

Combating late frost injuries in apple by variety breeding

Dr. F. Ruess¹, B. Scherrer¹ and M. Meyer²

Abstract

Global warming has led to apple blossom occurring earlier and earlier. In the 1960s of the last century the fruit blossom in Southern Germany took place in the middle of May, nowadays it occurs in early to mid-April. Due to this shift in flowering time the risk of late frost damages has increased dramatically. The frost sensitivity of the fruit blossom depends strongly on the development stage of the flower bud. Early phenological stages are much more tolerant to low temperatures than late stages. By shifting the flowering time back into May the natural frost resistance of the phenological stage of the fruit blossom can be used to counteract climate change. In the first part of this research project several late flowering apple varieties were collected based on literature data but also unknown old landscape varieties which were found by growers. These varieties were planted on the research station Heuchlingen to compare the described phenological data at one site. Six varieties were found which reached the requirement of flowering at least two weeks later than commercially grown varieties. In the second part of the research project these varieties were used as parents for breeding. Over several years about 3.500 progeny seedlings were planted. Unfortunately, the hypothesis that the germination time of the seedling is also an indicator of its flowering time was not confirmed. However, there is a high correlation between the timing of bud break and flowering. All clones from the 2020 crossing year showed flower buds in 2025 and could be evaluated concerning their flowering behavior. As expected, the flowering time of most of the breeding clones lies in the middle of the flowering times of the parent varieties and thus two weeks after the flowering of the commercial varieties. These clones are already out of the "danger zone" for late frosts in Southern Germany. Among the clones five individuals were found with good characteristics for fruit growing or at least for further breeding.

Keywords: Pome fruit, late flowering, selection, breeding, varieties.

Introduction

Climate change has led to apple blossom occurring earlier and earlier. While in the 1960s the fruit blossom in Southern Germany took place from the beginning to the middle of May, today it occurs from the beginning to the middle of April. This earlier shift in flowering time has dramatically increased the risk of late frosts, as the frequency of late frosts in April has remained unchanged (Büchle *et al.* 2023). Frost damage to blossoms is now expected in the Neckar region every second year. In commercial fruit growing, investments are therefore being made in multi-risk insurance and in irrigation for frost protection. Both options are very expensive for the farmers.

¹ LVWO Weinsberg, DE-74189 Weinsberg; franz.ruess@lvwo.bwl.de

² KOB Bavendorf, DE-88213 Ravensburg-Bavendorf

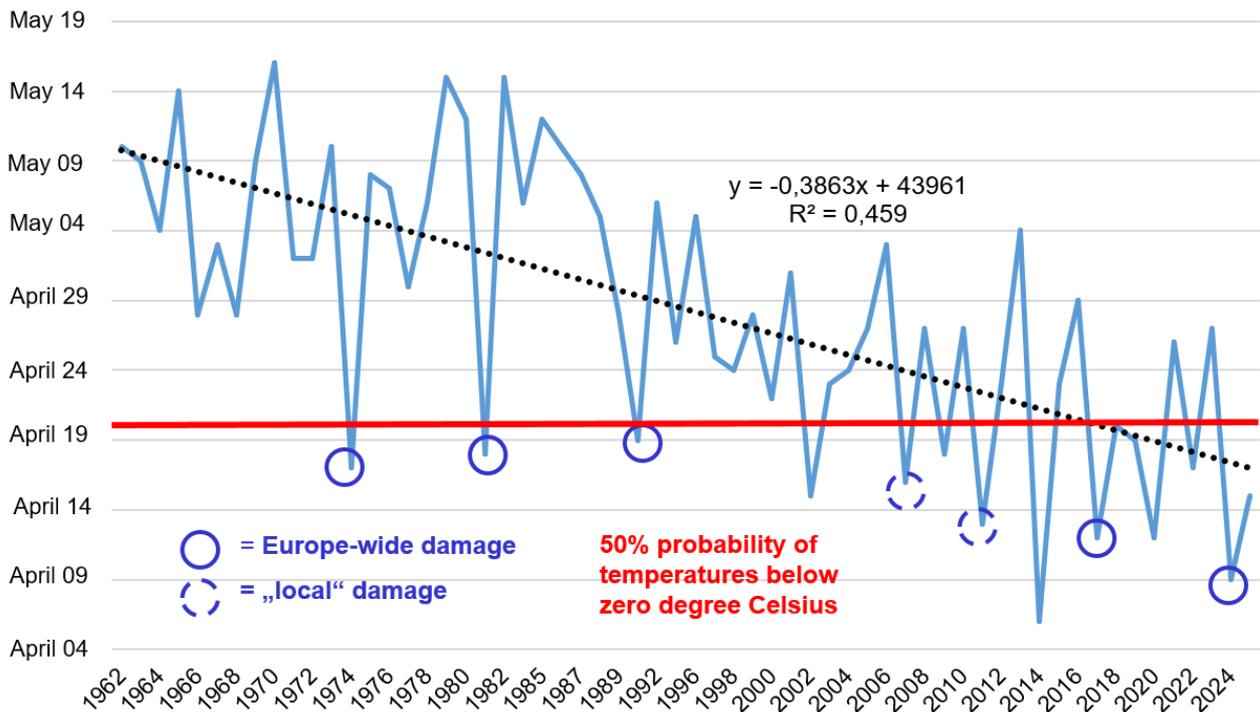


Figure 1: Development of full blossom (BBCH 65) in apple trees and occurrence of late frost damage in the Neckar region from 1960 to 2025, data LVWO Weinsberg

The frost sensitivity of the fruit blossom depends strongly on the development stage of the flower bud. While in the phenological stage BBCH 54 (mouse ear) temperatures below minus 5.5°C lead to damage, the frost tolerance reduces from stage BBCH 56 (green bud) with temperatures below minus 4°C up to stage BBCH 65 (full blossom), where even 0°C can lead to heavy damages. By shifting back the flowering time into May, the natural frost resistance of the phenological stage of the fruit blossom can be used to counteract climate change.

Material and Methods

In the first part of the research project, several late flowering apple varieties were collected based on literature data but also unknown old landscape varieties which were found from growers. These varieties were planted at the research station Heuchlingen to compare the described phenological data at one site. Six varieties, which reached the requirement of flowering at least two weeks later than the commercially grown varieties, were found.

Table 1: Characteristics of selected late-flowering parent varieties

Variety	Origin	Ripening time	Description
Spätblühender Taffetapfel	Stuttgart-Hohenheim, 1860	Beginning of September	Well-known late-flowering apple variety, latest flowering of all varieties, still relatively early maturity, moderately vigorous growth, yellow fruits with a pale red sun-exposed side, very acidic
Heslacher Gereutapfel	Stuttgart-Heslach, 1820	End of September	Very late flowering, bright red fruits, very acidic, robust tree with medium growth
Christiansapfel	Metzingen Neuhausen, rediscovered 2020	End of September	Late to very late flowering, remarkably long flowering period, red and yellow striped, flat-round, because of its good taste preferentially used for crossbreeding work, medium growth with good branching
Engelsberger	Öhringen 1854	Beginning of October	Late flowering but only one week after the main assortment has flowered, very small fruits, acidic, variety suitable for juice and cider, medium growth
Hans Ulrichs Apfel (Syn, Piemonteser)	Oberrieden, Zürichsee 1820	mid-October	Late flowering but only one week after the main assortment has flowered, healthy trees, medium-sized fruits, yellow fruits, firm flesh, juicy
Königlicher Kurzstiel	Stuttgart 1565	End of October	Late flowering, but flowering begins only one week after main assortment has finished flowering, excellent table fruit, due to the good taste preferred crossbreeding partner in many breeding programs, flat-round, carmine-red fruits, weak growth, good yield, due to its late ripening, it is only suitable for warm locations

In the second part of the research project these varieties were used as parents for breeding. Over several years about 3.500 progeny seedlings were planted. Due to the different flowering times of the parent varieties, the pollen of the father variety was partially harvested and frozen in the previous year. At the time of flowering of the mother variety, the pollen of the father variety was applied with a brush onto the stigma of the mother variety's flower. To prevent unwanted cross-pollination by insects, the flowers were protected by fine-mesh nets before they opened until the end of flowering. At harvest time the apples resulting from the crossbreeding were harvested and the seeds were removed.

Table 2: Overview of the crosses performed, (Rvi6, Rvi10 = *Venturia inaequalis* resistance genes, PI2 = Powdery mildew resistance gene)

Late-flowering parent	Years of crossing	Crossing partners	Resistance genes	Number of seeds
Spätblühender Taffetapfel	2020 2021	Flavia, Enterprise	Rvi6	212
Heslacher Gereutapfel	2020 2021	Flavia, Enterprise	Rvi6	354
Christiansapfel	2020 2021 2022 2023 2024	Flavia, Enterprise, Mammut	Rvi6	1'417
Königlicher Kurzstiel	2022 2023	Mammut, Y6, Enterprise	Rvi6, Rvi10, PI2	432
Spätblüher aus Schwabbach	2022	Mammut	Rvi6,	180
Belle Fille de Salins	2024	Y6, Wellant	Rvi6, Rvi10, PI2	920

The hypothesis that the germination time of the seedling is also an indicator of its flowering time as reported by Mehlenbacher and Voordeckers (1991) could not be confirmed (Scherrer *et al.* 2024). This method could have been useful for an early selection of seedlings in the greenhouse. A parallel study conducted at the University of Hohenheim with the aim of identifying genetic markers for the "late-blooming genes" also yielded no success by the end of the project (Scherrer *et al.* 2024). Therefore, all produced seedlings were planted in the open field at a distance of 30 cm and are now being evaluated with regard to their bud break, as there is a high correlation between the bud break and flowering date (Murawski 1967). Therefore, at least two years after pollination, the seedling population in the field can be reduced to 10–20% of individuals displaying the desired late-flowering characteristic.

First results

All descendants from the 2020 crossbreeding year showed flower buds in 2025 and could be evaluated with regard to their flowering behavior. As expected, the flowering time of the vast majority of cultivated clones lies in the middle of the flowering times of the parent varieties and thus two weeks after the flowering of the commercial assortment (e.g. 'Gala'). Thus, these progenies are already out of the "danger zone" for late frost events in the Neckar region. The next few years will be dedicated to selecting suitable new varieties for commercial cultivation from these progenies. Certainly, further backcrossing will be necessary to improve quality and will require further years of breeding.

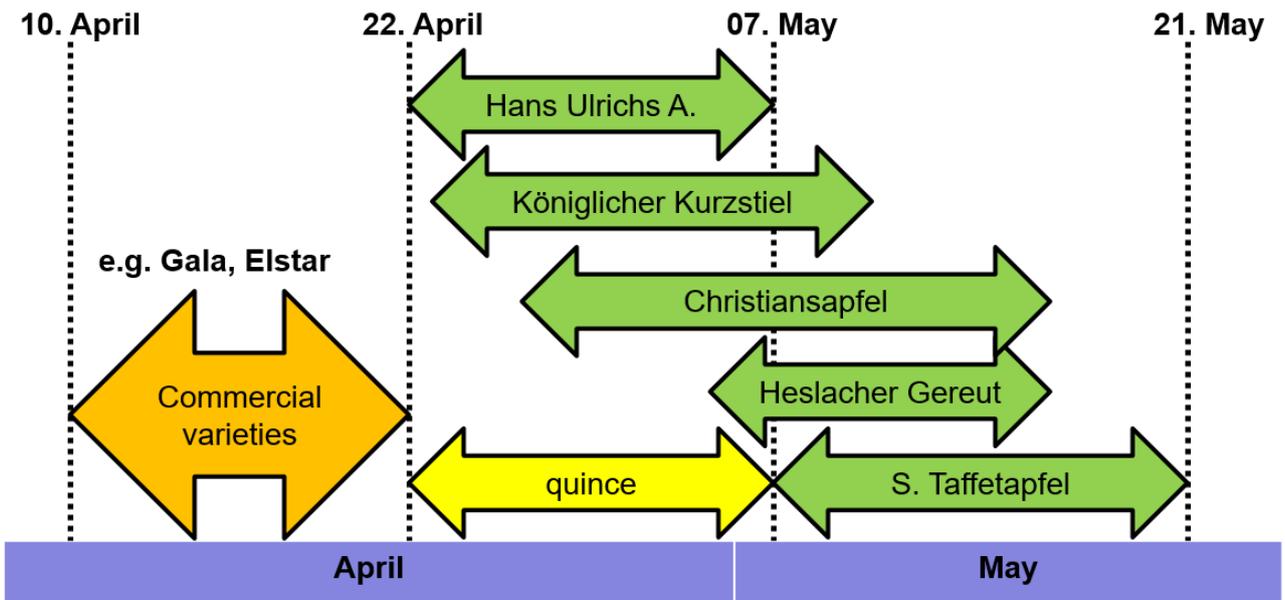


Figure 2: Flowering data of commercial grown varieties and late-flowering apple varieties in 2025 in comparison to quince blossom

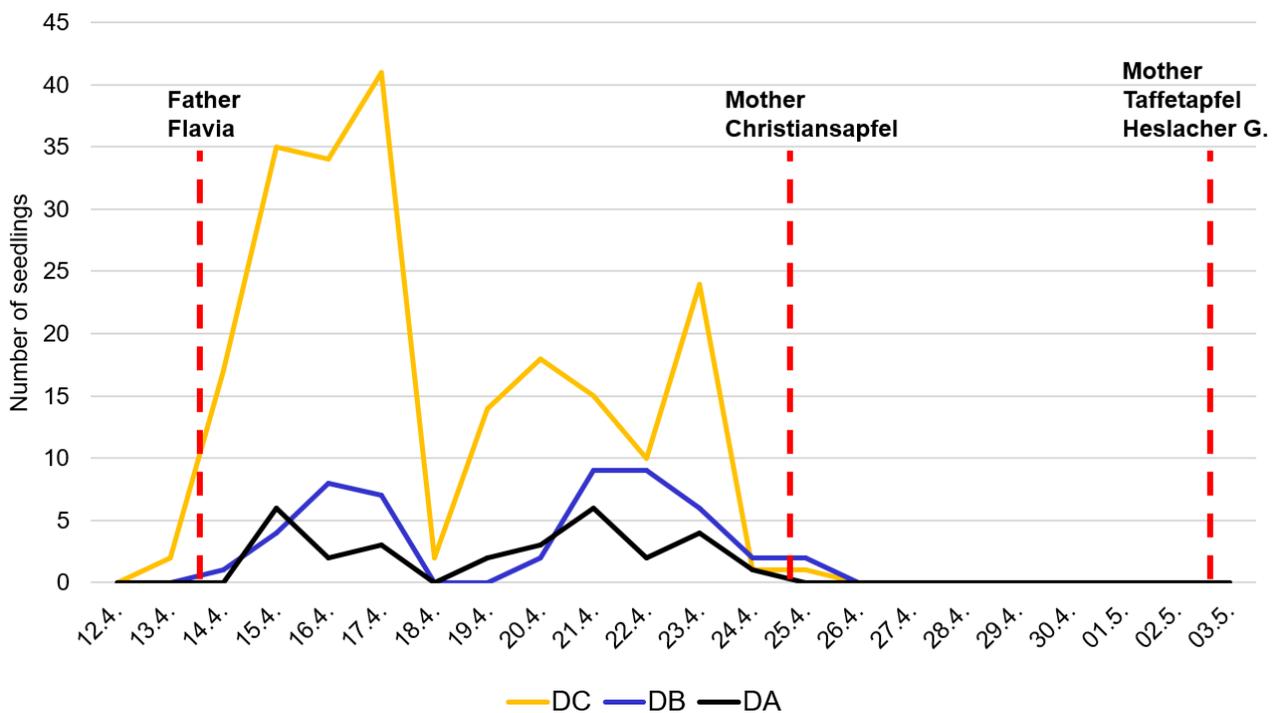


Figure 3: Flowering data (BBCH 61) of the 2020 breeding series in 2025, father Flavia, mother, Heslacher Gereutapfel (= DA), Spätblühender Taffetapfel (= DB) and Christiansapfel (=DC)

Discussion

Late flowering is considered important to avoid disastrous spring frost damage (Janick *et al.* 1996). One objective of this breeding program is to develop cultivars that flower late enough to avoid the main risk of damage to the blossoms from late frost. A fair estimate of mean flowering date of the progeny can be obtained from the mid-flowering time of the parents. The distribution of seedlings around the mean appears to be normal and the spread is such

that seedlings flowering later than either parent will be normally found (Janick et al. 1996). In the current study this was not the case but may be in one of the following. Good correlation between the time of leaf emergence and season of flowering was found by Tydeman (1958, 1964) and Murawski (1959, 1967). Thus, early or even midseason leafing seedlings can be discarded in their second year of growth. This procedure will be done with the breeding series 2021-2024. Among the clones of the 2020 series five individuals were found with good characteristics for fruit growing or at least further breeding.

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