Breeding and Evaluation of New Rootstocks for Apple, Pear and Sweet Cherry

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HISTORICAL PERSPECTIVE

Horticulture Research International-East Malling (formerly East Malling Research Station) has a reputation worldwide for the breeding and development of rootstocks for temperate fruit species. This began in the 1920s when two of its former directors (Drs. Wellington and Hatton) sorted out the incorrect naming and mixtures then widespread in apple rootstocks distributed throughout Europe. These verified and distinct apple rootstocks were then distributed throughout the world as Types, initially Type I through Type IX (Table 1) (Hatton, 1917). Later, further types were added to the original nine, though most of these were invigorating rootstocks which have since disappeared largely from commerce. Although distributed under type names, the apple rootstocks rapidly became known under Malling (or M.) designations and eventually the Roman numerals were replaced by the more normal Arabic ones. Only two of these original Malling selections, M.9 (Jaune de Metz) and M.7, are now used extensively by commercial orchardists.

In collaboration with the John Innes Institute, then based at Merton, a further series of rootstocks was produced, all exhibiting resistance to the woolly apple aphid (*Eriosoma lanigerum*) (Preston, 1955). This was, and still remains, a very serious pest in many parts of the southern hemisphere, where it attacks the root systems of apple trees. MM.106 and MM.111, two of the Malling Merton (MM.) series of rootstocks that gained resistance to woolly apple aphid from their Northern Spy parent, are still used extensively throughout the world.

A further apple rootstock breeding program at East Malling, using the dwarfing M.9 as one parent, produced two more valuable dwarfing rootstock clones (Preston, 1967). M.26, the result of a cross between M.16 and M.9, is semi-dwarfing and exhibits better tolerance to winter cold and drought than M.9. M.27, a super dwarfing rootstock originating from a cross between M.13 and M.9, is mainly used for vigorous scion cultivars planted in high density planting systems on fertile soils. Other apple rootstocks bred and developed by East Malling in the past, such as the invigorating but precocity-inducing M.25 or the super dwarfing M.20, have to date received only limited and localized adoption by fruit growers around the world.

Rootstocks for other temperature fruit species that have been bred and developed by East Malling have also achieved popularity in fruit growing areas throughout the world.

Two selections of Angers type quinces (*Cydonia oblonga*), EM Quince A (QA) and EM Quince C (QC), are widely used by pear (*Pyrus communis*) growers in Europe. These stocks reduce the natural high vigor of pears and induce precocious and abundant crops of good-sized fruits. However, although the graft compatibility of these quince rootstocks is good with varieties like Conference and Comice, it is poor with many other varieties.

Two rootstocks for sweet cherry have been produced and distributed from East Malling. The invigorating Mazzard stock (*P. avium*) F.12/1, which was originally selected for its resistance to bacterial canker (*Pseudomonas mors prunorum*), has now fallen from favor amongst commercial fruit growers who are seeking more dwarfing rootstocks for this species. Colt, a hybrid between *Prunus pseudocerasus* and *P. avium*, was released in the 1970s as a semi-vigorous rootstock for sweet cherries. Colt is much easier to propagate than F.12/1 and, in many situations, it induces better precocity and yield efficiency in the scion.

> *Dwarfing rootstocks which are able to overcome replant disease, show resistance to soilborne pests and diseases and compete with weed species for water and nutrients will be required.*

SUBCLONES OF M.9

Difficulties in propagating the original Malling selections of M.9, including the virus-free EMLA clone, prompted nurserymen in several European countries to re-select within the existing M.9 populations for subclones exhibiting improved propagation on the stoolbed. There are now many M.9 subclones originating in the Netherlands (NAKB 337-340 and Fleuron 56), Belgium (Nicolai 29), Germany (Burgmer) and France (Pajam 1 and 2) as well as the well-known EMLA subclone. Tests conducted at HRI-East Malling (Webster and Hollands, 1999) showed that when trees of similar quality (feathering and size) were planted at East Malling on the different M.9 subclones, differences in tree vigor, yield efficiency and fruit sizes were usually small (Tables 2 and 3). Several subclones were slightly more invigorating than average (e.g., EMLA, Nicolai 29 and Burgmer 984), whilst others such as NAKB 337 and Pajam 1 were slightly more dwarfing than average. Yields were generally related to tree size and few differences in yield efficiency were recorded, although the EMLA and T337 clones performed best in one trial (Table 2). The subclones had no effects on fruit size at grade out. Where tree quality at planting is more variable and soil conditions less than ideal, the more invigorating subclones may establish more quickly and differences between subclones may prove more significant. One subclone not tested at East Malling, Fleuron 56, is reported by Wertheim (1997) to be the most dwarfing one tested so far.

NEW APPLE ROOTSTOCKS FROM EAST MALLING

The range of rootstocks produced by East Malling in the past, embracing M.27, M.9, M.26, MM.106, MM.111 and M.25 in increasing vigor potential, is considered by many to be adequate for the needs of the UK apple producer. However, limitations in the performance of these rootstocks have been recognized:

M.27 produces poor fruit size on many sites and shows poor drought tolerance. It is too dwarfing in most situations, poorly anchored, and is sensitive to woolly apple aphid.

M.9 is difficult to propagate and poorly anchored with brittle roots. In many parts of the world it exhibits sensitivity to winter cold and to fire blight (*Erwinia amylovora*). Like M.27, it is sensitive to woolly apple aphid. A rootstock with vigor intermediate between M.9 and M.27 is needed for high density production systems where vigorous scion varieties are chosen.

M.26 produces abundant burrknots and, in some situations, it takes up calcium poorly from the soil. It is also sensitive to fire blight and woolly apple aphid.

MM.106 is sensitive to collar (crown) rot (*Phytophthora cactorum*).

Breeding of apple rootstocks is continuing at HRI-East Malling with the aims of overcoming the above problems as well as developing rootstocks which are improvements in terms of induced yield efficiency or fruit size and quality. It is also anticipated that with the trend toward production systems using minimal or nil pesticides (including organic systems) dwarfing rootstocks which are able to overcome replant disease, show resistance to soilborne pests and diseases and compete with weed

TABLE 1

The first nine Paradise (Malling) apple rootstock selections.

Type	Common/original name	Malling clone name	Vigor
I	Broad-leaved English Paradise	M.1	Vigorous
II	Doucin	M.2	Vigorous
III	No name	M.3	Semi-dwarf
IV	No name	M.4	Intermediate
V	Doucin Ameliore (Improved Doucin)	M.5	Vigorous
VI	Rivers' Nonsuch Paradise	M.6	Very vigorous
VII	No name	M.7	Semi-dwarf
VIII	French Paradise (Clarke Dwarf)	M.8	Dwarf
IX	Jaune de Metz	M.9	Dwarf

TABLE 2

Influence of M.9 subclones on the vigor and cropping of Queen Cox apple trees planted at HRI-East Malling in 1983.

M.9 subclone	Origin	Crown volume 1989/90 (m^3)	Cumulative yields 1984-88 (kg/tree)	Mean yield efficiency 1986-88 (g/cm^2)
T337	Netherlands	11.7	41.3	953
T340	Netherlands	14.5	39.0	879
Nic. 29	Belgium	17.6	38.7	881
Burg. 984	Germany	18.0	46.0	961
Burg. 751	Germany	15.9	39.8	899
Burg. 719	Germany	16.6	36.4	871
M.9A	UK	14.9	37.8	873
EMLA	UK	18.8	48.4	1045

TABLE 3

Influence of M.9 subclone on the vigor and cropping of Queen Cox apple trees planted at HRI-East Malling in 1987.

M.9 subclone	Origin	Crown volume 1992/93 (m^3)	Cumulative yields 1988-93 (kg/tree)
Pajam 1 (Lancep)	France	21.3	66.2
Pajam 2 (Cepiland)	France	24.6	68.0
Nic. 29	Belgium	25.0	74.8
EMLA	UK	23.8	70.6

species for water and nutrients will be required. Global warming and climate change may also create a need for more drought tolerant dwarfing rootstocks in many apple production areas.

The apple rootstock breeding at HRI is funded partly by the UK Ministry of Agriculture and partly by the Apple and Pear Breeding Club. Several promising new apple rootstocks are emerging from this HRI-East Malling program of breeding and selection.

AR86-1-25

AR86-1-25 is a selection from an M.27 x MM.106 cross. It produces trees with similar vigor, yield and fruit size to MM.106 but has the great advantage compared with MM.106 in its strong resistance to collar rot. This selection has performed particularly well on collar rot infected soils in New Zealand. It is also resistant to woolly apple aphid and to the effects of specific apple replant disease in the UK. AR86-1-25 shows average propagation ability on the stoolbed. It is anticipated that AR86-1-25 will be released within the next 2 years. Used with a dwarfing interstock, AR86-1-25 should produce semi-dwarf apple trees on sites unsuited to use of M.9 or M.26.

AR86-1-20

AR86-1-20 is a sibling from the same cross as AR86-1-25. It induces trees of similar vigor and cropping performance to those on AR86-1-25, although in one trial mean fruit size was slightly smaller on AR86-1-20. This rootstock could prove useful where a semi-vigorous stock is required with resistance to soilborne pests and diseases and good anchorage. Its use in cider plantations is being considered in the UK.

Several other rootstocks from the HRI-East Malling program have shown preliminary promise in orchard screening trials and are now being propagated in increased numbers for multi-site testing. The new selections with vigor similar to, or slightly greater than, M.27 are shown in Table 4. A few of these are inducing fruit size better than on M.27. The new selections with vigor similar to M.9 are shown in Table 5. One other HRI-East Malling selection, AR801-11 (M.26 x M.1), with vigor similar to M.26, has shown particular promise in terms of the very high yield efficiency it has induced in a preliminary orchard screening trial.

TABLE 4

New rootstock selections from the HRI-East Malling apple rootstock breeding program with vigor similar to M.27 or intermediate between M.27 and M.9.

Rootstock clone no.	Origin
AR10-2-5	M.27 x MM.106
AR69-7	AR10-2-6 open pollinated
AR360-19	M.9 x M.27
AR628-2	Ottawa 3 x MM.106
AR672-1	M.9 x 3426
AR669-1	M.7 x M.27
AR682-6	M.26 x M.793

TABLE 5

New rootstock selections from the HRI-East Malling apple rootstock breeding program with vigor similar to M.9.

Rootstock clone no.	Origin
AR120-242	M.27 x MM.106
AR295-6	Robusta 5 x Ottawa 3
AR486-1	Ottawa 3 x M.27
AR680-2	M.26 x M.27
AR852-3	AR363-16 [M.27 x Ottawa 3] open pollinated

TESTING APPLE ROOTSTOCKS FROM OTHER BREEDING PROGRAMS

Apple rootstocks from breeding programs in Poland, Russia, the USA, Canada, Germany, the Czech Republic and Sweden have been tested, or are still under trial, at East Malling.

Apple growers in the UK do not, for the most part, use supplementary irrigation and many trials at East Malling in the past were not irrigated. One such trial showed that nonirrigated trees of the apple variety Queen Cox on the Polish rootstocks P.22, P.2 and P.16 and the Russian selection B.146 made much less growth than in similar trials in The Netherlands where the soils were deeper and irrigation was provided. The weak growth and poor fruit size of trees on these rootstocks were exacerbated by the slightly high budding height in the trial. The message must be that, if using these dwarfing Polish and Russian rootstock selections, the grower should plant low worked trees with their unions close to the soil surface but not buried. Thereafter, trees on these rootstocks will need regular irrigation if they are to perform to their potential.

Although the USA selection Mark has produced poor results in some trials in other fruit growing areas of the world, at East Malling it performed adequately, producing trees with vigor intermediate between M.9 and M.26. Soil line proliferation was noticeable beneath the soil surface only when the trees were grubbed. The Canadian stock, Ottawa 3, performed poorly in comparison with M.9 in a trial at East Malling.

In an existing trial, several apple rootstocks from the Czech Republic, Germany, Sweden and Poland are being compared and the preliminary results are presented in Table 6. Trees receiving trickle irrigation in the first 4 years following planting in 1994 are compared with nonirrigated trees in this trial. Irrigation has increased vigor of growth on most of the rootstocks, but not on the German rootstock J9. The Polish clone P.60 and the Czech clone J-TE-E seem to be very sensitive to irrigation. Trees on two of the Czech clones, J-TE-E and -F, are similar in vigor to trees on M.9 EMLA. The other rootstocks are inducing vigor more similar to M.26. Cumulative yields are, to date, very high on the dwarfed trees on J-TE-F rootstock where irrigation

TABLE 6

Influence of Czech, German, Polish, Swedish and UK rootstock clones on the size of irrigated and nonirrigated Queen Cox apple trees planted in 1994.

		Crown volume (m^3) 1997		Cumulative yield 1995-99^Z	
Rootstock	Origin	Trickle irrigation^Y	No irrigation	Trickle irrigation	No irrigation
J-TE-E	Czech Republic	9.5	4.5	46.7	28.7
J-TE-F	Czech Republic	9.5	7.7	78.4	41.3
Bemali	Sweden	13.5	7.3	64.8	37.7
M.9 EMLA	UK	11.4	9.7	45.2	41.0
P.60	Poland	12.9	8.4	72.0	48.0
M.26	UK	13.9	10.1	44.9	48.1
J-TE-H	Czech Republic	15.2	11.9	73.5	56.2
J9	Germany	12.9	14.1	59.1	73.7

^{Z}yields lost due to severe frost in 1997.
^{Y}trickle irrigation applied 1994-1997.

was applied. No consistent effects on fruit size have been observed.

In another trial planted in 1994, several selections from the Cornell University program at Geneva, New York, USA, are being compared (Table 7). Trees on G.30 are similar in size, or slightly larger than, trees on MM.106 but with lower yields to date. Trees on CG.179 and CG.210 clones are similar in size to trees on M.9, with slightly higher early yields. Trees on G.11 and CG.202 are intermediate in vigor between M.9 and MM.106 with good yields.

NEW ROOTSTOCKS FOR PEARS

This program focuses on producing new improved quince and *Pyrus communis* rootstocks for the common pear (*Pyrus communis*). The problems experienced with quince rootstocks in many pear production areas of the world, namely, sensitivity to winter cold injury, drought, and high alkalinity in soils, are not problems in the UK and have not been prime objectives in our quince rootstock improvement program. Of greater interest to UK pear producers has been increased dwarfing by quince rootstocks and their effects in improving yields or fruit size.

One new HRI-EM quince clone, now under test at several European sites, is QR193-16. This selection is very easy to propagate and induces vigor intermediate between Quince A and Quince C. Its main advantage is that it induces larger fruit size than Quince C in varieties such as Conference and Concorde. However, on some sites and with some scion varieties, precocity of cropping is poorer on this rootstock in comparison with Quince C, and further results from trials are awaited before any decision to release it is made.

Renewed interest has been shown recently in The Netherlands in an HRI-EM quince rootstock selected from a seed batch obtained many years ago from Caucasus region of Europe. This rootstock, C132, produces slightly smaller trees than Quince C and should give advantages to growers wishing to establish high density planting systems of pears. Even more dwarfing, on the evidence of one screening trial, are the quince rootstock clones QR530-4 and QR530-11 which in a preliminary trial produced trees only half the size of trees on Quince A. However, further trials will be needed before the advantages and disadvantages of these two clones can be fully appraised.

The HRI-East Malling program is also producing selections of *Pyrus communis* and testing these as potential rootstocks. *Pyrus communis* rootstocks have advantages over quince stocks in that they are fully graft compatible with pear scions. They are also more tolerant of unfavorable environmental conditions, including temporary drought, high soil pH and severe winter cold. Unfortunately, most *Pyrus communis* types are very difficult to propagate vegetatively, have little or no potential for dwarfing scions grafted onto them and induce poor yield precocity and fruit size in these scions.

One HRI-East Malling *Pyrus communis* rootstock selection, QR708-36 (BP1 x Old Home), shows good early promise as a semi-dwarfing rootstock. It is easy to propagate from semi-hardwood cuttings under mist or by micropropagation. It produces scion trees of similar vigor to Quince A or to the slightly larger trees on Provence quince (BA29). Moreover, it induces good precocity and yield efficiency in comparison with other *Pyrus* rootstocks under test. QR708-36 is now in trial in France and Italy and has been introduced in the USA for future trialing.

Two other selections from the same BP1 x Old Home cross as QR708-36, namely QR708-12 and QR708-2, were more dwarfing than QR708-36 in a preliminary screening trial. However, these clones are also more difficult to propagate (except by micropropagation) and induce poorer yield precocity. Further trials are in progress with these and other selections from the HRI-East Malling breeding program.

PEAR ROOTSTOCKS FROM OTHER BREEDING PROGRAMS

Trials of the Old Home x Farmingdale (OHF) *Pyrus* rootstock selections conducted in earlier years showed them to be too invigorating for UK requirements. In a recent trial the South African dwarfing *Pyrus* selection BP1 has proved extremely sensitive to the phytoplasma causing Pear Decline and most trees have died. In a new trial planted in spring 1997, the promising selection Pyrodwarf, bred at Giesenheim in Germany, is being compared with QC and QA as rootstocks for the pear variety Conference. Tree size at planting was very small on Pyrodwarf and the trees have been slow to establish, making much less growth than trees on QA. The poor floral precocity of the trees on Pyrodwarf recorded in this trial to date may be partly attributable to this slow establishment and smaller tree size. Results from future years will be essential to enable us to determine whether the promising results reported from Germany (Jacob, 1998) on this rootstock can be repeated in UK conditions.

Difficulties in propagation have limited the trialing of the French Brossier *Pyrus* rootstock selections. Although these rootstocks are known to be dwarfing (Michelesi, 1990), they can be propagated using only micropropagation methods. Moreover, weaning and establishment of micropropagules have proved extremely difficult. The most dwarfing clone from this series, RV139, has been abandoned by most researchers on account of these difficulties.

NEW ROOTSTOCKS FOR SWEET CHERRIES

The rootstock Colt bred and released by HRI-East Malling in the 1970s is a sterile triploid and of little use as a parent for further breeding. To overcome this, a fertile hexaploid clone of Colt was created by treating *in vitro* callus cultures of Colt with the mutagen colchicine (James et al., 1987).

As well as using the hexaploids created as parents in further rootstock breeding, they were also tested directly as rootstocks for sweet cherry varieties. Preliminary trial results showed that trees on these hexaploid clones of Colt produced approximately 39% less shoot growth and were 30% smaller at grubbing than trees on the conventional triploid clone of Colt (Table 8). This effect is mainly attributable

TABLE 7

Preliminary records of growth and yields of Queen Cox planted in 1994 on several apple rootstock clones bred at Geneva, New York.

Rootstock clone	Crown volume 1998 (m^3)	Cumulative yields 1998 + 1999 (kg/tree)
G.11	17.9	19.8
G.30	23.0	26.7
CG.179 (76.O3.R5.179)	14.5	18.7
CG.210 (75.O3.R5.210)	14.7	16.3
CG.202 (75.27.R5.202)	16.3	26.0
M.9	13.9	14.7
MM.106	20.4	33.6

to reduced branching on the trees and pruning (heading) techniques will need to be developed to create well-branched trees to take full advantage of the reduced vigor. In other respects, such as ease of propagation, induction of yield precocity, yield efficiency and fruit size, the performance of hexaploid Colt is similar to that of the triploid clone.

A small program of species and hybrid rootstock breeding and selection is also in progress at East Malling and several selections are showing preliminary promise as dwarfing rootstocks inducing high yields.

SWEET CHERRY ROOTSTOCKS FROM OTHER BREEDING PROGRAMS

Over the last 25 years many *Prunus* species and hybrids have been tested as potential dwarfing and semi-dwarfing rootstocks for the sweet cherry. The most promising selections so far tested on the HRI-East Malling site have been Gisela 6 (Giessen 148/1) and Weiroots 10 and 13 (Table 9). These stocks have shown high yield efficiencies on trees slightly smaller in size than those on Colt. Also, the variety Summit which usually crops poorly in UK conditions has performed well on the French *P. cerasus* rootstock selection Tabel®/Edabriz. However, some tree losses during the establishment years have been noted on Tabel by commercial sweet cherry growers in the UK. A new trial has recently been planted, as part of an International European initiative, to compare 14 new dwarfing rootstocks for sweet cherries.

ROOTSTOCK NEEDS IN THE FUTURE

If the current trend toward reduced pesticide use continues, new dwarfing rootstocks will be required which are:

- resistant to soilborne pests
- resistant to soilborne diseases
- resistant to specific replant disease
- better able to compete with weeds and grass for water and nutrients

These goals can probably be achieved using conventional hybridization techniques and crosses between existing rootstock clones. However, in some instances it could be beneficial to take advantage of new germplasm obtained from the wild. Also, advances in molecular biology will undoubtedly offer exciting opportunities for the genetic transformation of existing rootstocks to provide resistance to biotic and abiotic stress factors, as well as dwarfing. Work in Geneva, New York, and in Sweden has already shown promise using such techniques. It is currently uncertain, however, whether the European consumer will accept fruits produced on genetically transformed rootstocks. It is hoped that this consumer resistance to the use of GMOs in fruit production can be overcome in the near future.

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TABLE 8

Growth and cropping of Merchant sweet cherries planted on triploid or hexaploid clones of Colt rootstock in spring 1987.

			Yield efficiency^Z (g/cm^2 TCA^Y)				
			Year				
Colt ploidy	**Wt. of tree at grubbing in 1995 (kg)**	**Total shoot length/tree 1987-1990 (m)**	**1991**	**1992**	**1993**	**1994**	**1995**
Hexaploid	55	46	91	195	163	95	50
Triploid (control)	79	76	103	193	168	122	56

^{Z}Yield efficiency is yield adjusted for tree size.

^{Y}TCA is trunk cross-sectional area, a measure of tree size.

TABLE 9

Growth and cropping of Van sweet cherries planted in spring 1983 on Colt, Weiroot 10, Weiroot 13 or Gisela 6 rootstocks.

Rootstock	Crown volume 1992 (m^3)	TCA^Y 1992 (cm^2)	Tree weight at grubbing 1992 (kg)	Total cum. yield/tree 1986-92 (kg)	Cum. total yield/efficiency^Z 1986-92 (g/cm^2 TCA)	Average fruit size 1986-92 (g)
Weiroot 10	44.3	190	77.5	159	918	7.3
Weiroot 13	32.4	178	61.6	114	709	7.8
Gisela 6	29.0	173	62.0	111	693	7.7
Colt	52.9	282	112.1	133	514	7.9

^{Z}Yield efficiency is yield adjusted for tree size.

^{Y}TCA is trunk cross-sectional area, a measure of tree size.