

Thesis of the Doctoral (PhD) Dissertation

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Hungarian University of Agriculture and Life Sciences

**Frost hardiness and floral biological traits of
apricot varieties**

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1 BACKGROUND AND OBJECTIVES

Apricot is one of the fruit species that is difficult to grow in our country, we can cultivate it economically in certain growing areas only, primarily due to its poor ecological adaptability and sensitivity to frost. Its yield security is largely determined by frost damage, which is now caused less by winter frosts than spring frosts. Therefore, the frost tolerance of overwintering organs, primarily flower buds, is one of the most important aspects of evaluating apricot varieties. In Hungary, due to the incorrect choice of the growing area of plantations and the inadequate variety composition, crop losses are common and the annual total yield fluctuates greatly from year to year.

The aim of our experimental work was to determine the frost tolerance, microsporogenesis and flowering biological characteristics of apricot varieties bred abroad, thereby confirming or denying their suitability for domestic cultivation. We chose two well known domestic clone varieties as controls. In addition to traditional methods, we also used modern laboratory methods during our experiments.

Our detailed objectives:

1. Determination of the frost tolerance of apricot varieties by artificial freezing tests.
2. Determination of the frost tolerance of apricot varieties by field frost damage evaluation.
3. Determination of the year effect influencing the frost tolerance of flower buds by statistical tests.
4. Grouping apricot varieties based on their frost sensitivity by statistical methods.
5. Determination of the rate and sequence of microsporogenesis of apricot varieties.
6. Determination of the flowering sequence and flowering time of apricot varieties.
7. Examination of the fruiting shoot types and determination of the flower bud set of the apricot varieties.
8. Grouping the varieties based on the set of the fruiting shoots by statistical methods.

With our new research results, we aimed to determine the suitability of the studied apricot varieties in the domestic cultivation environment and their phenological characteristics influencing their yield security, and to expand domestic apricot cultivation knowledge with this information.

2 MATERIALS AND METHODS

2.1 Experimental plants

The experiments were conducted in the Soroksár experimental orchard of the Department of Fruit Growing of the Hungarian University of Agricultural and Life Sciences (GPS coordinates: 47.398820, 19.149270), and the samples necessary for the experiments were also collected from there, between 2019 and 2023.

The average annual precipitation in the Soroksár area over the past 20 years was 586 mm (OMSZ, 2023), the average number of hours of sunshine was 1988 hours, and the prevailing wind direction was northwest. The area is located in the Danube floodplain, so most of the soils are floodplain soils formed on the calcareous sand alluvium of the Danube. Its humus content is between 0.5% and 1.4%, the soil pH is relatively high (7.6 - 8.1), the lime content is around 2%, and the Arany-type stiffness (KA) is 24. The experimental orchard was established in 2013, the trees were planted in a 5 m x 3 m spacing, the row spacings were grassed. All grafts were grafted on myrobalan seedling rootstock. Integrated cultivation technology was used in the orchard, the trees were pruned to a compact vase crown shape, and the trees received plant protection. There was no irrigation in the area. The varieties selected for the experiments are listed in Table 1.

Table 1: Experimental varieties and their origin

Variety name	Origin (parents) [owner]	Synonyms, brand name (series)
Aurora	USA, 1995 (RR17-62 x NJA13)	Early Blush
Bergarouge	France (Bergeron x Orange Red)	
Bhart	USA (Lasgerdi Mashhad x NJA2)	Orange Red
Farbaly	France [New Cot]	IPS 2.4.37 (Carmingo)
Goldrich	USA, 1954 (Sun Glo x Perfection)	Sungiant, Jumbo Cot
Hargrand	Canada, 1972 (V51092 x NJA1)	
Harlayne	Canada, 1970 (V51092 x Sun Glo)	
Harogem	Canada, 1971 (Rouge de Roussillion x NJA 2)	
Kurezia	Germany, 1999	Kuresia
Magyar kajszai C.235	Hungary, 1976	
Petra	Italy	
Pinkcot	France [New Cot]	Cotpy (Carmingo)
Primaya	France [New Cot]	(Carmingo)
Rózsakajszai C.1406	Hungary, 1955	
Sweet Red	France [Escande]	Red Sylver

Tsunami	Francie [Escande]	
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2.2 Experimental methods of frost hardiness

The frost tolerance of the flower buds of the selected varieties was tested by artificial freezing in three years between 2019 and 2023, with the exception of the winter of 2020-2021, when we could not conduct the tests due to technical reasons. Field frost damage surveys were conducted in late winter/spring of 2021, 2022 and 2023.

2.2.1 Artificial freezing

From October to February, artificial freezing tests were performed once a month in a Rumed 3301 (Rubarth Apparate GmbH) climate chamber, based on a protocol developed at the department (Szalay et al. 2010). For each treatment, branches were collected from at least five different trees (where possible), set with short, medium and long fruiting shoots. After each treatment, at least 100 flower buds per variety were examined, which were cut longitudinally and then evaluated based on the discoloration of the tissues.

Based on the extent of frost damage, taking into account the results of all treatment temperatures, the LT_{50} value characteristic of the variety for the given phenological stage was determined using a smooth spline regression model, and then Hierarchical cluster analysis (Ward method, squared Euclidean distance) was applied to classify the apricot varieties into classes.

2.2.2 Field frost damage evaluation

In each of the study years, there were periods of freezing that caused frost damage to the generative organs of apricot trees. Before the flowering period, after the days with temperatures causing frost damage had passed, we recorded natural frost damage on the 16 varieties included in our study in the three years between 2021 and 2023. We examined frost damage to flower buds on three different types of fruiting shoots, on short, medium and long fruiting shoots. For each variety, 5-5 of each type of fruiting shoots were collected from the trees for the study.

After the flower buds were longitudinally cut, the extent of frost damage was determined based on the discoloration of their internal tissues. During the statistical analysis, each shoot was considered a replicate. We calculated the mean and standard deviation from the test results, and determined the homogeneous groups using one-way analysis of variance.

2.3 Experiments of the development of the flower bud

We examined the rate of flower bud development in three years between 2020 and 2022, and determined the end of endodormancy state of flower buds for each variety using the microsporogenesis method.

2.3.1 Microsporogenesis

During the winter dormancy period, from January 1st until the beginning of flowering, we collected samples from the trees, initially weekly, then every two to three days as the development processes accelerated. We collected fruiting shoots as samples, if possible from separate trees, at a height of between 1.5 m and 2 m, alternately located on the sunny and shady sides of the crown, and examined the flower buds located on them. We removed the anthers from them, placed them on a slide, then stained them with different dyes (pelican blue or carmine acetic acid), and finally closed them with a coverslip. Then, by gently pressing the coverslip, the anthers were crushed, making their internal tissue visible, which was examined under a microscope.

Each time we examined anthers extracted from 8-10 flower buds per variety. We noted which developmental stages of the microsporogenesis process were visible and in what proportion. By plotting the temporal development of the individual developmental phases of microsporogenesis on a graph, we obtained sigmoid curves. The phenological stages gradually transitioned into each other. During the statistical analysis, the 50% quantile of the sigmoid curves was considered the transition time in the microsporogenesis process. The end of endodormancy is marked by the date when the string stage is already visible in 50% of the anthers of the given variety (Szalay et al., 2006; Julian et al., 2009; Hajnal et al., 2013).

2.4 Time and date of flowering

The determination of the flowering time of apricot varieties was carried out by visual inspection in the experimental orchard over four years, between 2020 and 2023. Six stages of flowering were distinguished (in brackets indicating the state according to the BBCH phenological scale for stone fruits):

- red bud stage (BBCH51)
- bud burst (BBCH53)
- hollow ball (BBCH59)
- beginning of flowering (BBCH61)
- full flowering (BBCH65)
- end of flowering (BBCH69)

The flowering state was determined by visual evaluation every two days during the flowering period. We examined 5-10 trees per variety and determined the current, variety-specific phenological phase by averaging their phenological status. Flowering time was characterized as the period between the beginning of flowering and the end of flowering.

2.5 Experiments of the flower bud set of fruiting shoots

During the examination of the fruiting parts, we distinguished three types of fruiting parts with different lengths:

- short fruiting shoots: between 0-20 cm long
- medium-length fruiting shoot: between 20-40 cm long
- long fruiting shoot: over 40 cm long

The flower bud set of the fruiting shoots was examined in three experimental years, from 2021 to 2023, each year at the beginning of March, before the flowering period. For each variety, 5-5 samples were collected per fruiting shoot type. The trees used for sampling and the location of the fruiting shoots on the tree were also randomly selected during collection. The following measurements were made on the fruiting shoots:

- total length (the length of the fruiting shoots was measured)
- number of nodes (by visual inspection)
- number of flower buds (by visual inspection)

During the tests, the length dimensions of the different fruiting shoots, the number of flower buds and nodes were recorded in a table, and then the flower bud set parameters suitable for characterizing the varieties were calculated from these data.

3 RESULTS AND THEIR DISCUSSION

3.1 Experiments of frost hardiness of apricot varieties

3.1.1 Results of artificial freezing tests

The LT₅₀ values suitable for characterizing the frost tolerance or frost sensitivity of each variety were determined by artificial freezing treatments in all three experimental years. Five treatments were performed each year, from October to February, once a month, preferably in the middle of the month. The LT₅₀ values characteristic of the varieties were calculated using the spline regression method, and then the frost tolerance profile characteristic of the variety was outlined based on the results, each year separately.

The method for determining the frost tolerance profile is presented with the results of the year 2019/2020. During this dormancy period, the first sampling and artificial freezing treatments took place in mid-October. The treatment temperatures and the extent of frost damage are included in Table 2.

Table 2: Temperature data of artificial freezing treatments and the extent of frost damage for each variety in October 2019

Variety	Treatment temperature (°C)				LT ₅₀ value (°C)
	-9	-11	-13	-15	
Frost damage (%)					
Petra	5	61	99	100	-10,6
Tsunami	3	61	99	100	-10,6
Sweet Red	4	54	98	100	-10,8
Primaya	3	46	94	100	-11,2
Aurora	1	40	88	100	-11,4
Pinkcot	0	36	84	100	-11,6
Bhart	0	28	80	100	-11,8
Goldrich	0	24	70	99	-12,1
Magyar Kajszi C.235	0	22	64	98	-12,4
Hargrand	0	16	58	95	-12,6
Farbaly	0	15	58	95	-12,6
Kurezia	0	10	50	90	-13
Bergarouge	0	9	50	90	-13
Harogem	0	6	44	84	-13,3
Rózsakajszi C.1406	0	2	30	64	-14,2
Harlayne	0	1	24	56	-14,6

Our first treatment temperature was -9 °C, at which temperature most of the tested varieties had not yet suffered any frost damage, and even in the case of the damaged varieties, the degree of frost damage remained low, the most damaged variety was ‘Petra’ with 5% frost damage. The next treatment temperature was -11 °C, at this temperature we found damaged buds for all tested varieties, but the degree of damage varied over an extremely wide range. The two most sensitive varieties were ‘Petra’ and ‘Tsunami’ with 61% frost damage, while the least sensitive variety was ‘Harlayne’ with 1% bud loss. We further reduced the treatment temperature to -13 °C, as a result of which the degree of frost damage ranged from 24% (‘Harlayne’) to 99% (‘Petra’ and ‘Tsunami’). Our last treatment temperature in the month was -15 °C, at this temperature all varieties suffered at least 50% frost damage, the least sensitive variety here was ‘Harlayne’ with 56%, while 7 varieties suffered total (100%) frost damage.

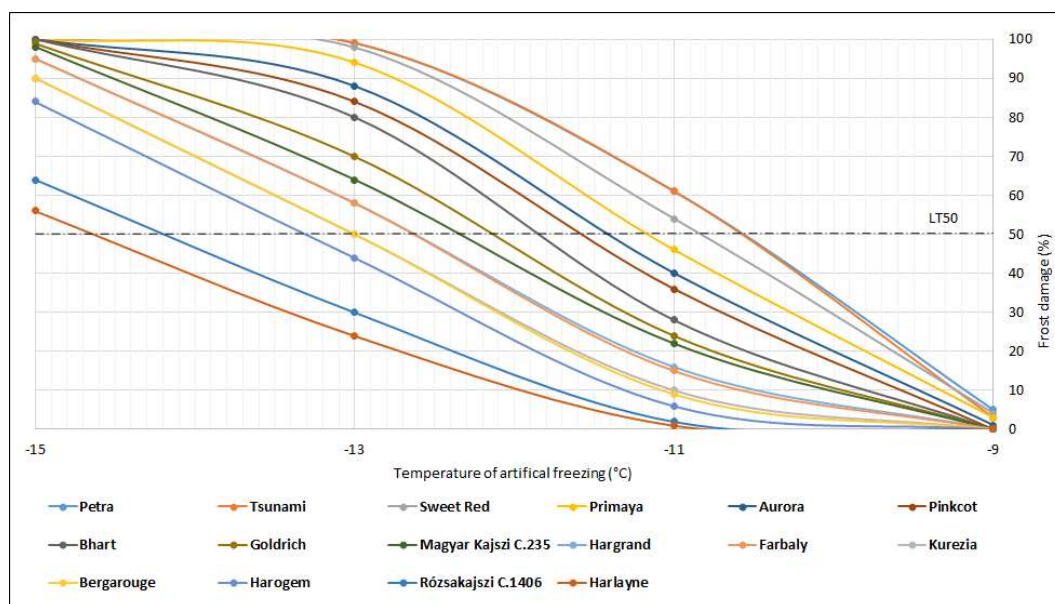


Figure 1: Frost damage of flower buds of apricot varieties after artificial freezing treatment in October 2019

From the frost damage values measured during the four treatments, we used a smooth spline regression method to determine the LT_{50} value specific to the variety, which showed us the temperature at which 50% frost damage occurred during the given period. Based on the October results, the varieties ‘Petra’ and ‘Tsunami’ were the most sensitive, with an LT_{50} value of -10.6 °C, while ‘Harlayne’ proved to be the most frost-tolerant, with an LT_{50} value of -14.6 °C. The October frost damage values of all tested varieties are shown in Figure 1.

The first stage of the frost tolerance profile is hardening, which begins before leaf fall, in response to the increasingly shorter days and decreasing temperatures, in preparation for the winter dormancy period. This stage lasts until mid-winter, during which time the plant’s flower buds gradually become more resistant to winter frosts.

The second phase of the profile is the preparation of flower buds for flowering, during which they gradually lose their hardiness (dehardening), their resistance to winter and then spring frosts continuously decreases. The turning point between the two periods typically occurs at the end of December or the beginning of January, depending on the climatic conditions of the current winter.

The frost hardiness profile was drawn based on the results of the test period from October to February for each tested variety. The frost tolerance profiles for the year 2019/2020 are included in Figure 2.

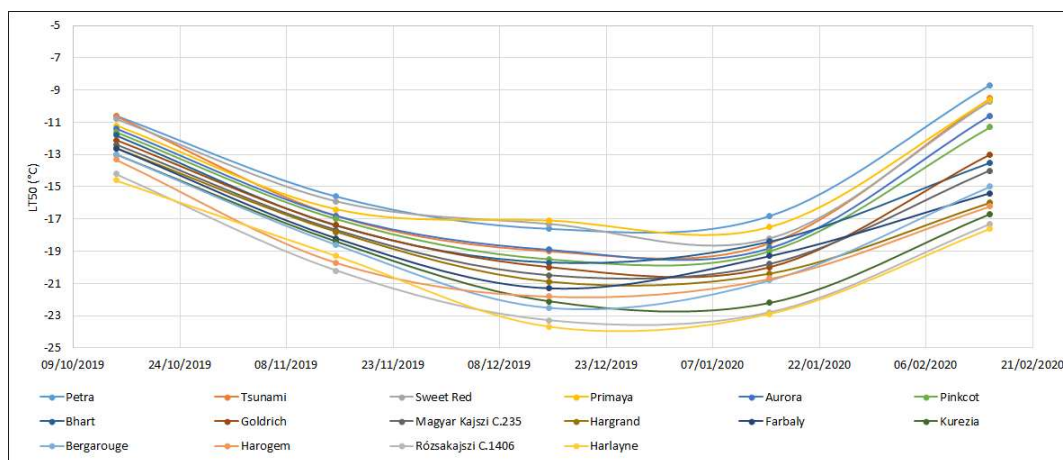


Figure 2: Frost hardiness profile of apricot varieties based on LT_{50} values during the 2019-2020 dormancy period

During the 2019/2020 dormancy period, we observed that the hardening process and the length of the hardening period varied depending on the variety. The hardening of some varieties (e.g. 'Harlayne', 'Harogem', 'Bergarouge') took place completely gradually with continuously increasing frost tolerance values until they finally reached a turning point, from where they were characterized by a gradual, increasingly accelerated frost sensitivity until the beginning of flowering. In other varieties (e.g. 'Primaya', 'Sweet Red', 'Tsunami'), we experienced that the initial rapid hardening process temporarily slowed down, then began to strengthen again, until they finally reached a turning point, from where the flower buds then lost their hardening at an accelerating rate.

We also observed that the length of the hardening phase and the turning point marking its end also varied depending on the variety. Some varieties (e.g. 'Bhart', 'Farbaly') reached their maximum LT_{50} value, i.e. their maximum hardiness, by mid-December 2019, while for other varieties (e.g. 'Kurezia', 'Goldrich', 'Sweet Red') the turning point occurred sometime in the first week of January.

The next two test periods were the dormancy periods of 2021/2022 and 2022/2023. In these years, we also conducted our artificial freezing tests in a similar manner, with one sample per month from October to February and 4-6 temperature treatments, and then based on the results obtained, we prepared a frost tolerance profile for all varieties.

The tested varieties were classified into classes according to their frost tolerance based on the results of the artificial freezing tests. Classification was performed using hierarchical cluster analysis (Ward method), both for each year separately and for the three years as a whole. The dendrogram of the cluster analysis for the results of the 3 years together is shown in Figure 3.

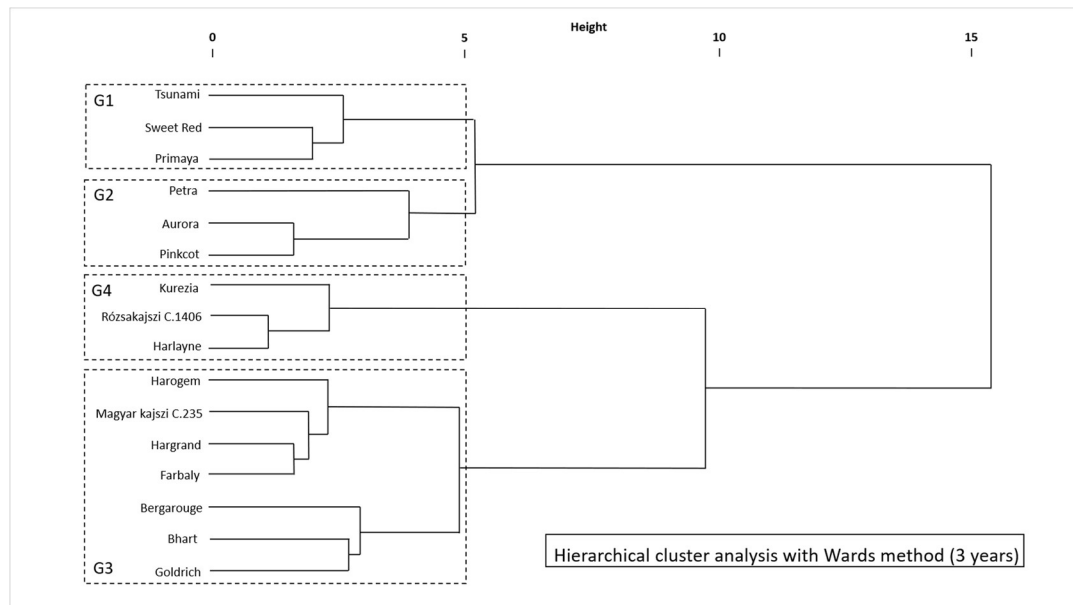


Figure 3: Grouping apricot varieties according to their frost hardiness using hierarchical cluster analysis (Ward method; 3 experimental years in one)

Four groups (G1-G4) can be distinguished on the dendrogram. Group G1 includes apricot varieties whose flower buds are most sensitive to frost, while group G4 includes apricot varieties that are most resistant to frost. The classification of the sixteen apricot varieties examined according to frost hardiness is given in Table 3.

Table 3: Classification of tested apricot varieties according to frost tolerance using hierarchical cluster analysis (each year separately and all three years together)

Variety name	19 / 20	21 / 22	22/ 23	3 years together	frost hardiness groups
Primaya	G1	G1	G1	G1	
Tsunami	G1	G1	G1	G1	G1 – very sensitive
Sweet Red	G1	G1	G1	G1	
Aurora	G1	G2	G1	G2	
Pinkcot	G1	G2	G1	G2	
Petra	G1	G2	G2	G2	G2 - sensitive
Bhart	G2	G2	G2	G3	
Goldrich	G2	G2	G2	G3	
Bergarouge	G3	G2	G2	G3	
Magyar Kajszi C.235	G2	G3	G3	G3	G3 - tolerant
Hargrand	G2	G3	G3	G3	
Farbaly	G2	G3	G3	G3	
Harogem	G3	G3	G3	G3	
Kurezia	G3	G4	G4	G4	G4 – very tolerant
Rózsakajszi C.1406	G4	G4	G4	G4	
Harlayne	G4	G4	G4	G4	

3.1.2 Discussion of the results of artificial freezing

Temperature is the most important environmental factor affecting the development and loss of hardiness, and thus the frost tolerance of overwintering organs (Quinones et al., 2020), but several other factors can also influence this, such as the genotype of the variety (Dumanoglu et al., 2019), the rootstock (Lichev et al., 2006), the health of the trees, irrigation or the applied agrotechnical methods (Bálo et al., 2005). Flower buds acquire frost tolerance during cold acclimation, in response to low but above-freezing temperatures (Chinnusamy et al., 2007). This complex process involves changes in gene expression, modifications of cell membranes (Orvar et al., 2000), accumulation of soluble sugars (Ma et al., 2009), amino acids and antioxidants, and a decrease in water content. However, the increase in autumn and early winter temperatures can trigger deacclimatization, leading to a loss of frost tolerance (Vyse et al., 2019). Related to these metabolic processes, several environmental factors, such as temperature fluctuations, soil nutrient content, precipitation, irrigation, load from the previous year's crop, or sunlight, can have a modifying effect on the actual frost tolerance of a variety during a given dormancy period. Due to this complex background, the frost tolerance of individual varieties

varies from year to year. Therefore, multi-year studies are needed to determine the frost tolerance of a given variety.

In this work, sixteen apricot cultivars were tested to determine the frost tolerance of their flower buds during the dormancy periods of three years. In our experiment, we tried to exclude all factors other than the genetic capabilities of the cultivars, the experiment was carried out at a single location, the soil and weather conditions were the same, all cultivars were grafted onto the same rootstock, and the same integrated cultivation technology was applied throughout the entire experimental plantation, including maintenance pruning, fertilization and plant protection, in order to maintain the good health of the trees. In the rare cases when a plant over-set, fruit thinning was applied, although in most years the apricot trees suffered serious frost damage. A frost tolerance profile was determined for each cultivar based on the LT_{50} values obtained during artificial freezing tests.

The frost tolerance of overwintering organs gradually increased during the hardening period and reached its maximum by the end of December and the beginning of January, then gradually decreased during the ecodormancy period. The differences in frost tolerance of the varieties were the smallest in October (3.43 °C difference between the least and most frost-tolerant varieties on average over three years), then this difference increased slightly in each month thereafter (3.97 °C, 4.43 °C and 5.07 °C), and finally the largest difference was measured in February (6.03 °C). The LT_{50} values of the flower buds of the individual varieties were different in each study year, which shows the significant role of temperature in the development of hardening and loss of hardiness, and thus in the changes in the frost tolerance of the varieties. A separate comparison of the LT_{50} values of each variety over the three years, broken down by month, showed that the differences within varieties were between 2.8 °C ('Petra') and 5.1 °C ('Bergarouge') in October, 2.3 °C ('Kurezia') and 6.3 °C ('Harogem') in November, 0.6 °C ('Primaya') and 5.8 °C ('Bergarouge') in December, 3.0 °C ('Petra') and 8.1 °C ('Bergarouge') in January, and 1.9 °C ('Petra') and 7.2 °C ('Harlayne', 'Goldrich') in February. Due to the mild winter weather, the flower buds of the cultivars, similarly to other fruit species (Szalay et al., 2017; Vitasse et al. 2018), did not reach the genetically possible level of frost tolerance. Several authors have reported that apricot flower buds can survive very low temperatures, even below -25 °C, but this requires a harsh winter without major temperature fluctuations, which is suitable for gradual, strong hardening of the flower buds (Istrate et al., 2013; Szymajda et al., 2013; Korzin et al., 2021). In our experiment, the lowest measured LT_{50} temperature was -23.7 °C in December 2019 for the very frost-tolerant 'Harlayne' cultivar. The highest measured LT_{50} temperature during the same period was -17.5 °C for the frost-sensitive 'Primaya' cultivar. This was the harshest winter of the three years of the experiment, resulting in the largest difference (-6.2 °C) in the frost tolerance of the varieties. In the other two years of the experiment, the winter was milder, resulting in smaller differences between the LT_{50} values of the most frost-sensitive and frost-tolerant varieties (-3.1 °C and -3.6 °C). Similarly, in the October period, during the first half of the hardening process, as well as in the late February period, during the loss of the

hardening state, we found that the differences in LT₅₀ values were smaller in mild winters.

Based on the hierarchical clustering classification, eight of the sixteen varieties belonged to the same group in all three years. The varieties ‘Tsunami’, ‘Sweet Red’ and ‘Primaya’ were very frost sensitive (G1), the varieties ‘Bhart’ and ‘Goldrich’ were slightly frost sensitive (G2), the variety ‘Harogem’ was slightly frost tolerant (G3), while the varieties ‘Rózsakajsi C.1406’ and ‘Harlayne’ were very frost tolerant (G4) in all three years of study. The other half of the varieties showed minor differences in frost tolerance from year to year. The varieties ‘Petra’, ‘Aurora’ and ‘Pinkcot’ varied between very frost sensitive (G1) and slightly frost sensitive (G2), the varieties ‘Magyar kajsi C.235’, ‘Hargrand’, ‘Farbaly’ and ‘Bergarouge’ varied between slightly frost sensitive (G2) and slightly frost tolerant (G3), while the variety ‘Kurezia’ varied between slightly frost tolerant (G3) and very frost tolerant (G4). Based on the classification carried out for three years together, the varieties ‘Tsunami’, ‘Sweet Red’ and ‘Primaya’ were very frost sensitive (G1), ‘Petra’, ‘Aurora’ and ‘Pinkcot’ were slightly frost sensitive (G2), ‘Magyar kajsi C.235’, ‘Hargrand’, ‘Farbaly’, ‘Bergarouge’, ‘Goldrich’, ‘Bhart’ and ‘Harogem’ were slightly frost tolerant (G3), while ‘Kurezia’, ‘Rózsakajsi C.1406’ and ‘Harlayne’ were very frost tolerant (G4).

3.1.3 Results of field evaluation of frost damage

The field evaluation of frost damage to flower buds was carried out in three years, a few days after the freezing periods that caused frost damage. Table 4 shows the time of severe freezing days and the exact temperatures. The flower buds were already in a state of ecodormancy at all three events. The natural frost damage to flower buds was examined separately on three different types of fruiting shoots.

Table 4: Lowest temperatures and dates before field frost damage to flower buds in Soroksár

date	temperature (°C)	development stage of flower buds
2021. February 14.	-11	ecodormancy
2022. March 12.	-12	ecodormancy
2023. February 11.	-9	ecodormancy

Significant differences were found between the varieties at each test date, and frost damage to flower buds also differed by fruiting shoot type. The evaluation of the varieties in terms of frost tolerance was carried out based on the averages of the test results of the three years. The results of the statistical evaluation of the test results are presented in Figure 4 and Table 5. Based on the combined evaluation of the frost damage results measured on the three fruiting shoot types, only the ‘Rózsakajsi C.1406’ variety was in the best frost tolerance category. Two Canadian varieties, ‘Hargrand’ and ‘Harlayne’, proved to have good frost tolerance. ‘Bhart’, ‘Farbaly’, ‘Harogem’, ‘Kurezia’ and ‘Magyar kajsi C.235’ showed medium frost tolerance

based on the field frost damage evaluation of flower buds. The varieties ‘Bergarouge’, ‘Goldrich’, ‘Petra’, ‘Pinkcot’, ‘Primaya’ and ‘Tsunami’ proved to have poor frost tolerance, while the varieties ‘Aurora’ and ‘Sweet Red’ were in the weakest frost tolerance category.

The differences between the fruiting shoot types were only significant for the varieties ‘Bhart’, ‘Harlayne’, ‘Kurezia’, ‘Magyar kajszí C.235’, ‘Pinkcot’ and ‘Tsunami’, and it varied depending on the variety whether the shorter or longer fruiting part shoot was more susceptible to frost damage. For the other varieties, the difference between the fruiting shoot types was not significant.

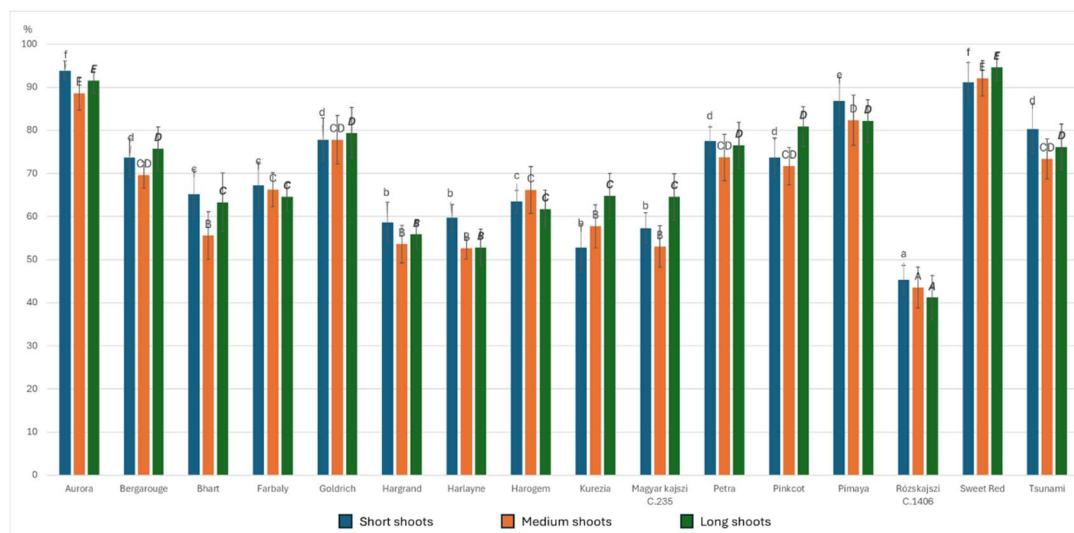


Figure 4: Frost damage to flower buds of apricot varieties based on the results of natural frost damage surveys, three-year average (Soroksár, 2021-2023).

Explanation: The height of the columns indicates the mean values, the lines indicate the standard deviation, the labels indicate homogeneous groups, those with different letters are significantly different from each other based on the results of the analysis of variance, significance level: 95%; lowercase letters are for short shoots, simple capital letters are for medium-length fruiting shoots, bold italic capital letters are for long fruiting shoots based on the test results

Table 5: Evaluation of the frost tolerance of apricot varieties based on the results of natural frost damage to flower buds

number	variety	short shoot	medium shoot	long shoot	frost hardiness category
1	Aurora	93,8 f	88,6 E	91,6 E	1 (very weak)
2	Bergarouge	73,7 d	69,6 CD	75,7 D	2 (weak)
3	Bhart	65,2 c	55,6 B	63,3 C	3 (medium)
4	Farbaly	67,2 c	66,3 C	64,6 C	3 (medium)
5	Goldrich	77,8 d	77,8 CD	79,4 D	2 (weak)
6	Hargrand	58,7 b	53,7 B	55,8 B	4 (good)
7	Harlayne	59,7 b	52,6 B	52,8 B	4 (good)
8	Harogem	63,5 c	66,2 C	61,8 C	3 (medium)
9	Kurezia	52,8 b	57,8 B	64,8 C	3 (medium)

10	Magyar kajszzi C.235	57,3 b	53,1 B	64,6 C	3 (medium)
11	Petra	75 d	73,7 CD	76,5 D	2 (weak)
12	Pinkcot	73,7 d	71,7 CD	80,9 D	2 (weak)
13	Primaya	86,8 e	82,4 D	82,2 D	2 (weak)
14	Rózsakajszzi C.1406	45,3 a	43,5 A	41,2 A	5 (excellent)
15	Sweet Red	91,1 f	92,1 E	94,6 E	1 (very weak)
16	Tsunami	80,3 d	73,4 CD	76,2 D	2 (weak)

Explanation: The averages of the test results of the three years by type of fruiting shoots, the letters represent homogeneous groups identified based on statistical analysis.

3.1.4 Discussion of the results of the field frost damage evaluation

In the Soroksár variety collection of the Department of Fruit Growing of MATE, the frost tolerance of many domestic and foreign varieties was examined between 2007 and 2020 with open-field frost damage recordings (Szalay et al., 2021). Large differences were found between the varieties within both groups. Among the Hungarian varieties, 'Rózsakajszzi C.1406' and 'Budapest' had excellent frost tolerance. 'Ceglédi arany' and 'Mandulakajszzi' showed good frost tolerance. 'Gönci magyar kajszzi', 'Magyar kajszzi C.235', 'Pannónia' and 'Ceglédi kedves' had medium frost tolerance, among others. 'Ceglédi óriás', 'Ligeti óriás' and 'Ceglédi bíborkajszzi' were included in the group with poor frost tolerance. Among the foreign varieties, 'Bergeron' and the varieties bred in Canada were the most frost-tolerant, with the exception of 'Veecot' and 'Harcot'. Among the new fashionable varieties, only 'Kioto' showed good frost tolerance. 'Bergarouge' is medium, while the other recently very fashionable varieties ('Pinkcot', 'Spring Blush', 'Sylvercot', 'Sweet Red', 'Carmen Top') all belonged to the group of particularly frost-sensitive varieties (Szalay et al., 2021).

During our experimental work, we conducted field frost damage surveys in three years between 2021 and 2023, the results of which are published in this paper. During this time, there were three occasions with very low temperatures during the ecodormancy periods, causing significant frost damage. Of the 16 varieties tested, the flower buds of the varieties 'Aurora' and 'Sweet Red' were damaged the most each time. The varieties 'Bergarouge', 'Goldrich', 'Petra', 'Primaya', 'Pinkcot' and 'Tsunami' were also found to have poor frost tolerance. 'Rózsakajszzi C.1406' was damaged the least and thus proved to have excellent frost tolerance. The other varieties were classified as medium and good frost tolerance based on the results of the field tests.

3.1.5 Comparison of the results of artificial freezing tests and field frost damage surveys

One of the important questions of artificial freezing tests is how well they can model frost damage events that may occur in the open field and how accurate information is obtained about the frost tolerance of varieties. Therefore, we

compared the results of the two test series, the results of which are included in Table 6. The varieties were ranked based on the results of artificial freezing, where we classified the varieties into four categories, starting with the most frost-sensitive variety (category 1) and moving towards the most frost-tolerant category (category 4). During the field frost damage recording, we classified the varieties into five categories based on their frost tolerance (1 is the most frost-sensitive, 5 is the most frost-tolerant). Overall, we can say that we experienced a strong correlation in the results of the two testing methods.

Table 6: Comparison of the results of artificial freezing and open field frost damage surveys

frost hardiness category by artificial freezing	variety	frost hardiness category by open-field frost damage
1	Sweet Red	1
1	Tsunami	2
1	Primaya	2
2	Aurora	1
2	Pinkcot	2
2	Petra	2
3	Bhart	3
3	Goldrich	2
3	Bergarouge	2
3	Magyar kajszai C.235	3
3	Hargrand	4
3	Farbaly	3
3	Harogem	3
4	Kurezia	3
4	Harlayne	4
4	Rózsakajszai C.1406	5

3.2 Results of microsporogenesis studies of apricot varieties

The microsporogenesis process of our sixteen apricot varieties was monitored in three study years, between 2020 and 2022, from January 1st to flowering. We determined the quantile (m) corresponding to the 50% value of the sigmoid curves characterizing the transition of each stage, as well as the speed factor characterizing the slope of the curve, by fitting a sigmoid regression model to the study data.

The study years were compared according to the starting time of each phenological phase, the duration of each phenological phase, and the rate factor characterizing the transition of the stages, for which we used MANOVA model

The study results for 2020 are shown in Figure 5. The times on the horizontal axis of the diagram are expressed in Julian days, i.e. the number of days since January 1st. From the archesporium stage to the formation of the strings, 8-22 days were required, depending on the variety. The string stage, which is also considered the beginning of the microsporogenesis process, lasted relatively short, the detachment of the pollen mother cells from the strings occurred in 6-9 days. The formation of tetrads took 16-18 days, depending on the variety, while the development of microspores took 9-11 days for all varieties. Mature pollen grains developed from the microspores in another 17-21 days, while another 14-17 days passed until the beginning of flowering, depending on the variety. In 2020, the beginning of flowering, which also marks the end of the ecodormancy state, fell between March 20 ('Sweet Red' and 'Primaya') and March 27 ('Rózsakajszki C.1406' and 'Harlayne'), depending on the variety.

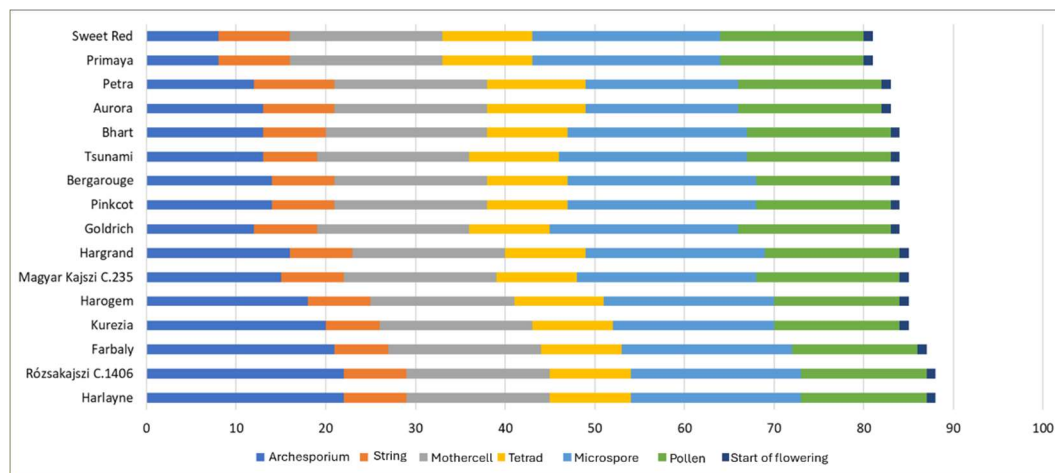


Figure 5: Rate of microsporogenesis of apricot varieties (2020)

Summarizing the results of the three years of study, we observed that the differentiation of the initial undifferentiated tissue in the anthers and the formation of the strings show a very large difference between the early and late flowering varieties, expressed in calendar days, this occurred with a difference of 14-16 days in all three years of study. The duration of the transition to the following stages is much less variable, and as time progresses, the developmental differences between the early and late flowering varieties decrease, with the formation of mature pollen grains and the beginning of flowering the large time difference is reduced by half. The beginning of flowering occurred with a difference of 7-8 days in all three years of study, comparing the earliest and latest flowering varieties.

Although the statistical analysis did not show a significant variety effect, when examining the varieties, we observed that the sequence of microsporogenesis

of each variety was almost the same in all three years. In the case of early flowering varieties, such as ‘Sweet Red’, ‘Aurora’, ‘Petra’ and ‘Primaya’, all stages of microsporogenesis started and ended earlier than in the other varieties, and in the case of late flowering varieties (‘Farbaly’, ‘Harlayne’ and ‘Rózsakajsz C.1406’) the opposite was true, with all stages occurring later in time.

3.2.1 Discussion of microsporogenesis studies

The development of flower buds during winter dormancy can be well monitored by examining the process of microsporogenesis. The course of microsporogenesis is also genetically determined, like all phenological processes, but it is significantly affected by environmental factors, especially temperature (Hajnal et al., 2013; Julian et al., 2014). This is the reason for the significant differences between individual years, which was also confirmed by our experimental results. Based on studies over the past three decades, although increasingly mild winters delay the end of the endodormancy period, during ecodormancy, the process of microsporogenesis accelerates, the transition between the individual stages is shortened, and overall leads to earlier flowering (Szalay et al., 2019).

The microsporogenesis of apricot varieties was examined in detail in the experimental plantations of the Department of Fruit Growing of MATE and its predecessor institutions between 1994 and 2020. (Szalay, 2006; Szalay et al., 2006, 2008, 2019; Szalay and Németh, 2010; Szalay, 2024). Based on the results of experiments conducted with numerous varieties over 26 years in Szigetcsép and then in Soroksár, the variety and year effects were clearly detectable. During the 26 years examined, the string stage gradually started later and the tetrad stage gradually started earlier (Szalay, 2024). Joining this research program, I examined the microsporogenesis of 16 apricot varieties in three years between 2020 and 2022. In addition to standard varieties, I also included varieties for which there was no information on winter flower bud development.

During the three-year study period, we examined the microsporogenesis of the 16 apricot varieties included in the study, using ‘Magyar kajsz C.235’ and ‘Rózsakajsz C.1406’ varieties as controls. Based on our study results, we ranked the tested varieties in terms of their microsporogenesis rate. A similar order emerged in all three years, which can also be considered an order indicating crop safety. The earliest varieties to emerge from dormancy are ‘Sweet Red’, ‘Aurora’, ‘Petra’ and ‘Primaya’, and also earlier varieties than ‘Magyar kajsz C.235’ are ‘Pinkcot’, ‘Tsunami’, ‘Goldrich’, ‘Bhart’ and ‘Bergarouge’, the cultivation of these varieties in Hungary involves a higher risk due to their rapid winter flower bud development. The varieties ‘Kurezia’, ‘Farbaly’, ‘Harlayne’, ‘Harogem’ and ‘Hargrand’ transit from endodormancy to ecodormancy later than ‘Magyar kajsz C.235’, and their yield security is therefore more favorable.

3.3 Flowering time of apricot varieties

The flowering time of the apricot varieties studied was examined over four years, from 2020 to 2023, and the results are shown in Figure 6. The beginning of flowering was marked by the time when 5% of the flowers on the trees had opened, and the end of flowering was marked by the time when 95% of the flowers on the trees had already bloomed and their petals had fallen. The duration of flowering was characterized by the time elapsed between the two times. In the figure, the varieties were arranged in order based on the beginning of flowering in 2023, but this order varied slightly in the other three years.

In 2020, the earliest varieties ('Sweet Red' and 'Primaya') began flowering on March 16 and ended on April 3, while the latest-flowering variety ('Rózsakajsz C.1406') began flowering seven days later, on March 23, and ended 5 days later, on April 7. Depending on the variety, the total flowering period lasted 15-17 days.

By arranging the varieties in order of flowering time and comparing the flowering times of the four years, we found that the order of flowering time of the varieties varied slightly depending on the year. 'Sweet Red' started flowering the earliest every year, but the varieties 'Primaya', 'Aurora', 'Goldrich' and 'Tsunami' also bloomed early every year. The 'Petra' variety bloomed very early between 2020 and 2022, but in 2023 it started to bloom together with the mid-flowering varieties. The 'Bergarouge', 'Bhart' and 'Pinkcot' varieties bloomed sometimes early and sometimes mid-time, depending on the year. The 'Magyar kajsz C.235', 'Hargrand' and 'Harogem' were stably mid-flowering varieties, while the 'Kuresia' and 'Harlayne' varieties were mid- or late-flowering, depending on the year. The 'Rózsakajsz C.1406' and 'Farbaly' varieties were always late-flowering.

We observed a negative correlation between the start of flowering and the total duration of flowering; in the two years (2020, 2023) when flowering began earlier, the duration of flowering was prolonged compared to the other two years.

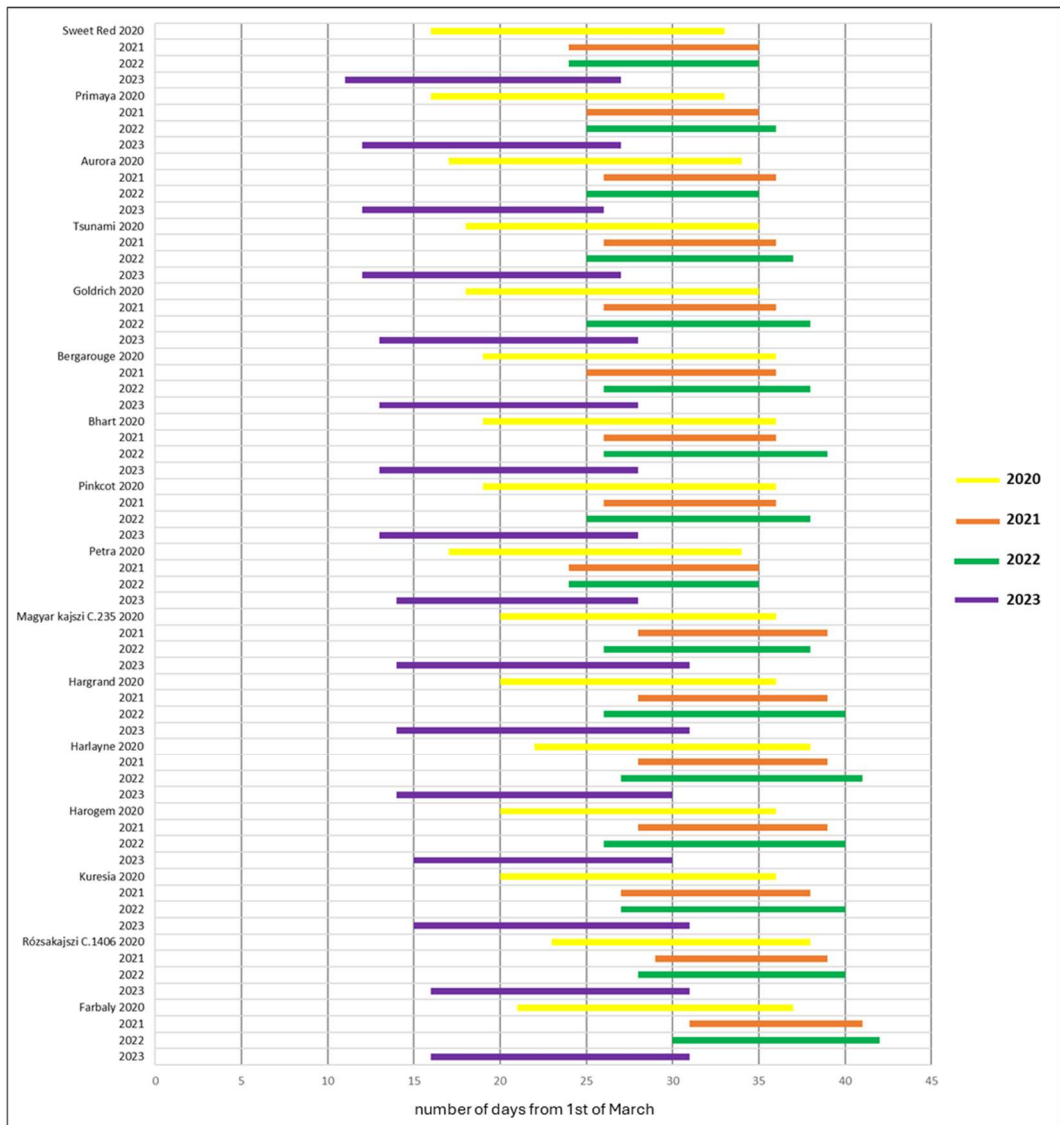


Figure 6: Flowering time of tested varieties in the period 2020-2023

3.3.1 Discussion of results of flowering time

Based on the results of studies conducted on a large range of varieties in the experimental plantations of the MATE Department of Fruit Growing over 26 years, there was a 49-day difference between the beginning of flowering in the earliest and latest flowering year. In addition, a gradual shift in flowering time was also shown, with flowering starting 0.3 days earlier each year on average (Szalay, 2024).

Based on the results of studies conducted on 16 varieties over four years in Soroksár, significant differences could be detected between the years even in this short period. According to the literature, the order of flowering time of varieties is generally constant, but our results did not confirm this. The order of flower opening of the varieties was not completely identical in different years.

Knowing the flowering time is equally important for determining the suitability of the growing site and for planning variety compositions. Early flowering varieties should not be planted in growing sites at risk of frost. For self-sterile varieties, a pollen-bearing variety from the same flowering time group should be chosen.

3.4 Fruiting sets of apricot varieties

During our studies, we determined the flower bud set of the apricot varieties studied in three years (2021, 2022, 2023) on three different fruiting shoot types (short, medium and long fruiting shoots), which was characterized by two parameters, the number of flower buds per centimeter of the fruiting shoot (hereinafter VR/cm) and the number of flower buds per node of the fruiting shoot (hereinafter VR/node).

To determine whether the number and density of flower buds formed on the fruiting shoots are significantly influenced by the genotype, the effect of the year, and the type of fruiting shoot, we performed a three-factor bivariate analysis of variance. Based on the Wilk's lambda values, it can be said that the flower bud set parameters are significantly affected by the variety, the type of fruiting shoot, and the year. In addition, all interactions between factors were also significant. After the significant MANOVA results, we performed an ANOVA test for each variable with Bonferroni correction. In the case of both examined parameters (VR/cm; VR/node), the effects of variety, year, fruiting shoot type, and all interactions between them were also found to be significant. Due to the significant interactions, in the post-hoc analysis, the variety effect was analyzed separately by year and fruiting shoot type, the year effect by variety and fruiting shoot type, and the effect of fruiting shoot type by variety and year.

3.4.1 Effect of variety

Based on the Tukey/Games Howell post hoc tests, we were able to detect significant differences in the flower bud set parameters between the varieties in all three years and for all three fruiting shoot types, the only exception being the VR/node parameter in the case of long fruiting shoots in 2021, where we were unable to detect a significant difference between the varieties.

In the case of long fruiting shoots, the number of flower buds per centimeter varied between 0.7 ('Kurezia') and 1.21 ('Farbaly') in 2021, between 1.28 ('Primaya') and 2.06 ('Bhart') in 2022, and between 0.75 ('Goldrich') and 1.77 ('Pinkcot') in 2023 (Figure 7).

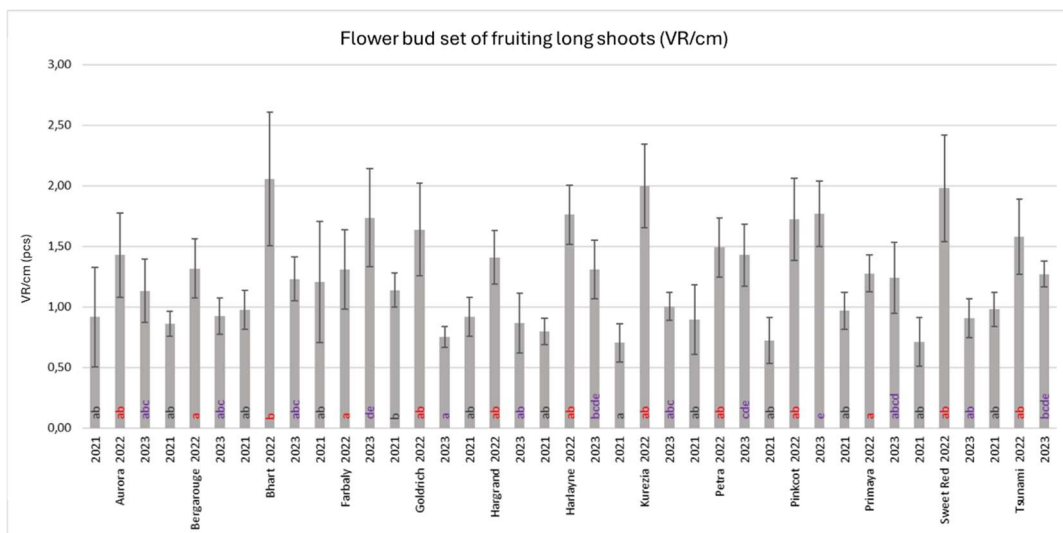


Figure 7: Flower bud set of long fruiting shoots (VR/cm). The height of the bars indicates the mean of the measurements, the lines indicate the standard deviation. Different letters indicate significantly different groups based on the Tukey/Games Howell post hoc tests ($p < 0.05$). (Black letters indicate the 2021 measurements, red letters indicate the 2022 measurements, and purple letters indicate the 2023 measurements)

In terms of the number of flower buds per centimeter, considering the data of the three years and the three fruiting part types together, the varieties 'Aurora', 'Bergarouge', 'Primaya', Harlayne and 'Hargrand' were found to be weaker, while the varieties 'Petra', 'Bhart', 'Pinkcot' and 'Tsunami' proved to be outstanding. In terms of the number of flower buds per node, considering the data of the three years and the three fruiting part types together, the varieties 'Primaya' and 'Hargrand' were found to be weaker, while the varieties 'Bhart', 'Farbaly', 'Goldrich' and 'Tsunami' proved to be outstanding. Examining the two flower bud set parameters together, the varieties were classified into five categories (Table 6).

Table 6: Flower bud set of tested varieties based on the combined evaluation of the three years

	Flower bud set category (VR/cm)	Flower bud set category (VR/nódusz)	Flower bud set category (combined)
Aurora	weak	medium	weak
Bergarouge	weak	medium	weak
Bhart	good	good	very good
Farbaly	medium	good	good
Goldrich	medium	good	good
Hargrand	weak	weak	very weak
Harlayne	weak	medium	weak
Kurezia	medium	medium	medium

Petra	good	medium	good
Pinkcot	good	medium	good
Primaya	weak	weak	very weak
Sweet Red	medium	medium	medium
Tsunami	good	good	very good

3.4.2 Effect of year

Flower bud formation is affected by a number of factors that are specific to the given year. The amount of fruit on the tree is decisive; growing a large amount of fruit on the tree has an opposite effect on flower bud formation, strongly hindering it. Extreme weather conditions, such as summer heat stress or lack of precipitation, can also have a negative effect. Plant health problems in a given year, such as monilia infection or aphid infestation, can also have a detrimental effect. The exact reasons for this are difficult to determine, but based on descriptive statistics, it is clear that significant differences can be measured in flower bud set parameters between individual years (Table 7).

Table 7: Flower bud set values of the three study years

year	# of samples	VR/cm (avg.)	VR/cm (std. dev.)	VR/node (avg.)	VR/node (std. dev.)
2021	195	1,11	0,44	1,49	0,44
2022	195	1,72	0,5	2,25	0,52
2023	195	1,24	0,47	1,84	0,61

Analyzing the results, it can be said that some varieties react to the year effect to different degrees. We found the varieties 'Aurora' and 'Primaya' to be the least sensitive, while we also found greater or lesser sensitivity in the case of the varieties 'Goldrich', 'Tsunami', 'Farbaly', 'Bhart', 'Petra', 'Pinkcot' and 'Hargrand'. In the case of the varieties 'Bergarouge', Harlayne, 'Kurezia' and 'Sweet Red', we measured a significant year effect for all shoot types, these varieties were the most sensitive.

3.4.3 Studies of fruiting shoot types

The interaction of the factors (year, variety, fruiting shoot type) proved to be significant for the examined flower bud set characteristics, so during the post-hoc analysis, the effect of the shoot type was analyzed separately by variety and year.

Regarding the two flower bud set characteristics, it can be said that the effect of the fruiting shoot type affected both characteristics to a similar extent, with a significant effect in the number of flower buds per centimeter in 41% of cases, while in the number of flower buds per node in 49% of cases.

3.4.4 Discussion of the results of flower bud set

The flower bud set of apricot cultivars is of paramount importance for yield, yield security, and the extent of possible frost damage, and is therefore an important factor in assessing the value of the cultivar. In our experiment, we found significant differences in the flower bud set values of individual apricot genotypes, which have been similarly demonstrated in previous experiments for apricot (Albuquerque et al., 2004), peach and nectarine (Okie and Werner, 1996), and cherry (Thurzó et al., 2006). Among the apricot cultivars we examined, we found information from previous experiments on ‘Goldrich’, which, like ours, was classified in the “medium” or “good” flower bud set category in several cases (Albuquerque et al., 2004; Szabó et al. 2010). In cherry (Maguylo et al., 2002) and plum (Radovic et al., 2016) experiments, the effect of the rootstock on flower bud set was also demonstrated.

We also measured significant differences between years, and we also observed that this year effect affected some varieties more and others less, which was also experienced by others in previous research (Szabó et al., 2010). In contrast, Albuquerque and his colleagues did not measure a significant year effect (Albuquerque et al., 2004), with the remark that fruit thinning was performed every year between experimental years.

Comparing the fruiting shoot types, in line with previous research (Mészáros et al., 2020; Albuquerque et al., 2003), we found that the number of buds per centimeter is generally higher on short shoots, but in some varieties, longer shoots can be more densely set (Thurzó et al., 2006). However, if we project the number of flower buds per node, we generally get higher values for longer shoots.

4 CONCLUSIONS AND RECOMMENDATIONS

One of the biggest risks for apricot growing is winter and spring frosts. As a result of climate change, the autumn and winter months are often warmer, milder and often characterized by significant temperature fluctuations, with smaller and larger warmings and coolings, which greatly hinders the preparation of flower buds for the cold. The increasingly frequent occurrence of frost damage is increasing the rate of crop loss. For these reasons, frost tolerance is an important selection criterion in apricot breeding, as in the case of other temperate fruit species. Some areas of Hungary are suitable for apricot growing, however, when planning apricot orchards, it is now essential to take into account the frost tolerance of the selected varieties and the characteristics of the growing site. Accordingly, it is very important to have adequate information on the frost tolerance of different apricot varieties, which must also be incorporated into the variety descriptions.

Grouping the varieties in our studies according to their frost tolerance, we can say that the highly frost-sensitive varieties 'Sweet Red', 'Tsunami' and 'Primaya', and the slightly frost-sensitive varieties 'Petra', 'Aurora' and 'Pinkcot' are recommended for planting only in more protected, frost-free areas. The varieties 'Magyar kajszai C.235', 'Hargrand', 'Farbaly', 'Bergarouge', 'Goldrich', 'Bhart' and 'Harogem' were found to be slightly frost-tolerant, while the varieties 'Kurezia', 'Rózsakajszai C.1406' and 'Harlayne' were found to be very frost-tolerant, so we consider them suitable for the establishment of commercial plantations and breeding programs.

There are several biological methods for examining the development of flower buds and determining the end of endodormancy, of which we chose the microsporogenesis method, which is considered the most reliable based on literature data. Based on our test results, we ranked the tested varieties in terms of their microsporogenesis rate. A similar order emerged in all three years, which can also be considered an order indicating crop safety. The flower buds of the 'Sweet Red' variety, which released endodormancy the fastest, started to develop between January 8 and 19, while the flower buds of the 'Farbaly' variety, which released the slowest, only between January 21 and February 3. Of the varieties tested, the varieties 'Sweet Red', 'Primaya', 'Petra', 'Tsunami', 'Goldrich', 'Pinkcot', 'Aurora', 'Bhart' and 'Bergarouge' ended their endodormancy earlier and their flower buds started developing earlier than the 'Magyar kajszai C.235' variety used as a control, so we consider the cultivation of these varieties to be riskier and therefore we do not recommend them. The varieties that started developing later than 'Magyar kajszai C.235' were, in order: 'Hargrand', 'Harogem', 'Kurezia', 'Harlayne', 'Rózsakajszai C.1406' and 'Farbaly'. Their yield security is better, so we recommend them for cultivation.

Based on the studies of flowering time, we found that the beginning of flowering of the tested varieties occurs in the same order, determined by the genotype, regardless of the year. Our control variety was 'Magyar kajszai C.235', which can be said to have a medium-term flowering. In our studies, the varieties that bloomed earlier than this were the following, starting with the earliest flowering:

'Sweet Red', 'Primaya', 'Petra', 'Aurora', 'Goldrich', 'Tsunami', 'Bergarouge', 'Bhart' and 'Pinkcot'. Due to their early flowering, these varieties are more sensitive to spring frosts, so their yield security is weaker under domestic growing conditions. The varieties that bloomed later than 'Magyar kajsz C.235' were the following in order of flowering: 'Hargrand', 'Harogem', 'Kurezia', 'Harlayne', 'Rózsakajsz C.1406' and 'Farbaly'. Due to their late flowering, these are less sensitive to spring frosts, therefore their yield security is better.

The flower bud set of apricot varieties is also an important factor in terms of yield security, and thus in assessing the value of the variety. In the event of frost damage, varieties with more abundant set may perform better in terms of yield. It is also worth examining the varieties based on the set of fruiting shoot types, so that we can make better decisions based on this knowledge during shoot selection and pruning. Flower bud set was measured in three years for 13 varieties, distinguishing three fruiting shoot types. Comparing the varieties, we found the varieties 'Hargrand' and 'Primaya' to be very weakly set, and the varieties 'Aurora', 'Bergarouge' and 'Harlayne' to be weakly set, therefore we do not recommend them for planting due to their lower yield security. We found the varieties 'Kurezia' and 'Sweet Red' to be moderately set, we found the varieties 'Farbaly', 'Goldrich', 'Petra' and 'Pinkcot' to be well set, and we found the varieties 'Bhart' and 'Tsunami' to be very well set, we recommend them for planting due to their better yield security. Comparing the years, we found varieties that were less sensitive to the year effect based on the three years, these were the varieties 'Aurora' and 'Primaya', and we found varieties that were particularly sensitive to the different effects of the given vintage, these were the varieties 'Sweet Red', 'Kurezia', 'Bergarouge' and 'Harlayne'. In the latter case, we have to take into account that the flower bud set varies significantly from year to year, which provides less predictable growing conditions. When examining the different types of fruiting shoots, we found that the shortest fruiting shoots (under 20 cm long) were better set with flower buds, but for longer shoots, regardless of the length, the flower bud density was similar. When comparing the varieties, we found that the difference in fruiting shoot set is typically not significant in the case of some varieties, such as 'Petra' and 'Primaya'. In these varieties, longer fruiting shoots should be preferred, due to their better nutrient transport capacity and the later flower opening on longer fruiting shoots. In the case of other varieties ('Kurezia', 'Pinkcot', 'Tsunami'), we measured significant differences in fruiting rate between the fruiting shoot types, so in these varieties, short shoots should be preferred due to their better fruiting ability.

Overall, based on our test results, the factors influencing the yield security of the varieties, the frost tolerance profile, the time of breaking endodormancy, the flowering time and the degree of flower bud set, we found the 'Farbaly' variety to be outstanding. It comes out of endodormancy the latest, has the latest flowering and its frost tolerance values were also found to be good. In addition, among the frost-tolerant varieties, we found its flower bud set parameters to be the best. We also found the 'Kurezia', 'Rózsakajsz C.1406' and 'Harogem' varieties to have good yield security, and their values also proved to be adequate for all tested parameters.

Based on the test results, the varieties not recommended for planting are the 'Sweet Red', 'Tsunami', 'Primaya' and 'Aurora' varieties due to their increased frost sensitivity, shorter endodormancy and early flowering. We recommend planting the other tested varieties with extreme caution.

5 NEW SCIENTIFIC RESULTS

1. I determined the frost tolerance of flower buds of sixteen apricot cultivars (fourteen foreign and two domestic) during the dormant period using an artificial freezing procedure and a smooth spline regression model, and classified the cultivars into four sensitivity groups.
2. I also determined the frost tolerance of flower buds of the apricot cultivars using an open-field frost damage evaluation, and classified them into five sensitivity groups.
3. Based on the studies of flower bud development and flowering during dormancy, I determined the order of microsporogenesis and flowering of apricot cultivars, and I determined the rate of microsporogenesis and the beginning and end of flowering times in the Central Hungarian region.
4. I determined the flower bud set parameters of apricot cultivars, and classified them into five groups. I have confirmed the different sensitivity of apricot varieties to the year effect.
5. By summarizing the results of our studies, I have confirmed the suitability of one domestic ('Rózsakajszai C.1406') and three foreign ('Kurezia', 'Farbaly', 'Harogem') apricot variety for cultivation in terms of frost sensitivity and flowering biology, under domestic ecological conditions.

6 PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

Scientific articles:

[1] Bakos József L., Ladányi Márta, Szalay László: Frost hardiness of flower buds of 16 apricot cultivars during dormancy. *FOLIA HORTICULTURAE* (0867-1761 2083-5965): 36 1 pp 81-93 (2024)

[2] Szalay László, Bakos József László, Froemel-Hajnal Veronika, Németh Szilvia, Karsai Ildikó: Changes in apricot microsporogenesis, flowering and ripening time based on 26 years of field observations in Hungary. *SCIENTIA HORTICULTURAE* (0304-4238 1879-1018): 336 Paper 113357. 13 p. (2024)

[3] Szalay László, Bakos József, Tósaki Ágnes, Froemel-Hajnal Veronika: Kajszi fajták virágrügyeinek és virágainak fagyűrése a természetes fagykárak felmérése alapján. *KERTGAZDASÁG* (1998-) (1419-2713 3003-9959): 53 2 pp 3-15 (2021)

[4] Szalay László, Bakos József, Tósaki Ágnes, Keleta Belay Teweldemedhin, Froemel-Hajnal Veronika, Karsai Ildikó: A 15-year long assessment of cold hardiness of apricot flower buds and flowers during the blooming period. *SCIENTIA HORTICULTURAE* (0304-4238 1879-1018): 290 Paper 110520. 12 p. (2021).

[5] Szalay László, Froemel-Hajnal Veronika, Bakos József, Ladányi Márta: Changes of the microsporogenesis process and blooming time of three apricot genotypes (*Prunus armeniaca* L.) in Central Hungary based on long-term observation (1994–2018). *SCIENTIA HORTICULTURAE* (0304-4238 1879-1018): 246 pp 279-288 (2019)

[6] Mendelné Pászti Edina, Bakos József László, Szalay László, Mendel Ákos: Kajszi fajták virágrügyeinek fagyűrés- és fagykár vizsgálati eredményei. *KERTGAZDASÁG* (1998-) (1419-2713 3003-9959): 54 4 pp 14-23 (2022)

Proceedings (abstracts):

[7] Bakos József László, Szalay László: Kajszi fajták termésbiztonsága a tavaszi fagykárak fényében. In: XXVIII. Növénynevelési Tudományos Napok: Összefoglaló kötet. Keszthely: Magyar Növénynevelők Egyesülete, pp 96-96 (2022). ISBN: 9789632699875