Dwarfing Rootstocks: Past, Present and Future

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The aim of this article is to consider, first, why we choose to use rootstocks and whether there are any suitable alternatives to their use. Secondly, I shall discuss our present and future needs in rootstocks for pome and stone fruits. Finally, I aim to discuss the methods by which new rootstocks might be produced in the future, who will fund their production and whether investments in rootstock breeding are economically viable.

WHY USE ROOTSTOCKS?

Propagation

Traditionally, rootstocks were used primarily as a method for propagating selected scion cultivars. Tree fruit species do not develop true-to-type when propagated from seed and propagation of selected scion cultivars is possible only by vegetative methods. Propagation of most cultivars of temperate tree fruits is very difficult using traditional stooling/layering or cutting methods, although some cultivars of morello tart cherry *(Prunus cerasus)* and plum *(Prunus domestica)* have always proved an exception to this rule. Horticulturists have used techniques of budding and/or grafting for millennia and the simplest and most reliable method for vegetative propagation of fruit trees has relied on combining a rootstock with the scion cultivar via budding/grafting. Originally, all of the rootstocks used were raised from seeds (either collected in the wild or from fruits harvested from cultivated trees) or from suckers dug up from beneath cultivated trees. The variability in scion performance commonly experienced when using such rootstocks was of little consequence to the early horticulturists whose only objective was to multiply trees of an especially valuable scion selection.

Rootstocks still provide fruit tree nurserymen with their primary method of fruit tree scion propagation. Although alternative strategies for tree propagation are now available (see below), they have yet to prove preferable to the use of rootstocks.

Control of Tree Vigor

In a few species of temperate fruits, rootstocks provide the principal method of controlling the excessive inherent vigor of the scion cultivar. The vigor of apple, pear, plum and, more recently, sweet cherry trees can be controlled very effectively by choice of an appropriate rootstock. This option has been available for apples and pears for several centuries, but commercially viable dwarfing and semi-dwarfing rootstocks for stone fruit species have been introduced only over the last 80 years or so.

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How control of vigor by the rootstock is brought about is still not understood, even though such dwarfing rootstocks have been used in apples and pears for centuries. Attempts to explain how rootstocks dwarf trees, which have focused on their effects on supply of mineral nutrients, assimilates and water to the scion, have largely proved unsuccessful. More recent studies aimed at understanding rootstock effects on tree vigor have focused on their influence on the production and movement of endogenous hormones within the stion (rootstock + scion) tree (Soumelidou et al., 1994; Kamboj et al., 1999; Sorce et al., 2002).

Control of excessive scion vigor has become increasingly important in recent years as the economic viability of fruit production has declined in many countries. Trees of reduced stature allow the majority of tree management and hand harvesting to be carried out from ground level. Larger trees demand the use of ladders or expensive mechanical aids, and the cost per unit of quality fruit produced is higher than where dwarf trees, which facilitate improved resource productivity (mainly labor), are used. Also, there are environmental benefits associated with dwarfed trees. Spray targeting and the minimizing of spray drift are much improved on trees of reduced stature.

Not all crops have the same constraints, however. Production of crops such as walnuts, which are harvested mechanically and are resistant to harvesting damage, is improved on large, vigorous trees. Indeed rootstock selection for this crop, carried out in France, focuses on the need for rootstocks inducing increased scion vigor.

Also, there is an increasing ground swell of public opinion in several countries demanding the return of large traditional fruit trees. These are perceived, albeit on very little evidence, to be better for sustaining populations of wild bird species and have also more aesthetic appeal than modern dwarf trees to recreational walkers and tourists. However, unless governments support the planting of these traditional large trees (via grants or subsidies) they are unlikely to prove economically viable for fruit production.

Indeed, the producers of many non-temperate fruit species (e.g., avocados, mangoes) recognizing the economic benefits of reduced tree size have endeavored for some years to develop suitable dwarfing rootstocks.

Control of Tree Cropping and Fruit Size/Quality

Producers of apples and pears have recognized for a long time that by choice of suitable rootstock their trees can be induced to crop earlier in their lives (exhibit improved precocity) and crop more abundantly and consistently. More recently it has been shown that certain rootstocks can also influence fruit size and quality. For instance, the apple rootstock M.9 induces larger fruit size than many other rootstocks and this effect cannot be explained in terms of reduced crop loads. Quince rootstocks also often produce better fruit size and quality of pears than when seedling or clonal *Pyrus communis* rootstocks are used.

How rootstocks bring about these effects is still not fully understood. Dwarfing rootstocks usually induce better yield precocity and abundance than more invigorating rootstocks. This is explained by the increased numbers and quality of floral buds produced on dwarfed trees. This, in turn, is likely to be partially attributable to the earlier cessation of shoot extension growth in the summer on trees on dwarfing rootstocks and the redirection of the trees' assimilates and nutrients toward the production of floral buds. Nevertheless, certain invigorating rootstocks also induce better flowering than others (e.g., the apple rootstock M.25) and the reasons for these differences are not understood.

Induction of cropping early in the life of an orchard is essential if the orchard investment is to prove viable in comparison with other alternative investments. Regular cropping is also vital for economic viability and in addition is required by marketing agencies, which endeavor to provide the multiple retailers with continuity of supply volume throughout the year. Although world supply of commodities such as apples is now so large that significant shortages are unlikely, retailers still desire a continuity of supply from their national producers.

Resistance/Tolerance to Soil-Borne Pests and Diseases

Soil-borne pests and diseases are, in many areas of production, a major constraint on fruit and nut production. Rootstocks have been selected that provide resistance or tolerance to the most damaging of these pests and diseases and are essential, often providing the only means by which the fruit crops can be produced in these areas. Soil-borne diseases (such as *Phytophthora* sp.) are the most damaging although pests such as the woolly apple aphid *(Eriosoma lanigerum)* are equally important in some production regions. Currently there is little understanding concerning why some rootstocks show improved resistance/tolerance to these damaging organisms.

Resistance/Tolerance to Abiotic Stress Conditions

Rootstocks are also used to adapt scion cultivars to soils or climatic conditions that are otherwise not fully suited to their cultivation. Areas of production that experience sustained periods of very low (sub-zero) winter temperatures need rootstocks that are tolerant to winter cold. Similarly, climatic areas or soils subject to transient drought conditions require rootstocks capable of competing with weeds and/or grasses for reduced water reserves and/or inducing efficient water use by the scion cultivar. Transient waterlogging and anaerobic soils are also occasionally a problem, although only a few stone fruit rootstocks are able to tolerate this problem. Rootstocks prove extremely useful in providing tolerance to high levels of free calcium in soils and the associated problem of lime-induced chlorosis.

Unfortunately, as with most other rootstock effects on scion growth and performance, there is only limited understanding of how rootstocks provide tolerance to cold, drought and high pH.

WHAT ARE THE ALTERNATIVES TO ROOTSTOCK USE?

Propagation

Research, much of it conducted over the last 30 years, shows that most scion cultivars can now be propagated vegetatively without recourse to budding/grafting onto rootstocks (Webster, 1995). Advances in micropropagation techniques have paved the way for most scions to be propagated on their own roots. The technique is not without its problems, however (Webster et al., 1985; Zimmerman, 1997). Micropropagated trees are difficult and slow to establish in the nursery or orchard in many climatic conditions. Moreover, many micropropagated trees show a type of false juvenility, which is induced during the *in vitro* culturing. This juvenility delays cropping on the trees and in some species changes the branching habit. Increased suckering and burrknotting are also common problems with many apple trees raised directly from micropropagules.

Micropropagation can be justified only if the trees that are produced perform as well as trees on rootstocks and are cheaper to produce. Currently, neither of these criteria is achieved using micropropagated scions of most tree fruit species. The micropropagated trees lack vigor control, are often slow to begin cropping, produce smaller fruits and may also show problems of suckering, burrknotting and poor anchorage. Although micropropagated trees theoretically are cheaper to produce than trees on rootstocks, the difficulties of establishment in nurseries and their initial slow growth have meant that the price per tree is often no different from that of trees on rootstocks.

The problem of induced false juvenility mentioned above is avoided if propagation is by methods other than *in vitro* techniques. Research in the UK has shown that, by using modern improvements to conventional macro cutting propagation techniques, most cultivars of apple can be propagated successfully. However, as with micropropagation, all of the other benefits of rootstock use are lost and the trees are not significantly cheaper to buy.

It can be argued, therefore, that rootstocks currently continue to offer the best method of propagating most cultivars of temperate fruits. This may change in the future if developments in genomics and biotechnology continue at their current rapid pace. Identification and isolation of the genes responsible for ease of vegetative propagation and their introduction into scion cultivars could contribute to the demise of the rootstock in future generations. Some progress has already been made toward this objective. However, unless genes responsible for all the other beneficial traits conferred by rootstocks are also introduced to each and every commercially important scion cultivar, the rootstock will still remain supreme. The cost of introduction of such an array of genes into the full range of commercial scion varieties and the resultant cost of trees to the fruit grower may well prove prohibitive.

Control of Tree Vigor

Rootstocks have never provided the only means of controlling the vigor of fruit trees. Supplementary control often has been provided by choice of compact or spur-type scion cultivars, by shoot or root pruning or manipulation techniques and by use of plant growth regulating chemicals.

Compact Scions. Compact scion cultivars have proved very popular for apple cultivars such as Delicious and McIntosh where they have produced trees of reduced stature and good yield performance. More recently, a range of peaches/nectarines with compact habit has been produced which appears quite promising in preliminary trials. Unfortunately, the performances of many other compact types (e.g., the spur/compact types of the apple varieties Granny Smith, Cox's Orange Pippin and Bramley's Seedling and of the sweet cherry varieties Compact Van and Compact Stella) have been less satisfactory, with reduced yield productivity or fruit quality often a concern. More research is needed on the causes of the poor productivity of these reduced vigor scion types. Another major problem when using compact scion cultivars concerns their stability; many revert back to vigorous or otherwise inferior types when planted in the orchard. This is often due to their chimaeral nature and is a problem irrespective of whether they originate naturally, as mutants found in orchards, or are from using techniques of induced mutation.

If compact scions are to provide a real alternative to use of dwarfing rootstocks in the future then the above problems will need to be addressed. Modern techniques of genetic modification where specific genes controlling valuable tree attributes are introduced into commercial cultivars may provide a partial answer. Such genetically modified scions should exhibit good stability and be free from negative reversions.

The problem of poor productivity may remain, however. Most of the currently researched dwarfing genes appear to bring about their effects by shortening internodes (often by suppression of gibberellin biosynthesis). If, as is quite possible, the poor productivity of many of the current compact types is due to poor use of incident light due to excessive overlapping of leaves, then genetically modified dwarfed trees will be no better. Rootstocks bring about the dwarfing of scions differently. They slow the rate of extension shoot growth and cause it to terminate earlier in the growing season; they do not usually shorten internodes. What is really needed is the identification and introduction into scions of genes capable of simulating the rootstock effect.

Shoot and/or Root Pruning and Manipulation. Shoot pruning has provided for centuries a vital method of controlling, albeit only temporarily, the size of fruit trees. The problem is that trees strive to achieve a balance of shoot and root growth. Severe pruning of shoots reduces tree size only temporarily, as the tree immediately grows new shoots most vigorously in order to restore this disturbed shoot:root ratio. An additional negative consequence of severe pruning is the associated reduction in cropping due to reduced tree size and the production of vegetative rather than floral organs. Shoot pruning is rarely a useful technique for reduction of tree size if used alone. However, if combined with other techniques, such as dwarfing rootstocks, root pruning and/or sprays of chemical growth retardants, it can have considerable value in achieving an optimum balance of vegetative and floral growth in the tree.

Root pruning induces the reverse effect to shoot pruning as the tree strives to reinstate its preferred root:shoot ratio by reducing its shoot growth and increasing its root growth. Although this appears to fulfill the objective of controlling the vigor and growth of the branches and shoots, there are problems with the technique. Tree anchorage is reduced and, more importantly, fruit size at harvest also is reduced in most cases.

Manipulation of shoots or roots may offer more promise than their pruning. Bending extension shoots toward or below the horizontal induces reduced shoot growth. It also induces the production of more and sometimes stronger floral buds on many fruit cultivars. With very vigorous scion cultivars it is insufficient on its own to provide adequate control of tree size but, used in combination with growth regulating chemicals or other techniques, it can provide an alternative to use of dwarfing rootstocks. Limiting root growth by growing trees within root restriction membranes is also very effective in reducing shoot growth. However, as with root pruning, fruit size and tree anchorage often are influenced negatively.

Plant Growth Regulating Chemicals. Several chemicals capable of reducing the excessive shoot growth of temperate fruit trees have been developed since the 1960s. Most of these products function by limiting the production or movement of gibberellins within the tree. This in turn results in shortened internodes and reduced tree size. Unfortunately, this method of tree size control is becoming increasingly unpopular with fruit consumers, often for no rational reason. Alar (daminozide) was withdrawn from use many years ago and Cultar (paclobutrazol) has never gained approval in many countries of the world. CCC (Cyclocel), an excellent growth retardant when used on pear trees, also has come under fire in recent years and its use probably will decline in many countries in the future.

A newer product, Apogee (prohexadione-Ca), shows considerable promise as an effective growth retardant, being much less persistent in the soil and tree than Cultar. However, its future success, and that of all other plant growth regulating chemicals, will depend much on the attitudes of consumers and the multiple markets to fruits from trees treated with these products. It is hoped that the additional benefits of Apogee in alleviating fire blight will be taken into account when judging its future.

Improving Tree Yield and Fruit Quality

The yield and fruit quality produced by fruit trees are controlled by many factors although choice of rootstock is an important component in this control. Use of improved clones of the chosen scion cultivar coupled with various management techniques can all improve fruit yields and grade outs significantly.

Improved Scion Clones. In apple there has been much selection for improved clones of scion cultivars in recent years. The aim primarily has been improved fruit color, although larger fruit size and other quality attributes also have featured. Modern clones of cultivars such as Red Delicious, Gala, Braeburn and Jonagold have been selected to provide improved fruit color and higher grade outs of top quality fruits. Improved clones of Golden Delicious have provided less russeted fruits, while new clones of Gala are reported to yield fruits of larger size. In pear selections exhibiting increased russeting (Taylor's Gold) or less russeting (clones of Conference) have also found favor with certain markets. Selections of the pear varieties Comice, Williams (Bartlett) and d'Anjou with red skin color also have proved popular with consumers, although some of these clones are relatively unproductive compared with the original cultivars. Rootstocks cannot provide the benefits afforded by these improved scion clones.

Techniques for Improving Yields and Fruit Quality. Fruit growers use a combination of management techniques, all aimed at maximizing yields of high quality fruits. These include optimum pruning/training techniques, nutrition and irrigation as well as applications of plant growth regulating chemicals (growth retardants and thinning agents). All of these are essential but in themselves are not capable of delivering the optimum yields and grade outs unless coupled with an appropriate rootstock.

Control of Soil-Borne Pests and Diseases

Most soil-borne pests and diseases that cause economic damage to tree fruit crops can be controlled by applications of appropriate pesticides. However, the pesticides often are expensive and need to be applied on a regular basis. An additional problem is that many of the pesticides used for control of these problems are being withdrawn from use in many parts of the world. Increased stringency in the legislation concerning pesticide use and the very high costs of gaining or renewing approval for their use are resulting in many chemicals becoming unavailable to fruit growers. This problem will increase in the future. The increased popularity of organically produced fruits, where such chemicals are not permitted, also will force growers to consider methods of control other than those dependent upon agrochemicals.

Traditional strategies such as long-term crop rotations can help alleviate some of these soil-borne problems, but these often are not possible on small farm units that are intensively managed.

Biological methods may have a role to play in the future. Replant diseases, which are commonly experienced when planting the same or a closely related crop back into soil previously occupied by this crop, have a variety of causes. They are generally overcome by partially sterilizing soils using chemicals such as methyl bromide or chloropicrin. Use of these chemicals is being withdrawn and alternative methods of overcoming the problem are needed urgently. Recent evidence from trials in Spain indicates that some temporary reduction in symptoms of replant disease can be achieved using dips of mycorrhizae.

Nevertheless, the case for using resistant or tolerant rootstocks for control of soil-borne pests and diseases, including the replant syndrome, has never been stronger.

Overcoming Abiotic Stress Conditions

Certain popular rootstocks that have many favorable attributes are, unfortunately, sensitive to winter cold injury. This is true of the M.9 rootstock for apple and Colt rootstock for sweet cherry. There are no fully reliable management methods of ensuring that these rootstocks withstand very severe winter cold and selection of more resistant rootstock cultivars remains the best strategy.

Transient drought can, of course, be avoided by installation of an irrigation system, providing adequate supplies of water are available to the orchard. However, in many areas of the world water is becoming a scarce and expensive resource. The adoption of organic systems of production with no use of herbicides often results in increased competition from weeds for water and nutrients. Rootstocks that can compete efficiently with weed species for this water and nutrients will be essential in such systems of production. Use of rootstock/scion combinations that use water efficiently undoubtedly will become increasingly important in the future.

Soils with a high content of free lime (high pH) can be improved by use of acidifying fertilizers, although this can take many years and is usually only partially effective. Usually, the only strategy employed is to spray trees with chelated forms of iron. Use of rootstocks that have some resistance to high pH conditions will continue to have an important role to play in alleviating the problem of lime-induced chlorosis in fruit trees.

WHAT ARE THE PRESENT AND FUTURE SPECIFIC NEEDS IN ROOTSTOCKS?

This presentation will discuss only the specific needs of pome and stone fruit producers. However, rootstocks are widely used for other crops such as grapes and citrus species and we should not forget there is a vital need for improved rootstocks for a whole range of subtropical and tropical fruit species, as well as for many of the nut crops.

General Rootstock Attributes

Many rootstock attributes or desired characteristics are common for most of the temperate fruit tree species (Table 1). The relative importance of these attributes varies depending upon the climatic and soil conditions of the site and the management systems used by the fruit grower. The grower should, therefore, prioritize his or her objectives before selecting an appropriate rootstock. All too often fruit growers order late and accept a less than ideal rootstock from their nursery supplier.

In the past, the only important rootstock

TABLE 1

General attributes of the ideal rootstock.

Nursery requirements:

- Ability to propagate reliably and cheaply.
- Good graft compatibility.
- Good nursery growth performance.

Orchard requirements:

- Vigor control and uniformity of scion growth.
- Induction of precocious, regular and abundant cropping in the scion.
- Induction of good fruit size and quality.
- Resistance/tolerance to pests/diseases.
- Resistance/tolerance to drought or anaerobic soils.
- Tolerance to soils with high pH.
- Tolerance to severe winter cold.
- Tolerance to viruses and phytoplasmas.
- Freedom from abundant suckering or burrknots.
- Low costs.

characteristics were their ability to propagate, their compatibility with the scion, their anchorage and their ability to induce strong vigor in the scion. This last objective is now only important when producing certain nut species or fruit trees for mechanical harvesting (e.g., cider apple production). The other objectives remain important and have been supplemented by many more (Table 1). In the future, characteristics such as resistance to soil-borne pests and diseases, drought tolerance and even anchorage are likely to assume increased importance. The withdrawal of chemical pesticides, limitations on water use and the general movement to more sustainable systems of production (e.g., organic production) will all stimulate this shift in priorities.

The ability to dwarf scions likely will remain important for many fruit crops but the present shortcomings of many dwarfing rootstocks (e.g., poor anchorage, sensitivity to soil-borne pests and diseases and drought) will need to be remedied.

Apple Rootstocks

Although seedling-raised rootstocks are still used for apples in some parts of the world (e.g., China) clonal (vegetatively propagated) rootstocks are fast becoming the norm in most countries. Attempts some years ago showed that seedling variability in apple rootstocks could be overcome by using species of certain apomictic species of *Malus* (Schmidt, 1988). However, these apomictic types were difficult to select in the nursery, were vigorous and had few of the other vital rootstock attributes.

Following the early breeding programs for clonal apple rootstocks carried out at East Malling, many other programs have since produced new rootstocks. The objectives of these programs have reflected the local needs in the countries of production. Most of the programs have sought to produce dwarfing rootstocks with additional attributes (such as resistance to winter cold, woolly apple aphid, collar rot, etc.) to the traditional M.27, M.9 and M.26. A list of some of the rootstocks currently available or in advanced trials is included (Table 2).

The economics of apple production is currently very poor in many countries of the world. In the present political climate, the cause of the decline in apple profitability, primarily oversupply of fruits to world markets, is unlikely influenced by import restrictions or other trade embargoes. To remain in viable economic production of commodity apple varieties (i.e., the world's leading cultivars) produced using conventional (nonorganic) techniques, growers will need to reduce significantly their costs per unit of quality apples produced. This will be essential if they are to compete more effectively with areas of production where resource costs (mainly labor) are much less expensive. The alternative is to find some way of increasing the price per kilo received for the fruits, i.e., achieve a premium price.

The three main cost centers in apple production in the UK and many European countries are the labor for pruning, thinning and harvesting. If these are to be reduced, systems of mechanization may be the only answer in the future. Previous attempts at mechanization have not proved very effective or economical and have caused damage to the fruits. If mechanized aids are to prove more successful in the future, the whole system of production will need to change. Mechanization of orchards grown with conventional tree shapes is possible only at very high costs. Trees with more simple architecture will be needed. Improved rootstocks will play only a small part in any such innovative systems. However, dwarfing or semi-dwarfing rootstocks with good induction of cropping still will be needed and ideally these rootstocks should be better anchored than those currently available. Such a rootstock is currently needed by the cider apple industry in the UK where dwarfing rootstocks have too poor anchorage to cope with the shaking techniques used for harvesting.

Increasing the premium price paid for fruits most likely will be achieved by the production and positive marketing of new superior cultivars and/or the production of fruits using sustainable (organic) techniques for which the consumer is willing to pay more. As stated above, sustainable systems of production bring with them increased requirements in rootstocks for resistance to weed competition, drought and soil-borne pests and diseases. None of the currently available rootstocks combines dwarfing with all of these attributes.

Pear Rootstocks

Currently several types of rootstocks are available for pears worldwide. The common or European pear *(Pyrus communis)* is usually raised on either rootstocks of the same species or rootstocks of the quince, *Cydonia oblonga*. The Asian or Chinese pears, in contrast, are invariably propagated on seedling-raised root-

TABLE 2

Rootstocks currently available or in advanced trials.

Super-dwarfing apple rootstocks:			
M.27	(UK)	P.22	(Poland)
M.20	(UK)	P.59	(Poland)
J-TE-G	(Czech)	P.61	(Poland)
G.65	(USA)	P.66	(Poland)
B.491	(Russia)	V.3	(Canada)
BM.527	(Sweden)	Voinesti 2	(Romania)
Dwarfing apple rootstocks:			
M.9	(UK)	Supporter 2	(Germany)
M.8	(UK)	Supporter 3	(Germany)
J-TE-E	(Czech)	Ottawa 3	(Canada)
J-TE-F	(Czech)	V.1	(Canada)
J-OH-A	(Czech)	P.2	(Poland)
B.9	(Russia)	P.16	(Poland)
B.469	(Russia)	P.60	(Poland)
Mark	(USA)	P.62	(Poland)
G.16	(USA)	P.63	(Poland)
JM 2&7	(Japan)	CG.3007	(USA)
Jork 9	(Germany)	CG.3041	(USA)
Supporter 1	(Germany)	CG.4013	(USA)
Semi-dwarfing apple rootstocks:			
M.26	(UK)	G.11	(USA)
P.1	(Poland)	G.202	(USA)
P.14	(Poland)	G.179	(USA)
Supporter 4	(Germany)	AR 801-11	(UK)
B 62-396	(Russia)	V.7	(Canada
Bemali	(Sweden)	J-TE-H	(Czech)
Semi-invigorating apple rootstocks:			
M.4	(UK)	G.210	(USA)
M.7	(UK)	M.116	(UK)
MM.106	(UK)	(AR 86-1-25)	
MM.111	(UK)	V.2	(Canada)
G.30	(USA)	KSC Selections	(Canada)

TABLE 3

The current range of rootstocks for pears.

Quince rootstocks	Pyrus rootstocks
EM C	Pyrodwarf
Adams	BP 1
EM H	Fox 11 and 16
EM A	OH x F Series
Sydo	
BA 29	

TABLE 4

The current range of rootstocks for cherries.

Prunus avium (Mazzards)	seedling or clonal (e.g., F.12/1)
Prunus mahaleb (St. Lucies)	seedling or clonal (e.g., S.L. 64)
Prunus cerasus (Sour or tart cherries)	all clonal Tabel (Edabriz) Weiroot series (e.g., 53, 72, 158)
Prunus hybrids	all clonal Colt MaxMa 14 Gisela series, e.g., 5, 6 PHL series Inmil Damil

stocks of the same species, *Pyrus pyrifolia*. Most pear producers striving for high productivity of quality fruits on dwarf trees should choose a quince rootstock. However, many cultivars of European pear and all cultivars of Asian and Chinese pears appear to be graft incompatible with quinces and this severely limits their use. Much of this incompatibility can be overcome by use of a bridging interstem (e.g., a variety such as Beurre Hardy) but this strategy has not found favor with many nurserymen or fruit growers. Unfortunately, quince rootstocks also have other negative attributes, in addition to their variable graft compatibility with pear scions. They are very sensitive to winter cold injury, to soils with moderately high pH and also to drought.

On sites unsuited to use of quince rootstocks, either seedling or clonal selections of *Pyrus communis* are used. Such stocks are fully graft compatible, very tolerant to drought and moderately tolerant of high pH soils. Unfortunately, they are mostly difficult to propagate vegetatively, and few show any ability to dwarf scions worked upon them. Recently, however, new clonal selections of *Pyrus communis*, such as Pyrodwarf, appear capable of reducing the vigor of pear scions and are reported to be relatively easy to propagate. A list of the rootstocks for pears currently available and in advanced trials is shown (Table 3).

Future needs in pear rootstocks are many. In addition to the possible requirements for organic production, new quince rootstocks with improved winter hardiness and tolerance of high lime soils and drought are required. Also required are *Pyrus communis* and *Pyrus pyrifolia* selections that propagate easily, are dwarfing and induce similar yield productivity and fruit quality to quince stocks.

Cherry Rootstocks

Until recently, only invigorating or semi-invigorating rootstocks were available for the sweet and sour (tart) cherries. Most trees were grown on seedling rootstocks raised from either the sweet cherry species *Prunus avium* or the Perfumed Cherry (St. Lucie), *Prunus mahaleb*. However, with the breeding and release of new dwarfing rootstocks from several European countries the first real opportunity has evolved for production of sweet cherries in high density planting systems. A list of the rootstocks currently available or in advanced trials for the sweet cherry is shown (Table 4).

Almost all of the promising new rootstocks are either clones of the sour (tart) cherry *Prunus cerasus* or hybrids between several closely related species of *Prunus*. Most of them have, to date, received only limited commercial trialing and it will be several more years before clear recommendations can be made. Nevertheless, the dwarfing rootstock Gisela 5 is performing well in most trials, although sensitivity to *Phytophthora* could be a problem on heavy, poorly drained soils. Tabel (Edabriz) is also a most promising dwarfing rootstock, although it can prove difficult to establish on some sites in the first few years following planting. Growers requiring slightly less dwarfing in their sweet cherry trees should consider the German selection Gisela 6 or the French/USA selection MaxMa 14.

Future needs in rootstocks for sweet cherry are difficult to predict until all the advantages and disadvantages have been ascertained for the rootstocks produced in recent years.

Plum and Prune Rootstocks

The majority of prunes (*Prunus domestica*) is produced on trees of moderate vigor suitable for machine harvesting. Although the rootstocks used usually are not fully invigorating, very dwarfing rootstocks are not required. In contrast, fully dwarfing rootstocks are sought for the production of plums for the fresh market where harvesting is carried out by hand. Most of the breeding work carried out on rootstocks for prunes in recent years has focused on creating rootstocks with tolerance to unfavorable soil conditions. Resistances to poorly drained or very droughty soils have been high priorities, as has resistance to soils with high pH. In contrast, producers of fresh plums in western Europe have sought increased dwarfing in their rootstocks. Among the few dwarfing selections available, the St. Julien selection Pixy has not proved popular on account of difficulties in propagation and its tendency to induce the production of scion fruits of slightly reduced size. Ferlenain (Plumina) is more promising in that it produces fruits of very good size and has vigor slightly less than Pixy in many situations. VVA1, a selection from eastern Europe, is also showing promise in trials in Europe, although much more testing will be required before it can be recommended. A list of the plum/prune rootstocks currently available or in advanced trial is given (Table 5).

TABLE 5

Some of the current range of rootstocks for plums and prunes.

Prunus domestica	Brompton, Eruni, GF 43, Pershore, Torinel/Avifel
Prunus insititia	Fercien, GF 655-2, Pixy, Polizzo, St. Julien A
Prunus cerasifera	Myrabi, Myrobalan B, Myrocal/Fercino, Mr.S.2/5
Prunus Munsoniana	GF.8-1, Marianna, Maridon
Hybrids	Damas 1859, GF.31, Ishtara/Ferciana, Jaspi/Fereley, Julior/Ferdor, Myran, Plumina/Ferlenain, VVA1

FIGURE 1

Apple rootstock origination from M.9 Juane de Metz.

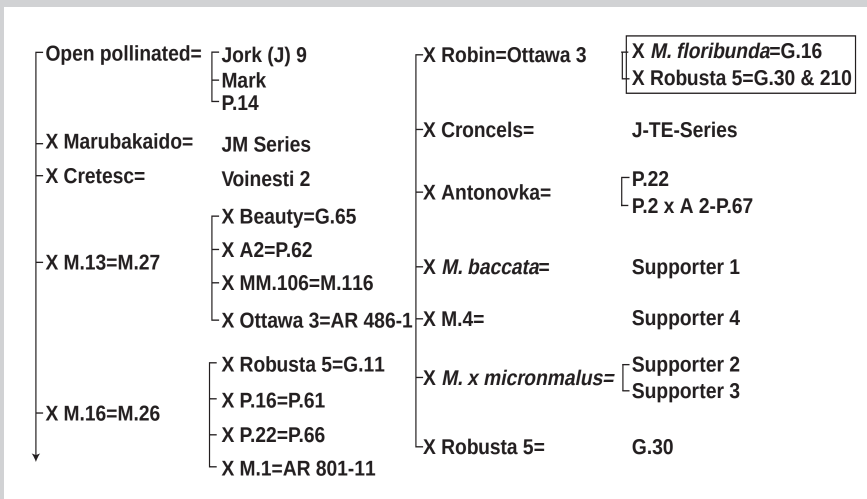

FIGURE 2

Apple rootstocks originating from M.8 (French Paradise).

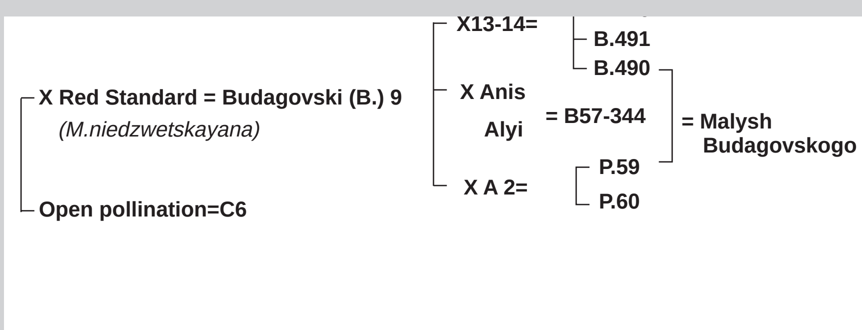

Figure 2. Apple rootstocks originating from M.8

HOW WILL NEW ROOTSTOCKS BE PRODUCED IN THE FUTURE?

Traditionally, rootstocks have been produced using conventional hybridization breeding techniques. The disadvantage associated with such breeding methods is the very long time interval between making the cross and the release of a new rootstock. This can be as much as 25 years in some situations. The problem is that fruit breeders have at their disposal few if any pre-selection techniques for many of the important rootstock characteristics. There is no way of pre-selecting rootstocks for their effects on scion cropping and, although there is an anatomical technique which can aid the selection of dwarfing apple and pear rootstocks, this method in itself is very time consuming.

The result is that breeders of rootstocks generally make their initial screening on the basis of other less important characteristics so as to reduce the number of plants for budding/grafting and full orchard evaluation. There is, therefore, a strong possibility of discarding the most valuable types at this first screen. However, where resistance to pest and diseases is high on the rootstock attribute list of priorities then early pre-selection is usually possible. For instance, successful pre-selection for resistance to fire blight and collar rot has been achieved in several breeding programs for apple rootstocks.

After pre-selection, there follows a period of 10 or more years during which time the rootstock selections are field tested after budding/grafting with scions. If the breeding program is targeting international markets, the period required for field evaluation can be 20 years or more. Once selected the new rootstock must be checked for virus and other diseases and then multiplied to commercially viable numbers. A period of 25 years between making the cross and marketing the first trees on the new rootstock is not uncommon. It is questionable whether such long development periods and the associated very high costs can be sustained and funded in the future. New improved methods of rootstock pre-selection will be vital if rootstock breeding programs based on conventional hybridization techniques are to continue in the long term. Modern techniques using molecular markers, which are being developed following the rapid advances in recent years in molecular biology, could help greatly in speeding up the selection of new rootstocks in the future.

Although breeding programs for stone fruit rootstocks have used many species and cultivars in attempts to produce improved clones, this usually has not been the case with programs focused on breeding rootstocks for apples and pears. It can be argued that many of the apple rootstock breeding programs have used a very narrow range of parents. M.9 has been used as a parent for almost all the dwarfing rootstocks currently in commerce, although French Paradise (M.8) has also featured as a parent in eastern European programs (Fig. 1 and 2). With the opening up to plant collecting expeditions of the areas of the world where the apple originated, in Central Asia, surely it is time that some alternative source of dwarfing is found and used in future apple rootstock breeding.

There are several alternatives to the use of conventional breeding techniques, although these are still being developed largely for use in scion rather than in rootstock breeding. The simplest but the least rewarding is to select clones within existing rootstock cultivars. Over the last 15 years there has been much activity selecting "improved" clones of the apple rootstock M.9. Unfortunately, the improvements achieved with these clones usually have had minimal benefit for the fruit grower. Most of the clones of M.9 are improvements only in their ability to propagate from stools or layers and differences in the growth of scion trees worked upon them tend to be small (Webster and Hollands, 1999). Although of value to the nurseryman, these clones have little to offer the fruit producer, as the simpler propagation of the rootstock has not translated into stion trees that are significantly cheaper to the fruit grower. None of the major defects of M.9, its poor anchorage, sensitivity to fire blight, sensitivity to winter cold, etc., have been alleviated by clonal selection.

Very recently fruit breeders have begun to examine the possibilities of using techniques of molecular biology and gene transfer in the production of new rootstocks. The aim is to improve an already good rootstock by modifying its gene expression or introducing new genes. Initially the work has focused on improvements in propagation (Welander and Zhu, 2000) and in resistance to fire blight (Aldwinckle, personal communication). The improvements possible using such techniques are immense, however. Unfortunately, the mechanisms by which rootstocks bring about their beneficial effects on the vigor and cropping of scions are still very poorly understood. Until more research is conducted on this and the genes controlling the processes are identified, progress in this area may be slow. However, faster progress should be possible on producing genetically modified rootstocks with resistances to damaging soil- and aerial-borne pests and diseases and maybe also drought and cold tolerance.

What is not yet known is the public response to the use of genetically modified rootstocks in the production of tree fruits. While believed to be fully safe in terms of human health and the environment, public opinion in Europe is often very negative toward the use of genetically modified crops. Although these opinions are considered by many scientists to be irrational, the major markets for fruits have to take these opinions into account. It would be unfortunate and misguided, but it is very possible, that the large major multiple stores will, in the medium term, choose to reject fruits from trees produced on genetically modified rootstocks. Only time will tell if this proves to be the situation.

WILL IT BE ECONOMICALLY VIABLE TO BREED NEW ROOTSTOCKS?

It can be questioned whether, considering the very long time scales and high costs involved, rootstock breeding will be considered a viable investment by funding organizations in the future. There is no doubt that, if the trend toward reduced pesticide use in fruit and nut production continues, the need will increase for new rootstocks that are tailored to the requirements of these systems. However, it will be essential to find methods of reducing the costs of producing new rootstocks and increasing the returns on investments in this breeding. The new molecular biology techniques may help here, but so also would more rapid methods of pre-selection of rootstocks produced using conventional techniques. The new technologies of molecular markers could play a vital and interesting role here. Further research in this area is urgently required.

Another important consideration in the future will be who will be willing to fund rootstock breeding and development. Governments are becoming increasingly reluctant to fund long-term breeding projects and it is possible that this source of funding will diminish significantly in the future. Commercial funding of breeding is a possibility and has already become the norm in some areas. However, protection and controls on the distribution, planting and marketing of varieties produced under such agreements will inevitably be much tighter than the simple Plant Variety Rights to which we have all become accustomed.

It is likely, however, that these tighter types of agreements (e.g., Variety Clubs) will be more appropriate for marketing scion varieties than for rootstocks. It is anticipated that most rootstock marketing will continue to be controlled by nurseries and maximizing distribution and sales will continue to be the prime goals of such nurseries.

REFERENCES

Kamboj, J.S., P.S. Blake, J.D. Quinlan and D.A. Baker. 1999. Identification and quantitation by GC-MS of zeatin and zeatin riboside in xylem sap from rootstock and scion grafted apple trees. Plant Growth Regulation 28:199-205.

Schmidt, H. 1988. Criteria and procedures for evaluating apomictic rootstocks for apple. HortScience 23:104-107.

Sorce, C., R. Massai, P. Piciarelli and R. Lorenzi. 2002. Hormonal relationships in xylem sap of grafted and ungrafted *Prunus* rootstocks. Scientia Hort. 93:333-342.

Soumelidou, K., D.A. Morris, N.H. Barrely and J.R. Barnett. 1994. Auxin transport capacity in relation to the dwarfing effect of apple rootstocks. J. Hort. Sci. 69:719-725.

Webster, A.D. 1995. Temperate fruit tree rootstock propagation. NZ J. Crop Hort. Sci. 23:355-372.

Webster, A.D. and M.S. Hollands. 1999. Orchard comparisons of 'Cox's Orange Pippin' grown on selections of the apple rootstock M.9. J. Hort. Sci. & Biotech. 74:513-521.

Webster, A.D., H.V. Oehl, J.E. Jackson and O.P. Jones. 1985. The orchard establishment growth and precocity of four micropropagated apple scion cultivars. J. Hort. Sci. 60:169-180.

Welander, M. and L.H. Zhu. 2000. The rooting ability of *rol*B transformed clones of the apple rootstock M.26 and its relation to gene expression. Acta Hort. 521:133-138.

Zimmerman, R.H. 1997. Orchard variation in micropropagated trees of 'Redspur Delicious' apple. HortScience 32:935-936.