Pear Breeding

Manfred Fischer

1 Origin of Pears

The genus *Pyrus*, the pears, includes a wide range of species used partially as rootstocks but not or very rarely as human food. The genus *Pyrus* is a part of the family of Rosaceae with 34 chromosomes (2*n*). Judging by the supposed geographic origin, some wild species could be considered to be the ancestors of the cultivated pear: *P. pyraster* (L.), *P. elaeagrifolia* (Pallas), *P. spinosa* (Forssk.), *P. syriaca* (Bois.), *P.* × *nivalis* (Jacq.), *P. caucasica* (Fed.), etc. There is no doubt that the first one is the base of Central European varieties, but the lack of evidence makes it impossible to exactly determine the participation of other species in the evolution in terms of time and geography. *P. pyraster* (L.), the wild pear or wood-pear played an important role in the domestication of the cultivated pear—the European pear—*P. communis* (L.). Pears might have the same paleontological background as apples. The centres of genetic diversity of apples and pears are Central Asia; minor centres for pears are the Northern Caucasus, Minor Asia and the mountains of Northern Africa and Southern Europe. Asian pear, P. *pyrifolia* (Burm.) ('Nashi' pear, Japanese pear, Chinese pear and Sand pear) are cultivated throughout the whole of central and southern China, in the far east of Russia, Korea, Japan, South-East Asia, New Zealand, Australia and USA (California) and recently in southern parts of Europe as 'exotic' fruits. Most of the wild pears are diploid and crossable with cultivated pears and themselves. This can explain the relatively high variability of the genus *Pyrus* (Moore and Ballington 1992; Fischer and Weber 2005).

M. Fischer
IPK Gatersleben, Genbank Obst Dresden-Pillnitz (former affiliation), Söbrigener, Str. 15, D - 01326, Dresden, Germany
e-mail: manfr.fischer@googlemail.com

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2 History

Information on the first pear cultivation commences from the Chinese Tsing and Han dynasties 2000 years ago. Primitive types were certainly cultivated earlier. Wild pears were eaten like wild apples by the Babylonian and Persian people, and in this way they were selected and propagated down the Silk Road before they were transported to Minor Asia and Europe. Nearly 1000 years ago, primitive pear growing was done in Europe with many different varieties. Belgium, North France and Italy developed as European centres of pear cultivation in the Middle Ages, where we find the oldest descriptions of pear varieties. Starting points for the development of the sources of modern varieties were *P. communis* for the European pears and *P. pyrifolia* as soon as *P. ussuriensis* for Asian pears. To the north in Europe, the Caucasian *P. caucasica* had some influence on the selection of more hardy primitive types of pear varieties (Janick 2004).

The domestication of Asian pears began in China about 2000 years ago. Today, more than 1000 varieties are known, which exist as many landraces. Even now we find wild populations with small fruits and a lot of grit cells in central China. An ‘explosion’ of pear breeding and growing occurred in Europe in 16th to 19th century. Especially in France and Belgium, many gardeners were working mostly as intelligent breeders, monks and nurserymen. Jean Baptiste van Mons (1765–1842) received more than 80,000 (!) seedlings for selection. All breeders were working more pragmatic with lots of opinions and practical knowledge. Scientific pear breeding started in the beginning of the 20th century in Belgium, France, USA and Germany. Today, the capacity of pear breeding is much smaller than apple breeding. However in Canada, USA, France, Italy, Czech Republic, Romania, Germany, Japan, China and Korea scientific institutions and private breeders have some remarkable successes in breeding new varieties. Recently, activities could be observed in China, USA and Switzerland for crossing Asian and European varieties for new desirable qualities (Petzold 1989; Fischer and Weber 2005).

3 Agricultural Aspects

The pear today is an alternative to apples. Asian and European pears were more important in the Middle Ages than they are now, but they are becoming more popular at present because of the dominance of apples in the market. Pear production is increasing in particular in countries with excellent climatic conditions, such as in Southern Europe, China, Argentina and Chile. In East Asia, main pear crops are Asian pears; in all other countries, there is a greater inclination to grow the European types of pears (Table 1). Nashi pears tend to be regarded as ‘exotic’ fruit in Europe. There is great deal of variability in

Table 1 Top 10 pear-producing countries (FAO 2004)

Country	1989–1992	1999–2002	%	Main cultivars
World	9870	16,606	+ 68	Ya Li, Bartlett, Tsu Li
China	2689	8679	+ 223	Ya Li, Tsu Li, Xuehua Li
Italy	892	896	+ 1	Abate Fetel, Bartlett, Conference
USA	841	861	+ 2	Anjou, Bartlett, Bosc
Spain	509	685	+ 34	Blanquilla, Conference
Argentina	265	546	+ 106	Bartlett, Packhams
Japan	437	388	–11	Kosui, Hosui, Nijisseiki
Turkey	417	369	–11	Santa Maria, Coscia, Ankara
South Korea	174	347	+ 99	Niitaka
South Africa	197	291	+ 48	Packhams, Bartlett, Forelle
France	345	269	–22	Bartlett, Guyot

size, shape, colour, flavour and ripening time. Use of fruits depended on the inherent quality and consistence. The eating quality is reached after different storage periods, possibly under controlled atmosphere. The fruits can be either canned or used for preparing juice and mixed drinks. Aromatic and sweet fruits can be processed to brandy under conservation of the typical pear flavour ("Williams Brandy").

The worldwide production of *P. communis* is dependent on relatively few cultivars. In a recent survey of major cultivars, 'Bartlett' ('Williams') is the major cultivar in many countries, followed by 'Beurre Bosc', 'Conference', 'Passa Crassane' and 'Doyenne du Comice'. The most important Nashi cultivars are 'Nijisseiki', 'Kosui', 'Chorujo' and 'Hosui'. Some cultivars in Asia are based on *P. ussuriensis* and *P. bretschneideri*, like 'Ya Li' and 'Tsu Li' of China. The major pear cultivars now are susceptible to some pests and diseases, especially *Pseudomonas syringae, Erwinia amylovora, Venturia pirina, Psylla* spp. and others. The present risks to production are significant, with the potential to cause yearly loss of marketable fruit, long-term problems on yield or the loss of trees. Many cultivars are deficient in production, fruit quality or storability. This is one of the reasons why the pears are not of economic importance comparable to apples. But germplasm accessions with better fruit features and tolerance or resistance to the most diseases and pests are known. More personnel and financial resources are needed to improve this situation. This would mean more work with genetic resources and an effective breeding of pears (Fischer and Weber 2005).

4 Breeding Efforts

The main breeding aims in the Middle Age to the beginning of the 20th century were

- excellent fruit quality for fresh consumption,
- pears for cooking,
- pears for drying, and
- vigorous trees.

The sowing of seeds after open pollination was the mostly used method of breeding. In this way, it was possible to receive a wide variability for the selection of new varieties. Many of enthusiastic people were integrated in testing of selected material in monasteries or fruit nurseries.

Controlled crossing (combination breeding) of selected parents begun in the middle of 19th century. A scientific base was given with the first results after evaluation of populations in different European and American institutions. The method of combination breeding by using heredity analyses is the main method of pear breeding in all the time. The most appreciated pear varieties have high degrees of heterozygosity. Cross-breeding leads to high degrees of variability in the progenies, thus making the selection of new genotypes using this traditional method easy.

There are numerous objectives of European pear genetic improvement, which are in large part dependent on the evolution of marketing and technological sectors. Previously, great emphasis was focussed on the improvement of agronomic and pomological characteristics, such as tree vigour, productivity and fruit appearance. Recently, however, there has been an increasing interest in the fruit-growing genetics and physiology, aimed at the development of production procedures capable of maintaining a correct balance of the fruit ecosystem. Thus, breeding objectives have been streamlined for tolerance or resistance to the most dangerous pests and diseases, adaptability to environmental factors, tree vigour control, extension of harvest period, fruit longevity and self-fertility. Particular attention deserves fruit quality, taste and nutritional characteristics (Petzold 1989; Brown 2003).

4.1 Breeding Objectives

The main breeding aims today are

- high and regular cropping,
- excellent fruit quality,
- winter pears with storage longevity,
- no grit cells,
- red or bicoloured fruits and
- fire blight resistance.

More detailed aims are different according to the region of breeding:

- compatibility with quince rootstocks
- attractiveness of the fruits
- drought tolerance (North America)

- calcium tolerance
- minimising the chilling requirement (South and North Africa, South America)
- winter frost tolerance (Northern China, Northern and East Europe, Canada)
- dwarf growing of tree (Europe)
- no alternate bearing
- virus tolerance or resistance
- resistance to pear psylla
- resistance to scab (*V. pirina*)
- resistance to pear decline
- resistance to *Pseudomonas*
- resistance to *Gymnosporangium sabinae*
- self-fertility

4.2 Genetics of Agronomic Traits

Knowledge of heritability of main characteristics is very important for the successful breeding work. The first steps are long-term evaluation of varieties in the field, in gene banks or in cropping plantations. The second steps have to be the testing of parents and populations. Many opinions exist today as summarised next by utilising the international literature and the results of German pear breeding. The following varieties, for example, are carrier of the genes for

- winter varieties—'Paris', 'Verté', 'Nordhäuser Winterforelle'
- summer varieties—'Bunte Juli', 'Trevoux', 'Clapp's Favourite', 'Bartlett', 'Starking', 'Santa Maria', 'Early Morettini'
- excellent fruit quality—'Doyenne du Comice' ('Vereinsdechantsbirne')
- poor fruit quality—'Countess de Paris'
- good fruit quality in combination with high yield—'Bosc's' ('Kaiser Alexander'), 'Dr. Jules Guyot', 'Präsident Drouard'
- very bad cropping—'Anjou', 'Packham's Triumph', 'Doyenne du Comice'
- fire blight resistance—'Seckel', 'Kieffer', 'Old Home', 'Harrow delight', 'Harrow Sweet', 'Harrow Gold', 'Alexander Lucas' (*P. communis*), 'Ya Li', 'Tzu Li' (*P.* × *bretschneideri*)
- scab resistance—'Bartlett' ('Williams'), 'Beurre Hardy' ('Gellert'), 'Kieffer', 'Dr. Jules Guyot'
- mildew resistance—'Doyenne du Comice', 'Winter Nelis'
- resistance to *Pseudomonas* blight—'Beurre Hardy', 'Forelle'
- tolerance to fruit rot—'Passa Crassana', 'Clapp's Favourite', 'Louise Bonne d'Avranches'
- cold hardiness—'Seckel', 'Doyenne du Comice', 'Erika', 'Delta'
- resistance to pear psylla—'Karamanka', 'Jerisbasma', 'Vodenjac', 'Monica'
- red colouration of fruits—'Nordhäuser Winterforelle', 'Rubia', 'Red Silk'
- dwarfness—'Armida', 'David', 'Abate Light'

The success of breeding for genetic resistance to diseases and pests is strongly dependent on the genetic value of varieties and species used in hybridisation. For a high level of resistance in new varieties, a cross-combination with resistant varieties is necessary (unfortunately, mostly they are of poor fruit quality, e.g., 'Sekel') or the use of different wild species for crossing, like

- *P. cordata*—scab resistance, mildew resistance
- *P. nivalis* –tolerance to pear decline
- *P. calleryana*—fire blight resistance
- *P. ussuriensis*—fire blight resistance, cold hardiness
- *P. elaeagrifolia*—generally fungal and bacterial resistance without fire blight

Using wild species is very problematic because of its extremely bad fruit quality and small fruit size. Four to five backcrosses are needed to evolve a type with acceptable fruit quality. Perhaps, biotechnology tools can help to solve the transmission of resistance genes into established varieties. Unfortunately in pear, heritability studies on resistance to diseases, and on many other important traits, are less advanced compared to apple (Zwet et al. 1974; Zwet and Keil 1979; Fischer and Mildenberger 1998; Hunter and Layne 1999; Andreies 2002; Bellini and Nin 2002).

Most pear varieties are susceptible to various viral, bacterial and fungal diseases. In addition, there are numerous animal pests, and crop protection measures must be taken. Protection against virus diseases is effected by utilising healthy planting materials. Virus-infected trees grow more slowly, the crop is smaller, the fruit quality, especially because of grit cell formation, is much worse and the compatibility between rootstock and grafted varieties is disturbed. Only streptomycin preparations are effective against the most important bacterial disease fire blight (*E. amylovora*); however, their use is disputed and not allowed in a number of pear-producing countries. Constant monitoring of the trees is necessary wherever this preparation is not usable so that infested young shoots can be detected in good time and eliminated. In damp and cold regions, bark blight (*Pseudomonas* spp.) can also appear in autumn. Cuprous agents help as a preventive measure against this. Dangerous fungus diseases affecting pears are scab (*V. pirina*) and mildew (*Podosphaera leucotricha*). Depending on climatic conditions, 6–20 fungicide sprayings are necessary in commercial cultivation to produce healthy fruits. When utilising organic production methods, only other plant sprays are applied. It is, therefore, impossible to obtain good fruit quality without plant protection measures (Brown 2003; Fischer and Weber 2005).

The best protection against these diseases is the utilisation of resistant varieties, with the aim to substantially reduce the amount of pesticides required. Resistant varieties help to solve many plant protection problems, specifically with regard to organic fruit growing. Therefore, the resistance breeding against fungi and bacterial diseases is one of the most important parts of pear breeding in the future.

There are numerous harmful animal pests. The most significant of which are pear psylla (*Psylla pyrisuga, P. piri, P. piricola*), codling moth *(Cydia pomonella*), various types of aphids (*Aphis* spp., *Dysaphis* spp., *Brachycaudus* *helchrysi, Myzus persicae, Hyalopterus pruni* among others), the woolly aphid (*Eriosoma lanigerum*), scale insects (*Eulecanium corni, Lepidosaphis ulmi, Quadraspidiotus* spp. among others) and the red spider mite (*Panonychus ulmi*). Only insecticide and acaricide sprays help against these. Unfortunately, there are only a few varieties, land races or wild species with insect resistance or tolerance. That is why there are only few breeding possibilities to improve the resistance of new varieties in the future, and a success is not expected in the next time (Jones and Aldwinckle 1990; Weber 2001).

4.3 Biotechnology

4.3.1 In Vitro Culture

The contribution of in vitro techniques and molecular tools to genetic studies and breeding has advanced considerably in the recent past. Haploidisation via in situ parthenogenesis induced by irradiated pollen and in vitro rescue of the haploid plantlets has been developed (Chevreau et al. 1998; Bellini and Nin 2002). The aim is receiving double haploids (DH) for crossing with better knowledge on inheritance (Bouvier et al. 2002). This technique can be of interest especially for resistance breeding if it is possible to double heterozygous genes to ‘homozygous’ ones in DH plants. Techniques of adventitious bud regeneration from in vitro leaves have been developed for several genotypes of European and Asian pears. So far, applications of these techniques for the induction of somaclonal variation have been very limited (Chevreau et al. 1998; Dondini et al. 2002). Increased tolerance to fire blight has been obtained in somaclonal variants of some varieties (Chevreau and Skirvin 1992; Brown 2003).

4.3.2 Molecular Breeding

A major evolution of pear biotechnology is the development of *Agrobacterium tumefaciens* mediated transformation. About 10 genotypes were successfully transformed (Bell et al. 1999; Reynoird et al. 1999). Projects have started in several countries to express various transgenes in pear. Molecular markers developed now include isoenzymes, ALFPs, ISSRs, RAPDs and RFLPs. They have been used mostly for varietal identification of European and Asian pears. Markers have been developed recently for a few genes of interest, such as a black spot resistance gene and an ACC synthase gene (Chevreau et al. 1998; Oliveira et al. 1999) or the S-alleles for self-incompatibility of pears (Zuccherelli et al. 2002). But no genetic map of pear like for apples is yet available. About 20 genes have already been cloned mostly from Asian varieties. They are involved in fruit ripening or quality and self-incompatibility (Chevreau 2002; Lebedev et al. 2002; Tartarini and Sansavini 2003; Bell and Peterka 2004).

The use of biotechnical methodologies, the exploiting of somaclonal variation, and the setting up of early selection methods could make induced mutation techniques more reliable (gamma rays, chemical substances, etc.). It has intrinsic limitations, but it offers good prospects for further contributions to pear variety development and improvement as well (Hirata 1989; Masuda et al. 1997; Predieri 2002).

The pear consumer accepts improvements in a standard variety more easily than those that are completely new (Paprstein and Bouma 2000; Fischer and Weber 2005). In this way, spontaneous and induced mutations (in vitro or directly on plants) can be important for improvement of single traits of an already outstanding variety (Malnoy et al. 2000; Dondini et al. 2002; Monte-Corvo et al. 2002; Durel et al. 2004).

4.4 Cross-Combination Breeding in Germany

4.4.1 Breeding Aims and Selection

The aims of the German breeding program were excellent fruit quality, a good appearance and shape of fruit, early and abundant cropping and resistance to scab and fire blight. A special aim of selection was to find high-quality summer varieties and varieties with long storability. The crossing program involved only European varieties (*Pyrus communis*). For selection, following criteria were used: fruit quality (taste, colouring, no grit cells, consistency), ripening time, storability, growing capacity, susceptibility to scab and fire blight, yield and alternate bearing.

4.4.2 Results

The selection rate is listed in Table 2. Table 3 indicates the most successful cross-combinations with more than 10% elected seedlings in the populations. The

Table 2 Conclusion of selection rate in pears after three selection steps

	Seedlings	Elected clones	
Mother parent	*n*	*n*	%
Bunte Juli	751	26	3.46
Clapps Favourite	1342	33	2.45
Bartlett	587	22	3.74
Comice	1126	24	2.13
Madame Verté	451	1	0.09
Countess of Paris	1124	23	2.04
Nordhäuser Winterforelle	2261	54	2.38
Beurre Bosc	36	1	2.78
Gaishirtle	33	0	0
Desportes	37	1	2.70
Kongress	16	0	0

Table 3 Specific combination ability for good fruit quality

More than 10% selected clones received only from the following cross-combinations:
Clapps Favourite × Bunte Juli
Clapps Favourite × Nordhäuser Winterforelle
Nordhäuser Winterforelle × Baierschmidt
Nordhäuser Winterforelle × Madame Verté
Comice × Red Bartlett
Jules Guyot × Comice

Table 4 Breeding of winter varieties

	Percentage of seedlings ripened in		
Combination	Summer	Autumn	Winter
late × late (e.g., Nordh. Winterforelle × Countess of Paris)	5	87	8
late × early (e.g.. Comice × Trevoux)	42	54	4
early × early (e.g., Bunte Juli × Trevoux)	82	18	0

summary of cross-combinations to receive late ripening varieties is listed in Table 4.

The selection rate was never better than 4%, mostly only 1–2% without the cross-combinations listed in Table 3. Early ripeness dominated about late ripeness. It needs much more crossings for receiving winter varieties.

For all ripening groups, new varieties were selected. We found varieties for all production possibilities: for intensive and extensive cultivation methods for fresh market, for home gardening and for landscaping. All varieties are the result of improvement of the more or less known old pear varieties. The recommended and new pear varieties are

- summer (in time of ‘Bunte Juli’)—‘Hermann’, ‘Isolda’,
- autumn (in time of ‘Bartlett’)—‘Gräfin Gepa’,
- late autumn (in time of ‘Bonne Louise’)—‘Armida’, ‘Manon’,
- autumn to early winter (in time of ‘Conference‘)—‘Hortensia‘, ‘Gerburg’, ‘Graf Dietrich’, ‘Thimo’ and ‘Elektra’.
- winter (in time of ‘Alexander Lucas’)—‘David’, ‘Eckehard’, ‘Uta’, ‘Graf Wilhelm’.

The following conclusion listed the most important characteristics of the new German pears to explain the progress in breeding work. It was impossible to realise all the aims in one new variety. Every variety of necessity is a compromise.

- Yield, fruit size, growing capacity

The newly bred summer variety 'Isolda' has a stronger growth and is more yielding as 'Clapps Favourite'. 'Hermann' ripens much earlier but yield and fruit size are only average. But the colouration of 'Hermann' is excellent. The fruit size varies between 130 g ('Hermann') and 170 g.

Of the autumn varieties, 'Hortensia' is most productive, followed by 'Thimo', 'Elektra' and 'Graf Dietrich'. They are better yielding than 'Bartlett'. 'Armida' and 'Gräfin Gepa' are not too productive, but they have a very good fruit quality. 'Armida' is one of the prominent dwarfing varieties we know. 'Graf Dietrich', 'Gräfin Gepa' and 'Hortensia' grow stronger than 'Bartlett'. The fruit size of the autumn varieties varies between 170 and 250 g. 'Manon' has an excellent taste and good shape with mild susceptibility to fire blight, but it is susceptible to *Pseudomonas*.

Within the late varieties, 'Conference' is only surpassed by 'Eckehard' in yield, but all other varieties have a better fruit size and fruit quality than 'Conference'. 'Uta' and 'David' are very dwarf as regards their growing capacity; 'Eckehard', 'Gerburg' and 'Graf Wilhelm' are vigorously growing varieties.

- Fruit quality

One of the best varieties is 'Graf Wilhelm', a late winter variety with good appearance, but a poor yielder meant for lovers of pear fruits or enthusiasts only. 'Uta', 'Thimo', 'Elektra', 'Armida' and 'Isolda' have an excellent taste; all other varieties are good and better than 'Conference'.

- Yield capacity

The yield capacity is from high ('Gräfin Gepa', 'Graf Dietrich', 'Gerburg', 'Thimo', 'Elektra', 'Uta') to very high ('Eckehard', 'Hortensia'). 'Gerburg', David' and 'Armida' yielded only average.

- Ripening time and storability

'Hermann' ripens very early followed by 'Isolda'. They ripen before 'Clapps'. Within the group of autumn varieties, 'Graf Dietrich' 'Elektra' and 'Thimo' can store to November/December. 'Manon' ripens in September. The winter varieties in cold storage last until February/March ('Eckehard', 'Graf Wilhelm', 'Uta',) and March/April ('David'). The picking time and the storability vary greatly under different climatic conditions. We tested the storability only in cold storage, not under CA conditions. It may be possible to store 'Uta' and 'David' under CA conditions up to April (5–6 month). 'Eckehard', 'Gerburg' and 'Uta' obtain the best eating quality in December to February. Some of the improved varieties are given in Fig. 1.

- Compatibility

All varieties grow on seedling rootstocks and on quince with interstem 'Beurre Hardy'. The direct compatibility with quince is not yet tested for all varieties. 'Uta' and 'Isolda' are incompatible with quince in direct grafting.

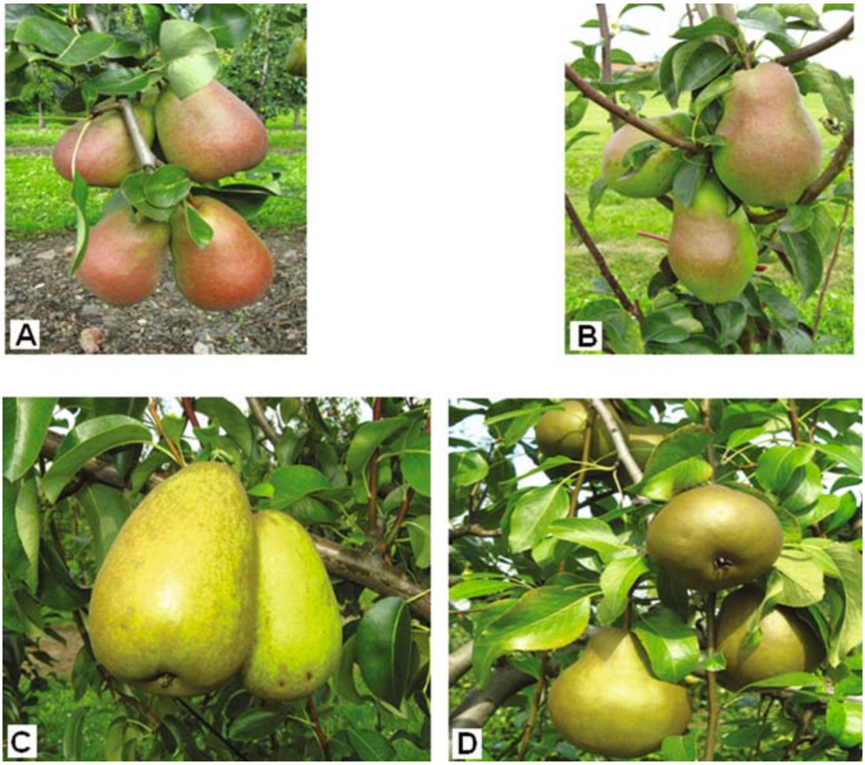

Fig. 1 A few improved varieties of Pears: Eckehard (**A**); Elektra (**B**); GrafWilhelm (**C**) and Uta (**D**) (*See* Color Insert)

- Resistance

We found no scab (*V. pirina*) and no *Pseudomonas* infection (out of 'Manon') in any of the named varieties. Varieties with pear decline and scab infection were eliminated. 'Isolda', 'Manon' and 'Uta' are only slightly infected by fire blight after artificial inoculation; all other varieties are susceptible to fire blight. The field test took place under a limited plant protection program, not without such measurements.

- Winter frost damage

After temperatures of –28°C, only a small damage occurs in wood or on buds of the new Pillnitz varieties 'Armida', 'David', 'Uta' and 'Eckehard', and in the Nashi pear from Japan, 'Shinseiki', 'Conference' and the new variety 'Concorde' from UK. The damage gives an indication of the reaction of varieties under extreme temperature stress conditions, but it is not a final characterisation of the frost resistance of the varieties (Fischer and Mildenberger 1998, 2000, 2004).

4.4.3 Short Description of some Recommended New German Pear varieties

Armida™ *
Origin: 'Jules Guyot' × 'Comice'
Tree: very dwarfing growth with good ramification, flat crown
Maturity: autumn, after 'Bartlett'
Quality of fruits: good taste, but on unsuitable soils, formation of stone cells is noted
Fruit size: large, oblong, slim, under-colour green, over-colour yellow, 170 g
Yield: middle to high, early bearing, mostly regular, not biennial
Resistance: good resistance against spring frosts, tolerant to scab or mildew infection, susceptible to fire blight
Pollination: diploid, good pollinators include 'Bartlett', 'Conference', 'Clapps Favourite', 'Hortensia'

David®
Origin: 'Jules Guyot' × 'Comice'
Tree: dwarfing growth with good ramification, flat pyramidal crown
Maturity: late autumn, with 'Alexander Lucas', storable to March
Quality of fruits: good after storage, very good transportability after picking
Fruit size: large, skin green, after storage it turns yellow-green, 180 g
Yield: middle, early bearing, regular
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, good pollinators include 'Bartlett', 'Anjou', 'Uta', 'Clapps Favourite', 'Paris'; for a good fruit set needs high temperature in the time of pollination; bad fruit set with 'Hortensia' and 'Conference'

Eckehard™ *
Origin: 'Nordhäuser Winterforelle' × 'Clapps Favourite'
Tree: vigorous growth, flat pyramidal crown
Maturity: winter, a few days before 'Alexander Lucas', storable until February/March
Quality of fruits: good to excellent, flesh in some years a little coarse with some grit cells
Fruit size: large to medium, skin under-colour green, over-colour to 50% vermilion to brown-red, 250 g
Yield: very high, early bearing, without fruit-thinning tendency to a less alternate bearing
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, pollinators include 'Bartlett', 'Clapps Favourite', 'Conference', 'Tongern', 'Anjou', 'Uta', 'Paris'

Gerburg™ *
Origin: 'Clapps Favourite' × 'Nordhäuser Winterforelle'

Tree: vigorous growth, pyramidal crown, needs to form up the branches for earlier beginning of cropping and higher yield
Maturity: late autumn, a few days after ‘Conference’, storable to December/ January
Quality of fruits: good, aromatic, juicy
Fruit size: large, skin under-colour green –-yellow, over-colour to 60% red, attractive, 300 g
Yield: middle to low, late beginning of cropping
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, pollinators include ‘Bartlett’, ‘Clapps Favourite’, ‘Uta’, ‘Tongern’, ‘Conference’, ‘Anjou’, ‘Paris’, ‘Hortensia’

Graf Dietrich® *
Origin: ‘Clapps Favourite’ × ‘Nordhäuser Winterforelle’
Tree: vigorous growth, pyramidal crown, ramification loose, needs to form up the branches for earlier beginning of cropping
Maturity: autumn, like ‘Conference’, edible to December
Quality of fruits: very good, aromatic, juicy, for transportation needs early picking
Fruit size: medium to large, skin under-colour green, over colour yellow to brownish-yellow to vermilion, attractive, 250 g
Yield: middle to high, early bearing, better on quince than on seedling
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, pollinators include ‘Bartlett’, ‘Clapps Favourite’, ’Uta’, ‘Tongern’, ‘Paris’, ‘Hortensia’

Graf Wilhelm™ *
Origin: ‘Comice’ × ‘Nordhäuser Winterforelle’
Tree: medium to vigorous growth, pyramidal crown
Maturity: late autumn, a few days before ‘Alexander Lucas’, storable to February/March
Quality of fruits: excellent, aromatic, juicy, for transportation needs early picking
Fruit size: large, skin under-colour green-yellow, over-colour yellow-brownish, attractive, 250 g
Yield: middle to low, form up the shoots can be helpful for a better cropping
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, pollinators include ‘Bartlett’, ‘Uta’, ‘Conference’, ‘Paris’, ‘Hortensia’

Gräfin Gepa™ *
Origin: ‘Nordhäuser Winterforelle’ × ‘Baierschmidt’
Tree: medium growth, pyramidal crown
Maturity: early autumn, a few days before ‘Bartlett’

Quality of fruits: very good, aromatic, juicy, for transportation needs early picking
Fruit size: medium to large, skin under-colour green, over-colour to 90% red to vermilion, attractive, 220 g
Yield: middle to high, early bearing
Resistance: no scab or mildew infection, susceptible to fire blight, wood a little susceptible to winter frost
Pollination: diploid, pollinators include 'Bartlett', 'Clapps Favourite', 'Conference', 'Anjou', 'Uta'

Hermann® *
Origin: 'Jules Guyot' × 'Bunte Juli'
Tree: medium growth, flat pyramidal crown
Maturity: summer, a few days after 'Bunte Juli', no storable
Quality of fruits: good, aromatic
Fruit size: medium to small, skin under-colour green, over-colour to 20% brown-red, 150 g
Yield: middle to high, early bearing
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, pollinators include 'Bartlett', 'Clapps Favourite', 'Conference', 'Tongern', 'Anjou', 'Hortensia'—incompatible with 'Uta'

Hortensia®
Origin: 'Nordhäuser Winterforelle' × 'Clapps Favourite'
Tree: medium to vigorous growth with good ramification, flat pyramidal crown
Maturity: late autumn, a few days before 'Conference'
Quality of fruits: good
Fruit size: large, skin under-colour green-yellow, over-colour to 75% red to brown red, attractive, 220 g
Yield: very high, early bearing, regular
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, good pollinators include 'Paris', 'Clapps Favourite', 'Bartlett', 'Anjou', 'Conference'

Isolda
Origin: 'Jules Guyot' × 'Bunte Juli'
Tree: medium growth with good loose branch structure, flat pyramidal crown
Maturity: very early, a few days after 'Bunte Juli'
Quality of fruits: good to excellent
Fruit size: large to medium, skin under-colour yellow to green-yellow, over-colour yellow, to 20% vermilion (not in all years), 180 g

Yield: high, early bearing, regular
Resistance: no scab or mildew infection, susceptible to fire blight
Rootstocks: not directly compatible with quince
Pollination: diploid, good pollinators include ‘Anjou’, ‘Clapps Favourite’, ‘Bartlett’, ‘Conference’, ‘Tongern’, ‘Paris’

Manon™ *
Origin: ‘Beurre Bosc’ open pollinated
Tree: medium to dwarf growth with good loose branch structure, flat pyramidal crown
Maturity: middle of September
Quality of fruits: good to excellent
Fruit size: large, skin under-colour yellow to green-yellow, over-colour gold-bronze a little russeting, 250–300 g
Yield: medium, regular
Resistance: no scab or mildew infection, susceptible to *Pseudomonas*, susceptibility not too high to fire blight
Pollination: diploid, good pollinators not yet tested

Thimo®*
Origin: ‘Nordhäuser Winterforelle’ × ‘Madame Verte’
Tree: vigorous growth, ramification loose, needs to form up the branches for earlier beginning of cropping
Maturity: late autumn, like ‘Conferece’, storable to December/January
Quality of fruits: good, aromatic, juicy, a little coarse
Fruit size: medium to large, skin under-colour green-yellow, over-colour to 50% vermilion, attractive, 190 g
Yield: high, starts early, alternate bearing possible
Resistance: no scab or mildew infection, susceptible to fire blight
Pollination: diploid, good pollinators include ‘Bartlett’, ‘Anjou’, ‘Uta’, ‘Clapps Favourite’, ‘Conference’, ‘Paris’, ‘Hortensia’

Uta®
Origin: ‘Madame Verté’ × ‘Beurre Bosc’
Tree: dwarfing growth with good loose ramification, pyramidal flat crown
Maturity: winter, like ‘Alexander Lucas’, storable until February/March
Quality of fruits: excellent, very good transportability
Fruit size: large, skin under-colour green, 100% gold-bronze russet, very attractive, 280 g
Yield: very high, early beginning, regular
Resistance: no scab or mildew infection, only low susceptibility to fire blight, after full crop somewhat susceptible to winter frost
Rootstocks: not directly compatible with quince rootstock

Pollination: diploid, good pollinators include 'Clapps Favourite', 'Bartlett', 'Conference', 'Tongern', 'Paris'—incompatible with 'Anjou', 'Armida' and 'Hermann'

*These varieties are registered under the label 'SAXONIA'^{TM}-variety.

5 New Pear Varieties International

It is very difficult to introduce new varieties into the market. The main varieties worldwide are 'Bartlett' ('Williams'), 'Conference', 'Beurre Bosc', 'Abate Fetel', 'Anjou' (USA) and 'Comice'. The trade is not very flexible and does not accept many changes. Introduction of new varieties is more in local markets rather than in global markets. Nevertheless, new varieties are needed for more variation in supply, better resistance, better storability and longer shelf life. Well-adapted varieties are very important to the different climatic and soil conditions. Every nationally or regionally organised breeding program has its own legitimacy on this basis. Cosmopolitan pear varieties are very few and are the result of cross-combination breeding. New varieties introduced into the market are listed in Table 5.

- From *Italy* come dwarf growing, more or less tolerant to fire blight and pear psylla varieties: 'Tosca', 'Turandot', 'Norma', 'Carmen'.
- The *Canadian* breeding program is focussed to breed fire blight resistant varieties. Ready for tests are 'Harrow Delicious', 'Harrow Red', 'Harobig', 'Harrow Gold', 'Harrow Crisp'.
- Different institutions in *USA* bred especially for better hot climate adapted varieties: 'Elliot', 'Gourmet', 'Potomac', 'Summercrisp', 'Blacke's Pride', 'Rubia', 'Red Satin', 'Red Jewel', 'Red Spot', 'Red Silk'.
- The *Russian* breeding aimed frost-resistant and scab-tolerant varieties: 'Krasavitsa Chernenko', 'Bronzovaja', 'Svetljanca', 'Yanvarskaja', 'Smugljanca'.
- Further, intensive breeding programs at present take place in Estonia, Latvia, especially varities for better adaption to climatic conditions. Latvia, Estonia print in italics.
- *Czech Republic* are bred 'Bohemica', 'Erika', 'Dicolor', 'Delta', 'Decora', 'Dita', 'Jana', 'Omega', 'Barbara'.
- From *France* come 'Angelys', 'Delmire', 'Delwini', 'Delsavor', 'Delbuena', 'Bronstar', 'Beauroutard'.
- From a co-operative breeding program of *Switzerland* and *Great Britain* derived the more or less resistant to scab and mildew varieties 'Valerac' and 'Champirac'.
- In *Romania* were bred the disease-tolerant varieties 'Haydea', 'Monica', 'Euras', 'Getica', 'Daciana', 'Carpica' and 'Ina Estivale'.

Furthermore on pear breeding are working in Switzerland, Sweden, Moldova, Poland, Belgium, Australia, India, New Zealand, South Africa,

Table 5 New pear varieties

Variety	Origin	Growing capacity	Susceptibility	Flowering	Yield	Fruit	Comment
Angelýs®	France, 1963, INRA 'Winterdechant' × 'Comice'	Semi vigorous	Moderate to fire blight	Medium	High to medium	Sweet, juicy, fine aromatic, medium crisp	Eating time 11 to 3, needs optimal conditions for growing
Benita™ (Rafzas®)	Switzerland, 1996, 'General Leclerc' × 'Hosui'	Vigorous	Scab not yet, fire blight	Medium	Medium to high	Juicy, no much aroma, sweet	Eating time 9 to 11, for home gardener
Concorde®	Great Britain, 1993, 'Comice' × 'Conference'	Semi-vigorous, upright	Moderate scab, fire blight	Medium to late	High, regular, early beginnig	Good aroma and flavour, fine, crisp	Eating time 11 to 3, for direct selling
Condo	Netherlands, 1965, CPRO, Wageningen, 'Conference' × 'Comice'	Semi-vigorous, upright	Chlorose, moderate scab and spring frost, fire blight	Medium, it is a good pollinator	Medium, regular, early beginning	Juicy, sweet, aromatic, short shelf life	Eating time 10 to 2, for direct selling
Dessertnaja	Crimea, 1970, 'Boscs' × 'Olivier de Serres'	Semi-vigorous, good for slender spindle	Fire blight	Medium	Medium, regular, needs fruit thinning	Juicy, crisp, good aroma and taste	Eating time 8 to 9, for direct selling and home gardener
Highland®	USA, 1944, 'Bartlett' × 'Comice'	Semi-vigorous	Moderate scab, fire blight	Late	High	Only under optimal conditions juicy and aromatic	Needs very good conditions for growing, eating time 9 to 11

Table 5 (continued)

Variety	Origin	Growing capacity	Susceptibility	Flowering	Yield	Fruit	Comment
Harrow Sweet®	Canada, 2000, 'Bartlett' × ('Old Home' × 'Early Sweet')	Semi-vigorous, good ramification	Resistant to fire blight and pear psylla	Medium, it is a good pollinator	Medium to high, needs fruit thinning	Sweet, fine, aromatic	Fire blight resistant, difficult in growing, eating time 10 to 12
Verdi™ (Sweet Blush®)	Netherlands, 1997, 'Gute Luise' × 'Comice'	Vigorous	Fire blight, spring frost	Medium	Medium to high, needs fruit thinning	Very juicy, aromatic, fine	Juicy, eating time 9 to 11, incompatible with quince rootstocks

Chile, Argentina (*P. communis*) and Japan, China and Korea (*P. pyrifolia*) (Schuricht 1995; Hunter and Layne 1999; Paprstein and Bouma 2000; Andreies 2002; Bell and Puterka 2004; Fischer and Weber 2005).

6 Pear Rootstock Breeding

6.1 Breeding Aims and Methods

The main breeding aims for pear rootstocks are

- dwarfing
- free standing of trees
- precocity and productivity of varieties
- high yield efficiency
- positive influence to fruit quality and size
- efficient propagation ability
- compatibility
- cold hardiness
- tolerance to iron and calcium chlorosis
- resistance to fire blight
- resistance to pear decline
- no spins on the layers

In rootstock breeding dominates the European pear, *P. communis*, and quince, *Cydonia oblonga*. For Asian pears, other species are used: *P. pyrifolia, P. pashia, P. calleriana, P. ussuriensis, P. betulifolia*. All species without *P. communis* and *P. pyrifolia* used as rootstocks have problems with incompatibility (Jones and Aldwinckle 1990; Zwet et al. 1988).

Most of the breeding programs are based on combination breeding methods. They use cross-combinations between

- *P. communis* × *P. communis*
- *P. communis* × wild species
- *Cydonia* × *Cydonia*

The selection steps of vegetative propagated rootstocks are the following:

- seedling plants (morphology, phenology, rooting, resistances)
- mother plants in stoolbed (propagation ability, resistances, morphology)
- test for alternative propagation methods (in vitro, green cuttings, seeds)
- nursery tests in combination with varieties (compatibility, growing capacity, resistances)
- field tests in combination with varieties (yield, precocity, fruit quality, compatibility, dwarfing, tolerance to calcium and iron chlorosis, steadiness, healthiness)

Only few efforts were known in mutation breeding or clonal selection. Some quince selections, for instance, were found by using these methods. Seedling rootstocks can be selected by evaluation of populations after open pollination. ‘Kirchensaller Most’ and ‘Fieudiere’ are samples of successful election of donor varieties for seedling rootstocks (Wertheim 2000; Weber 2001; Webster 2003; Brown 2003).

New techniques, which can reduce the time scale for breeding a new rootstock in the future, will be very important. Currently, the marker-assisted selection techniques would appear to offer the most promise, although it will inevitably take some years to develop. If successful, and markers for useful characteristics, such as dwarfing, induction of scion cropping, pest and disease resistance and graft compatibility, can be developed, the techniques could significantly reduce the time and costs of rootstock breeding. The field evaluation would still be needed in the final phase of selection.

Genetic engineering can help to find more resistant rootstocks (fire blight) and new agronomic possibilities in growing herbicide resistance of the rootstocks. Some years of intensive research are still needed for its practical use (Lebedev et al. 2002; Dondini et al. 2002; Tartarini and Sansavini 2003).

Early selection methods could help to shorten the long time for selection especially in resistance tests for biotic and abiotic damages and in stoolbed performance.

6.2 New Rootstocks International

For intensive plantations, dwarfing vegetatively propagated rootstocks (clonal rootstocks) is needed. Internationally, it is much more difficult than in apple rootstock selection. In USA, the OH × F-rootstocks were selected (crossings between the fire blight resistant varieties ‘Old Home’ × ‘Farmingdale’). There is not enough dwarfing, but it is very important to have resistance against fire blight, pear decline and calcium chlorosis.

The ‘Perry’ pears from France (RV 139) possesses medium growing capacity; they are well suited for trees in landscape and not in intensive plantations. The ‘Retuziere’ rootstock series derived from the variety ‘Old Home’ (OH 11, 20, 33) grows like quince A and is free standing. The BP rootstocks from South Africa and the Fox rootstocks from Italy grow vigorously. ‘Pyrodwarf’ from Germany (Geisenheim) and some OH rootstocks from France (‘Pyriam’ = OH 11) have a medium fire blight resistance and they grow moderately. They are compatible with most of the varieties and are easy to propagate, but the fruit size of varieties on these rootstocks is smaller.

Some institutions are involved in selection of quince rootstocks. Important are the Polish activities for more frost-resistant quince rootstocks (Quince 'Sydo'). All others focussed the work for better compatibility, more dwarfing, better resistance to pests, tolerance to chlorosis and better free standing of trees (Great Britain, France, Italy). Not all attributes could be realised in a single genotype. In comparison to apple rootstocks, pear needs much more breeding and field test work. Quince has not enough resistance against frost and fire blight and not all varieties are compatible with quince. All other rootstocks have deficits in dwarfing, free standing and disease resistance. Therefore, though new rootstocks have advantages in many characteristics, it is still a long way to achieve the 'ideal' rootstock (Grzyb 1987; Fischer 1996; Wertheim 2000; Jacob 2002; Webster 2003; Fischer and Weber 2005).

6.3 Rootstock Cross-Combination Breeding in Germany

The aims of the German pear rootstock breeding program had been to improve propagation dwarfing, resistance to biotic and abiotic damages, sufficient anchorage, positive influence on yield and fruit quality of the varieties, and free of suckers and burr knots. Results were received from long-term randomised trials and from field tests in farms under different production conditions. Approximately 6000 seedlings borne out of crosses between wild species and known pear varieties were grown. Finally, seven clones were selected (Table 6).

The new Pillnitz pear rootstocks are moderate to propagate in stoolbeds, but easy by green cuttings under mist (Table 7) and in vitro. They are more frost resistant against winter frost than quince rootstocks, and the growing capacity is intermediate between quince and seedling.

Pomological testing with 'Clapps Favourite' was done under a minimal pruning regime to evaluate the cropping potential. Compatibility with several

Table 6 New German pear rootstocks (Dresden-Pillnitz)

Rootstock (breeding no.)	Growing capacity	Propagation	Parents
Pi-BU 1 (IID 2-68)	Medium–strong	Easy	Clapps F. × *P. longipes*
Pi-BU 2 (523-15)	Medium–dwarf	Easy	Clapps F. × *P. longipes*
Pi-BU 3 (IID 7-109)	Dwarf	Medium	*P. longipes* open pollinated
Pi-BU 4 (A 26-86)	Medium–strong	Medium	*P. pyrifolia* open pollinated
Pi BU 5 (IID 11-120)	Very dwarf	Easy	*P. sinaica* × *P. pyrifolia*
Pi BU 6 (IID 20-68)	Medium–strong	Medium	*P. bretschneideri* × *P. sinaica*
Pi-BU 7 (IID 5–52)	Medium	Easy	*P. pyrifolia* open pollinated

Table 7 Rooting of green cuttings of *Pyrus* progenies under mist

Cross-combination	No. of Years	Clones	Rooted cuttings (%)	Root evaluation 0 (without) to 5 (+)
Clapps F. × *P. elaeagrifolia*	9	4	60.5	3.9
Bartlett × *P. elaeagrifolia*	6	4	49.5	4.2
J. Guyot × *P. sinaica*	7	4	43.7	2.7
P. aromatica× *P. sinaica*	14	2	86.1	3.6
P. sinaica × Nordhäuser	3	3	86.0	3.1
P. sinaica × *P. heterophylla*	5	3	73.5	2.4
P. nivalis × M. Verté	5	3	13.3	2.5
P. nivalis × *P. longipes*	35	2	85.2	3.1
P. longipes × *P. nivalis*	5	3	87.7	2.9
P. sinensis × J. Guyot	18	2	94.1	4.0
P. ussuriensis × *P. pyraster*	11	2	90.1	2.5

varieties was satisfactory. Promising clones were quickly multiplied using in vitro propagation. At present, new pear rootstocks undergoing field tests are Pi-BU 2 and Pi-BU 3 together with the new German rootstock from Geisenheim, 'Pyrodwarf'.

Most of the populations were tested and selected after artificial inoculation with aggressive strains of fire blight, *E. amylovora*. The results are listed in Table 8. Only two populations were found with moderate infected progenies: *P. canescens* × *P. serrulata* and *P. betulifolia* × *P. ussuriensis*. *P. canescens* and *P. serrulata* are described as susceptible to fire blight. Less susceptible progenies can also segregate from susceptible parents. Evidently, an accumulation of resistance genes is necessary for an expression of idiotypic resistance to fire blight. This indicates a polygenic resistance. Apparently, *P. betulifolia* and *P. ussuriensis* are carriers of blight-resistance genes and can be used in resistance breeding furthermore.

First results in testing the growing capacity of the new German rootstocks demonstrate that they are dwarf, but not dwarf enough for intensive plantations. The dwarfness of the new rootstocks was tested in nursery and field tests with different varieties (Fischer 1969, 1996, 2004). Results of nursery tests are compared in Fig. 2.

Table 8 Fire blight on populations and clones of Pyrus progenies

Population	Resistance evaluation: 1 = totally infected; 9 = resistant		
	1. Test	2. Test	3. Test
Clapps Favourite × *P. longipes*	–	1,0	1,1
Clapps Favourite × *P. pashia*	–	–	1,7
Comice × *P. pashia*	1,2	1,6	–
P. betulifolia × *P. communis* var. *caucasica*	2,9	1,4	–
P. pyrifolia × *P. communis* var. *caucasica*	1,0	1,2	1,6
P. pyrifolia × *P. longipes*	1,3	1,2	–
P. longipes × *P. nivalis*	1,0	1,0	–
P. nivalis × *P. longipes*	1,0	1,0	–
P. nivalis × *P. calleryana tomentella*	–	1,0	1,0
P. aromatica open pollinated	1,8	2,1	1,6
P. sinaica × Nordhäuser	1,0	1,5	3,4
P. sinaica × J. Guyot	1,9	1,5	–
P. aromatica × *P. sinaica*	2,6	1,3	1,7
P. regelii × Kieffer	1,1	1,2	–
P. communis × *P. sinaica*	1,0	1,0	–
P. X bretschneideri × *P. sinaica*	1,0	–	1,6
P. X bretschneideri × *P. salicifolia*	1,2	–	–
P. X bretschneideri × Kieffer	1,0	–	1,6
P. X bretschneideri × *P. pyraster*	1,2	1,3	1,4
P. X canescens × *P. serrulata*	8,3	–	4,3
P. X canescens × *P. betulifolia*	1,7	–	1,6
Verté × *P. betulifolia*	–	1,3	–
P. communis × *P. betulifolia*	–	1,3	1,3
P. betulifolia × *P. ussuriensis*	2,6	6,0	–
P. communis × *P. ussuriensis*	–	1,0	1,0
P. ussuriensis × *P. pyraster*	1,3	1,0	3,4
P. pyraster open pollinated	1,0	1,0	1,4
P. pyrifolia open pollinated	1,0	1,0	–
Quince BA 29	1,5	–	–
Quince A	1,0	1,0	–
OHF 333	5,7	–	–
Kirchensaller Most, seedlings	1,0	–	–
Pyrodwarf	4,2	–	–
Pi-BU 2	2,0	–	–
Pi-BU 3	1,7	–	–

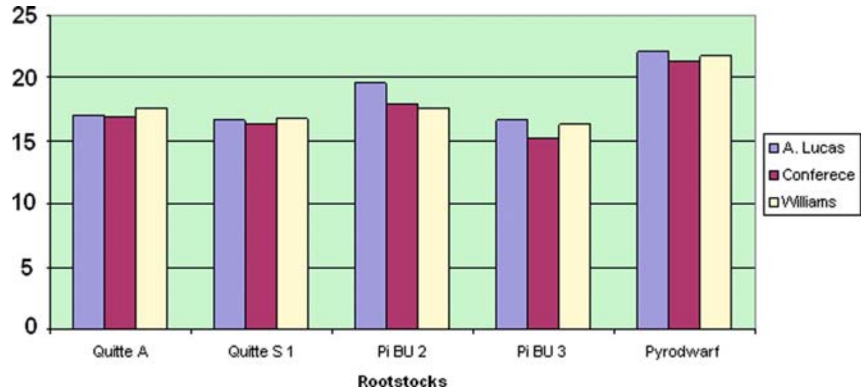

Fig. 2 Trunk diameter of 2-year-old maiden trees of three varieties on five rootstocks (*See* Color Insert)

References

Andreies, N. (2002) Achievements and prospectives in pear breeding at the Fruit Research Station Voinesti, Romania. *Acta Hort*. 596, 261–264.

Bell, R.L., Scorza, R., Srinivasan, C. and Webb, K. (1999) Transformation of 'Beurre Bosc' pear with the *rolC* Gene. *J. Amer. Soc. Hort. Sci.* 124,570–574.

Bell, R.L. and Puterka, G.L. (2004) Modes of host resistance to pear psylla, a review. *Acta Hort*. 663,183–188.

Bellini, E. and Nin, S. (2002) Breeding for new traits in pear. *Acta Hort*. 596, 217–224.

Bouvier, L., Guerif, M., Djulbic, M. and Lespinasse, Y. (2002) First doubled haploid plants of pear (*Pyrus communis*). *Acta Hort*. 596,173–175.

Brown, S.K. (2003) Pome fruit breeding: Progress and prospects. *Acta Hort*. 622, 19–34

Chevreau, E. (2002) Pear biotchnology: Resent progresses and future breeding applications. *Acta Hort*. 596, 133–140.

Chevreau, E. and Skirvin, R.M. (1992) Pear biotechnology. In: *Biotechnology of perennia fruit crops* (Hammerschlag, F.A. and Litz, R. eds.) C.A.B. Int., 263–276.

Chevreau, E., Brisset, M.N., Paulin, J.P. and James, D.J. (1998) Fire blight resistance and genetic trueness-to-type of four somaclonal variants from the apple cultivar Greensleeves. *Euphytica*. 104,199–205.

Dondini, L., Tartarini, S., Norelli, E. and Sansavini, S. (2002) Cloning and characterisation of resistance gene Angolus (RGA) in European pears (*Pyrus communis*). *Acta Hort*. 596, 207–210.

Durel, C.E., Guerif, P., Belounin, A. and Lezec, M. (2004) Estimation of fire blight resistance heritability in the French pear breeding program using a pedigree-based approach. *Acta Hort*. 663, 251–255.

FAO (2004) Faostat-database, www.fao.org, March 2004.

Fischer, M. (1969) Verklonung von Unterlagenzuchtmaterial von *Malus, Pyrus* und *Prunus mahaleb* unter Sprühnebel. *Arch. Gartenbau*, Berlin, 17, 15–32.

Fischer, M. (1996) Results of resistance tests to *Erwinia amylovora* (Burrill) Winslow et al. of *Malus* and *Pyrus* progenies within the rootstock selection programme. *Acta Hort*. 411, 401–407.

Fischer, M. (2004) New pear rootstocks from Dresden-Pillnitz. Int. Symposium on integrating canopy, rootstock and environmental physiology in orchard systems. Budapest 2004, abstr. 116.

Fischer, M. and Mildenberger, G. (1998) The Naumburg/Pillnitz pear breeding programme results. *Acta Hort*. 484, 135–138.

Fischer, M. and Mildenberger, G. (2000) New Naumburg/Pillnitz pear breeding results. *Acta Hort*. 538, 735–739.

Fischer, M. and Mildenberger, G. (2004) New pear cultivars from Dresden-Pillnitz. *Acta Hort*. 663, 899–901.

Fischer, M. and Weber, H.J. (2005) *Birnenanbau, integriert und biologisch*. Eugen Ulmer, Stuttgart, 164 pp.

Grzyb, Z. (1987) Selected quince rootstocks suitable for rootstocks (*polish*). *Ogrodnictwo* 3, 6–7.

Hirata, N. (1989) Self-compatible mutant in Japanese pear. Gamma Field Symposia.Production of mutants in tree crops. July 20–21, Institute of Radiation Breeding, NIAR MAFF, Ibaraki, Japan, 28, 71–78.

Hunter, D.M. and Layne, R.E.C. (1999) Tree fruit breeding programmes at Harrow, Ontario, Canada. *Acta Hort*. 484, 187–192.

Jacob, H. (2002) New pear rootstocks from Geisenheim, Germany. *Acta Hort*. 596, 337–344.

Janick, J. (2004) Genetic alterations with the origins of fruit culture. *Acta Hort*. 663, 683–692.

Jones, A.L. and Aldwinckle, H.S. (1990) *Compendium of Apple and Pear Diseases*. APS Press, The Am. Phytopath. Soc., 100 pp.

Lebedev, V.G., Dolgov, S.V. and Skryabin, K.G. (2002) Transgenic pear clonal rootstocks resistant to herbicide 'Basta'. *Acta Hort*. 596, 193–197.

Malnoy, M., Reynoird, J.P. and Chevreau, E. (2000) Preliminary evaluation of new gene transfer strategies for resistance to fire blight in pear. *Acta Hort*. 538, 635–638.

Masuda, T., Yoshioka, T., Inoue, K., Murata, K., Kitagawa, K., Tabira, H., Yoshida, A., Kotobuki, K. and Sanada, T. (1997) Selection of mutants resistant to black spot disease by chronic irradiation of gamma-rays in Japanese pear 'Osanijisseiki'. *J. Japan. Soc. Hort. Sci*. 66, 85–92.

Monte-Corvo, L., Goulao, L. and Oliviera, C. (2002) Discrimination of pear varieties with RAPD and ALFP and ISSR. *Acta Hort*. 596:187–191.

Moore, J.N. and Ballington, J.R. (1992) Genetic resources of temperate fruit and nut crops. *Acta Hort*. 290, 655 ff.

Oliveira, C.M., Mota, M., Monte-Corvo, L., Goulao, L. and Silva, D.M. (1999) Molecular typing of *Pyrus* based on RAPD markers. *Scientia Hort*. 79, 163–174.

Paprstein, F. and Bouma, J. (2000) New pears from the Czech Republic. *Acta Hort*. 538, 741–744.

Petzold, H. (1989) *Birnensorten*. Neumann, Radebeul, 3th ed., 256 pp.

Predieri, S. (2002) The importance of induced mutations in pear improvement. *Acta Hort*. 596, 161–166.

Reynoird, J.P., Morgues, F., Norelli, J., Aldwinkckle, H.S., Brisset, M.N. and Chevreau, E. (1999) First evidence for improved resistance to fire blight in transgenic pear expressing the attacin E gene from *Hyaloptera cecropia*. *Plant Sci*. 149, 23–31

Schuricht, W. (1995) Birnensorten, In: *Farbatlas Obstsorten* (Fischer, M., ed.) Eugen Ulmer, Stuttgart, pp. 90–113.

Tartarini, S. and Sanasavini, S. (2003) The use of molecular markers in pome fruit breeding. *Acta Hort*. 622, 129–140.

Weber, H.J. (2001) Birnenunterlagen für den Intensivanbau. *Erwerbsobstbau* 43, 99–105

Webster, A.D. (2003) Breeding, selection of apple and pear rootstocks. *Acta Hort*. 622, 499–505.

Wertheim, J. (2000) Rootstocks for European pear: A review. *Acta Hort*. 596, 299–307.

Zuccherelli, S., Broothaerts, W., Tassinari, P., Tartarini, S., Dondini, L., Bester, A. and Sansavini, S. (2002) S-allele characterisation in self-incompatible pear (*Pyrus communis*): Biochemical, molecular and field analysis. *Acta Hort*. 596, 147–152.

Zwet, T. van der and Keil, H.L. (1979) Fire blight, a bacterial disease of Rosaceous plants. *Agriculture handbook*, Beltsville, 510 pp.

Zwet, T. van der, Oitto, W.A. and Westwood, M.N. (1974) Variability in degree of fire blight resistance within and between *Pyrus* species, interspecific hybrids, and seedling progenies. *Euphytica* 23, 259–304.

Zwet, T. van der, Zoller, B.G. and Thomson, S.V. (1988) Controlling fire blight of pear and apple by accurate prediction of the blossom blight phase. *Plant Disease* 72, 464–472.