996 to 2000 (Canning et al. 2010). Unfortunately, this trend to eat out more tends to decrease the consumption of fruits and vegetables (Guthrie et al. 2005), although there are efforts by fast food and other food service venues to develop offerings that are healthier (Martinez 2007; Sloan 2007). Nevertheless, as postharvest and packaging technology improves, more washed, peeled, precut, and packaged produce will be there in our future (Handy et al. 2000; Allende et al. 2006).

Convenience, along with health issues, is a major driving force in the food marketing business, and time constraints are an important barrier to eating healthy. Thus, healthy snacks based on fruits and vegetables that deliver one or several servings are being actively developed (Sloan 2007; Jaeger 2006). A convenient fresh fruit needs to be consistently available, keep well, not be susceptible to bruising or other postharvest damage, not be messy to eat, eaten without a utensil, and be suitable for a range of uses (meals, snacks, desserts). Fruits differ dramatically in their convenience, with apples and bananas being excellent and peaches, melons, and mangoes not very convenient to eat (Jaeger 2006).

Although convenience and health are important desires, fruits also need to have consistent quality and flavor. The difficulty to make good on these requirements varies widely from fruit to fruit. Nuts, citrus, apples, and grapes are easier to deliver with consistently good quality and flavor than stone fruit, strawberries, and blackberries. Surveys have identified the lack of consistent quality as a major reason people do not buy peaches (Byrne 2005). In addition, there is a willingness of consumers to pay more for better quality (Opara et al. 2007), which is the reason for developing branded fruit that consistently delivers quality fruit (Jaeger 2006).

3.4 Producer Expectations: Simplified Management

To stay in business, a producer needs to produce high yields of quality fruit for a minimum of expense both economically and from a management perspective. Thus, any cultivar used needs to be productive and produce quality fruit as has been discussed previously. In fruit and vegetable production, the two largest variable expenses are for labor and for agricultural chemicals to protect the crop from damaging diseases and pests (Lucier et al. 2005).

The high cost and need for trained labor, especially in developed countries, has led to a research emphasis on modifying tree size, growth, and cropping, simplifying training techniques, and mechanization of fruit tree production. Dwarfing rootstocks have been available and commercially used for apple for 60 years to create orchards with smaller, easier-to-handle trees that generally produce more precociously and at a higher yield. Unfortunately, in most crops (i.e., cherries, pears, peaches, plums), dwarfing rootstocks are a relatively new innovation which is currently being researched with renewed excitement (Webster 2006; Reighard 2000; Reighard and Loreti 2008; Lang 2000).

This approach is complemented by developing scion cultivars that do not set excessive fruit, set fruit without cross-pollination or with parthenocarpy (Kappel 2008; Socias i Company 1990, 1998; Sansavini and Lugli 2008; Lespinasse et al. 2008), grow less (spur, compact types), and have unique growth forms that lend themselves to high-density, highly productive plantings (columnar/pillar, weeping) that may simplify or allow the mechanization of pruning, thinning, harvesting, and other processes of orchard management (Webster 2006; Liverani et al. 2004; Scorza et al. 2006).

Beyond the environmental and health costs of using agricultural herbicides, fungicides, and pesticides, their use requires a substantial economic and management cost. Thus, there is an increasing need for scion and rootstock cultivars that are tolerant/resistant to a wide array of nutrient problems, pests, and diseases.

4 Trends in Fruit Breeding Goals

These broad trends influence the objectives of breeding programs in many ways as the breeder is always trying to anticipate the future needs of the fruit industry. The importance of each trend varies with the crop and environment. The major trends are to develop cultivars which simplify orchard practices, have increased resistance to biotic and abiotic stress, extend the adaptation zones of the crop, create new fruit types, create fruit cultivars with enhanced health benefits, and provide consistently high quality.

4.1 Simplifying Orchard Practices

A major driver of this category is the cost of labor and management of fruit crop production. The high cost of labor, especially in developed countries, has led to research emphasis on modifying tree size or growth, simplifying training techniques, and the mechanization of fruit and nut tree production over the last 50 years. The objective of limiting the vegetative growth of tree fruit and nut species is particularly a problem on fertile soils and in lower chill subtropical and tropical zones, where the growing season is greatly extended as compared to temperate production zones. Among tree fruits, the apple has led the way with its use of size-controlling rootstocks, high-density orchards, and specialized pruning techniques to maximize precocity, yields, and quality while minimizing pruning and general management costs. This success has spurred research in other fruit tree crops and substantial progress has been achieved in pears, cherries, peach, and plum (Beckman and Lang 2003; Lang 2000; Fideghelli et al. 2003; Scorza et al. 2006; Reighard 2000; Reighard and Loreti 2008; Webster 2006).

There are two complementary genetic approaches to modify the tree size and architecture. One can work on the rootstock and/or the scion component of the orchard system. In apple, pear, and cherry, all generally large orchard trees, most effort has been invested in developing rootstocks that induce less scion growth and greater precocity. These dwarfing rootstocks were essential in the development of the modern high-density apple orchard by providing an inexpensive approach to control the scion growth as well as improving precocity, light penetration within the canopy, and allowing greater efficiency of pesticide applications. In the last 20 years, especially with stone fruit, there has been a shift from seedling to clonal rootstocks (Beckman and Lang 2003) which has facilitated the use of interspecific hybrids as rootstocks, especially those between distantly related species which are more probable to result in rootstocks that are able to dwarf the scion cultivar.

The approach from a scion perspective has been to modify tree architecture. This ranges from selecting within the standard growth type for better branching habit and increased spur formation to developing cultivars with unique tree architecture. These new growth habits range from dwarf, semi dwarf, compact, pillar, and weeping (Hu and Scorza 2009; Scorza et al. 2006; Liverani et al. 2004; Fideghelli et al. 2003; Webster 2006; Lauri et al. 2008; Segura et al. 2007; Schuster 2009). Between 1990 and 2000, 56 of the 2,700 fruit cultivars released had unique growth types. The most common being dwarves and spur types (apples). Unfortunately, with the exception of the spur-type apples which were mainly bud sports of established cultivars, these releases are mainly for garden use due to their current lack of fruit quality (Fideghelli et al. 2003). More recent work on pillar types in peach has resulted in several new cultivars with improved quality (Scorza et al. 2006; Liverani et al. 2004).

The most promising growth modifications useful for high-density and/or higher yielding capacity appear to be the pillar type and spur growth habit. Both these allow better light penetration, require less pruning, and potentially could deliver greater yield efficiencies (Fideghelli et al. 2003; Kodad and Socias i Company 2006; Scorza et al. 2006; Socias i Company 1998; Kenis and Keulemans 2007). The weeping habit is also being explored by several peach breeding programs as a growth habit that would decrease management costs (Scorza et al. 2006; Bassi and Rizzo 2000). Whatever results from this work, it is clear that the optimal training system needs to be developed for each unique tree architecture (Scorza et al. 2006) and marketing needs to bundle these unique cultivars with the optimal training systems.

Beyond facilitating harvest by modifying tree growth and architecture, there is an increasing interest in mechanical harvesting to reduce labor cost and time required for harvest. There are already mechanical harvesting systems for a range of crops but mainly for processing as the cosmetic appearance requirements are less demanding. Nevertheless, breeding for more uniform ripening, ease of detachment, non-bruising types, and better firmness should lead to cultivars better adapted to mechanical or at least to a once-over harvest approach as compared to the multiple harvests needed with the current cultivars.

4.1.1 Fruiting Stability

All breeding programs select for high fruit set and are always looking for stability of fruit set in spite of the climatic conditions. An important trait to ensure consistent fruit set is self-fertility. Currently, there are various dioecious species (pistachio, kiwi), monecious species (pecan, walnut), and species with perfect flowers that display self-incompatibility (apple, plum, sweet cherry, almond) which require cross-pollination either via wind or insects as pollinators. This need for cross-pollination requires the planting of pollinizers, management of pollinators, and the presence of appropriate weather during the pollination period which complicates management and creates more uncertainty in production. No work is ongoing to transform dioecious or monoecious crops into perfect-flowered, self-compatible, or parthenocarpic crop. This is basically what happened during the development of the modern grape which began as a dioecious species in the Neolithic period and was, over thousands of years, transformed into the current perfect-flower, self-compatible fruit crop (Riaz et al. 2007). Currently, there is active work in the development of sweet cherry, Japanese pear, apricot, and almond cultivars that are self-fertile, and in the development of pear and persimmon cultivars that consistently set fruit parthenocarpically or are self-fertile (Gradziel 2008; Gradziel and Kester 1998; Socias i Company 1990; Apostol 2005; Kappel et al. 2006, 2011; Sansavini and Lugli 2005; Okada et al. 2008; Yamada et al. 1987). These incompatibility systems have been studied genetically, and currently there are markers that can be used for characterizing the incompatibility alleles present in various species (Tao and Iezzoni 2010; Schuster et al. 2007; Kodad and Socias i Company 2009; Guerra et al. 2009; Bokszczanin et al. 2009).

4.2 Resistance to Insect and Disease Problems

Concerns about the safety of agricultural workers, potential of environmental contamination, and safety of the consumer have spurred the development of tighter governmental restrictions on the use of agricultural chemicals and on alternate pest and disease control strategies. This has led to greater governmental and privately funded work in integrated pest and disease management systems to reduce the amount of pesticides and fungicides used in the production of fruit (Dimitri and Greene 2002; Dimitri and Oberholtzer 2005; Weibel et al. 2007). One facet of these management systems is the use of genetic resistance to various diseases and pest problems.

Each crop has multiple important disease/pest problems (Table 1.4), some which are worldwide in distribution while others regional. Throughout the world, there has been an increased emphasis on the development of higher levels of disease and pest resistance in fruit scion and rootstocks. In Europe, there are 64 pome fruit breeding programs of which two-thirds are in apple breeding and one-third in pear breeding. Most of the scion programs are developing new pome cultivars with disease resistance (scab, powdery mildew, fire blight) as important objectives, and from 2000 to 2004 almost half of the apple cultivars released by these programs had resistance to scab and many times to other pathogens as well (Lespinasse 2009). Unfortunately, the vast majority of the apple and pear production does not use disease-resistant cultivars even in IFP because the market demands high quality and consumers

Table 1.4 Disease and pest problems of major tree fruit crops

Crop	Disease	Pathogen/pest	Comments
Pome fruit	Apple scab	*Venturia*	Genes/markers identified, many resistant apple cv.
	Powdery mildew	*Podosphaera*	Genes/markers identified, resistant apple cv.
	Fire blight	*Erwinia*	Active work, resistant apple/pear cv. and rootstock
	Black spot	*Stemphylium*	Little work, widespread on pear
	Psylla	*Cacopsylla*	Transmit pear decline
Stone fruit	Brown rot	*Monolinia* spp.	Little progress, some less susceptible cv.
	Bacterial leaf spot	*Xanthomonas*	Good progress, polygenic, resistant cv.
	Plum pox	*Potyvirus*	Genes/markers identified, active breeding, transgenic resistant plum
	Peach scab	*Cladosporium*	Little work, widespread problem
	Root knot nematodes	*Meloidogyne*	Genes/markers identified, resistant rootstocks
Citrus	Citrus greening	*Candidatus Liberibacter*	No resistance known
	Citrus canker	*Xanthomonas*	Tangerines moderately resistant, polygenic resistance
	Citrus tristeza virus	*Closterovirus*	Genes/markers identified, resistant rootstocks, active breeding
	Phytophthora	*Phytophthora*	Resistant rootstocks
	Nematodes	*Tylenchulus*	Genes/markers identified
Grapes	Powdery mildew	*Erysiphe*	Gene identified, active breeding
	Pierce's disease	*Xylella*	Gene identified, active breeding
	Nematodes	*Meloidogyne*	Dominant gene, resistant rootstocks
	Phylloxera	*Daktulosphaira*	Resistant rootstocks

Source: Brown (2003); Lespinasse (2009); Lespinasse et al. (2008); Fischer et al. (2003); Byrne (2005); Gmitter et al. (2007); Riaz et al. (2007); Ramming et al. (2009)

generally do not sacrifice quality for less pesticide use. In addition, the pome market's cultivar specificity makes it very difficult for a new cultivar to enter the market without a substantial promotion effort (O'Rouke et al. 2003; Weibel et al. 2007; Fischer et al. 2003).

From a breeding perspective, the incorporation of a simply inherited adaptation trait, such as low chilling in peach, Pierce's disease resistance in grape, and scab resistance in apple from a wild germplasm, takes at least three cycles of backcrossing into high-quality genotypes to reach a commercially acceptable fruit quality (Byrne et al. 2000; Ramming et al. 2009; Brown 2003). These disease-resistant cultivars, although acceptable and compete well in the local market, do not necessarily compete well with the quality of the cultivars available in the regional or international markets. Thus, several more generations of breeding are necessary. Unfortunately, multiple resistances are needed in each cultivar, which makes incorporating disease resistance with excellent quality and production a much more challenging goal.

Nevertheless, on the few diseases that have received substantial attention such as apple scab, bacterial leaf spot in peach, plum pox in apricot, fireblight in pear, and Pierce's Disease in grape, rapid progress has been achieved in transferring good resistance into commercially acceptable background. Thus far, the effort expended on developing disease/pest resistance in tree fruit crops has been minimal, and as this effort increases resistant cultivars that have the quality and production characteristics needed for widespread commercial use will emerge as has been seen in the major agronomic and vegetable crops.

Efforts and advances in development of genomic tools facilitate the identification of genes involved in resistance to diseases and the implementation of molecular markers for the selection and introgression of resistance genes into fruit crops. There has been excellent progress in identifying markers for resistance genes to apple scab, various nematode species, plum pox, and powdery mildew (Riaz et al. 2009; Gardiner et al. 2007; Esmenjaud and Dirlewanger 2007), although their incorporation into breeding programs is still in its infancy. The use of transformation to increase the disease resistance of fruit is species specific. Transgenic plants are much easier to generate in species, such as apple, pear, and citrus, than in stone fruits, such as peach, almond, plum, or apricot. Nevertheless, this effort has led to a plum pox-resistant European plum cultivar which is currently being field tested (Scorza 2000; Ravelonandro and Scorza 2009). Once these techniques are better developed, transformed cultivars could lead to reduced pesticide use, but the public acceptance of such cultivars is still not known.

4.3 Expansion of Production Zones

With the strong demand for fruit availability on a year-round basis and with the advances in postharvest, communications, and transportation which have made the sourcing of fruit from any place in the world a possibility, production is shifting into new production regimes and regions. According to FAO figures (FAOSTAT, http://apps.fao.org/), the production of the major fruits in the world has increased two- to threefold over the past 30 years. This production increase has not been even throughout the world, as the fruit industries' importance in developed countries, such as Japan, Canada, the USA, and many European countries, has leveled off or decreased over the last 20–30 years, whereas it has rapidly increased in Asia (mainly China), Africa, and South America.

Temperate-zone breeding programs of most fruits and nut crops have successfully extended the harvest season by developing earlier and later ripening cultivars and by breeding cultivars adapted to the extremes of the temperate zones. Peach breeding efforts in North America and Europe have extended the fruit availability from about 1 month to 6–8 months. The limitation is the climatic cycle. Work to overcome climatic restrictions has led to the production of fruit crops under protection (greenhouses to high tunnels) to extend the harvest season forward or backward. This has been increasingly used in the temperate zone, and with stone fruit can move the

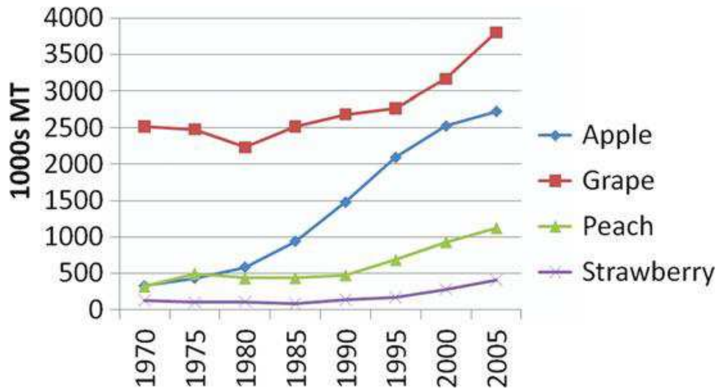

Fig. 1.3 Fruit production in medium- and low-chill zones of the Americas and Northern Africa

harvest forward 30–90 days and with some small fruits could allow year-round production (Jiang et al. 2004; Lang 2009; Gaskell 2004; Demchak 2009). Currently, the cultivars used are those developed for field production. For more efficient production, specialized cultivars adapted to the greenhouse environment would be the best. These would be low- and medium-chill cultivars with a short fruit development period (if the objective was early ripening) and medium vigor, ability to grow well under low light conditions, ability to set fruit under high temperatures, and high quality since the soluble solids of protected culture produce fruit are usually 1–2% Brix lower than field-produced fruit (Jiang et al. 2004; Byrne 2010). These structures are also used to protect the crop from rain to minimize disease issues, avoid fruit cracking, and can generally lead to better and more consistent fruit production and quality.

Within temperate-zone production, off-season fruit can be produced in the opposite hemisphere. Consequently, over the last 30 years, fruit production in the temperate zone of the Southern Hemisphere (Chile, Argentina, South Africa, Australia, and New Zealand (Table 1.3)) has increased to supply the winter fruit demand in the Northern Hemisphere markets (Europe, North America, and Asia). Even so, there are still gaps in the supply of many fruits in March/April and October to December. These gaps are being closed more and more by the production of temperate fruit species in the subtropical and tropical zones.

There is a trend toward increased production in subtropical and tropical regions in the Americas (Brazil, Bolivia, Mexico, Uruguay, and Ecuador), northern Africa (Algeria, Egypt, Morocco, and Tunisia) (Fig. 1.3), and Asia. Although the climates vary tremendously in the subtropical and tropical regions, the major climatic restrictions found in these regions are heat related: chilling requirement and heat tolerance. Initially, production in tropical zones took advantage of the cooler tropical highland conditions, where traditional medium to high chill cultivars could be grown either directly or with some cultural manipulation to compensate for a lack of chilling. These production systems have evolved to include lower chill cultivars, especially as the production moved to warmer zones and the dormancy management systems were improved. These production systems are exemplified by the double cropping systems developed for grapes and peaches in the warm tropics and continuous production possibilities for berry and peach production in the cool tropical highlands (1,500–2,500 m above sea level) (Clark 2005; Lavee 2000; George and Erez 2000).

The pioneering work in low-chill fruit breeding was done with peaches. This began in California and continued in Florida (USA), Texas, Louisiana, Mexico, Brazil, and South Africa. In many low-chill breeding programs, the emphasis is to develop early ripening cultivars to extend the harvest season forward to capture the lucrative early fruit market. In contrast, the Brazilian programs, although early cultivars were developed, many mid-season and late-ripening cultivars were also released to support their local produce/processing industry (Byrne et al. 2000). Currently, most of the peach production in many subtropical and tropical regions is sold in the regional market. This success has encouraged increased activity in stone fruit, pome fruit, and berry medium- and low-chill breeding programs (Byrne et al. 2000; Hauagge and Cummins 2000; Darnell 2000; Hancock 2000; Lyrene 2005) with the resulting commercial development of fruit production enterprises in these zones.

As the production moves out of the tropical highlands to the warmer tropical climates, the tolerance to high heat during bloom and throughout the fruiting cycle becomes critical. Fruit crops vary tremendously in their sensitivity to heat. Among those most sensitive to poor fruit set under high heat conditions (25°C) during flowering are peaches, nectarines, strawberries, and blackberries, whereas apples, plums, and grapes appear to fruit well under warmer conditions (Lavee 2000; Hancock 2000; Clark 2005; Jackson 2000; Byrne 2010). Heat during the growing season can also affect bud initiation and development and fruit quality while the fruit is developing. In many crops, high temperatures (>25°C) can lead to poor fruit bud initiation and development, more rapid fruit development, problems with good fruit sizing, fruit shape, and fruit color (anthocyanin) development (Byrne 2010; Kozai et al. 2004; Hancock 2000; Hauagge and Cummins 2000). Although much more work needs to be done, there has been progress in developing low-chill genotypes that are heat tolerant in peach, apple, strawberries, blackberries, and other crops, and this bodes well for future work.

Beyond the adaptation traits of low chilling requirement and tolerance to heat during bloom and fruit development, there is a need to select genotypes well-adapted to the cultural manipulations used to avoid dormancy and induce the flowering/fruiting cycle in the cropping systems used in the tropics. This would include the ability of the genotype to rapidly develop flower buds to allow a rapid cycling, ease of induction via hormone application or cultural manipulation, and the ability to crop well through multiple cycles of fruiting per year.

Various other abiotic challenges are encountered more as fruit production expands to new regions, where the soil/water combination is nonoptimal for fruit production due to soil pH, salinity, or moisture status. In many fruit crops (peach, pear, citrus, grape), there has been some work to develop rootstocks adapted to calcareous soils which are commonly found in the more arid fruit production zones but much less work on rootstocks adapted to soils that are waterlogged, acid (high aluminum), or heavy textured. These objectives will continue to maintain regional importance, but the major focus will shift to the ability to grow fruit with less quantity or less quality of water in the future. Several of the major arid fruit production areas that depend on irrigation for production, such as the central valley of California, are beginning to experience problems with both the quantity as well as the quality of water. Breeders of agronomic crops (maize, cotton, sorghum) have worked extensively on the development of drought (Cattivelli et al. 2008; Sinclair 2011) and salinity tolerance (Flowers and Flowers 2005; Ashraf and Akram 2009) with moderate success. Although much has been done to increase the efficiency of managing water and salinity among fruit, little has been done to develop rootstocks and/or scion cultivars that use water more efficiently or are tolerant to salinity. At this point, the major emphasis is at the point of identifying differences among germplasm in their response to drought (Grant et al. 2010; Rieger et al. 2003; Kocsis et al. 2009; Cochard et al. 2008) or salinity stress (Musacchi et al. 2006; Syvertsen and Melgar 2010).

4.4 Diversification of Fruit Types

In multiple studies, it has been shown that the consumers throughout the world, especially as their income level rises, are looking for interesting foods that are convenient to consume (Blisard et al. 2002; Frazão et al. 2008). This is reflected in the doubling of items available in the produce section of the grocery store in the USA (Davis and Stewart 2002). This consists of several classes of items: new cultivars of traditional fruit, more exotic fruits, organic versions of traditional fruits, and minimally processed fruits.

Many studies have documented the heterogenous nature of consumers and more recently have been characterizing the various flavor classes within a given fruit (Jaeger et al. 2003; Jaeger and Harker 2005; Tomala et al. 2009; Ross et al. 2010; Crisosto et al. 2006, 2007). With apple and pears, the fruit is sold by the cultivar name, whereas with stone fruit and small fruit this is not generally the case. Thus, as new flavor classes are introduced into the market, the consumer gets confused as it is not obvious from the external appearance what the flavor of the fruit is. Consequently, it has been suggested that stone fruit as well as others are sold in a way that the flavor class is obvious (Byrne 2002; Crisosto et al. 2006, 2007; Ross et al. 2010). Although unique fruit products may not be sold in high volumes, it is clear that if the new offering has sufficient quality there will be consumers willing to pay a premium for it (Jaeger and Harker 2005; Gamble et al. 2006).

In the case of peach, there is a wide diversity of regional peach and nectarine types traditionally grown throughout the world. Most are regional preferences, such as low acid white and pantao peaches in China and Japan, yellow-fleshed acid types in North America, and nonmelting yellow–orange peaches in many regions of Latin America. Now, given the globalization of the produce market and the need for new produce items, more types of these previously regionally grown peaches are being sold in any given market. The nectarine was initially developed in the USA in the

1950s and 1960s, and now nectarine production is approaching the production level of the peach crop in the USA and Europe. Thus, the USA market has evolved over the decades from mainly yellow-fleshed acid peaches to a market that has both peaches and nectarines that are either white or yellow flesh with low or high acidity. Recently, low-acid pantao peaches have been appearing in the market. This offering will expand into a series of pantao cultivars and then will diversify to have the range of flesh colors, acidity, and skin types (peach/nectarine). Other unique types being developed would include cultivars with nonmelting red or orange flesh, skin/flesh without anthocyanins, and enhanced flavor and health properties (Byrne 2005; Pascal et al. 2009; Nicotra and Conte 2003; Monet and Bassi 2008; Vizzotto et al. 2007). Similar emphasis on developing unique shapes, colors, and flavors is seen in other fruits. Examples of this would be a range of colors and flavors among seedless table grapes, development of bright yellow- and red-fleshed plums (Halgryn et al. 2000), work toward developing red-fleshed apples (Volz et al. 2009a, b), and development of a low-acid sweet kiwifruit (Wismer et al. 2005).

Convenience is a major driver of innovation in the food industry and should be considered as new fruit cultivars are developed. There are several factors that influence whether a fruit is a convenient item to consume. These include the following: consistent availability, good postharvest traits, easy to eat and not messy, and suitability for a variety of uses (breakfast, snacks, dessert). Most nut crops qualify as convenient food as do fruits, like apples, grapes, and bananas, while others, such as peaches, mangos, and melons, do not (Jaeger 2006).

Traits that make fruit more difficult to eat would be seeds in the fruit, need or difficulty of peeling the fruit, size of the fruit, need to cut or use utensils to eat the fruit, and juiciness of the flesh. Thus, we want a fruit that is seedless, can be eaten without peeling, is bite size, and does not spurt juice out when eaten. Such innovations are already here for some fruit and being developed for others. In citrus breeding, two essential traits are the ease of peeling and seedlessness (Stover et al. 2005) and table grapes are already bite-size fruits which do not need to be peeled and have no seed. Along these lines, work is active to develop bite-size kiwifruit, stone fruit without a pit, and stone fruit and berries with a longer postharvest life (Clark and Finn 2008; Byrne 2005).

And as people throughout the world eat more of their meals away from home (Normile and Leetmaa2004; Stewart et al. 2006; Gale and Huang 2007; Frazão et al. 2008), the importance of minimally processed foods increases both in the food service business and for personal use (Handy et al. 2000). Products, such as peeled baby carrots, bagged salads, and precut vegetables of many types, are now mainstays in most grocery stores in the USA, but similar products with fruits are still not common. When whole versus fresh cut apples were offered in elementary and middle schools in the USA, more fruit was eaten when offered as a fresh cut product (McCool et al. 2005). This approach would help encourage children and others to eat more fruit. The best example of a fresh cut product being offered in a fast food restaurant would be the fruit salad (sliced apples, grapes, and walnuts) offered by MacDonald's. This demonstrates the effort of fast food and other restaurants to develop healthier menus for a consumer that is increasingly health conscious (Martinez 2007).

The development of healthy snacks, whether they are minimally processed, precut, and peeled fruits, dried, pickled, or juice preparations that supply the equivalent of one serving of fruit, needs to be accelerated to adapt to the new consumption patterns seen in our modern world. There have been impressive advances with postharvest treatment and packaging strategies to prolong the shelf life of these products; nevertheless, the selection of the appropriate cultivars is important as this industry develops and expands into the fruit arena. This requires collaboration among food scientists and plant breeders to best match the genetics and traits of the fruit with the requirements of the processing required. Some work is looking at the suitability of cultivars for this use (DeEll et al. 2009), but no breeding program has yet embraced this objective.

4.5 Health Benefits of Fruit

The health benefits of fruits and other produce always seem to be in the news (Variyam and Golan 2002). The initial work compared different fruit crops for their varying levels of antioxidant activity, carotenoids, phenolics, anthocyanins, and other phytochemicals. At times, this data was contradictory as only one or a few cultivars were generally used to represent the crop (Mattila et al. 2006; Sun et al. 2002; Vinson et al. 2003; Wang et al. 1996). The appearance of this type of information and other studies showing that the consumption of fruits has protective properties against various pathological conditions, such as inflammation, cancer, atherosclerosis, and other circulatory problems (Prior and Cao 2000; Wargovich 2000; Southon 2001) has fed the current interest in the health benefits of consuming fruits. Furthermore, this work also showed that fruits had a higher level of phenol antioxidants than common vegetables (Vinson et al. 2003).

From this work, the concept of a "superfruit" emerged in the marketing world which has encouraged the increased consumption of multiple fruits and fruit products. Thus, as you stroll through the supermarket, it is common to see a range of health claims on fruit products, with the most common being high in antioxidants, high in vitamin C, B6, and B12, heart healthy, low in saturated fats and cholesterol, low sodium, and, for cranberry, promotes urinary tract health.

As the public becomes more aware of the health benefits of fruits and is being told to eat a colorful diet, there is a potential to create a new market for cultivars specifically developed for their health benefits. Such "health-enhanced" cultivars would provide a new product that could be sold fresh or processed (total crop or as an outlet for the cull fruit) into extracts that are natural sources of antioxidants, antimicrobials, and colorants (Byrne 2002). The prerequisite of developing these "health-enhanced" cultivars is that there is genotypic differences in the traits that provide health benefits: i.e., cultivars and selections differ in the bioactivity or phytochemical levels. This has been shown to be the case with peaches, plums (Cevallos-Casals et al. 2002, 2006; Chang et al. 2000; Cantín et al. 2009; Gil et al. 2002; Tomas-Barberan et al.

2001;Vizzotto et al. 2007; Byrne et al. 2009), blueberries (Connor et al. 2002a, b), apples (Yoshizawa et al. 2005; Lata et al. 2005; Lee et al. 2003), blackberries (Wang and Lin 2000; Connor et al. 2005b, d), raspberries (Connor et al. 2005a, c; Weber et al. 2008), grapes (Stringer et al. 2009; Pastrana-Bonilla et al. 2003; Xu et al. 2010; Yang et al. 2009; Vilanova et al. 2009), and many other crops. Although there is still a lack of knowledge of the genetics of these various phytochemicals, the data that exists indicates that this process of developing cultivars with "enhanced" levels of antioxidant activity, polyphenolics, and anthocyanins should be a straightforward process (Connor et al. 2002b, 2005a, c; Cantín et al. 2009).

Anthocyanins are generally reported as high in many berry crops (Mattila et al. 2006), but there is also a great potential to develop tree crops with red flesh. Thus far, it has been shown that some peach and plum cultivars can rival the anthocyanin, total phenolics, and antioxidant activity of blueberries (Cevallos-Casals et al. 2006; Vizzotto et al. 2007; Byrne et al. 2009). In the case of developing red flesh among normally green, yellow, and white tree fruit (apples, pears, peaches, plums) cultivars, there appear to be a few major genes that condition this anthocyanin production in various fruits (Sekido et al. 2010; Werner et al. 1998; Volz et al. 2009a). Currently, several fruit breeding programs are exploring or developing berry and tree fruit crops with greater levels of anthocyanins (Byrne et al. 2009; Connor et al. 2002a, 2005a, c; Cantín et al. 2009; Volz et al. 2009a, b; Sekido et al. 2010).

One very important decision in any plant breeding program is to select the target. In the case of developing a health-enhancing cultivar, one has to decide what chemical(s) and levels to select for. This is not as simple as it may seem. Although there is a substantial body of literature which describes the antioxidant activity, antiproliferative activity to various cancers, ability to inhibit LDL oxidation, anti-inflammatory activity, among many other useful actions of fruits and their extracts, most of this work is done either in cell culture experimental systems or in small animal experimental systems. These approaches are very useful at identifying potential effects but do not necessarily translate well to a human system (Finley 2005). Although there has been a substantial amount of work to establish the antioxidant levels of fruits and it is generally considered that the consumption of more antioxidants is good for one's health, there is not definitive proof to confirm that supplemental antioxidant consumption reduces the incidence of chronic disease (Amiot 2009). Consequently, more research is needed to identify the target phytochemicals and, probably more difficult, the target concentration needed in the fruit to be effective at promoting the long-term health of the consumer as compared to a normal cultivar. Nevertheless, fruit breeding programs are exploring and actively breeding for cultivars with enhanced levels of antioxidants, phenolics, carotenes, and anthocyanins (Vizzotto et al. 2007; Cantín et al. 2009; Connor et al. 2002a, b, 2005a, c; Volz et al. 2009a; Stringer et al. 2009; Weber et al. 2008; Battino and Mezzetti 2006; Khanizadeh et al. 2009) and we are beginning to see the promotion of specific fruit cultivars as health enhanced.

4.6 Consistent High Fruit Quality

For repeat purchasing, a good experience is essential. Surveys with stone fruit in Southeast Asia, the USA, and in Europe have indicated that inconsistent fruit quality is the major impediment to greater sales (Clareton 2000; Crisosto et al. 2003, 2007; Moreau-Rio 2006; Wei 2001). In addition, the earliest fruit to harvest is commonly of lesser quality which has the potential to depress the market as has been seen in citrus (Poole and Baron 1996) and stone fruit. The fruit industry needs to deliver what the consumer wants: an excellent quality piece of fruit every time.

Although the specific quality traits may differ among fruits, for most fruits the most important traits are flavor, most commonly measured as total soluble solids and titratable acidity and texture, measured as firmness, crispiness, and/or juiciness (Poole and Baron 1996; Racskó et al. 2009; Kajikawa 1998; Crisosto et al. 2003, 2006, 2007; Crisosto et al. 2004; Crisosto and Crisosto 2005; Péneau et al. 2006; Harker et al. 2008; Turner et al. 2008). Common complaints for fruit would be the lack of flavor and mealy flesh without juice as seen in stone fruit with internal breakdown (Crisosto et al. 1999; Peace et al. 2005a, b) and in apples (Jaeger et al. 1998; Racskó et al. 2009). Aroma, although important, is difficult to measure and external qualities, such as shape, color, and size, which are easily standardized during packing, are usually of secondary importance to flavor and texture. Other flavor components that consumers complain about would be off flavors and astringency (Crisosto et al. 2007). To maximize the consumption of fruit, high quality needs to be delivered consistently as previous experience influences future purchasing decisions (Racskó et al. 2009; Poole and Baron 1996). There is evidence that consumers are willing to pay more for significantly better tasting fruit (Gamble et al. 2006; Opara et al. 2007).

The ability to produce high-quality fruit depends on many factors, some out of the control of the producer, such as the weather, and others dependent on the production practices, such as irrigation, fertilizer application, pest/disease management, pruning, and fruit thinning (Crisosto et al. 1997; DeJong et al. 2002). Harvest practices are critical in producing high-quality fruit as picking at an immature state results in poor quality (Iglesias and Echeverría 2009). In many crops, the quality increases and firmness decreases during fruit ripening, so a decision to harvest is a compromise between maximizing quality and having sufficient firmness to allow easy fruit handling for cleaning, sorting, packing, and shipping. Once harvested, the postharvest treatment can make or break a shipment of fruit.

Crops differ in their ability to produce a consistent product. Pome fruits, citrus, and table grapes are better at delivering a consistent high-quality product as compared to stone fruit, strawberries, blackberries, and raspberries. Part of this is due to the crop's postharvest behavior. In general, pome, citrus, and grapes can be stored for several months to a year, whereas many stone fruits can be stored for less than 6 weeks and many soft berry crops for less than 3 weeks. There have been great strides made in postharvest handling and transportation technology in the last decades which have made the produce industry a global enterprise with the ability to deliver fresh fruit thousands of miles to the market and still maintain high quality (Huang 2004; Frazão et al. 2008). Although these advances have been critical, the success also depends on the genetics of the fruit cultivar.

In the past, fruit breeders have been criticized for developing productive, large, firm, and very attractive fruit cultivars that were lacking in flavor. These criticisms are being taken seriously by many programs which have increased emphasis on high quality and the postharvest behavior of the cultivars that they are developing. In addition, there are several large international programs that are focusing their efforts on developing better genetic tools to improve the quality of fruits. These include the RosBREED project in the USA (Iezzoni et al. 2009, http://www.rosbreed.org/) and the FruitBreedomics project in Europe (http://fruitbreedomics.com/) among others.

Soluble solids are important in all fruit crops to ensure high quality. In apples, the soluble solids were associated with price in Japan (Kajikawa 1998). Common levels of soluble solids found in fruit range from 8–10 Brix in some blackberry and early-ripening peach and plum cultivars, 15–25 Brix for sweet cherries and table grapes, and over 30 Brix in apricot cultivars from Central Asia. In blackberry breeding, the newer cultivars, such as Navaho and Ouachita, have soluble solid levels of 10–12 Brix which has made this fruit more palatable to a wider audience, and further improvement to 15 Brix appears possible (Clark and Finn 2008).

Among stone fruit, consumer-acceptable levels of soluble solids differ with the fruit and its acidity, with minimum levels of 11 Brix for acid peaches, 12 Brix for low-acid peaches and plums, and 16 Brix for sweet cherries (Crisosto et al. 2003, 2004, 2006, 2007; Ross et al. 2010). Unfortunately, many common peach, plum, and apricot cultivars, especially early-ripening cultivars, have soluble solid levels of 8–10 Brix. Genetic studies in peach have documented a negative genetic correlation between soluble solids and fruit development period (days from full bloom to commercial ripe) and fruit weight (Souza et al. 1998, 2000; Byrne 2005). Thus, it may be difficult to develop high-soluble-solid peaches that are large and early-ripening. Nevertheless, current collaborative work between Texas A&M University and the USDA (Kearney, CA) indicates that it is possible to combine good soluble solids (12–15 Brix) with good fruit size with a fruit development period of less than 100 days.

There has been excellent progress in developing high-soluble-solid peaches/nectarines for the mid- and late-season harvest periods, and levels of 15% or greater should be our goal. There are nectarine cultivars in California (Crisosto et al. 1998; Byrne et al. 2000) and peach cultivars in Italy (Nicotra and Conte 2003) that are reported to be in this range. In the last decade, 172 peaches and 134 nectarines have been patented/released in the USA. Of these, 40% were described as having low- (<11 Brix), 40% medium- (12–15 Brix), and 20% high- (>15 Brix) soluble solids. When the group of releases with high-soluble solids is examined by ripening season, 84% were mid- or late-maturing cultivars (after mid June). Only 16% were those that ripened during the early season and 90% of these early-maturing cultivars were nectarines which tend to have higher soluble solids than peaches (Wen et al. 1995a, b). In addition, the early-season high-soluble solid releases are lower chilling (range 375–700 CU, mean ~500 CU) than those that ripen in mid season (range 500–800 CU, mean ~600 CU) or late season (range 600–850 CU, mean 700 CU). This approach helps because the lower chilling cultivars bloom earlier than the higher chill cultivars. Thus, for a given ripening season, the lower chill cultivars have a longer fruit development period than the higher chilling cultivars which means that the lower chill cultivars have more time to accumulate sugars. Additional challenges are to combine high sugars with high yields (especially early), large size, and for nectarines good skin finish (few speckles and lenticels) and low cracking. As demand for quality increases, there may be some compromises on fruit size and nectarine skin appearance if high quality can be guaranteed.

Beyond high sugars, many other factors are considered in the development of high-quality fruit cultivars, including aromatic components of flavor, relative amounts of specific sugars (sucrose, glucose, fructose, sorbitol), texture, mouthfeel, and acidity. Finally, since the growing practices (pruning, fertility, irrigation, harvesting) have such a great influence on the ultimate quality of the fruit, there is a need to specify the minimal cultural practices to obtain the highest potential quality of the cultivar.

4.6.1 Firmness and Postharvest Competence

Good fruit firmness, beyond being important in consumer-perceived quality while eating, is essential for ease of harvesting, handling, marketing, and for storage of all fruit crops. Firm fruit tends to be more resistant to rain-induced cracking in cherries, allows for more ripening on the tree and consequently better quality, and frequently has a better postharvest life (Kappel 2008; Giovannini et al. 2006a, b; Sherman and Lyrene 2003; Sansavini and Lugli 2008; Oraguzie 2010). Thus, firmness has been an important selection criterion for fruit breeders, and advances in firmness have transformed stone fruit and, more recently, small fruits, such as strawberries, blackberries, and raspberries, from locally marketed crops to fruits with potential to be shipped thousands of miles to the market. Further advances are needed in all crops to facilitate a global sourcing required to supply high-quality fruit throughout the year, as this requires extended storage life to allow the transport in the most carbon-friendly means: by boat.

Fruit ripening has been extensively studied in tomato (Giovannoni 2004) which has aided much of the work in other fruit systems, such as apple and peach. The two major pathways that have been studied extensively would be the ethylene-mediated pathway that induces ripening and the endopolygalactaronase (EndoPG) cell wall softening pathway. Variations of these seem to be well-conserved over a wide range of species, including our common tree and small fruit crops.

Ethylene is known as the ripening hormone and many postharvest procedures focus on reducing the level of ethylene that fruits are exposed to or reducing the response of fruits to ethylene (i.e., 1-methylcyclopropene, 1-MCP) as a protocol to extend the storage life of fruit. In both apples and peaches, the corresponding genes that code for 1-aminocyclopropane-carboxylase (ACC) synthase (ACS), ACC oxidase (ACO), and ethylene receptor (ETR) proteins that are key to the fruit ripening process have been identified (Wang et al. 2009; Marić et al. 2009). Interestingly, apples and peaches do not respond the same when 1-MCP, an ethylene blocker, is applied (Cin et al. 2006) indicating that these systems differ significantly as does their postharvest competence. With apples, various allelic forms of ACO and ACS have been characterized across cultivars, and the allelic states that condition the best firmness have been identified with molecular markers opening up the possibility of using these in the selection for better postharvest quality in apple (Tatsuki et al. 2009; Oraguzie 2010; Zhu and Barritt 2008).

Among stone fruits, peach has been studied the most, but similar systems probably exist across the various species. There are several traits that apparently reduce ethylene production identified in peach: the slow or nonripening genes described in peach (Brecht et al. 1984; Brecht and Kader 1984) and plum (Yamaguchi and Kyotani 1986) and the stony hard (SH) gene described in peach (Haji et al. 2005). Of these, the most studied is the stony hard gene which has the potential to extend the postharvest life of the peach. Various breeding programs are actively working toward and/or have developed cultivars with stony hard flesh (Giovannini et al. 2006a, b; Lu et al. 2008; Byrne 2005).

The low expression of the cell wall degradation enzyme, endopolygalactaronase (PG, EC 3.2.1.15), also seems important in the storage ability of the peach (Wakasu et al. 2006; Peace et al. 2005b). Throughout much of the world, the common flesh type used for fresh market peach is the melting-type flesh. Although much progress has been made at developing firm melting flesh types, it is still difficult to pick them firm enough at a high level of fruit quality. In contrast, the processing industry uses a firmer flesh type: the nonmelting flesh. This is conditioned by an allele at the PG gene which disrupts the activity of EndoPG (Peace et al. 2005b) resulting in a flesh that does not "melt." This firmer flesh type allows the harvesting at a higher quality, tree-ripe stage with enough firmness to the market. These types have been used for centuries for the fresh market in Latin America from Mexico south to Brazil and in Spain. The main objection to these types is that the flesh does not separate from the stone which is preferred for the fresh market. Nevertheless, since early-ripening peaches and nectarines are usually clingstone because they ripen before their pit/flesh separation occurs, many breeders have begun to develop earlier ripening peach and nectarines with nonmelting flesh. In the USA, this approach has been spearheaded by the work in Florida (Byrne 2005) and currently there are multiple fresh market releases with nonmelting flesh in the USA ('UFGold,' 'UFPrince,' 'Springprince,' 'Springbaby,' and 'Crimson Lady'), South America (Raseira and Nakasu 2006), and Europe (Giovannini et al. 2006a, b). Recent work has also reported semifree forms with nonmelting flesh which overcomes a potential problem in the fresh market and would also be a useful trait in the processing market (Beckman and Sherman 1996; Gradziel 2003).

Beyond ensuring that the fruit can maintain its firmness and taste during extended storage, work needs to be done on the genetic basis for the various postharvest disorders that occur in fruits. The most important post harvest physiological disorders seen are internal breakdown problems in stone fruit (Crisosto et al. 1999;

Peace et al. 2006; Ogundiwin et al. 2007, 2009) and bitter pit and superficial scald in pome fruit (Blazek et al. 2007; Pesis et al. 2009). Work has begun to identify the genotypic variation that promotes resistance of cultivars to these disorders (Crisosto et al. 1999; Trivedi et al. 2010; Volz et al. 2006), although, due to the difficulty of these evaluations, work is now focused on parental material and advanced selections. It is not yet sufficiently efficient for primary selection among seedlings. The development of reliable selection criteria for these storage disorders is essential for rapid phenotyping and genetic advance. There are several groups working toward this goal.

Currently, destructive sampling of fruit can detect particularly poor lots of fruit. However, to ensure consistently high-quality fruit, the testing needs to be done on an individual fruit basis. Work on nondestructive systems to measure quality using acoustical and near-infrared systems (Ariana et al. 2006; Nicolai et al. 2006; Valero et al. 2007; Ruiz et al. 2009; Kleynen et al. 2005) has led to commercial use in a packing line situation. This allows the selection of individual fruit for acceptable fruit quality and puts higher quality standards on the cultivars that are developed. Thus, high-quality cultivars are needed; if a cultivar consistently produces poor-quality fruit, it will not be accepted in the marketplace in the future.

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