Review Article

ROOTSTOCKS OF ALMOND

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Abstract : It is well known that rootstocks are used for tree size control but we may need to remind ourselves of their other benefits. They have other specific influences such as winter hardiness, early yield, good fruit size, phytopthora and collar rot resistance, replant disease tolerance and mildew and woolly aphid resistance. The one thing they all have in common is that they produce a uniform stand of trees .The attributes required for a rootstock have become more sophisticated over the years, but limiting excessive growth, precocity ,enhancing cropping efficiency and wider adoptability to biotic and abiotic factors remains the primary targets while using rootstocks. In recent past, clonal rootstocks of temperate fruits developed in Russia, Poland, USA, UK, France etc are being evaluated in the different areas of the world (M,MM, P, Bud, MAC, Ottawa series in Apple, OH x F, Oregon series in Pear, Gisela series in Cherry, Peach x Almond hybrids rootstocks etc). "Lapins" sweet cherry cutivar had lowest trunk cross sectional area under Giesela 5 but yield efficiency was highest. Mariana plum rootstock GF 8-1 resisted to water logging for 145 and 50-60 days in winter and summer respectively, highest than other stocks studied. Various clonal and seedling rootstocks of apple, pear, peach, plum, cherry etc have been rated for their resistance, tolerance or susceptibility to biotic and abiotic factors by different researchers Cherry rootstock Avima Argot and CAB 11 E resulted in 100% survival as compared to Colt (84.6%) under non irrigated conditions from 1996 to 2004 . Modern genetic engineering technology is starting to realize much of its promise in the identification of markers that will reduce reliance on tedious, expensive, long-term field trials and thus accelerate progress. Much good scientific work and challenges remain.

Keywords : Almond, Rootstocks, Tree

INTRODUCTION

Almond (*Prunus dulcis* M.) is one of the major and oldest nut tree crop known to the mankind with wide spread popularity throughout the world. The probable origin of this nut trees crop is believed to be the area around central Asian mountains including Iran, Afghanistan, India and Pakistan. Because of climatic limitations, the principal production areas for almonds have been the central valley of California, area bordering the Mediterranean sea, south east and central Asia, limited areas in Chile, south Africa and Australia with highest production in USA fallowed by Spain. In India, almond is mainly grown in the state Jammu and Kashmir and Himachal Pradesh. However, its large scale cultivation is confined mainly to the valley of Kashmir, occupying an area of 17153 ha with a total production of 12497 MT (Anonymous, 2009-2010). The productivity of J&K is 0.73 t/ha which is more than the national productivity of 0.7 t/ha but less than the global productivity of 1.15 t/ha.
Almond is grown mainly for its kernels which are concentrated source of energy rich in fat (54.0 g), protein (19.0 g), various minerals and vitamins. The kernels and their oil (Rogne-Badam) are known for their medicinal values and are important material media in Ayurvedic and Unani system of medicine. The performance of deciduous trees with respect to crop yield, fruit size, fruit quality, storability adaptability and long term productivity are highly dependent on root stocks. Nut crops are relatively long lived species whose performance reveals the integration over time of the plants genetic composition (both of scion and the root stock in grafted plants) with the effects of the site (composed of edaphic, climatic and other biotic variables), under the cultural system used for management. There is indeed a great potential for brining more area of land under almond cultivated , provided appropriate root stocks are available which overcome the problems of seedling almonds. Thus, development of improved root stocks for almond requires an understanding, appreciation and control of that entire potential source of variation.
Root stock influences are more obscure than scion effects. Systematic root stock development through breeding require the same commitment of time and resource for scion breeding while the demonstration of rootstock efficiency require additional care in test establishment and long term monitoring. Furthermore, various site specific challenges within otherwise homogenous regions of cultivar adaptation introduces additional complexity which possibly limiting broad deployment. The historic pattern of root stock development across nut crops has been one of the dynamic interaction between a knowledgeable grower community comprised of nursery men, traditional farmer and orchardists, an active plant introduction programme and an observant scientific community, all riding a mounting wave of developing technology.
Rootstock selection criteria vary between traditional and intensive culture system, the choices are primarily between almond seedling root (for day calcareous sites), peach seedling rootstock (for acid

sites), peach almond hybrids (vigorous growth on calcareous, dry sites) and mareanna plums (for use on heavy soil). In more intensive agricultural system, other rootstocks can contribute necessary attributes; peach seedling rootstock such as 'Nemaguard' has tolerance to nematode and may have an advantage on well-trained, acidic, irrigated sites. Breeding for a new generation of interspecific rootstocks of the type M x P, M x A and Mx (P x A) have been performed in a European project (1999-2003) in order to combine disease resistance carried by Myrobalan plum accessions P. 2175 and P. 2980 with major adaptive traits carried by the Amygdalus parent. Therefore several bi-specific or tri-specific hybrids between Myropalan plums and other source available have been characterized in different years for water logging (Dichio *et al.*, 2002; Dilewangel *et al.*, 2004), drought and chlorosis, after confirming their resistance against root knot nematode by biological testing (Rubio *et al.*, 2000) and applying MAS (Lecouls *et al.*, 2004).

The almond rootstock

Fruit trees, including almond, are complex individuals made up of the symbiotic scion/rootstock association. These two components interact mutually, depending on their genotypes and environmental influence. Rootstock characteristic however, have been less studied than those of the scion. Consequently, rootstock selection has been somewhat neglected and traditionally almond seedlings from unknown origin have been used. The root system, however, is very important as good production depends upon good adaptation of the root system to the soil conditions. A mistake in rootstock selection can only be solved by uprooting the orchard.

The genetic identity of almond rootstock was rarely maintained because of the difficulty of vegetative propagation. Consequently, almond seedlings of unknown origin have been traditionally used in all growing regions. Seedling from bitter almonds was preferred because they were believed to be more resistant to drought and to soil pests than sweet almond seedling. Additionally this offered a use for bitter kernels. These favorable characteristics, however, have not been confirmed in the orchard. In recent years seedling from selected cultivars have been recommended, because they are quite homogenous and show good nursery characteristics. This is the case for 'Dasmayo Roji', 'Garringuer' and 'Atocha' in Spain. An effort has been devoted to the selection of mother plants producing seedling with better characteristics (Oliver and Grasselly, 1988). Almond growing in irrigated conditions does not allow the use of almond seedling as rootstocks. Consequently, peach seedlings of selected cultivars such as 'Lovel' and 'Nemagourd' have been used, although the problem of tree heterogeneity has not been completely solved.

Repeated attempts to select a clonal almond rootstock have failed due to the difficulty of vegetative propagation in this species (Felipe, 1983, 1998; Nicotra and Pellegrini, 1989). Consequently, the first clonal rootstocks used for almond were different selections of plum, a species of generally easy vegetative propagation and good adaptability to soils with asphyscia and fungal problems. Plum rootstocks, however, require frequent irrigation and are not adapted to non-irrigated conditions. Moreover, plum rootstocks show cases of graft incompatibility with some amond cultivars (Felipe, 1977). Some hexoploid plum clones, however, show good graft compatibility with almond and can be used under irrigation. Therefore, breeding for a new generation of inter-specific rootstocks have been performed in a European project in order to combine disease resistance carried by Myrobalan plum with major adaptive traits carried by the Amygdalus parent (Xiloyannie *et al.*, 2007; Dichio et a., 2002 and Dirlorwanger *et al.*, 2004) developed several bi-specific and trispecific hybrids between Myrobalan plum and the Amygdalus and observed that genotypes derived from the cross P.2175 x GN15 were tolerant to water logging conditions and GN15 and GN22 showed greater sensitivity. Rubiocabetas *et al.* (2000) reported that P2175 x GN15-9, P2980 x GN15-9 clones which were genotypes with peach x almond hybrid percentage and the parent GN15 responded better to drought stress. The experience acquired during these studies has allowed the identification of different problems related to rootstock in almond and of the characteristics desired to solve these problems. Thus, we will review all the requirements of an almond rootstock in order to establish ideolypes according to biotic and abiotic factors by Dickmann *et al.* (1994).

Characteristics of an almond rootstock ideotype (Dickmann *et al.*, 1994).

1) **Nursery characteristics:**Easy propagation**,** seedling with high germination rates**,** homogenous plants, cuttings **(**early and unexpensive cutting production**,**easy rooting and strong root system) and nursery behavior**(**erect growth habit with few feathers at the budding point**,**easy distinction from the scion)
2) Graft compatibility : compatibility with all or most cultivars.
3) **Orchard characteristics:** High transplant rate**,** homogenous development**,** induced size adequate to the growing conditions**,** high precocity and productivity**,** high water and nutrient efficiency**,** good anchorage and low sucker production
4) **Resistance to biotic and abiotic factors:** Good adaptation to problematic soils (heavy and/or calcareous soils)**,**resistance to adverse conditions**,** drought**,** root crown asphyxia and soil pathogens**(**Nematodes**,** Insects (Capnodis

etc.)**,**Bacteria (Agrobacterium)**,** Fungi (*Verticullium, Armillaria* etc.)

5) **Good sanitary status:** Free from known virus, phytoplasmas

The various rootstocks used for almond are described below :

I) **Almond seedling rootstock:** These have been primarily used in Europe and other Mediterranean countries where most orchards grow on highly calcareous soil and often without irrigation (Graselly and Olivier, 1977; Loreti and Marsai, 1990). This stock has been traditionally used in Australia (Bankes and Gathercole (1977) and many parts of the world. In irrigated and highly fertile soils, use of almond seedling as rootstock has ceased due to the problems of slow initial growth and delayed productivity (Kester *et al.*, 1985).

Positive characteristics: Great rusticity shown by their ability to survive on poor soils with high limestone content as well as with a scarce availability of water. They are more tolerant to excess boron and chloride.

Negative characteristics

1. They suffer from transplantation shock
2. They are sensitive to soil diseases, *Agrobacterium, Phytopthora, Armillaria* etc.
3. They are sensitive to root and collar rot.

II) **Peach seedlings:** Peach seedlings are the dominant rootstock for almond in California and in various other parts of the world where irrigation is practiced, soils are slightly acidic and highly intensive production practices exist.

Negative characteristics: Sensitive to crown gall, *Vrticillium*, oak root fungus, root knot nematode. The several peach seedlings rootstocks are :

A) **Lovell:** Better anchorage than nemguard**,**slightly more tolerant of wet soils than nemaguard**.**more tolerant to ring nematode

Disadvantage: Less vigorous than nemaguard**,**susceptible to all nematodes, bacterial canker (less than nemaguard) phytopthora, oak root fungus, crown gall, high lime soils and high salt and water (sodium, chloride, boron).

B) **Nemaguard and nemared**

Advantages: Immune to root knot nematode**,** vigorous and compatible with all almond varieties**,**perform well in sandy loam and loam soils and decent anchorage and Industry standard in San Joaquin valley.

Disadvantages: Susceptible to ring and lesion nematode, bacterial canker, phytopthora, oak root fungus, crown gall, high soil pH/high lime and high salt and water in soil (sodium, chloride, boron).

III) Peach-almond hybrids

Advantages: Very vigorous**,** excellent anchorage**,** highly tolerant to root knot nematode, high pH and lime and more tolerant to high chloride and drought than peach

Disadvantages: Very vigorous i) tree get too big on deep, fertile soil ii) delay fruit maturity**,**very susceptible to ring nematode and bacterial canker (Fig. 1), phytopthora, oak root fungus, crown gall (Fig. 2).

Fig. 1. Bacterial canker of almond on Hansen 536 rootstock

Fig. 2. Crown gall on Hansen rootstock

Peach-almond hybrids include: Hansen 536, Nickels, Cornerstone, Titan, Bright's hybrids and Almond x Nema guard peach

IV) Marianna plums

They are believed to have originated from cross of Myrobalan plum (*P. cerasifera*) x *P. hortulana* in the United States (Day, 1953). From this hybrid various seedlings have been grown from which vegetatively propagated clones have been chosen and introduced as rootstock. Two selections used for almond in California are known as 'Mariana 2623' and 'Mariana 2624'.

a) Mariana 2624

Advantages: Resistant to rootknot nematode**,**tolerant to 'wet feet' and crown gall**,**resistant to heart rots and oak root fungus.

Disadvantages: Highly dwarfing rootstock**,**suckers profusely (Fig. 3)**,**incompatible with non-pareil and Livingston (Fig. 4, 5).marginal compatibility with Butte and Monterey lesion nematode and bacterial canker.shallow root system (Fig. 6).

Fig. 3. Root suckering of Marianna 2624 plum rootstock

Fig. 4. Overgrowth at union on Marianna 2624 rootstock

Fig. 5. Incompatibility symptoms of nonpareil on Marianna 2624 plum rootstock

Fig. 6. Marianna 2624 is very shallow rooted

V) Interspecific hybrids of peach, almond, apricot and plum : they include :

a) Viking: Vigour is similar to nemaguard**,** better anchorage than nemaguard**,** resistant to root-knot nematode and ring nematode**,** tolerant to bacterial canker than other commonly used rootstocks.**,**more tolerant of high lime soil than nemaguard**,** less susceptible to chloride than nemaguard and susceptible to dehydration during cold storage or transplanting

b) Atlas:less susceptible to chloride than Nemaguard and Lovell.**,** more susceptible to ring nematode than Viking**,** more precocious than Nemaguard.

c) Plum x almond hybrids : They show good rootability and are compatible with both almond and peach.

d) *Prunus besseyi* x Myrobalan plum: A selection P2037 is being used in France which provides semi-vigours tree with good compatibility to almond. Yield efficiency is high.

e) *Prunus tomentosa* x *P. besseyi* : Very compatible with almond and produce weak tree.

f) *P. besseyi* x peach: A selection originating from Illinois was tested in France that give good vigour and compatibility with almond but has poor anchorage.

g) 'Pollizo' plums: This group of plum rootstock, apparently *Prunus insititia* of the Saint Julien type has been traditionally utilized in the Murica district of Spain as rootstocks of peach, apricot and almond. This results from their adaptability to highly calcareous and compact soils in that area. Variation exists in their ease of propagation and compatibility with almond.

New Russian prunus rootstocks

1) Krymsk86: *Prunus persica* x prunus :Tree size similar to lovel, compatible with almonds, peach, nectarines, apricot and European plums, excellent graft or smooth union,tolerant to well and heavy soils and is cold hardy and high tolerance to high pH, precocious and increase fruit size and yield and with strong root system and propagate easily with soft and hardwood cuttings and perform well on replant sites
2) Kryansk 1 : *Prunus tomentosa* x *Prunus cerasifera*:Reduce tree size 40-50 per cent., compatible with peach, almond and nectarine, precocious with good field yield efficiency, tolerates to cold climate, wet and heavy soil conditions, sensitive to dry conditions,propagate easily with soft and hardwood cuttings
3) Krymsk 2: *Prunus incana* x *Prunus tomentosa*: Reduce size by 40 per cent, excellent graft union with no overgrowth, precocity with good yield efficiency, tolerant to dry soil conditions and cold climate and propagates easily with soft and hardwood cuttings

Rootstocks under trial (1) Butte (2) Colusa (3) Kern (4) San jaoquin

Problems to almond cultivation

The main problem for extension of almond cultivation (Dedampour *et al.*, 2006) are as under :High segregation of seedling rootstock, salinity and drought condition, calcareous and alkaline conditions, waterlogged condition, Diseases: Crown gall (*Agrobacterium* sp.), honey fungus (*Armillaria mellea*), crown rot and wet feet (*Phytopthora* sp.) and Nematode : Root-knot (*Meloidogyne* spp.), ring (*Mesocrickonema xenoplax*), lesion (*Pratylenchus* spp.), Dagger (*Xiphinema* spp.).To solve above problems, fruit breeders carried out research and released different rootstocks which can sustain these conditions. Dejampour *et al.* (2006) evaluated 120 genotypes and selected 11 promising genotypes were selected based on vegetative traits, cold hardiness, disease and pest resistance and stresses Tab.1

Table. 1 Hybrid rootstocks of almond

S. No.	Rootstock	Parentage	Vigor reduction with respect to GF677 (%)	Suckering	Adaptability (cold, disease and soil)
1.	HS419	Almond x peach	30	No suckering	Very good
2.	HS302	Apricot x plum	10	-do-	-do-
3.	HS312	Almond x peach	Similar to GF677	-do-	-do-
4.	HS407	Apricot x plum	10	-do-	-do-
5.	HS417	Almond x prune	10	-do-	-do-
6.	Hs324	Apricot x plum	30	-do-	-do-
7.	HS416	Apricot x prune	30	-do-	-do-
8.	HS411	Apricot x plum	20	-do-	-do-
9.	HS314	Almond x peach	10	-do-	-do-
10.	HS414	Plum seedling	50	-do-	-do-
11.	HN-1	Prunus Fenzlian	-	-	-

Pinochet *et al.* (2002) reported different response of rootstocks for root-knot, lesion nematode and crown gall which are indicated in Table 2.

Table 2. Rootstock resistant to nematodes

S. No.	Rootstocks	Parentage	RKN	LN	CG	Other interesting traits
1.	Cadaman	Peach	HR	S	S	-
2.	Flordaguard	Peach	HR	S	S	-
3.	Adarcias	peach x almond	4	S	-	Medium vigour
4.	Felinem	4	MR	MR	S	Resistance to iron chlorosis
5.	Mayor	4	S	S	-	11
6.	Ishatala	Plum	HR	S	-	Compatible with other prunus varietes
7.	Mareanna2624	Plum	HR	S	S	Resistance to Armilleria
8.	Torinal	Plum	MR	MR	MR	Multiple resistance to soil borne pathogen

RKN - Root-knot nematode, LN – Lesion nematode, CG – Crown gall
Resistance rating: HR – Highly resistant, R – resistant, MR – moderately resistant, S – susceptible
Anne-Chaire *et al.* (2004) observed Ma gene which is responsible for resistance in prunus speices. They observed different responses in prunus species which are indicated in Table 3.

Table 3. Nematode resistance in rootstocks

S. No.	Rootstock	Parentage	Host susceptibility				Resistance status and genetic control
			MA	MI	M J	M. sp. Florida	
1.	Nemared	Peach	R	R	R	S	Two homozygous genes to MI (Mi and Mij) and one homozygous gene to Mj/Mij (Lu *et al.*, 2000)
2.	Alnem1	Almond	R	S	R	S	One homozygous dominant gene to MI (Kochba and Spiegel Roy, 1975)
3.	Garfi	Almond	S	S	S	S	Esmenjaud *et al.*, 1997)
4.	GF.557	Almond x peach	R	R	S	S	Species specific resistance (Esmenjaud *et al.*, 1994)

MA – *Melordogyne arenaria*, MI – *M. Incognita*, MJ – *M. javanica*
R – resistant, S – susceptible

Dirlewanger *et al.* (2004) studied new interspecific hybrids between nematode resistant Myrobalan plums, *P. cerasifera* (P. 2980 and P. 2175) and peach (*P. persica*) x almond (*P. amyydalus*) and reported that P.2175 x GN has significantly greater tolerance to waterlogged condition than its control rootstock (GF677). Rubio-carbetas *et al.* (2000), Lecolus *et al.* (2004) studied various interspecific hybrids and found that P2175 x Gn15-9, P2980 x GN15-9 which are genotypes of peach x almond and GN15 parentage responded better to drought stresses.The other horticultural influence by use of rootstock are :

1) **Vigour:** Rootstock has dwarfing effect which resulted introduction of different fruit production system including Palmette, Fusetta, perpendicular-V, spindle, Spanish bush and others (Balmer, 2001; Long, 2001). Duncan and Edstrom (2006) studied vigour of carmel and non-pareil cultivar on 16 rootstocks (Fig. 7). The figure indicates that smallest trees were on the plum rootstocks (Penta, Julior, Adesoto and Kuban) while as Nickels and Hansan produced largest trees.

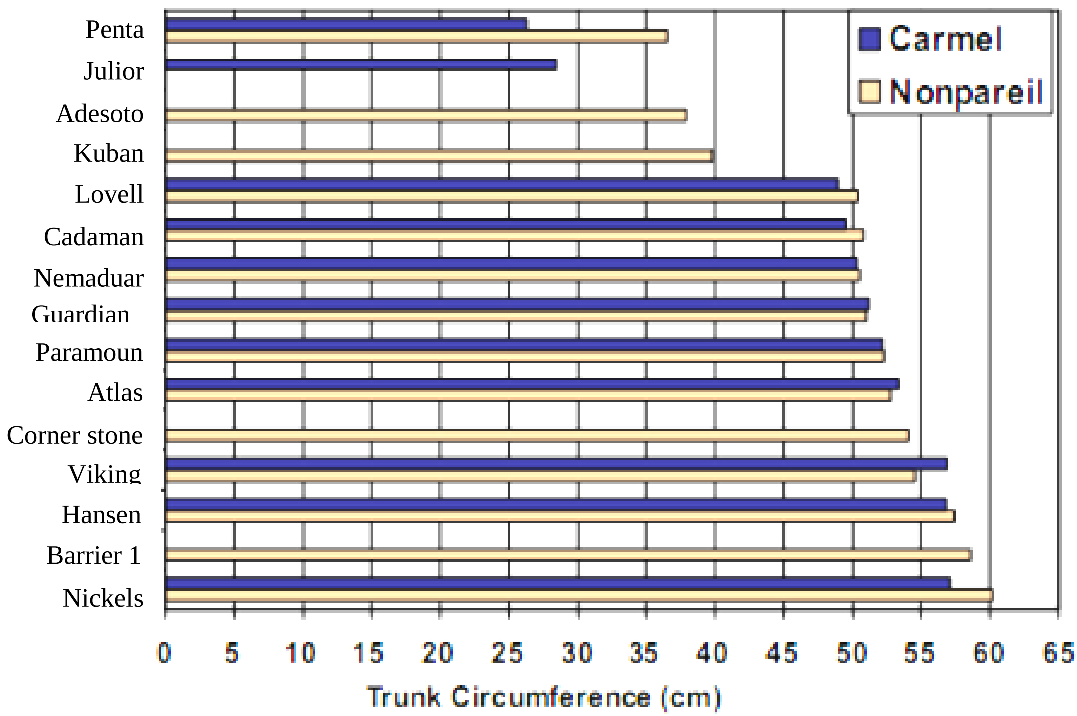

Fig. 7. Rootstock influence on size of 4th leaf nonpareil and carmel almond trees

2) **Bloom time:** The potential for a rootstock to promote or delay bloom probably deserves more attention than it receives while these effects are subtle for scion cultivars grafted onto rootstocks of same species, however, the use of other rootstock species can produce more significant shifts in bloom time (Reighard *et al.*, 2001). Such bloom date alternation can translate into proportional harvest date alternations and/or can be important for spring frost susceptibility or avoidance (Lang *et al.*, 1997). Duncan and Edstrom (2006) reported effect of different rootstocks on bloom percentage of almond scions (Fig. 8) which indicate that carmel bloom significantly later than non-pareil.

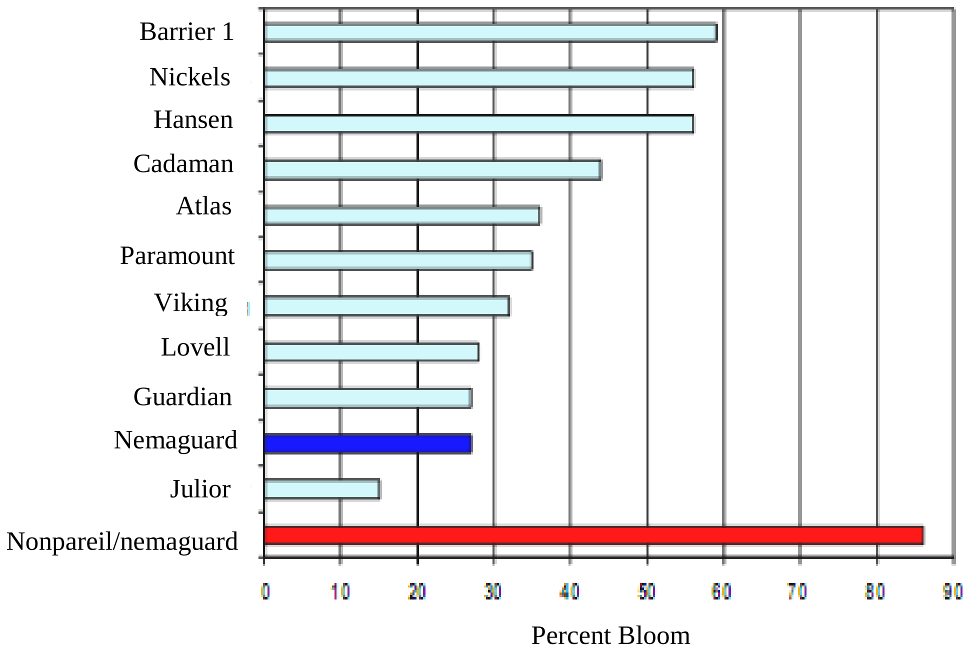

Fig. 8. Percent bloom of carmel almond as influenced by rootstock

3) **Precocity and productivity :** Perhaps just as important as vigour control, many of these rootstock induce profound increase in precocity and productivity, which have challenged researches and growers to develop appropriate crop insufficient annual growth (Choi and Andersen, 2001; Lang, 2001). Duncan and Edstrom (2006) studied effect of different rootstocks on the yield of carmel almond (Fig. 9).

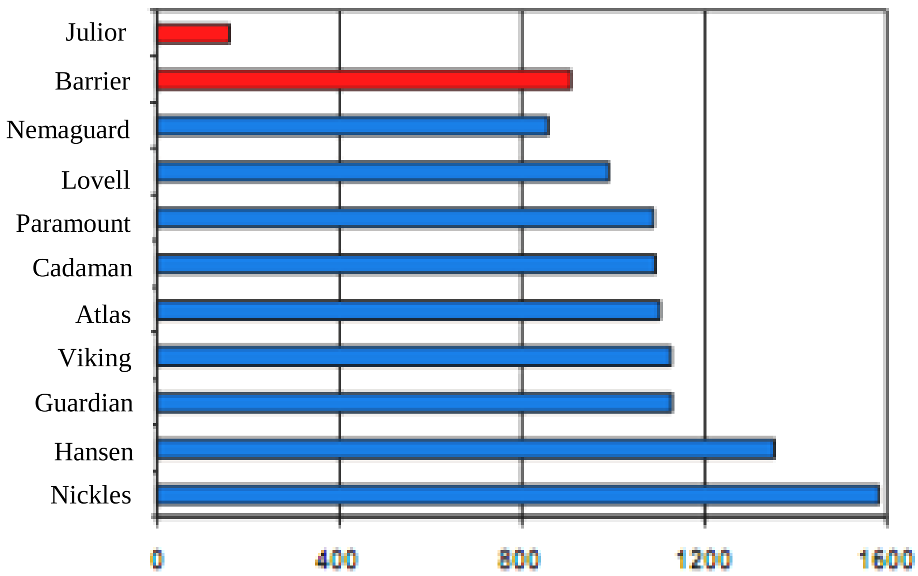

Fig. 9. Yield of 4th leaf Carmel Almond trees on various rootstocks

4) **Graft compatibility:** Scion/rootstock graft compatibility is a critical issue for orchard performance and longenvity. It is, perhaps most important problem in almond, apricot and cherry. Cannel (2006) identified two plum type rootstocks that were possibly compatible with non-pareil. The most important horticultural characteristics of several commercially available rootstocks are indicated in Table 4. The disease management of several commercially available almond rootstocks Table.5

Table 4. Most important horticultural characteristics of several commercially available rootstocks

S. No.	Rootstock	Parentage	Compatibility	Vigour	Anchorage	Drought rolerance	Salinity	Alkalinity	Boron tolerance	Wet feet	Suckering
1.	Lovel	Peach	Good	Low	Low	Low	Low	Low	Low	Medium	Low
2.	Nemaguard	Peach	Good	Medium	Medium	Low	Medium	Low	Low	Low	Low
3.	Nemared	Red leafed peach	Good	Medium-low	Low	Low	Low	Low	Low	Low	Low
4.	Peach x almond hybrids (Hansen, Brought, Nickele, Cornerstone paramount GF677	Peach x almond	Good	High	High	Medium	High	High	High	Very low	Low
5.	Mrianna 2624	Plum	Not compatible with Livingston marigineal compatibility with Buttle or Monterry	Low	High	Low	Low	Low	Low	High	High
6.	Atlas	Peach x almond x apricot x plum	Good	Medium-high	Medium	Medium	High	High	High	Low	Low
7.	Ishtera	Plum x wild peach x peach	Unknown	Low	Unknown	Unknown	Medium	High	High	High	High
8.	Krymsk86	Peach x plum	Unknown	Medium	High	Low	Low	Low	Low	High	Low
9.	Red titan	Red leafed peach x almond	Good	Medium-high	Medium-high	Medium	High	High	High	Very low	low

Table 5. Disease management of several commercially available almond rootstocks

S. No.	Rootstock	Parentage	RKN	RN	LN	Identified canker	Phytopthora	Crown gall	Armillaria
1.	Lovel	Peach	High	Low	Moderate	Low	Moderate	Moderate	Moderate
2.	Nemaguard	Peach	Resistant	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
3.	Nemared	Red leafed peach	Resistant	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
4.	Peach - almond hybrids (Hansen, Brought, Nickele, Cornerstone paramount GF677	Peach x almond	Most resistant paramount susceptible	High	Low	High	High	High	Moderate
5.	Mrianna 2624	Plum	Resistant	High	Moderate	High	Low	Low	Low
6.	Atlas	Peach x almond x apricot x plum	Resistant	High	Moderate	High	Moderate-high	Moderate-high	Moderate
7.	Ishtera	Plum x wild peach x peach	Resistant	High	Moderate	High	Low	Low	Low
8.	Krymsk86	Peach x plum	High	High	Moderate	High	Low	Low	Low
9.	Red titan	Red leafed peach x almond	Resistant	High	Low	High	High	High	Moderate
10.	Viking	Peach x almond x apricot x plum	Resistant	Low	Moderate	Low	Moderate-high	Moderate-low	Moderate

FUTURE WORK AND NEEDS

Preservation and Exchange of Germplasm

All breeding programs need germplasm as foundational, raw materials. Many recently introduced rootstocks are interspecific hybrids of conventional rootstock species with "exotic" unimproved species that often have no precedent in rootstock usage. A case in point is the USDA rootstock program in Georgia. Many of this program's *Armillaria*-resistant rootstock selections are hybrids with native North American plum species, which as a rule are woefully under-represented in the US Germplasm Repository system. Much of the "available" diversity in these native species is currently stored solely in the breeding collections of the stone fruit breeding programs outside the relative safety of the repository system. At the turn of the century, several hundred fresh market plum cultivars were available that were either selections or hybrids with native North American species (Wight, 1915). However, these were rapidly displaced by the introduction of improved plum cultivars utilizing introduced *P. salicina* materials. Today, barely a handful of the native species-based materials still exist, yet these and the native species from which they were developed have tremendous potential for utilization in solutions for many of our modern problems (Beckman and Okie, 1994). Moreover, much of the wild diversity has disappeared, either because of intentional eradication efforts to reduce wild reservoirs of diseases and insect pests, or because of land development. This is a worldwide problem and a troubling one.

As regionally-oriented stone fruit production industries grow and begin to provide product to national and international markets, a profound shift in germplasm usage also typically occurs as growers change varieties to suit these larger and often more lucrative markets. Such a shift has been seen in the Mexican peach industries, which utilized seedling land races or local cultivars grafted on locally-adapted seedling rootstocks. More dramatic shifts were seen as Spain's peach industry grew into a major supplier of stone fruit to European Union (EU) markets. Typically, no concerted effort has been made to preserve this potentially valuable germplasm since it is often viewed as "obsolete" and worthless.

Nevertheless, some of the most significant advances in rootstock adaptation were made with obscure germplasm, such as hardy peach accessions from northern China that produced clearly superior performers under harsh winter conditions in Canada (Layne, 1987). Germplasm exploration needs our continued support and involvement, but so does the preservation of native and naturalized materials in our own backyards that may be slowly disappearing right out from under our noses.

Efforts have been undertaken to evaluate and describe the variability and possible breeding value of some germplasm, such as the 'Vineyard' peaches in Yugoslavia (Vujanic-Varga *et al.*, 1994; Paunovic and Paunovic, 1996), Spanish peach seedling populations (Badenes *et al.*, 1998), and Mexican peach seedling populations (Perez *et al.*, 1993). With the exception of the 'Vineyard' peaches, only scion characteristics were evaluated. Some material has been collected and is being retained, if only on a regional basis at this time.

We also see an emerging problem as many breeding and development programs move forward in the production of complex interspecific hybrids. These materials often display varying levels of sterility, ranging from reduced flower density and set to complete infertility. In hybrids of both native North American plum species and complex plum hybrids with peach germplasm in the USDA program in Georgia, most interspecific hybrids have been completely infertile, producing non-germinating pollen (if any) and setting no fruit (T.G. Beckman, pers. obser.). This is a problem not only within a breeding program, but also for any external program hoping to build on another's releases. Hence, unlike variety breeding programs, which by definition must release materials capable of being intercrossed, many rootstock programs release materials that functionally are genetic dead-ends. A realization of the consequences of this should engender more, rather than less, cooperation and germplasm sharing between programs. However, the ever-expanding issues of intellectual property rights and their ownership may prove to be an increasingly difficult hurdle. Indeed, many programs already exchange and market material only with severe limitations on the use of that material in breeding programs. It is not unusual for non-propagation agreements to include "reach through" clauses giving the "donor" full rights to any hybrids made in the receiving program, be they F_1 or F_2, clearly a step above the traditional "essentially derived" definition of ownership.

Constraints on the exchange of materials will work against the progress and even survival of small and moderate breeding programs, unless they are part of a "group" of (most likely non-competing) programs that exchange germplasm and ideas freely among themselves. Corporate breeding programs, particularly vertically integrated ones that do not offer their cultivars for sale to the public (leasing them only to licensed growers), will end up becoming more or less 'one-way sinks' for germplasm and technology.

Seedling vs. clonal types

Despite the clear shift from seedling to clonal types over the last 10-20 years, seedling types still rule in most stone fruit industries. Obvious exceptions would be the use of peach x almond hybrids on calcareous soils, i.e., 'GF677' in southern Europe, and the likely large-scale shift to the new interspecific cherry hybrid selections where size control and precocity have been needed so badly. The reasons for the continued dominance of seedling types are obvious: low cost (pennies per plant vs. dollars in some cases) and convenience. The ease with which seedling types can be incorporated into the nursery production scheme should not be overlooked either. In those industries situated in suitable climates, the comparative ease of direct fall planting of a relatively hard to injure seed is a valuable asset compared to the management-intensive process of transplanting and caring for rooted cuttings or tissue-cultured plantlets. In many industries, the predominant production areas suffer from relatively few limitations and for those problems which seedling types have offered solutions, i.e. root-knot nematodes and PTSL, a clonally propagated alternative may be seen as overpriced. Niche planting is likely to be the most common use for many of the clonal materials produced to date, though this will not be true in some industries. The extensive need for tolerance to calcareous soils and adequate vigor on low fertility sites in many production regions of Europe will continue to drive the use of clonal peach x almond and peach x davidiana materials, since no comparable seedling counterpart has been developed.

One significant limitation to the future use of seedling types is the issue of uniformity. Outcrossing in seed production orchards no doubt varies widely but in peach appears to be typically between 2–6% (Beckman, 1998). The impact of these events goes largely unnoticed if only because of our inability to detect such events. The frustrating variability in delayed tree mortality due to graft incompatibility, as with certain seedling cherry and apricot rootstocks, is a clear example of the potential negative ramifications of this genetic variability. Also, as orchard management becomes more intensive in a highly competitive global market, increased uniformity of rootstock performance across various scion varieties will be more important for achieving efficient profitability. Virtually all of the dominant seedling stone fruit rootstocks lack any morphological feature, such as red leaves, to allow visual detection of outcrosses in the nursery setting. If good control of outcrossing, or at least efficient rogueing techniques, could be devised, then even interspecific hybrid seedlings could be made practical. Several potentially useful lines have been proposed and developed but have not enjoyed adoption due, in part, to problems with nursery production efficiency and uncontrolled outcrossing with resulting variability. This area is worthy of more attention.

The use of doubled haploids is another avenue that deserves consideration. In the absence of an outcrossing event, this allows the production of a "seedling clone" of the mother plant (Scorza and Pooler, 1999). Such seedlings could then be handled like any conventionally produced sexual seedling, with the attendant lower production and management costs compared to conventional clones produced via cuttage or tissue culture. A major obstacle is the relative rarity of haploids.

Molecular analysis of key rootstock traits

This is a promising research area, with molecular analyses becoming more routine, automated (such as DNA microarrays), and genetically powerful (with tools such as the Arabidopsis genomic library). While such work pertinent to stone fruit rootstock breeding is increasing, little has yet to be found in the scientific literature. In cherry, DNA microarrays have been created to examine rootstock and rootstock-induced scion gene expression, with particular emphasis on genes associated with dwarfing and perhaps grafts incompatibility . Similarly, a homolog to the Arabidopsis flowering-associated gene, LFY,\ has been identified in sweet cherry, and is being used to probe rootstock\ induction of scion precocity and flower spur formation (G. Lang, pers. commun.). The molecular analysis of such traits is expected to lead to more efficient capabilities for developing and/or evaluating the improved expression of key horticultural or pathological traits in stone fruit rootstocks and grafted scions.

Rootstock Evaluation Methodology

Current testing programs such as the NC-140 in the United States (Perry *et al.*, 2000), the Working Group on Rootstocks in Italy (Loreti, 1997) and the International Cherry Rootstock Trials in Europe (Kemp and Wertheim, 1996), among others, are laudable in both their aims and progress to date, and will likely continue to grow in their sophistication and usefulness. Most new rootstocks were developed at least in part with some improved resistance to a disease, pest or edaphic limitation. With the possible exception of climatic adaptation, these characteristics are difficult to evaluate accurately in the current regional and international testing trials. Indeed, it would not be practical to evaluate characteristics pertinent to longevity in conjunction with a horticultural trial typically utilizing as few as 8-10 single tree replications, as is the case of the NC-140 trials. Even minimal tree losses during the course of the trial would seriously compromise the collection of meaningful horticultural data. Nevertheless, in the absence of an organized effort to provide meaningful, broad evaluation of the non-horticultural characteristics of these new materials, they will likely be introduced into distant marketplaces with only tentative recommendations for their use in dealing with the very diseases and problems they were developed to address. We propose that some effort needs to be made to provide uniform testing of disease, pest and edaphic performance under realistic field conditions as a counterpart to the horticultural trials currently performed. Necessarily, these will have to be limited in number, as probably only regional trials will be practical and affordable, especially given the larger replication needed to evaluate problems that can result in the death of non-resistant materials.

For the evaluation of rootstock impact on fruit quality issues, an economic analysis would be a useful addition to typical horticultural testing. In many markets, there is currently no economic incentive to provide improved quality characteristics beyond some minimal base level for example % soluble solids. However, in virtually all markets there is a premium paid for larger size fruit, in which case some trade-offs (e.g., reduced total yield) can be more than made up with the premium paid for larger fruit. Appropriate application of pricing structures at each trial location would help growers and extension personnel sort out which rootstock may maximize economic return. Additionally, the type of long term production data typically generated in large scale performance trials lends itself to a variety of statistical analyses to reveal genotype × environmental interactions and performance stability (Olien *et al.*, 1991), as well as relative production risk (Harper and Greene, 1998). Such analyses would provide valuable feedback to breeding programs and better inform growers and extension personnel.

Impact of marker assisted selection (MAS)

Although MAS holds promise for all areas of rootstock breeding through reduced cost and increased efficiency (and speed) of evaluations, it has the best potential for profound impact on those characteristics that are particularly difficult to evaluate. This is because the testing procedure itself relies on a currently expensive methodology, and/or the opportunity to score populations is infrequent. Either problem can severely slow progress. Field evaluation of cold hardiness or dwarfing is examples. Diseases that cause tree mortality well after establishment would also be prime candidates for the development of markers. Field evaluation for resistance to both PTSL and Armillaria root rot is difficult not only because of the lack of uniformly infected field sites, but also because field screens typically require at least 5-7 years to achieve sufficient mortality to allow differentiation of the resistant lines from the susceptible. Efforts are underway to develop markers for many important traits, including graft compatibility, precocity, and resistance to root-knot nematodes, PTSL and Armillaria root rot.

Those traits controlled by only a few genes are more likely to provide usable markers than are those controlled by many genes. The investment in effort to produce and accurately score a suitable segregating population to generate the initial marker trait associations, will doubtlessly require substantial effort in many cases. Molecular markers having few alleles per locus such as RAPDs and AFLPs are likely to have low transferability rates between pedigrees and may require mapping in each segregating population. Microsatellite (SSR) based markers which are typically codominant and have multiple alleles per locus are likely to be much more informative in inbred species such as peach.
Another application of this technology is the use of markers for the purpose of identifying rootstock cultivars (Cantini *et al.*, 2001). This has utility not only for the protection of intellectual property rights, but also for the field verification of rootstock identity (Struss *et al.*, 2002), which is often difficult (if not impossible) in nursery or orchard situations, yet would be extremely helpful when diagnosing performance problems.

CONCLUSION

Considerable progress has been made in recent years in the development of better adapted rootstocks for stone fruits. Indeed, in a few cases, such as waterlogging tolerance for almond, progress has been such that there has been a significant reduction in the perceived importance of the problem. Progress has been made in the development of more efficient screening procedures, which in turn leads to the identification of useful variability, both of which by necessity precede the development of commercially useful materials. Modern genetic engineering technology is starting to realize much of its promise in the identification of markers that will reduce reliance on tedious, expensive, long-term field trials and thus accelerate progress. Much good scientific work and challenges remain.

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