7 Apricot

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7.1 Introduction

7.1.1 History of the Crop

Under the generic term apricot different species and one naturally occurring interspecific hybrid are usually included: *Prunus armeniaca* L., the common apricot; *P. armeniaca* var. *ansu* Komar, the Ansu apricot; *Prunus brigantina* Vill., the Briancon apricot or Alpine plum*; Prunus holosericea* Batal., the Tibetan apricot; *Prunus mandshurica* (Maxim.) Koehne, the Manchurian apricot; *Prunus mume* (Sieb.) Sieb. et Zucc., the Japanese apricot; *Prunus sibirica* L., the Siberian apricot, and *Prunus* × *dasycarpa* Ehrh, the black or purple apricot, a naturally occurring hybrid of *P. cerasifera* Ehrh. and

P. armeniaca L. (for reviews see Mehlenbacher et al. 1990; Layne et al. 1996; Faust et al. 1998). In addition, new interspecific hybrids have been recently obtained by artificial cross-pollination. Thus, "plumcot" is a putative hybrid between diploid plums (*Prunus salicina* Lindl.) and apricots (*P. armeniaca* L.) and "pluot" and "aprium" are complex hybrids considered to result from interspecific crosses of plums and apricots with subsequent backcrossing to plum (pluots) or to apricot (apriums) (Manganaris et al. 1999a; Ahmad et al. 2004). All apricot species are interfertile diploid species with eight pairs of chromosomes ($2n = 16$). In this review, we will pay attention to two cultivated species, *P. armeniaca*, the common or European apricot, and *P. mume*, the Japanese apricot.

Most cultivated apricots belong to the species *Prunus armeniaca* that originated in Central Asia where it has been cultivated for millennia and from where it was later disseminated both east and westward. Vavilov proposed three centers of origin: the Chinese Center (mountains of northeastern, central and western China), the Central Asian Center (mountains of Tien-Shan, Hindukush to Kashmir), and the Near-Eastern Center (mountains west of the Caspian Sea including the Caucasus and mountains of Georgia, Azerbaidjan, Armenia, Turkey and Northern Iran), the latter being a secondary center of diversification (Vavilov 1992). Bailey and Hough (1975) also suggested a North Chinese group (Siberian apricot and Manchurian apricot) and an East Chinese group (Ansu apricot).

According to Layne et al. (1996), the common apricot can be classified into six main ecogeographical groups: Central Asian, East Chinese, North Chinese, Dzhungar-Zailij, Irano-Caucasian, and European. Nevertheless, this classification is becoming complicated due to the introduction of new cultivars derived from crosses between genotypes of the different groups (Faust et al. 1998). The Central Asian group is the oldest and more diverse; most of the apricots belonging to this group are self-incompatible and show high chilling requirements. The Dzhungar-Zailij group includes mostly self-incompatible small-fruited cultivars. The Irano-Caucasian group includes mostly self-incompatible genotypes with low cold requirements from the Caucasian area, Iran, Iraq, North Africa and some cultivars from Southern Europe. The European group is the most recent and the least variable, comprising mainly self-compatible genotypes and includes the commercial cultivars of Europe, America, South Africa and Australia (for reviews see Mehlenbacher et al. 1990 and Faust et al. 1998).

Cultivation of *P. armeniaca* in China was practiced more than 3,000 years ago and spread through central Asia. Apricot culture was introduced in the Mediterranean region from Iran or Armenia around the first century BC (Zohary and Hopf 1993), although more recently new introductions were made from the Middle East, especially into Southern Europe (Faust et al. 1998). Thus, Spanish cultivars could be derived

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from North African genotypes brought by the Arabs (Hagen et al. 2002). As a result of trading and commerce, apricots were introduced into England and the United States (Virginia) in the 17th century (Ogawa and Southwick 1995). Later, apricot was introduced into California by the Spaniards in 18th century (for review see Faust et al. 1998).

The Japanese apricot (*Prunus mume* Sieb. et Zucc.) originated in Southeast China in warmer and more humid conditions than *P. armeniaca* (Mehlenbacher et al. 1990). It has been cultivated for over 3,000 years and wild forms can still be found in mountainous areas. In Japan, Japanese apricot has been planted as ornamental since ancient times. Later, ancient Japanese people found that Japanese apricot fruits have medicinal properties and the cultivation for fruit production started and spread across the country.

7.1.2 Botanical Description

P. armeniaca and *P. mume* are members of the family Rosaceae, in the genus *Prunus* L., subgenus *Prunophora* Focke and section *Armeniaca* (Lam.) Koch (Rehder 1940). Both *P. armeniaca* and *P. mume* are diploid ($2n = 16$). *P. armeniaca* has a small genome (5.9×10^8 bp) that is about twice the size of *Arabidopsis thaliana* and between that of two other important diploid species in *Prunus* with $n = 16$ such as peach (5.4×10^8 bp) and cherry (6.8×10^8 bp) (Arumuganathan and Earle 1991).

The common apricot grows in geographically diverse areas ranging from the cold winters of Siberia to the subtropical climate of North Africa and from the deserts of Central Asia to the humid areas of Japan and eastern China. However, commercial production areas are still very limited (Mehlenbacher et al. 1990). Some apricot cultivars are particularly prone to irregular productions that have been associated to the narrow adaptability range of the species. Indeed, while in other fruit tree species a few cultivars are grown all around the world, in apricot each cultivar is usually restricted to a particular geographical area with certain ecological conditions (Layne et al. 1996) and where apricot culture is most successful is in mild, Mediterranean climates. Rainfall and high humidity during the growing season, particularly at bloom or harvest, is a serious limitation due to fungal diseases, which can kill the flowers and shoots or rot the fruits (Ogawa and Southwick 1995).

Common apricots are small to medium sized spread trees capable of reaching 14 m in their native range. The one-year-old wood and spurs are thin, twiggy, and shorter lived than those of other *Prunus*. Leaves are elliptic to cordate and have serrate margins and long, red-purple petioles. Apricots produce perfect, perigynous, white to pinkish flowers borne singly or doubly at a node, with five sepals and petals and about 30 stamens, all of which emanate from the hypanthium or floral cup, and one pistil with a single carpel. In apricot, as in other *Prunus* species, two ovules are present in the flower although usually only one seed is produced (Rodrigo and Herrero 2002). Several cases of pollen sterility have been described and, although most commercial cultivars are self-fertile, self-incompatible cultivars exist (Schultz 1948). Floral buds are initiated in late spring or summer. The chilling required to initiate flowering (below 7 °C) ranges from 300 to 1,200 h. The heat requirement following chilling is very short, causing apricots to bloom early in most locations. The blooming period lasts one to two weeks in early spring. Dormant trees tolerate winter low temperatures, but early emergence from dormancy results in freeze injury to blossoms and even death of trees in some growing areas where late freezes occur. Thus, apricot is prone to frost injury due to the early bloom habit and, subsequently, the production area is limited by the danger of spring frost (Mehlenbacher et al. 1990; Layne et al. 1996).

The fruit of the apricot is a drupe consisting of a stony endocarp surrounding the seed, a fleshy mesocarp, and an exocarp (fruit skin). Fruits of the common apricot can be freestone or clingstone with round to oval shape and glabrous to pubescent fruit skin. Fruit flesh can be sweet or sour and flesh color is mostly orange, but a few white-fleshed cultivars exist (Layne et al. 1996). Fruits are climacteric and require 3–6 months for development, depending on cultivar (Jackson and Coombe 1966). Ripe fruits are soft to touch and highly susceptible to decay-causing organisms (Ogawa and Southwick 1995).

The Japanese apricot is a deciduous tree of large stature, occasionally reaching almost 10 meters in height. The type of petals is variable depending on the cultivar. Petals are either single or multiple, white, pink or red. Flowers consist of one pistil including two ovules and more than 50 stamens. Some cultivars show male-sterility or self-incompatibility. Fruit size is also variable from 5 to 50 g depending on cultivars. The fruits are clingstone and smaller than European

Table 1. FAO: Apricot production (t) (%), area (ha) (%), yield (t/ha). Average data from 2000 to 2004. (Faostat 2005)

Country	Production (%)	Area (%)	Yield
World	2,595,871 (100)	395,250 (100)	6.57
Turkey	448,800 (17)	63,665 (16)	7.05
Iran	278,664 (11)	30,929 (8)	9.01
Italy	182,570 (7)	16,044 (4)	11.48
France	138,548 (5)	15,431 (4)	9.01
Spain	132,893 (5)	22,630 (6)	5.87
Pakistan	130,113 (5)	12,985 (3)	10.02
Morocco	101,200 (4)	13,056 (3)	7.74
Syria	89,340 (3)	12,549 (3)	7.11
Ukraine	84,862 (3)	10,740 (3)	8.01
USA	82,274 (3)	7,645 (2)	10.76
China	81,873 (3)	17,680 (4)	4.65
Greece	72,389 (3)	4,700 (1)	15.40
Russia	70,400 (3)	19,400 (5)	3.63
Egypt	69,714 (3)	5,620 (1)	12.41
Algeria	67,562 (3)	25,378 (6)	2.66
South Africa	64,322 (2)	5,960 (2)	10.79

apricots. Since the fruits are sour, the entire production is utilized in some processed form (pickles, concentrate, liquor, or juice). With the development of fruit processing techniques, some cultivars with high quality for pickles have been selected (Horiuchi et al. 1996).

7.1.3 Economic Importance

The common apricot is an edible fruit mainly cultivated in Mediterranean climates. Apricot production is widely distributed and apricots are produced commercially in 60 countries on about 395,000 ha. Total world production has reached about 2.6 million tons although a few countries (Turkey, Iran, Italy, France, Pakistan and Spain) account for over than 50% of that production (FAOstat 2005). Yields average more than 6 t/ha, ranging from just 2 to over 15 t/ha in some European countries (Table 1).

Traditionally, apricot has been one of the few temperate fruit trees not affected by overproduction and often premium prices are reported for both fresh and processed fruits. However, this crop is challenged by a number of problems: yields are subjected to yearly fluctuation mainly due to frosts and low adaptation of many cultivars, several pests and diseases threaten the crop, and the spread of yield-efficient but tasteless cultivars often is causing consumer disaffection (Bassi 1999).

The variability within apricot species is large. However, only one or two major cultivars lead most of the production in each production area. This is partly responsible for large fluctuations in yield and makes apricots vulnerable to adverse environmental conditions, diseases and pests (Mehlenbacher et al. 1990). Thus, more than 80% of the world production is based on less than 30 cultivars. This situation is changing in Mediterranean countries where, due to the problems associated with sharka (caused by the Plum Pox Virus, PPV), new cultivars from North America and European breeding programs are being introduced (Badenes et al. 2003).

In some regions there is an enormous amount of diversity because trees have been commonly grown from seed for many centuries. Production from seedling orchards is still important in countries such as Turkey, Iran, Iraq, Afghanistan, Pakistan or Syria, whereas in other countries most of the production relies on a few clonally propagated cultivars well adapted to local conditions (Table 2).

Apricots are T- or chip-budded onto rootstocks usually during summer or fall, although June budding is practiced occasionally. Apricot seedlings are the most popular rootstock worldwide. Other root-

Table 2. Leading apricot cultivars in the world. (Mehlenbacher et al. 1990; Ogawa and Southwick 1995; Bassi 1999)

Country	Cultivar
Algeria	Canino, Amor Leuch
Australia	Hunter, Moonpark, Story, Trevatt, Pannach, Watkins
Canada	Goldcot, Goldrich, Harcot, Harglow, Hargrand, Harlayne, Harogem, Veecot, Velvaglo, Vivagold
China	Bak-Ta-Sin, Caoxing, Chu-In-Sin, Dahongxing, GulotiLochak, Hongjing zhen, Huax-iandjiexing, Hvang-Sin, Isko-Dari, Liganmeix-ing, Nan zhoudajiexing, Konak Doraz, Kzil Kumet, Luotao xhuang, Maj-Ho-Sin, Manti-Rujuk, Shi-Sin, Shoyinhouz, Tulaki,
France	Bergeron, Canino, Earlyblush, Fantasme, Goldrich, Hatif Colomer, Helena du Roussillon, Ivresse, Luizet, Malice, Modesto, Orange Red, Polonais, Rouge de Roussillon, Rouge de Fournes, Tirynthos, Tomcot
Greece	Bebeco, Tirynthos, Luizet
Hungary	Bergeron, Ceglédi Bìborkajszi, Ceglédi Orìas, Gönci Magyar Kajszi, Magyar Kajszi (Hungarian Best), Mandula Kajszi
Italy	Baracca, Bella di Imola, Boccuccia, Cafona, Canino, Ceccona, Fracasso, Goldrich, Monaco Bello, Palummella, Portici, Reale di Imola, San Castrese, Tirynthos, Vitillo
Iran	Tabarza, Tokbam, Damavand, Malayer, Lasgherdi
Morocco	Canino, Amor Leuch
New Zealand	CluthaGold, Sundrop, Valleygold
Pakistan	Shakarpara
Portugal	Bulida, Canino
Romania	Callatis, Comandor, Excelsior, Favorit, Litoral, Mamaia, Olimp, Neptun, Saturn
South Africa	Bulida, Empress, Imperial, Lady Sun, Palsteyn, Peeka, Royal, Soldonné, Super Gold
Spain	Bulida, Canino, Galta Rocha, Mauricio, Moniqui, Palabras, Paviot, Pepitos, Real Fino
Syria	Ajamy-Hamoy, Balladi Falik-Huby, Balladi Khashabi, Balladi Maourdi, Canino, Hamani, Hamoy, Klaby, Malty, Shahmy, Sindyany, Shakrbara, Tadmory, Wazary
Turkey	Aprikoz, Cataloglu, Cologlu, Darende, Hacihaliloglu, Hasanbey, Kabaasi, Sekerpare, Soganci, Tokaloglu, Yegen
Ukraine	Krasnoschekii, Krasnoshchekii Pozdnii, Krasnyi Partizan, Nikitskii
USA	Blenheim (Royal), Castelbrite, Katy, Modesto, Patterson, Tilton

stocks include peach seedlings, Myrobalan (*Prunus cerasifera*) cuttings or seedlings and *Prunus insititia* rooted suckers (for a review see Crossa-Raynaud and Audergon 1987).

There are many different uses of apricots. It is enjoyed as fresh fruit, but a large portion of the worldwide production is preserved primarily by drying (Faust et al. 1998). All fruits for the fresh market are hand-harvested. Mechanical trunk shakers and catching frames used for processed fruits may increase trunk injuries and incidence of canker diseases. Apricots are also utilized as canned, dried, frozen, and baby food. Other products include wine, brandy, jam, and nectar. Ground apricot pits are used to clean jet engines, and the kernel oil is used for soaps and perfume (Ogawa and Southwick 1995). In some Asian regions, apricots used for edible seed and for seed oil are more important than apricots grown for fruit (Bailey and Hough 1975; Layne et al. 1996). Seeds of Central Asian and Mediterranean apricots are generally "sweet" and, thus, the seeds can be used as a substitute for almonds, or crushed for almond-like cooking oil. Mature fruits for drying purposes are usually held for further ripening, treated with sulfur dioxide, and placed on wooden trays in the sun (Ogawa and Southwick 1995).

Apricot quality consists of a balance of sugar and acidity as well as a strong apricot aroma. Central Asian and Irano-Caucasian cultivars are lower in acidity than European and Japanese cultivars (Mehlenbacher et al. 1990). Fresh fruits have and edible portion of 94% and are an excellent source of Vitamin A (carotene) and Vitamin C (ascorbic acid) (Wills et al. 1983) (Table 3).

The cultivation of Japanese apricot for fruit production is limited to Japan, China and Korea and some other Asian countries. The annual fruit

Table 3. Nutrient composition of apricot fruit. (Wills et al. 1983)

Component	Unit	Range
Water	g/100g	85.3–85.6
Protein	g/100g	0.7–0.9
Dietary fiber	g/100g	2.0–3.0
Energy	kJ/100g	141–167
Sugars	g/100g	
Sucrose		4.4–5.1
Glucose		1.1–2.7
Fructose		0.3–0.5
Titratable Acidity	Meq H+/100g	17.5–33.7
Organic Acids	Mg/100g	1.5–2.6
Maleic		440–770
Citric		660–2130
Ascorbic		7–16
Carotene	Mg/100g	153–617
Thiamin	Mg/100g	0.02–0.03
Riboflavin	Mg/100g	0.03–0.04
Niacin	Mg/100g	1.1–1.4
Potassium	mg/100g	320–350
Sodium	mg/100g	1–3
Calcium	mg/100g	15–16
Magnesium	mg/100g	9
Iron	mg/100g	0.3
Zinc	mg/100g	0.1–0.2

production in Japan is approximately 100,000 tons. The fruits are not consumed fresh but rather processed in different ways to make them palatable. Most of them are processed and consumed as pickles ("Ume-boshi"). Japanese apricot fruits have a higher content of organic acids such as citric acid and malic acid than other fruits. The pickled fruits have been reported to aid the digestive system, increase saliva, and even act as a cure for a hangover. The flesh of the fruits produces an extract known as "bainiku-ekisu". This by-product is the grated, condensed flesh of the fruit. Recent studies (Chuda et al. 1999; Utsunomiya et al. 2002) have reported that "bainiku-ekisu" includes a bioactive substance, known as mumefral, produced during the fruit processing, which improves human blood fluidity. Other uses of Japanese apricot include traditional medicinal purposes and juices (Yoshida 1994). More than 300 cultivars have been described being 'Nanko', 'Shirokaga' and 'Ryukyo Koume' the most popular. The flowers of the Japanese apricot are revered for their beauty and mume trees have been increasingly used as ornamentals (Faust et al. 1998) and several cultivars such as 'Kankobai', 'Kobai', and 'Koume' are grown as early blooming, small landscape trees.

7.1.4 Breeding Objectives

The main objective of any fruit tree breeding program is to develop new cultivars with the best quality and in the most economical way possible. There is a wealth of diversity in common apricot germplasm, but cultivar improvement is slowed by the high degree of heterozygosity within the species. Although most of the production in many countries still comes from chance seedlings and local cultivars (Bassi 1999), the main cultivars of many of the producing countries belong to the European group that shows a narrow genetic base (Mehlenbacher et al. 1990). The main factors limiting the expansion of apricot growing areas include a lack of agronomic and adapted varieties, a limited market value of most native cultivars and a poor adaptability of cultivars out of their native area (Badenes et al. 1998). Thus, although apricot breeding objectives differ depending on the country and on the main use of the product (dry, fresh or canned), some selection criteria are common to most apricot breeding programs (Bailey and Hough 1975; Mehlenbacher et al. 1990; Layne et al. 1996; Lespinasse and Bakry 1999):

– One of the main objectives in most apricot breeding projects is climatic adaptation. Most apricot cultivars are highly specific in their ecological requirements. Consequently, commercial production is limited to some locations, where usually one or two cultivars account for most of the production. Therefore, there is a need to evaluate apricot cultivars in each production area to look for high and regular production. Depending on the location, this adaptation involves breeding for late blooming to avoid frost damages, for early blooming in frost free areas to develop early maturing cultivars or for greater midwinter cold hardiness in colder areas. Local fruit tree adaptation is expressed in terms of productivity and regularity of production, and directly related to specific environmental conditions.

- Fruit quality. Some of the most important characteristics for the fresh market are large size (more than 60 g), attractive appearance (a bright blush over bright orange or cream), freestone, firm flesh, resistance to skin cracking and uniform ripening. For canning apricots, good orange skin and flesh colors are preferred as well as uniform medium size, regular shape, good texture, high sugar content, small pit and a good balance of acid and sugar. For drying purposes, high soluble solids are needed.
- Introduction of self-compatibility in some self-incompatible interesting cultivars. Although most apricot cultivars are self-compatible, self-incompatibility is present in some interesting cultivars and cultivars used as parents in breeding programs.
- Disease resistance: important diseases include apricot chlorotic leaf roll (Mediterranean countries), bacterial canker caused by *Pseudomonas* spp., *Xanthomonas pruni* (America and South hemisphere), *Monilia*, *Gneumonia* (Eastern European countries). A special case is the menace of sharka, caused by the plum pox virus (PPV) that is causing important damages in most Mediterranean countries. There is no treatment to cure virus-infected trees, and once a tree is infected it serves as a source of infection for other trees. In countries where the level of infection is low and infected trees are restricted to limited areas, eradication has allowed to maintain a low level of infection and, more rarely, to eliminate the disease. However, eradication has proven insufficient in most countries because newly planted healthy trees become infected in a short time. Breeding programs for resistance/tolerance to sharka have been initiated in France (Audergon 1995), Greece (Karayiannis and Mainou 1999), Italy (Bassi et al. 1995) and Spain (Egea et al. 1999; Badenes et al. 2003) and they are yielding some interesting results (Egea et al. 2005).

Regarding Japanese apricot, its most notable biological characteristic is self-incompatibility although self-compatible cultivars are occasionally found. Some cultivars show also male sterility. Self-sterility limits fruit set in many locations and may force growers to plant unprofitable pollinating cultivars. Other important breeding objectives include in order of importance: big fruit size (more than 30 g), tolerance to gumming in fruits by which some fruits often lose their commercial value, late flowering which avoids frost damage, early ripening, and resistance or tolerance to scab and bacterial canker (H. Yaegaki, personal communication).

7.1.5 Classical Breeding Achievements

A high parent-offspring correlation was detected for fruit size and flesh firmness, two of the most important traits related to fruit quality, in the progeny analysis of some apricot crosses (Lapins et al. 1957). However, very little information is available in apricot about simple associations between morphological traits and fruit quality. Perez-Gonzales (1992) reported a wide range of variability among accessions representing apricot germplasm from Central Mexico for 20 morphological and phenological variables, especially for those factors associated with yield efficiency. Fruit weight was correlated with morphological traits such as tree growth habit, apical and basal diameter of fruiting spurs, and bud and leaf size. On the other hand, Badenes et al. (1998) showed a narrow range of variation among 55 cultivars from Spain, France, Italy, Greece, Tunisia, and USA for 18 morphological, phenological and fruit quality traits using principal component analysis. The only correlation observed between morphology and phenology was blossom and budbreak season with internode length. These results confirm that cultivars of the European group, the youngest in origin and the source of most of the commercial cultivars are difficult to sub-group morphologically and have a narrow genetic base (Bailey and Hough 1975; Layne et al. 1996).

In spite of its lower variability most of the progress in common apricot breeding has been carried out through hybridization and selection within the European group. However, a vast amount of mostly unexplored genetic variability is available within the other groups. A limited amount of published information of Irano-Caucasian cultivars comes from Armenia, Iran, Turkey, and North Africa. Soviet researchers published extensively on Central Asian cultivars and their hybrids. Information from Pakistan, Afghanistan, and China is very limited, although these areas are known to be rich sources of genetic diversity. Thus, information on genetic variability in apricot is primarily from collections where the European group is overrepresented lacking the enormous amount of variability

present in other groups (for review see Mehlenbacher et al. 1990 and Layne et al. 1996).

Most of the leading cultivars in the world come from local cultivars well adapted to one or very few areas (Bassi 1999). A number of apricot cultivars have been selected for several interesting traits such as disease resistance, climatic adaptation, fruit quality and tree growth habit (Mehlenbacher et al. 1990). Frost resistance has been also searched in apricots from wild species such as *Prunus sibirica* or *Prunus mandshurica* (Dosba 2003) and from native cultivars in Turkey (Akca and Sen 1999).

Released cultivars have been mainly obtained from open pollination, selfing, and, more recently, from controlled crosses (Layne et al. 1996). A number of apricot cultivars from controlled pollinations have been introduced in Argentina, Australia, Canada, Czechia, France, Hungary, Romania, Russia, South Africa, Spain, and the USA. While in most of these countries the production is still based on local cultivars, in others, like Canada and Romania, most of the production comes from cultivars developed from breeding programs specifically tailored for those regions (Bassi 1999).

The determination of the inheritance of a few traits of interest as self-compatibility (Burgos et al. 1997) or male sterility (Burgos and Ledbetter 1994) and to the identification of sources of tolerance/resistance to sharka (reviewed in Martinez-Gomez et al. 2000) have taken place in recent years. The genetic control of sharka resistance is still not very well known since contradictory reports have been published. Thus, the results of Dosba et al. (1991), Moustafa et al. (2001) and Vilanova et al. (2003a) suggested a two-loci control of the trait whereas the results of Dicenta et al. (2000) fit with a monogenic control and Guillet-Bellanger and Audergon (2001) suggest a control of the resistance by at least three loci. Further studies involving a larger number of individuals are needed to clarify the genetics of sharka resistance.

Regarding Japanese apricot, most main commercial cultivars resulted from natural selection carried out within the original areas of production. Because of the best quality for "Ume-boshi" processing, 'Nanko' is the most important cultivar so far. 'Nanko' was selected in Wakayama prefecture where more than half of total Japanese apricot fruits in Japan are produced.

Conventional breeding is still today the most important method of obtaining new European and Japanese apricot cultivars. As with other fruit tree species, this method is time-consuming and laborious; hence, the development of molecular markers linked to important biological character is absolutely required.

7.2 Construction of Genetic Maps

Genetic maps can be a useful tool to locate traits of interest to perform marker-assisted selection. Although advances in the construction of linkage maps in *Prunus* have been mainly obtained in peach, in the last few years, several genetic maps have been published in apricot:

- Hurtado et al. (2002a) developed two apricot maps composed of RAPD, AFLP, RFLP and SSR markers with 81 F_1 individuals from the cross 'Goldrich' × 'Valenciano'. A total of 132 markers (33 RAPDs, 82 AFLPs, 4 RFLPs, 13 SSRs) were placed into eight linkage groups in the 'Goldrich' map defining 511 cM of total map distance with an average distance between adjacent markers of 3.9 cM. A total of 80 markers (19 RAPDs, 48 AFLPs, 4 RFLPs, 9 SSRs) were placed into seven linkage groups on the 'Valenciano' map defining 467.2 cM of total map distance with an average interval of 5.8 cM between adjacent markers.
- Vilanova et al. (2003a) developed a map composed of AFLPs and SSRs from an F_2 population of 76 individuals from self-pollination of 'Lito' (an F_1 individual of 'Stark Early Orange' × 'Tyrinthos'). A total of 209 molecular markers (180 AFLPs and 29 SSRs) were assigned to 11 linkage groups covering 602 cM of total map distance with an average distance between adjacent markers is 3.84 cM.
- Lambert et al. (2004) used RFLP and SSR markers, previously mapped, in an F_2 progeny of the interspecific cross almond cv Texas × peach cv Earlygold (Joobeur et al. 1998; Aranzana et al. 2002) to develop two maps using 142 F_1 hybrids from a cross between the apricot cultivars 'Polonais' and 'Stark Early Orange' (Fig. 1); a total of 141 markers were placed on the map of 'Stark Early Orange' with a total length of 669 cM and 110 markers on the 'Polonais' map with a total length of 538 cM. Most markers present in each linkage group were aligned with those of the almond cv Texas × peach cv EarlyGold F_2 progeny map that is considered as a saturated

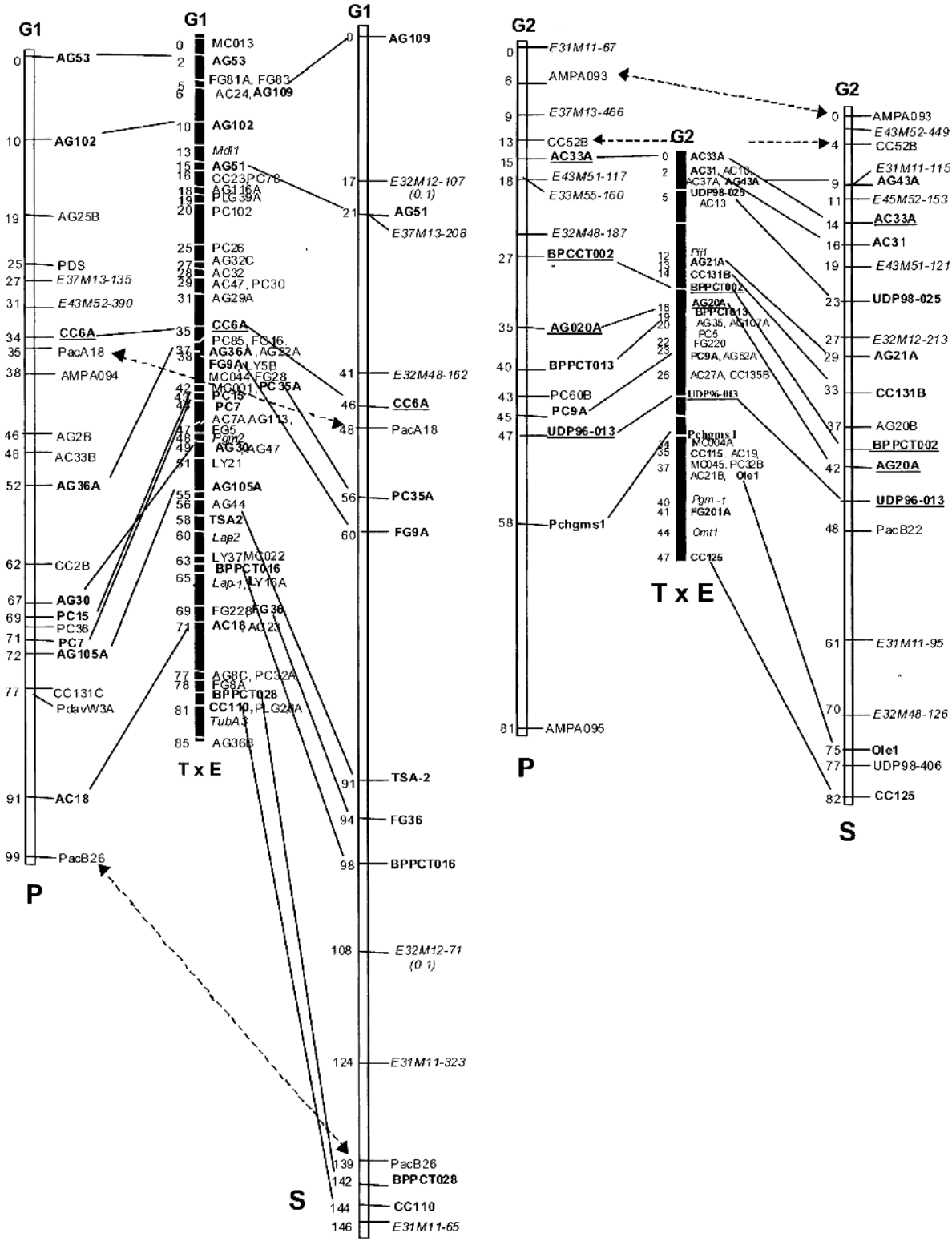

Fig. 1. Genetic maps obtained with the Polonais (P) × Stark Early Orange (S) (P×S) progeny compared to that of Texas × Earlygold (T×E) almond × peach. (Reproduced by permission of Lambert et al., Theoretical and Applied Genetics 108:1120–1130)

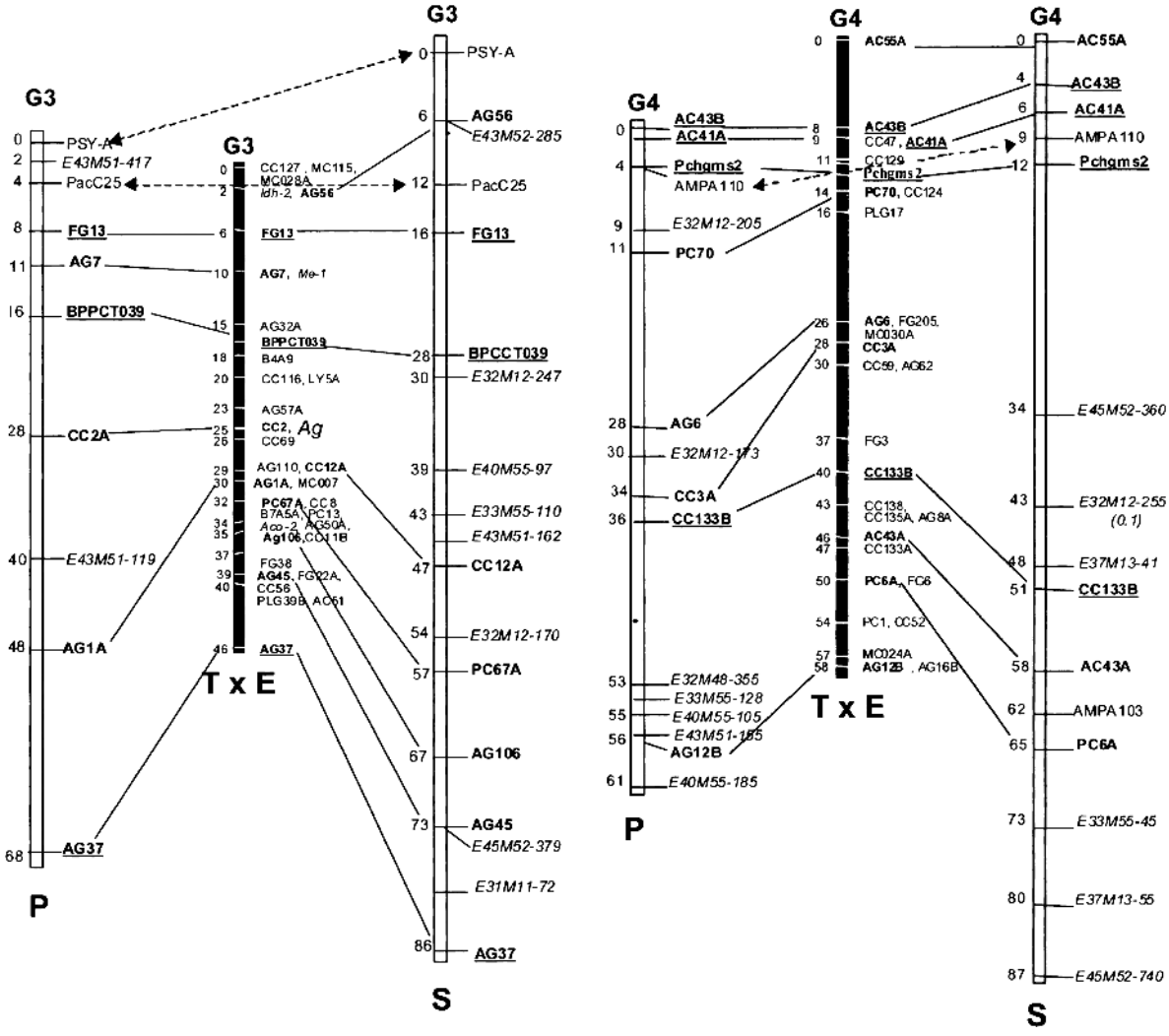

Fig. 1. (continued)

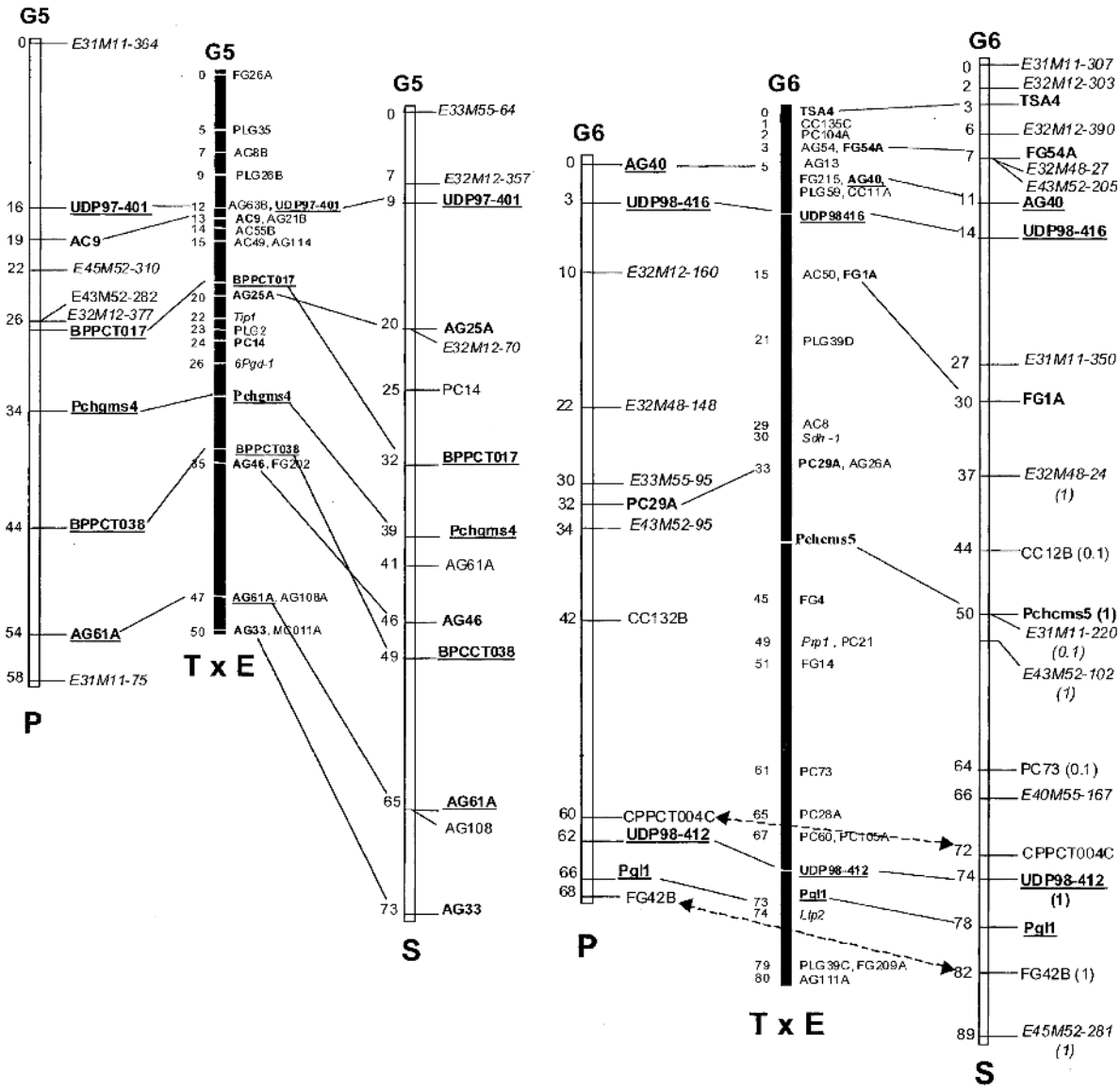

Fig. 1. (continued)

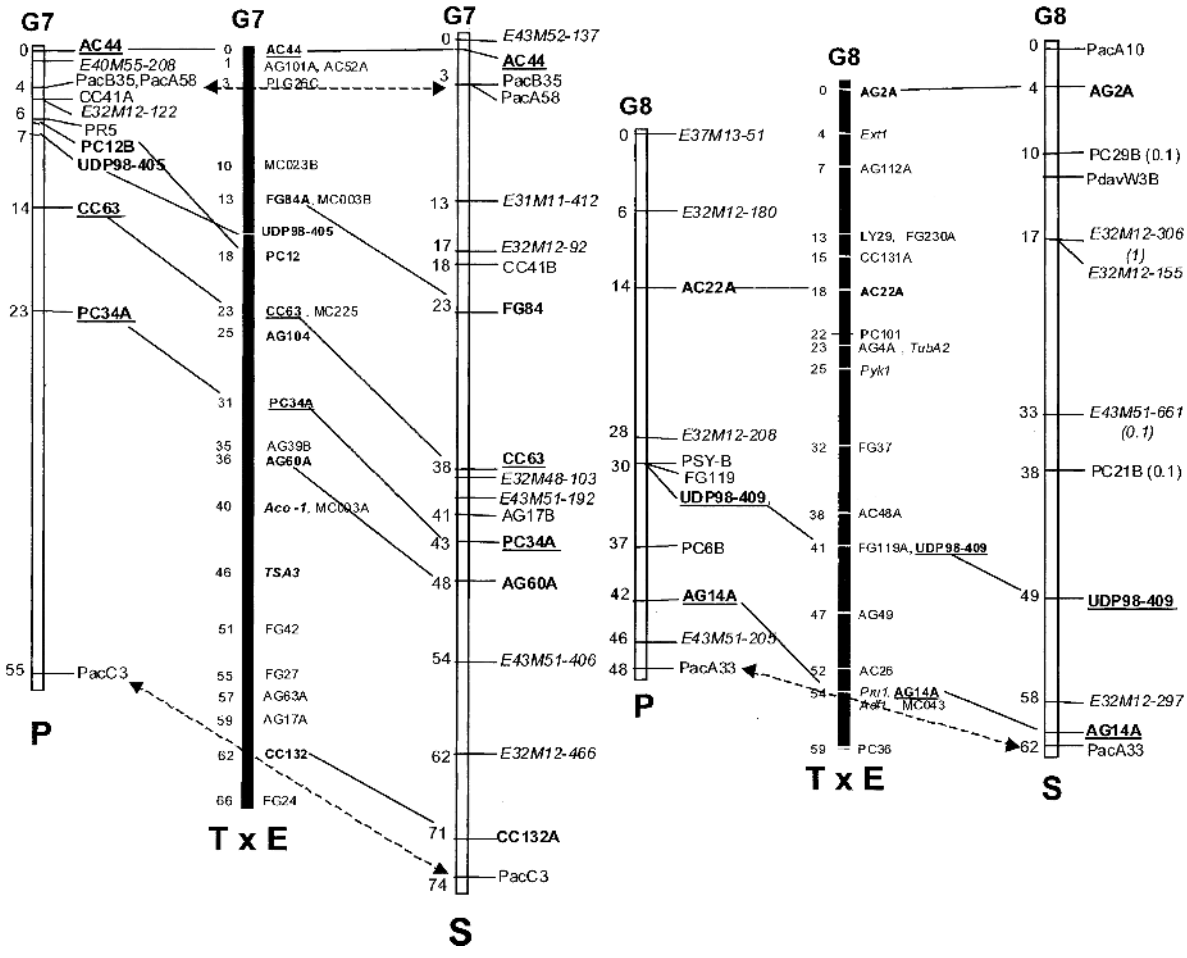

Fig. 1. (continued)

map (Joobeur et al. 1998; Aranzana et al. 2002). The results show a high degree of colinearity between the apricot and the peach and almond genomes suggesting a strong homology among *Prunus* genomes

Regarding Japanese apricot, although no reports of classical mapping efforts have been published to date, attempts to generate a first genetic map have been initiated recently (H. Yaegaki, personal communication).

7.3 Marker-Assisted Breeding:

7.3.1 Germplasm Screening

The information available on morphological apricot descriptors includes mainly varieties from the European group. They are based on a wide range of characteristics, such as tree vigor and growth habit, leaf size and shape, productivity, disease resistance or fruit quality (Crossa-Raynaud 1969; Brooks and Olmo 1972; Couranjou 1977, Fideghelli and Monastra 1977; Guerriero and Watkins 1984; Perez-Gonzales 1992; Badenes et al. 1998).

More recently, as in other fruit tree species (Wünsch and Hormaza 2002), different molecular markers have been used to fingerprint apricot cultivars and for genetic diversity studies. Molecular characterization of apricot cultivars was initially carried out using isozymes. Thus, Byrne and Littleton (1989a) studied isozymes on 69 accessions including European, Central Asian, North Chinese apricots and their hybrids, and found polymorphism at three of the seven examined enzymes; a few cultivars were uniquely identified. Battistini and Sansavini (1991) found four enzyme systems showing enzymatic polymorphism and could separate the 50 cultivars studied into 16 groups on the basis of the zymograms observed. Badenes et al. (1996) used 10 enzymatic systems, six of which were polymorphic, and were able to separate 94 apricot accessions in three geographical groups: North American, Irano-Caucasian and European. Likewise, Manganaris et al. (1999b) studied the enzyme variability among 17 apricot cultivars and 56 genotypes from intraspecific crosses using 20 enzyme systems, 15 of which were polymorphic. These studies with isozymes were not able to address the genetic diversity of apricot on a larger germplasm basis because of a lack of representative accessions from more diverse origins (Badenes et al. 1996; Manganaris et al. 1999b) or a lack of informative markers (Byrne and Littleton 1989a). Identification of interespecific hybrids between diploid plums and apricots has been also reported using isozymes. Thus, a useful marker was found for identifying plum × apricot hybrids among six enzymes (Byrne and Littleton 1989b) and 14 plum and 12 apricot specific alleles were found as useful markers for identifying plumcot, pluot and aprium hybrids (Manganaris et al. 1999b).

Due to the low polymorphism obtained with isozymes, in the last two decades efforts have been dedicated to obtain more efficient cultivar identification and diversity studies with the use of DNA-based molecular markers. Shimada et al. (1994) studied the genetic relationships among 54 Japanese apricot cultivars with 95 RAPD primers and classified them in seven groups that reflected their origin: 1) Taiwan mume, 2) Ko-ume, 3) Chuu-ume, 4) Ou-ume with white flower, 5) Ou-ume with pink flower, 6) Anzu-ume or Bungo-ume, and 7) Sumomo-ume. RAPDs were also applied to determine the parentage of Japanese apricot cultivars (Ozaki et al. 1995). Later, Takeda et al. (1998) investigated the relationships between 33 common apricot cultivars and two related species (*P. sibirica* L. and *P. brigantina* Vill.) with 18 RAPD primers, clustering the genotypes into two main groups, cultivars originated in the East (eastern China and Japan) and cultivars from the West (Europe, Central Asia and Western China). Mariniello et al. (2002) could identify 19 out of 25 cultivars analyzed with 44 RAPD primers.

RFLPs have also been used in apricot for fingerprinting and diversity studies. Thus, 45 different phenotypes from 52 apricot (*Prunus armeniaca* L.) cultivars (de Vicente et al. 1998) were identified using 31 selected probes developed in almond. The similarity matrix obtained from the molecular data was used to construct a dendrogram that separated the Spanish apricot cultivars from those from Europe and North America.

AFLPs have also been used for fingerprinting and diversity studies in apricot and the results obtained agree with the known historical movement of apricot cultivation. Hurtado et al. (2002b) examined 16 cultivars with six primer sets obtaining 231 polymorphic markers that allowed to distinguish all the cultivars studied. Similarly, Hagen et al. (2002) studied 47 apricot cultivars with five *Eco*RI-*Mse*I AFLP primer combinations revealing 379 polymorphic markers show-

ing a gradient of decreasing genetic diversity of varieties from the former USSR to Southern Europe. Panaud et al. (2002) studied 19 genotypes of a Saharian oasis with seven primer combinations producing a total of 197 amplification bands, of which 97 were polymorphic allowing the identification of all the genotypes studied. Similarly, Ricciardi et al. (2002) studied five apricot cultivars and 34 local Apulian ecotypes with four primer combinations resulting in 267 polymorphic bands from a total of 409 amplification fragments allowing the identification of all the genotypes. Geuna et al. (2003) used five primer combinations to unequivocally fingerprint 118 accessions resulting in 165 polymorphic fragments. Regarding Japanese apricot, recently 14 cultivars from China and Japan have been characterized with AFLPs with 12 primer combinations producing a total of 470 amplification bands, of which 284 were polymorphic allowing the identification of the genotypes studied and their grouping according to the known origin (Fang et al. 2005).

More recently, microsatellites have been used for genotype identification and variability studies in apricot. In a first step, primer pairs developed in other *Prunus*, mainly peach, were used. Thus, Hormaza (2002) identified 48 apricot genotypes with 20 primer pairs from peach grouping the cultivars according to their geographical origin and/or known pedigree information. Similar results were obtained by Zhebentyayeva et al. (2003) with 74 cultivars and 12 primer pairs, Romero et al. (2003) with 40 cultivars and 11 pairs of primers and Sánchez-Pérez et al. (2005) with 25 genotypes and 14 primer pairs. Ahmad et al. (2004) used 25 SSRs developed in cherry and three in peach to fingerprint seven apricot, one plumcot and six pluot cultivars confirming the transferability of SSRs among *Prunus* species. SSRs have also been used for identification of *P. mume* genotypes. Thus, Gao et al. (2004) reported the identification of 24 genotypes from diverse geographical areas with 14 SSRs derived from different *Prunus* species (nine from peach, five from sweet cherry and one from sour cherry). More recently, SSRs have also been specifically isolated in apricot. Thus, Lopes et al. (2002) and Messina et al. (2004) reported the isolation from genomic libraries of 21 and 99 SSRs, respectively, whereas Decroocq et al. (2003) isolated 10 EST SSRs from a leaf apricot cDNA library and Hagen et al. (2004) developed 24 new loci (13 from genomic libraries, eight from fruit EST libraries and three from a leaf cDNA library).

7.3.2 Marker-Assisted Selection and Gene Identification

The best example of the development of molecular markers linked to a trait of interest in Japanese apricot is self-incompatibility. Conventional assessment of self-incompatibility, as determined by pollination and pollen tube growth tests, requires several years after the tree reaches the flowering age. Recent identification of pistil and pollen-S determinants, namely S-RNase and SFB, respectively, enabled to develop molecular marker for S-haplotypes. Tao et al. (2002a) and Yaegaki et al. (2001) cloned cDNAs encoding S-RNases and established molecular typing system for S-haplotypes using the S-RNase sequence information. Cloning of cDNAs encoding pollen-S candidates, SFBs, led to a firm determination of S-haplotypes because the use of molecular markers for both pistil and pollen determinants became available (Yamane et al. 2003). This is very useful especially when S-RNase genes from different S-haplotypes gave the same PCR and RFLP bands. In addition, Tao et al. (2000, 2002b) and Yamane et al. (2003) revealed unique PCR or hybridization bands derived from S-RNase or SFB, linked to a mutated S-haplotype conferring self-compatibility in Japanese apricot. Regarding common apricot, the self-incompatibility trait has been mapped on linkage group G6 using an F_2 population derived from the self-pollination of an F_1 individual ('Lito') originated from a cross between 'Stark Early Orange' and 'Tyrinthos' (Vilanova et al. 2003a) and, more recently, the putative genes controlling gametophytic self-incompatibility have also been identified (Romero et al. 2004). Moreover, several research groups have determined apricot S alleles by PCR analysis (Halasz et al. 2005; Qi et al. 2005; Vilanova et al., 2005).

Another important trait for breeding purposes is resistance to sharka. Hurtado et al. (2002a) mapped the sharka resistance trait in linkage group 2 using an F_1 population derived from the cross between 'Goldrich' and 'Valenciano' whereas Vilanova et al. (2003a) mapped the trait in the G_1 linkage group using an F_2 population derived from the self-pollination of an F_1 individual ('Lito') originated from a cross between 'Stark Early Orange' and 'Tyrinthos'. The conservation of plant disease resistance genes has allowed the screening of apricot to isolate resistance gene analogs (RGAs) to find markers associated with resistance genes (Dondini et al. 2004; Soriano et al.

2005); one putative marker only present in sharka resistant genotypes has been recently reported (Dondini et al. 2004).

Regarding the study of specific genes, ripening-related genes are being widely studied in most *Prunus* species, including apricot, where fruit is the product of interest. Thus, a full length ACC-oxidase cDNA has been isolated from a cDNA library made from ripe apricot fruits based on sequence conservation among ACC-oxidases (Mbéguié-A-Mbéguié et al. 1999), a polyphenol oxidase expressed in leaves and mature fruits and turned off during fruit ripening has also been isolated from an immature green fruit cDNA library (Chevalier et al. 1999) and two expansins have been isolated from a ripe apricot fruit cDNA library (Mbéguié-A-Mbéguié et al. 2002). Expressions of ACC synthase and ACC oxidase have also been studied in Japanese apricot (Mita et al. 1999). As other fruit tree species, apricots contain some allergenic compounds and the most important is a protein that belongs to the family of lipid transfer proteins (LTP) (Pastorello et al. 2000) which is highly similar to peach and almond LTPs (Conti et al. 2001).

7.4 Future Scope of Works

Conventional apricot breeding has been successful for the development of new cultivars. New approaches with biotechnological tools offer the possibility of speeding up the development of new cultivars with improved characteristics. Promising results have been obtained in the development of molecular markers, fingerprinting and diversity studies although QTL analysis and gene identification, marker development and marker-assisted selection for important agronomic traits are strongly required to facilitate apricot breeding programs. Although genetic maps are a great advance to locate genes and QTLs, even in saturated maps, genetic markers are still too far in base pairs from genes. Physical maps can bridge the gap between markers and genes. Advances in the development of a physical map in peach (as a model species for the Rosaceae) will be very useful for apricot in the near future (Jung et al. 2004) due to the synteny observed among *Prunus* species. Similarly, the construction of BAC libraries in apricot can help in that direction (Vilanova et al. 2003b). Thus, any attempts for marker conversion such as EST analysis, saturated map construction and QTL detection (probably increasing the number of individuals in the progenies and improving the evaluation of phenotypic traits) or the application of gene analogs will undoubtedly open the door to clone and transfer genes of interest.

However, as in most *Prunus* tree species, the lack of an efficient transformation system hinders studies on the gain and loss of function in transgenic experiments. Plant regeneration from somatic seeds of adult trees is necessary to preserve genetic integrity of apricot cultivars but there are just limited reports of regeneration of transgenic apricot plants (Burgos and Alburquerque 2003). An efficient transformation system would allow the introduction of tolerance/resistance to sharka in adult material following the approaches used with by Da Câmara Machado et al. (1992) who regenerated from cotyledons transgenic plants with the PPV coat protein (PPV-CP).

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