Handbook of Plant Breeding

Marisa Luisa Badenes
David H. Byrne *Editors*

Fruit Breeding

Springer

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Fruit Breeding

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ISBN 978-1-4419-0762-2 e-ISBN 978-1-4419-0763-9
DOI 10.1007/978-1-4419-0763-9
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2011943557

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This book begins with a discussion of the overall trends in fruit breeding, intellectual property management, the breeding for cultivars with enhanced health benefits, and an assessment of some of the emerging fruit crops that have great potential for further development. The next three sections: small fruits, tree fruits, and nut crops contain crop-specific chapters describing the economic importance, use, adaptation, origin, domestication, breeding history, accomplishments, goals, breeding techniques, and the advances in the use of biotechnology for each crop. The crops reviewed have domestication history of millennium to decades and breeding activity ranging from thousands of generations to just a few generations. Likewise, their biology and ploidy levels (diploid to octoploid) are diverse which leads to a plethora of approaches to their genetic improvement.

Breeding of perennial fruit species is a long-term activity involving a high investment as compared to annual crops due to two challenges: long juvenile periods and large plant size. In spite of these difficulties, breeding programs have been developed in all important perennial fruit crops, aimed at the improved economic profitability of the crops by increasing yields, altering the harvest window, creating new fruit types, and improving fruit quality while simplifying management. The recent increase in activity has been encouraged by the integration of the intellectual property rights (IP rights) in fruit production which has created substantial research incentive in private and public spheres for innovation in the fruit industry.

Yield is intertwined with the ease of management, as a prerequisite of high yields is excellent adaptation to the environment. This includes the ability to grow and yield under the abiotic conditions of soil, temperature, and humidity and the biotic stresses, such as fungus, bacteria, nematodes, and viruses in the production zone. This later objective has recently increased in importance with the enhanced public awareness of the negative consequences of the use of agrochemicals. This has spurred the dramatic increase of research into the development of sustainable fruit production systems. The globalization of the fruit industry is resulting in increased activity in developing cultivars of temperate fruits adapted to subtropical and tropical environments. Beyond the simplification of management by reducing the use of agrochemicals, work on the modification of tree architecture either through dwarfing rootstock or unique scion growth habits and the conversion of self-incompatible crops to self-compatible or parthenocarpic crops continue to improve the quantity and consistency of yield and the ease of managing the crops.

The value of fruit generally increases when less is available. Thus, much breeding has been done to extend the harvest season both earlier and later when fruit supplies are lower. Consequently, there has been much progress. A good example would be the extension of the peach season from 1–2 months to 6–8 months through the breeding for shorter and longer fruit development periods. In addition to this, the shift of adaptation of cultivars to earlier and later blooming areas has contributed to these extended fruit marketing seasons. Although there has been success, much work needs to be done especially in the improvement of fruit quality at the extremes of the harvest season. Another approach to reduce the availability is to offer something unique. In the US peach industry, this has played out several times starting with the introduction of the nectarine, and then with white fleshed fruit, and now with pantao types. This work continues across all crops and involves traits, including appearance (flesh and skin color, shape, size), quality (flavor, aroma, texture, acidity, sugar, levels of health promoting phytochemicals, storability), and convenience (seedlessness, glabrous skin, ease of peeling, size, shelf life) traits.

The traditional breeding approach is the foundation of our success. Nevertheless, the integration of the new genetic and molecular tools into the breeding programs makes a major impact. These new tools increase the efficiency of the breeding programs by identifying important genes at the molecular level. Molecular markers have been developed for genetic studies and the identification of cultivars in the major fruit species. Genetic linkage maps are available in many perennial species, including stone fruits, pome fruits, strawberry, grapes, chestnut, and walnut. These maps have been key in the identification and selection of the target genes or markers linked to them. The advent of genomics, whole genome sequences (apple, peach, grape, strawberry, and citrus) and the rapidly improving DNA sequencing technologies have opened up new opportunities for developing new markers and for identifying and understanding the gene function which controls the important phenotypes in fruit breeding. In vitro technology has led to improved propagation and virus certification protocols, efficient procedures to grow out unique hybrid seedlings (embryo rescue, in vitro grafting, somatic hybridization), and to create transgenic plants.

This book tries to present a broad vision of fruit breeding to stimulate the thought process and hopefully inspire the next generation of fruit breeders to create the breakthrough cultivars of the future.

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Part I
General Chapters

Chapter 1
Trends in Fruit Breeding

David H. Byrne

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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M.L. Badenes and D.H. Byrne (eds.), *Fruit Breeding*, Handbook of Plant Breeding 8,
DOI 10.1007/978-1-4419-0763-9_1,

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,

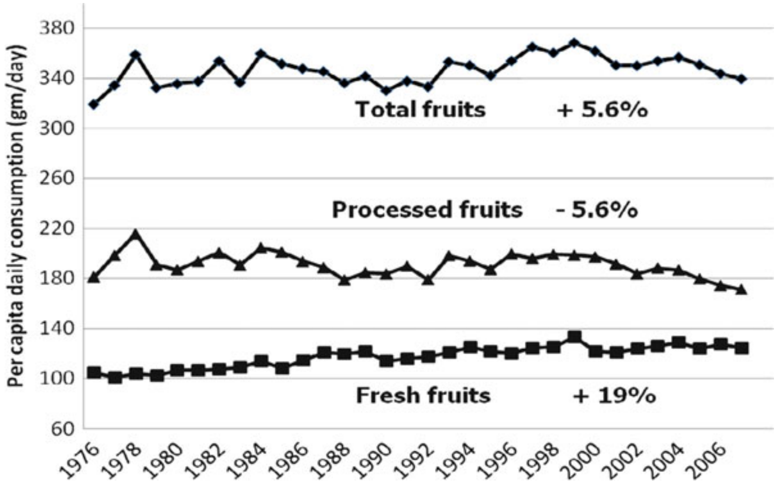

Fig. 1.1 Per capita fruit consumption in the USA (data from Pollack and Perez 2008)

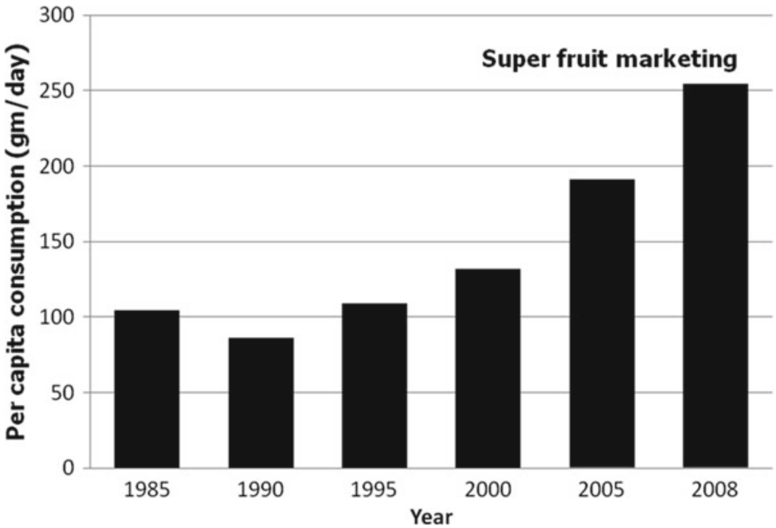

Fig. 1.2 Per capita blueberry consumption in the USA (data from Pollack and Perez 2008)

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