The Dresden-Pillnitz Long-term Apple Breeding Program and Its Results

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HISTORY

The apple breeding work in Germany was started in 1928 by Erwin Baur and Martin Schmidt. It has been continued at Dresden-Pillnitz since 1971 by Heinz Murawski, Christa Fischer and Manfred Fischer. The first aim was the combination of good fruit quality and high yield. In field evaluations all clones with high susceptibility to scab and mildew were eliminated. From this program the "Pi-series" of new apple cultivars has originated, which are Piros, Pinova, Pilot and others ("Pi"- = Pillnitz). The second step was a resistance breeding program begun in 1932 (Schmidt, 1938). At Dresden-Pillnitz the resistance breeding was expanded to include mildew, fire blight, bacterial canker, red spider mite and winter and spring frosts. The results are the cultivars of the "Re-series" ("Re"- = resistance). These cultivars represent the combination of high practical value in terms of fruit quality with good cropping and resistance to scab and other fungal and bacterial diseases.

SOURCES FOR IMPORTANT CHARACTERISTICS

The most important parent sources (cultivars, clones and wild species) for horticultural and resistance characteristics used in classic apple breeding were the following:

Sources for excellent fruit quality and stable high yield: Cox Orange, Oldenburg; Alkmene, Auralia, Clivia, Elstar, Golden Delicious, Helios, Idared, Jonathan, Undine; Pia, Piflora, Pingo, Pinova, Pilot, Pirol, Piros.

Sources for scab resistance: polygenic sources: Antonovka kamienna - VA, Reglindis and its seedlings, Discovery, James Grieve; mono- and oligogenic sources: *Malus x floribunda* - Vf, *Malus x atrosanguinea* - Vf or Vm, Malus x micromalus - Vm or Vf, Malus x *pumila/domestica* - Vr; Reka and Regia - Vr;

Sources for mildew resistance: polygenic sources: Dülmener Rosenapfel, James Grieve, Helios, Alkmene, Lord Lambourne, Remo, Rewena;monogenic and oligogenic sources: *Malus x zumi* Calocarpa, Malus x robusta Persicifolia, *Malus x micromalus*, *Malus x baccata*, *Malus prunifolia*;

Sources for fire blight resistance: polygenic sources: *Malus x floribunda, Malus x robusta* Persicifolia, *Malus prunifolia, Malus fusca*; resistant cultivars from the Pillnitz breeding program: Pi-A-44.14; Remo, Rewena, Realka, Reanda, Rebella, Regine;

Sources for red spider mite resistance: Reglindis and its seedlings;

Sources for winter frost resistance: McIntosh, Bancroft, Auralia, Helios, Piros;

Sources for spring frost resistance: Late blossoming cultivars such as: Golden Delicious, Remo and Rewena.

BREEDING TECHNIQUES

In long-term breeding programs (diallels, topcross, backcross and others) many different parent sources were combined. All seedlings had been screened against scab, fire blight and mildew in the first 3 years. After germination, seedlings were inoculated with scab and mildew in a greenhouse at the 3- to 5-leaf stage. Fire blight resistance was tested on grafted plants in a greenhouse and on seedlings in the first year after sowing in the open ground. Field testing also involved resistance tests against red spider mite, bacterial canker, and against

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spring frosts and winter frost. The first fruit quality tests take place after special management to enhance precocity in the greenhouse and after that on rootstock M.9 with interstem Hibernal in the field 4 to 5 years after crossing. Each year 8000 hybrid seeds are produced. After the first screenings 1000 to 1500 of the seedlings are planted into the field for screening for resistance and agronomic properties.

RESULTS: HIGH QUALITY AND COMPLEX RESISTANT CULTIVARS

In both series, Pi- and Re-, cultivars exist for all ripening times. Especially for the Re-cultivars® it is a high benefit because a plantation of only resistant cultivars would be possible under all farm conditions.

The Pillnitz Pi-cultivars can compete internationally with late ripening and long storage cultivars. They become accepted more and more nationally and internationally. Pinova and Pilot are among the most successful new cultivars at present in Europe. All other Pi- cultivars are in propagation in Germany and in trial in some European countries and in the USA. They are good cropping cultivars with excellent fruit quality in all ripening periods. They are not resistant but have very few disease problems in the field. Pia (early), Piflora (autumn to winter) and Pingo (very late) are the most promising of the newest cultivars—especially Pingo, as it can compete with the late winter cultivars.

In the first step of the resistance breeding work the selected cultivars (Re-cultivars™) possess only one resistance source. Very important is the fact that the first varieties of the Re-series are cultivars with different sources of scab resistance (Table 1):

Vf: Remo, Retina, Rewena, Rene, Reanda, Relinda, Releika, Resi, Renora, Rebella, Regine;

Vr: Realka, Releta, Remura, Reka, Regia;

VA: Reglindis

As a result of the following steps, the first high quality clones with two scab resistance sources are in field testing.

Some scab resistant cultivars, especially with the Vf-gene, proved to be mildew resistant. These are Remo, Rewena, Regine and Rebella. Other cultivars are only weakly susceptible. Problematically we found that some of the cultivars with Vf- and Vr-resistance were susceptible to mildew. Encouraging exceptions of the Vr-cultivars are Reka and Regia with resistance to mildew. The same problems with mildew susceptibility in the field in Pillnitz we found in Jonafree, Freedom, Liberty, Goldrush, Priscilla and most Co-op clones.

Commercial trials carried out over 15 years without fungicidal sprays have demonstrated that many of the Pillnitz resistant cultivars (Vf, VA and Vr) have up to now a durable resistance to scab and sufficient levels of resistance to mildew. Fungicides can be reduced by at least 80% for these cultivars. It was very encouraging to note that diseases caused by other fungi were also absent in these trials.

Fire blight resistance is very important because there are no efficient bactericides registered for use in orchards. Use of antibiotics is problematic. Donors of alleles for resistance have been found in progenies involving *M. x floribunda* and some cultivars. Progenies of Clivia, Golden Delicious, Alkmene and Pi-A 44.14 produce a good percentage of seedlings with a high level of resistance. Fire blight resistant varieties are Remo, Rewena, Rene, Reanda, Rebella and Realka.

Triple resistant selections with resistance to scab, mildew and fire blight are the cultivars Remo, Rewena, Rebella and Reanda (Table 1). Parents with triple resistance transmit a high degree of resistance to their progenies. The best combination, Pi-AS 44.14 x Rewena, on average produced one triple-resistant plant for every seven seedlings tested.

The resistance levels of different Pillnitz Re-cultivars® are listed in Table 1. Tables 2 and 3 show the ripening times.

The main breeding aim for resistance is multiple resistance and its stability. The most important fruit, tree and resistance characteristics can be combined by classic methods. Donors are available which transmit these different characteristics well. With classic combination breeding programs, without genetic engineering, new efficient cultivars were developed that are suitable for modern fruit production. The best example is the new multiple resistant cultivar Rebella. Rebella has attractive

TABLE 1

Multiple resistance in the Pillnitz Re- varieties.

		Resistance against						
Re-cultivar®	**Scab resistance genes**	**Scab[z]**	**Mildew**	**Fire blight**	**Bacterial canker**	**Red spider mite**	**Spring frosts**	**Winter frost**
Realka	Vr	x	#	x	o	o	#	o
Reanda	Vf	x	(x)	x	o	#	x	o
Rebella	**Vf**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Regine	Vf	x	(x)	x	(x)	x	x	x
Reglindis	VA	x	(x)	(x)	o	x	x	x
Reka	Vr	x	(x)	o	x	#	#	(x)
Releika	Vf	x	o	(x)	x	x	x	#
Releta	Vr	x	#	o	x	o	o	o
Relinda	Vf	x	(x)	o	x	#	(x)	x
Remo	**Vf**	**x**	**x**	**x**	**o**	**o**	**x**	**x**
Remura	Vr	x	(x)	o	o	#	o	x
Rene	Vf	x	#	x	(x)	#	x	o
Renora	Vf	x	(x)	o	o	o	(x)	(x)
Resi	Vf	x	o	o	x	#	x	#
Retina	Vf	x	(x)	o	o	(x)	x	#
Rewena	**Vf**	**x**	**x**	**x**	**x**	**o**	**x**	**o**

[z]X: resistant; (x): low resistant; o: low susceptible; #: susceptible.

fruits, high fruit quality, good yield and also multiple resistance against scab, mildew, fire blight, bacterial canker, red spider mite, winter frost and spring frosts. The cultivars Regine, Remo, Rewena and Reglindis also carry 6 or 5 different resistances, combined with high fruit quality and productivity. These multiple resistant cultivars can be the new base of breeding progress to increase the degree of the stable disease resistance in a long-term program. Apple breeding will continue to be successful in the future if classic breeding methods are combined with new molecular methods.

The best Pillnitz resistant clones and cultivars have been tested in commercial trials in several regions, being exposed to a wide range of environmental conditions. They demonstrated their ability to maintain their resistance and provide fruit either suitable for table use and/or for processing. Other diseases have not occurred. With their resistance properties they are suitable for ecological and integrated fruit production.

The multiple resistant dessert cultivars are Reka, Retina, Renora, Reanda, Reglindis, Releika, Resi, Regia, Regine and Rebella.

Special resistant cultivars for processing (canning) are Remo, Rewena, Rene, and Relinda.

Alternate resistant cultivars for both dessert and processing are Reglindis, Reanda, Renora and Rene, under warm conditions also Relinda and Remo.

The new multiple resistant cultivars are highly resistant against the most important diseases and damaging factors in the central European climate. For American conditions testing is underway.

With the Re-cultivars® we offer a concept for a new growing management and with a range of different cultivars. Only in an integrated system of different resistant cultivars in one orchard can the advantages of resistance be noticeable. Different resistance sources can be combined with different maturing periods of cultivars. In this way complete cross pollination and fruit set of the resistant cultivars are guaranteed. All Re-cultivars® are diploid and good pollinators (the same as the Pi-cultivars). The combination of different cultivars for different production aims—fresh eating, processing, landscape conservation—is possible.

SOLUTIONS TO PROBLEMS OF INSTABILITY OF SCAB RESISTANCE

Presently we know that the monogenic resistance from *Malus x floribunda* 821 can break down. Since 1983 we have known that different cultivars carrying the Vf gene can be infected by scab. Not only the older resistant cultivars Prima and Priam were attacked, but also the newer cultivars Florina, Freedom, Liberty, Baujade (Fischer et al., 1998).

At several locations apple scab attacks had spread to resistant apple cultivars. In the northern part of Germany, scab was found on resistant cultivars in 1997. The scab symptoms began very early in the vegetation period (typically the blossom period) due to very high infection pressure. In 1999 the same kind of scab infections were established on resistant cultivars at another location in the northeastern part of Germany. In these orchards the scab resistant cultivars Prima, Priam, Pionier, Gerlinde, Rene and Topaz were strongly attacked. The cultivars Florina, Remo and Rewena sporulated very slowly with single small lesions. The cultivars

TABLE 2

Ripening time and storage periods of the Pillnitz apple cultivars.

Cultivar	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
Piros	✓											
Pia	✓	✓										
Pirol		✓	✓	✓								
Pikant		✓	✓	✓	✓							
Piflora			✓	✓	✓	✓						
Pimona			✓	✓	✓	✓						
Havelgold				✓	✓	✓	✓					
G. Del.				✓	✓	✓	✓	✓	✓			
Pinova				✓	✓	✓	✓	✓	✓	✓		
Pingo				✓	✓	✓	✓	✓	✓	✓	✓	
Idared				✓	✓	✓	✓	✓	✓	✓	✓	
Pilot							✓	✓	✓	✓	✓	✓

TABLE 3

Ripening time and storage periods of the Pillnitz resistant apple cultivars.

Cultivar	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Retina	✓	✓									
Reka		✓	✓								
Releika		✓	✓	✓							
Reglindis		✓	✓	✓							
Resi			✓	✓	✓	✓					
Reanda			✓	✓	✓	✓	✓				
Rewena			✓	✓	✓	✓	✓				
Rebella			✓	✓	✓	✓	✓	✓			
Renora				✓	✓	✓	✓	✓	✓		
Regine					✓	✓	✓	✓	✓	✓	✓

Liberty, Reanda, Reglindis and Retina showed defense reactions on the leaves. Reka and Relinda remained healthy.

At the Ahrensburg apple selection orchard, where race 6 of scab was found, the scab attacks spread to more resistant cultivars in 1998. We found strong scab infections not only on the resistant cultivars Prima, Priam, Florina and Freedom, but also on Gerlinde, Ahrista, Relinda, Rene and Retina. However, only little sporulation was observed on Ahra, Renora and Rewena. The Re-cultivars® Reglindis and Reka remained healthy with defense reactions.

In the northwestern part of Germany resistant apple cultivars were observed with scab in 1999. In this trial the resistant cultivar Gerlinde was very strongly infected by scab and probably the scab spread from Gerlinde to the other resistant cultivars. In seven other locations more in the south of Germany (Dresden-Pillnitz, Müncheberg, Quedlinburg, Rostock, Veitshöchheim, Weinsberg and Wurzen) (Fig. 1) scab was not found on the same resistant cultivars.

The differential collection for scab races showed at several locations strong attacks for race 1, race 3, race 5 and race 6 on Prima. The test cultivars for race 2 and 4 were healthy at Ahrensburg in 1998 (Fischer et al., 1998). There is a trend for strong attacks on resistant cultivars in the orchard at Ahrensburg by the three aggressive scab races present. It appears that the new highly aggressive races spread to the adjacent locations south and east of the region of Ahrensburg.

In other cases to date we have not observed scab on the resistant cultivars in the orchards without fungicide sprays at Dresden-Pillnitz. Only the original *Malus x floribunda* and the hybrid *Malus x floribunda* 821 and different test cultivars for race 1 and race 3 were scab infected. The test cultivar for race 2 showed only slight scab sporulation in a few years. At Dresden-Pillnitz only races 1 and 3 were aggressive.

Other screenings of resistant cultivars were carried out in the greenhouse at Dresden-Pillnitz by inoculation with a highly aggressive mixture of scab including *Malus x floribunda* scab from the wild species orchard of the Fruit Genebank at Pillnitz. The results of the previous years were confirmed also in 1999. The cultivars Ahra, Karmina and the Re-cultivars® were not infected by scab; the cultivars Discovery, James Grieve and Ahrista showed only slowly sporulating reactions to scab. The tendency of the scab resistance breakdown (Vf) has been noticed since 1995 in greenhouse tests.

The most interesting source for scab resistance was found in the wild species *Malus x pumila* R 12 740 7a - Vr and its progenies. It appears that Vr-scab resistance is determined by 2 or 3 major genes and a few minor genes (Dayton et al., 1953). These genes cause the high scab resistance of the breeding clones and cultivars Reka, Realka and Regia. These cultivars have highly durable resistance based on more resistance genes. So far we have not found scab on these Vr-resistant genotypes.

The scab resistance from polygenic sources increases the stability of the resistant cultivars Reglindis and Discovery which show only little sporulation on leaves and no lesions on fruits.

The most important strategy in our breeding program is the combination or pyramiding of different resistance genes against scab observed over 40 years. New clones from these crossing programs have proven a highly stable scab resistance with combined resistance genes from Vf + VA, Vf + Vr and VA + Vr. The combination between these progenies will lead to the next step, that is, new clones with superior fruit and resistance characteristics are in the selection process.

FIGURE 1

Map of Germany showing the regions where scab resistance has been overcome.

CONSEQUENCES FOR GROWERS AND FOR RESISTANCE BREEDING

The consequences and conclusions for new resistant apple cultivars must be a quick adoption of the conditions relating to resistance durability in apple growing and apple trials.

- In apple growing areas, the orchards with resistant cultivars should be sprayed 2 to 3 times with fungicides at the beginning of the vegetative period each year when infection pressure of scab and mildew is most severe. This strategy can protect resistant cultivars against primary

infection. The first successful experience using this approach comes from the northern part of Germany.

- In apple production areas we must prevent monoculture of Vf-resistant cultivars. A mixture is important between Vf- and oligogenic/polygenic resistant cultivars to preserve the stability of the host-pathogen system. Reka, Reglindis and Freedom are tolerant to slight leaf infections.
- Vf-resistant cultivars are more at risk if in nearby fields very susceptible cultivars such as Gala, Golden Delicious, McIntosh and the Red Delicious group are growing without fungicide sprays. An especially high risk occurs during blossom time with very early scab infection in the flowers. This is the time when the first fungicide spray must be applied.
- There are advantages to using more polygenic resistant cultivars as donors, e.g., Antonovka, Discovery, James Grieve, Dülmener Rosenapfel and others. New screenings of the apple collection at the Fruit Genebank without fungicide sprays likely will show new sources of polygenic resistance against scab and mildew.
- In experiments within the EU project (D.A.R.E.) other polygenic cultivars are being investigated for durable resistance to scab and mildew in apple. In this project 36 cultivars are being examined for their scab susceptibility in different European countries. We hope to find polygenic resistant cultivars for use in the apple breeding programs.

Apple breeding will continue to be successful in the future if the classic breeding methods are combined with the new molecular biological methods.

SUMMARY

At Dresden-Pillnitz in the last years more than 20 new apple cultivars were developed. The aim was the combination of high yield and excellent fruit quality (the Pi-cultivars) and in a special breeding program the combination of different sources of resistance, good yield and fruit quality (the Re-cultivars®). The selection of the resistant cultivars was made in two lines: resistant dessert cultivars and cultivars for processing. The best of these cultivars include resistance to scab (*Venturia inaequalis*), mildew (*Podosphaera leucotricha*), fire blight (*Erwinia amylovora*), bacterial canker (*Pseudomonas syringae*), red spider mite (*Panonychus ulmi*), winter frost and spring frosts combined with good fruit quality.

Different scab resistance sources (Vf, Vr, Vm, VA genes) are used and will be combined in the next series of new cultivars. Crossing programs involving parents with various degrees of resistance to scab, mildew and fire blight were designed to obtain selections with multiple resistances.

The "conventional" bred Pi-cultivars represent cultivars in different ripening seasons with excellent fruit quality, early and high cropping and a sufficient level of insensitiveness or resistance to diseases and pests.

The new resistant Pillnitz Re-cultivars® guarantee the possibility of reductions of 80% and more in fungicide use in fruit cultivation and are suitable for ecological and integrated fruit production. Four of those, Remo, Rewena, Rebella and Reanda, are triple resistant to scab, mildew and fire blight and also good donors for multiple resistance.

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