An overview of almond cultivars and rootstocks: Challenges and perspectives

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Abstract. Almond growing in the Mediterranean area has been enduring sharp changes in the last decades. Whereas in some countries production has substantially decreased, in others a renewal of the concept of almond growing is taking place. In such a situation, new cultivars and rootstock are essential tools to achieve a success. Whereas in California 'Nonpareil' has been, and continues to be, the essential cultivar, and the new releases only represent a small percentage of the new plantings, the Mediterranean area showed an impressive change with the introduction of 'Ferragnès' by Charles Grasselly. An even more important change took place in Spain by the introduction of 'Guara' by Antonio J. Felipe. Now, the different breeding programmes aim at the release of late-blooming and self-compatible cultivars, two traits duly accompanied by autogamy and frost resistance, although not always these objectives are completely fulfilled. Most of the lately released cultivars are from Spanish breeding programmes, including those from IRTA, CEBAS, and CITA. In addition, only Israel has registered a new cultivar due to its large-sized kernel. For rootstocks, the changes have been in the same frame: small in California and sharp in the Mediterranean, where peach × almond hybrids have become the dominant rootstock, both in irrigated and non-irrigated conditions. 'GF-677' has been the most utilized rootstock in the past years, with an increasing utilization of new releases, more for the Spanish rootstocks from Aula Dei and CITA than for the Italian ones from the University of Pisa, looking for better management, adaptability and resistance to nematodes. New cultivars and rootstocks may improve almond production if they fulfil the requirements of modern fruit growing, as discussed in the presentation.

Keywords. Almond – *Prunus amygdalus* – Cultivars – Rootstocks – Breeding.

Passage en revue de cultivars et de porte-greffes d'amandier : Défis et perspectives

Résumé. *La culture de l'amandier dans la région méditerranéenne a subi dans les dernières décennies des changements appréciables. Si dans quelques pays la production a diminué considérablement, dans d'autres pays il y a eu un renouvellement du concept de la culture de l'amandier. Dans cette nouvelle situation, de nouveaux cultivars et porte-greffes sont essentiels pour aboutir à un succès. En Californie 'Nonpareil' a été, et continue à être, le cultivar principal et les nouvelles obtentions représentent seulement un pourcentage réduit des nouvelles plantations. Dans la région méditerranéenne, un changement considérable a eu lieu avec l'introduction de 'Ferragnès' par Charles Grasselly. Un changement encore plus important a eu lieu en Espagne avec l'introduction de 'Guara' par Antonio J. Felipe. Maintenant les différents programmes d'amélioration génétique ont comme but l'obtention de cultivars à floraison tardive et auto-compatibles, deux caractères dûment accompagnés par l'autogamie et la résistance aux gelées tardives, malgré que ces objectifs ne soient pas toujours accomplis totalement. La plupart des nouveaux cultivars proviennent des programmes d'amélioration espagnols, y compris ceux de l'IRTA, du CEBAS et du CITA. Par ailleurs, seulement Israël a enregistré un nouveau représentant des amandons de grand calibre. Pour les porte-greffe les changements ont été dans le même sens : réduits en Californie et profonds dans la Méditerranée, où les hybrides pêcher × amandier sont devenus le porte-greffe prédominant, tant dans des conditions d'irrigation comme en non irrigué. 'GF-677' a été le porte-greffe le plus utilisé dans les années précédentes, avec maintenant une utilisation majeure des nouvelles obtentions, plus pour les obtentions espagnoles d'Aula Dei et du CITA que pour les italiennes de l'Université de Pisa, en cherchant une culture plus efficace, une adaptabilité et résistance plus fortes aux nématodes. De nouveaux cultivars et porte-greffe peuvent améliorer la production de l'amandier s'ils parviennent à accomplir les besoins d'une culture moderne, comme discuté dans la présentation.*

Mots-clés. *Amandier* – Prunus amygdalus – *Cultivars – Porte-greffe – Amélioration.*

I – Introduction

The almond is characterized by peculiar climatic growing requirements related to the Mediterranean climate (Kester and Asay, 1975), including regions in the Mediterranean countries, the Central Valley of California, the Middle East, Central Asia, the Himalayan slopes and some equivalent areas in the Southern Hemisphere, in Chile, Argentina, South Africa and Australia. The Mediterranean climate is characterized by very low rainfall during late winter, the summer and early fall, which is needed because of rainfall interference in two almond man operations: pollination and harvesting. Rains during the fall disrupt harvesting operations while rains during bloom interfere with pollination by reducing the activity of pollinating insects. As a consequence, a strong negative correlation has been found in California between the total rainfall in February and final crop level (Alston *et al*., 1995).

Almond is also well adapted to mild winter and dry, hot summer conditions due to its low chilling requirement for early bloom, rapid early shoot growth and high tolerance to summer heat and drought. It has been the earliest temperate tree crop to bloom, which limited production to areas relatively free from spring frosts. Late-winter and early-spring frosts can damage, even completely destroy, almond crops.

World production is variable from year to year (Table 1), depending primarily on the climatic conditions, which affect both pollination success and disease and insect damage. In the Mediterranean and Asiatic regions, most almond orchards are not irrigated and rainfall, mainly in the winter and spring, is essential to ensure an acceptable crop.

Table 1. World almond production in the last years (in-shell tm, FAO web page)

Country	Year							Average
	2000	2001	2002	2003	2004	2005	2006	
USA	533,000	609,178	800,051	786,262	785,462	715,623	715,623	706,457
Spain	225,217	254,600	279,396	214,448	86,622	217,869	220,000	214,021
Italy	104,755	104,000	104,891	91,382	105,245	118,344	112,796	105,916
Syria	62,288	49,487	139,010	130,000	119,865	119,648	119,648	105,706
Iran	89,637	97,144	107,000	38,231	69,989	108,677	108,677	88,479
Morocco	65,044	81,820	82,400	70,808	60,200	70,629	83,000	73,414
Greece	50,956	55,115	38,130	36,480	48,177	47,088	47,088	46,148
Tunisia	60,000	32,000	18,500	40,000	44,000	57,000	50,000	43,071
Turkey	47,000	42,000	41,000	41,000	37,000	45,000	43,285	42,326
Lebanon	24,700	23,900	23,000	27,400	27,500	28,300	28,300	26,157
Libya	26,000	26,000	26,000	26,000	25,000	24,345	24,345	25,384
Portugal	27,038	15,743	30,850	23,829	13,953	13,823	11,166	19,486
Australia	17,420	9,475	10,040	9,554	9,430	11,755	11,755	11,347
Chile	8,140	8,600	9,100	8,800	9,000	10,153	10,153	9,135
Israel	5,068	4,418	9,142	4,900	4,210	9,118	11,242	6,871
France	6,936	6,931	6,800	6,800	6,800	2,137	1,781	5,455
Jordan	1,658	1,005	2,484	2,118	2,094	2,391	3,144	2,128
Argentina	470	470	480	480	486	491	491	481
Rest	122,986	130,939	137,951	127,180	147,539	153,130	163,633	140,480
World	1,478,313	1,552,825	1,866,225	1,685,672	1,602,572	1,755,521	1,766,127	1,672,465

Thus, new cultivars and rootstocks may take into account these problems in order to reduce their negative effect on almond production. The edible part of the fruit is the seed, and parthenogenesis does not ensure seed formation. As a consequence, efficient pollination is essential to obtain a crop and almond breeding programmes have stressed the development of new self-compatible cultivars. Late bloom is also a major aim to solve the problems of late frosts in many inland regions, with a more continental climate, where almond growing is now increasingly expanding. GREMPA Colloquia have been the most important forum for presentation and discussion of new cultivars and rootstocks, as seen in other presentations, with an impressive follow-up of self-compatibility. However, always more attention has been paid to cultivars than to rootstocks, although a specific seminar on almond rootstocks was held in 1988 (Felipe and Socias i Company, 1989). Now the most recent development of new plant material will be assessed.

II – Recent trends

Almond growing in the Mediterranean area has been enduring sharp changes in the last decades. Whereas in some countries production has substantially decreased, in others a renewal of the concept of almond growing is taking place. In such a situation, traditional cultivars and rootstock are being replaced by new ones in order to sustain an acceptable yield level and ensure a commercial production. However, in many old orchards the traditional cultivars and rootstocks can be still found and the most selected ones continue to be planted in new orchards, as 'Marcona' and 'Desmayo Largueta' in Spain (Table 2).

Table 2. Percentage of plants of each almond cultivar produced by the Spanish nurseries. (Spanish Ministry of Agriculture, Fisheries and Food web page)

Cultivar	Percentage
'Guara'	53.11
'Ferragnès'	13.34
'Ferraduel'	10.45
'Desmayo Largueta'	5.89
'Marcona'	4.54
'Tuono'	1.93
'Ramillete'	1.92
Others	8.82

Whereas in California 'Nonpareil' has been, and continues to be, the essential cultivar, and the new releases only represent a small percentage of the new plantings, the Mediterranean area maintained its traditional cultivars until the late 1960s when the late-blooming Puglia cultivars became widely planted owing to their more consistent yields. Of these, 'Tuono' and 'Cristomorto' were the most heavily planted cultivars. 'Cristomorto', however, because of lower quality and alternance, was rapidly replaced by 'Ferragnès' and 'Ferraduel' released in 1967 by the French breeding program (Grasselly and Crossa-Raynaud, 1980). 'Ferragnès' became the most successful new cultivar in European plantings with 'Ferraduel' often planted as a pollinizer. 'Ferragnès' dominance was ultimately ended with the release of newly developed self-compatible cultivars, as shown by impressive change taking place in Spain by the introduction of 'Guara' by Antonio J. Felipe (Felipe and Socias i Company, 1987), extensively planted during the last 20 years as shown by the plant nursery production (Table 2).

The French breeding program was the most successful program in Europe for many years. After the successful introduction of 'Ferragnès' and 'Ferraduel' in 1967, the later blooming self-incompatible cultivars 'Ferralise' and 'Ferrastar' were released in the late 1970s (Grasselly and Crossa-Raynaud, 1980), though with less success.

In Spain three active breeding programs released several cultivars in the 1980s and 1990s. In addition to 'Guara', the Zaragoza breeding programme released 'Aylés' and 'Moncayo' (Felipe and Socias i Company, 1987), with the same main objective of being self-compatible, but 'Moncayo', while showing self-compatibility in laboratory conditions was subsequently shown to be self-incompatible by Kodad *et al*. (2008). The breeding program from IRTA (Reus, Spain) placed greater emphasis on fruit quality and late blooming, with self-compatibility as a secondary objective. The first cultivars to be released were 'Masbovera', 'Glorieta' and 'Francolí' (Vargas and Romero, 1994) although 'Masbovera' has shown the highest success among the three despite the recognition that 'Francolí' is self-compatible (López *et al*., 2005). The breeding program from CEBAS-CSIC (Murcia, Spain) had as its main objectives self-compatibility and late-bloom time. The first releases in the late 1990s were 'Antoñeta' and 'Marta' (Egea *et al*., 2000).

Other programmes have been intermittently active in other countries (Kester and Gradziel, 1996), but not much information on their results is available or the diffusion of the new releases has been restricted, sometimes at a local level, as it may happen with some Iranian cultivars (Behboudi, unpusblished) or the Greek cultivar 'Alcyon' (Stylianidis, 2007).

For rootstocks, the changes have been in the same frame: small in California, where peach seedlings, mainly 'Lovell' and 'Nemaguard', remain the most utilized rootstocks, whereas in the Mediterranean area sharp changes have been taking place, with a shift from the utilization of different almond seedlings to the wide implantation of peach × almond hybrids. Due to the non-irrigated conditions of most Mediterranean orchards, almond seedlings had been the dominant rootstock for centuries, because of their deep growth and associated efficiency for mining nutrients and water. Often unselected rootstocks, even bitter almonds, were used for producing seedlings rootstocks although later some efforts were directed toward some seedling lines because of their homogeneity (Felipe, 1989) or resistance to nematodes (Kochba and Spiegel-Roy, 1976). More recently, peach × almond hybrids are showing promising performance under non-irrigation, due, in part, to the loss of the deeply mining almond tap-root when transplanting (Kester and Grasselly, 1987; Felipe, 2000). 'GF-677' has been the most utilized rootstock in the past years, with an increasing utilization now of new releases.

III – Current aims

An almond tree is a genetic compound made of a scion grafted on a rootstock, and both elements are essential tools to achieve a success, thus needing to be taken into account when designing a new orchard. The ultimate success of a cultivar or rootstock is dependent as much upon its freedom from deficiencies in any of the multitude of required productivity, resistance, and quality traits as it is upon the presence of desirable new traits such as self-compatibility (Felipe *et al.*, 1998; Socias i Company *et al*., 1998). The ultimate goal is the continued economic profitability of almond growing, either by increasing yields and prices and/or by reducing costs (Kester and Gradziel, 1996).

Now, the different breeding programmes aim at the release of late-blooming and self-compatible cultivars, two traits duly accompanied by autogamy and frost resistance, although not always these objectives are completely fulfilled. High levels of self-fruitfulness, achieved through the incorporation of both pollen-pistil self-compatibility and the capacity for self-pollination (autogamy) within the flower, has become a primary goal in almost all modern almond breeding programs, in order to minimize the problems associated with cross-pollination (Socias i Company, 1990). Despite a detailed genetic characterization of the self-self-compatibility major gene, variable expression is often observed (Alonso and Socias i Company, 2005) requiring a final field evaluation of productivity to determine cultivar value (Socias i Company *et al*., 2004; Kodad and Socias i Company, 2008).

The goal of late-blooming cultivars is the avoidance of late-winter/early spring frosts which are recurring threats to almond production because of its very early flowering season. This is particularly important in those regions where new plantings are occurring in inland regions with a more continental climate, and thus with an increasing risk of frosts. Concurrent with selections for late-blooming is selection for genetic resistance to low temperatures damage, which is known to vary among cultivars at the same phenological stage (Felipe, 1988).

Modified tree architectures maximizing fruit-wood renewal while significantly reducing pruning needs is also desirable in new cultivars (Socias i Company *et al*., 1998). This type of growth habit is characterized by the predominance of fruiting spurs, as found in the Puglia cultivars and their progeny (Grasselly, 1972). The presence of many spurs is essential for a very high bud density (Kodad and Socias i Company, 2006), resulting in a high potential fruit productivity, possibly also compensating for the damages from occasional frosts (Kodad and Socias i Company, 2008).

Ripening time is becoming more important in almond as it is in other fruit species, in order to advance harvest to a period with more favorable weather conditions and for earlier marketing. A range of successively maturing cultivars is also desirable to extend the harvest period for a more efficient and complete farm operation.

Resistance to pests and diseases is important goal with two main aspects: the reduction in costly chemical sprays and the reduction in the environmental damage from almond production.

Despite the difficulties in defining a kernel quality ideotype because of the sizable differences in consumer preferences (Janick, 2005), almond quality has become an important new goal for breeding (Socias i Company *et al*., 2008b), considering not only the chemical composition conferring a specific organoleptic quality, but also to physical traits related to industry processing. Thus, a different type of shell is preferred depending on the industry of each region, hard in most Mediterranean countries and soft in California and regions with similar growing system.

The chemical composition of almond kernels represents a new goal for breeding, not only because of the organoleptic aspect of quality, but also for the beneficial aspects of almond on human health, related to the anti-oxidant compounds of almond kernels, a high content of oleic acid among the fatty acids and the fiber content. Although these aspects have not yet been incorporated into the new releases, they are receiving an increasing attention not only among the almond breeders, but also among the growers, the industry and the consumers (Socias i Company *et al*., 2008b).

Most almond rootstocks are shared with other stone fruit species, primarily peach, but also have unique requirements from these other species. Tree-size reducing rootstocks are not as desirable in almond as in peach. Similarly, most plum rootstocks, because of their size reducing tendency, are only appropriate for almond plantings in heavy soils with problems of asphyxia, and greater disease presence. The use of plum for almond rootstocks also suffers from increased root suckering and unknown graft-compatibility with many cultivars.

Peach × almond hybrids, mainly the clonal types, are becoming the most utilized rootstock in Europe (Felipe *et al*., 1997). Desirable traits in new rootstocks include ease of propagation by hardwood cuttings and/or micro propagation, easy distinction of rootstock growth from scions (i.e., red leaves) to identify failed scion bud growth, tolerance to calcareous and poor soils, and high vigour. Increased tolerance to heavy soils and waterlogging is also becoming an important goal for new hybrids (Xiloyannis *et al*., 2007).

IV – New cultivars

1. Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Zaragoza, Spain

Self-compatibility has always been the main objective of this programme. Consequently all new releases from Zaragoza are all self-compatible cultivars including 'Blanquerna', 'Cambra' and 'Felisia' (Socias i Company and Felipe, 1999). 'Felisia' also incorporated the late-blooming trait for avoiding spring frost damage. In 2006, 'Belona' and 'Soleta' were released as self-compatible cultivars with improved kernel quality (Socias i Company and Felipe, 2007). In 2008, 'Mardía' has been released as an extra late-blooming cultivar (Socias i Company *et al*., 2008a).

'Blanquerna' is a 'Genco' open-pollinated seedling, self-compatible, of mid-blooming, open growth habit and medium vigour, high bloom density, with a very hard shell and a large kernel of excellent quality, very early ripening.

'Cambra' comes from the cross 'Ferragnès' × 'Tuono', self-compatible, late blooming, of slightly open growth habit and medium vigour, high bloom density, hard shell, kernel very similar to 'Ferragnès', medium ripening.

'Felisia' comes from the cross 'Titan' × 'Tuono', self-compatible, very late blooming, having inherited the late-bloom allele of 'Tardy Nonpareil' through 'Titan', open growth habit and medium vigour, high bloom density, preferably on shoots, medium-hard shell, small kernel, very low alternance, early-medium ripening.

'Belona' comes from the cross 'Blanquerna' × 'Belle d'Aurons', self-compatible, semi-erect growth habit and medium vigour, late blooming, hard and well-filled shell with a large kernel of an outstanding composition, medium ripening.

'Soleta' comes from the cross 'Blanquerna' × 'Belle d'Aurons', self-compatible, semi-erect growth habit and medium vigour, late blooming, hard and well-filled shell with a large kernel with an outstanding performance when roasted, medium-late ripening.

'Mardía' is a seedling from the cross 'Felisia' × 'Bertina', self-compatible, semi-erect growth and vigorous, extremely late blooming, with the same late-bloom allele than its parent 'Felisia', hard shell, kernel of high quality, disease and drought tolerant, early-medium ripening.

2. Centre Mas de Bover (IRTA), Reus, Spain

This breeding programme placed greater emphasis on fruit quality and late blooming traits. The most recent releases in 2006 further delay bloom time, with the self-compatible 'Constantí', 'Marinada' and 'Vairo', and the self-incompatible 'Tarraco' cultivars (Vargas *et al.*, 2008).

'Constantí' is a seedling from a selection of the cross 'Ferragnès' × 'Ferraduel' open pollinated, self-compatible, late blooming, of semi-erect growth habit and good vigour, tolerant to drought, hard shell, large kernel, mid ripening.

'Marinada' comes from the cross 'Lauranne' × 'Glorieta', self-compatible, very late blooming, of semi-erect growth habit and medium vigour, hard shell, large kernel, mid ripening.

'Tarraco' comes from the cross of a ('Ferralise' × 'Tuono') seedling × 'Anxaneta', self-incompatible, of semi-erect growth habit and medium vigour, very late blooming, tolerant to diseases, hard shell and very large kernel, mid ripening.

'Vairo' comes from the cross of a ('Primorskij' × 'Cristomorto') seedling × 'Lauranne', self-compatible, of a medium growth habit and high vigor, late blooming, hard shell with large kernel, early ripening.

3. Centro de Edafología y Biología Aplicada del Segura (CEBAS, CSIC), Murcia, Spain

Self-compatibility and late-bloom time are the main objectives of this breeding programme. Two more recent cultivars, 'Penta' and 'Tardona', are characterized by their extremely late blooming time (Dicenta *et al*., 2007).

'Antoñeta' comes from the cross 'Ferragnès' × 'Tuono', self-compatible, of spreading growth habit with dense branching and high vigour, late blooming, hard shell and large kernel, medium-late ripening.

'Marta' comes from the cross 'Ferragnès' × 'Tuono', self-compatible, of upright growth habit and high vigour, late blooming, hard shell with large kernel, medium ripening.

'Penta' comes from the cross of the CEBAS selection S5133 × 'Lauranne', self-compatible, of intermediate growth habit, vigour and branching, extremely late blooming, hard shell with intermediate kernel, very early ripening.

'Tardona' comes from the cross of the CEBAS selection S5133 × Grasselly's selection R1000, self-compatible, of intermediate vigour with dense branching, extremely late blooming, hard shell with small kernel, medium ripening.

4. INRA, Avignon, France

After the first self-incompatible cultivars, the 1989 releases 'Lauranne' and 'Steliette' were self-compatible (Grasselly *et al*., 1992), with 'Lauranne' being particularly successful in France (Duval and Grasselly, 1994). A recent release from this program has been 'Mandaline' (Duval, 1999).

'Lauranne' comes from the cross 'Ferragnès' × 'Tuono', self-compatible, with open growth habit and intermediate branching and vigour, late blooming, medium-hard shell with intermediate kernel and some double, early-medium ripening.

'Steliette' comes from the cross 'Ferragnès' × 'Tuono', self-compatible, with semi-erect growth habit, low branching and medium vigour, late blooming, semi-hard shell with some double kernels, early ripening.

'Mandaline' comes from the cross 'Ferralise' × 'Tuono', self-compatible, late blooming, medium to upright growth habit with medium vigour, hard shell with intermediate kernels, medium ripening.

5. Agricultural Research Organization, Ramat Yishay and Bet Dagan, Israel

The only other recent release from the Mediterranean region has been 'Shefa' (Holland *et al*., 2006), a self-incompatible seedling from 'Tuono', characterized by a very large nut.

'Shefa' is a selection from the cross 'Tuono' × '73' (a local cross), self-incompatible and combining good yield with high-quality kernel and early crop production. It is vigorous, early blooming, highly adapted to Israel conditions, of soft shell and large kernel, early ripening.

V – New rootstocks

1. Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Zaragoza, Spain

The most important breeding result has been the 'Garfi' × 'Nemared' crossing program at Zaragoza, giving rise to the nematode-resistant and red-leafed hybrid rootstocks 'Felinem', 'Garnem' and 'Monegro'. These rootstocks are characterized by a good adaptability to poor soils and easy propagation by hardwood cuttings (Gómez Aparisi *et al*., 2002).

'Felinem' comes from the cross 'Garfi' almond × 'Nemared' peach, with red leaves, low number of feathers, easy hardwood propagation, nematode resistant, good vigour, adapted to replanting and to poor and calcareous soils.

'Garnem' comes from the cross 'Garfi' almond × 'Nemared' peach, with red leaves, low number of feathers, easy hardwood propagation, nematode resistant, good vigour, adapted to replanting and to poor and calcareous soils.

'Monegro' comes from the cross 'Garfi' almond × 'Nemared' peach, with red leaves, low number of feathers, easy hardwood propagation, nematode resistant, good vigour, adapted to drought, to replanting and to poor and calcareous soils.

2. Estación Experimental de Aula Dei (EEAD, CSIC), Zaragoza, Spain

These releases resulted from natural selection, not from controlled crosses, and are more adapted to peach than to almond (Moreno, 2004).

'Adafuel' is a natural hybrid (probably seedling of 'Marcona' pollinated by a clingstone peach), of easy propagation, very vigorous, adapted to poor and calcareous soils.

'Adarcias' is a natural hybrid selection of unknown origin, of easy propagation, low vigour, adapted to calcareous soils, but fertile soils.

3. University of Pisa, Italy

The hybrid 'Sirio' (Loreti and Massai, 1998) comes from this programme. Also from the University of Pisa is the ISG rootstock series primarily derived from myrobolan, and so of limited application to almond (Cinelli and Loreti, 2004).

'Sirio' is a seedling from the open pollinated peach × almond rootstock 'INRA GF 557', of poor vegetative propagation but a good root system, induces low vigour and requires high input growing conditions.

VI – Conclusion

During the last decade many new cultivars and rootstocks have been offered by the different breeding programmes to the grower, but their utilization will only improve almond production if they fulfil the requirements of modern fruit growing under the appropriate cultural management. These requirements are essential in order to obtain the maximum yield potential of these selected plant materials.

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