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Influence of climatic indicators on the sustainability of fruit farming in the regions of Slovakia

Vplyv klimatických indikátorov na udržateľnosť ovocinárstva v regiónoch Slovenska

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ABSTRACT

Rising temperatures are already affecting fruit production, and phenological data are important in examining the agroclimatic conditions of the area. The research aims to analyse climate indicators for the sustainability of apple (*Malus domestica*, L.) production in Slovakia – the onset of the phenological phase of full flowering (BBCH 65) in 1931–2020, the occurrence of frost days in 1961–2020, and the analysis of the area and yield of apple trees in 2014–2022. The results show that in 1931–1960, full flowering began in the third decade of April (western Slovakia – April 24) and in the first decade of May (eastern Slovakia – May 3). On the contrary, over the past 30 years, the average onset begins already in the second decade of April (western Slovakia – April 18) and in the last decade of April (eastern Slovakia – April 25). This also caused a higher probability of frosts occurring between the 1st and 10th day after the onset of the BBCH 65 phase (Piešťany station – up to 137%), and thus a greater risk of flower damage. Due to climatic and economic factors, the total area of orchards is decreasing, but this is also related to the decrease in fruit harvest in Slovakia.

Keywords: climate change, full flowering, frosty days, *Malus domestica*

ABSTRAKT

Stúpajúce teploty už dnes ovplyvňujú ovocinárstvo, pričom práve fenologické údaje sú dôležité pri skúmaní agroklimatických podmienok územia. Cieľom predkladaného príspevku je analýza klimatických indikátorov pre udržateľnosť produkcie jablone domácej (*Malus domestica*, L.) na Slovensku – nástup fenologickej fázy plného kvitnutia (BBCH 65) v rokoch 1931–2020, výskyt mrazových dní v rokoch 1961–2020 a analýza výmery a úrody jabloní v rokoch 2014–2022. Z výsledkov vyplýva, že v rokoch 1931–1960 začalo všeobecné kvitnutie v tretej dekáde apríla (západné Slovensko – 24. apríl) a v prvej dekáde mája (východné Slovensko – 3. máj). Naopak, za posledných 30 rokov začína priemerný nástup už v druhej dekáde apríla (západné Slovensko – 18. apríl) a v poslednej dekáde apríla (východné Slovensko – 25. apríl). To spôsobilo aj vyššiu pravdepodobnosť výskytu mrazov v termíne od 1. do 10. dňa od nástupu fázy BBCH 65 (stanica Piešťany – až 137 %), a tým aj väčšie riziko poškodenia kvetov. Vplyvom klimatických a ekonomických faktorov klesá celková výmera ovocných sadov, ale s tým súvisí aj pokles úrody ovocia na Slovensku.

Kľúčové slová: klimatická zmena, všeobecné kvitnutie, mrazové dni, *Malus domestica*

INTRODUCTION

Since the 1980s, each decade has been warmer than the previous one. The 10-year average (2014–2023) was 1.20 ± 0.12 °C higher than the 1850–1900 average based on the datasets used, allowing for some degree of uncertainty. The average annual global temperature in 2023 was 1.45 ± 0.12 °C above pre-industrial levels (Markovič and Garčár, 2024). Over the past 30 years, Europe's air temperature has increased more than twice the global average, the most of any continent. With the continuing warming trend, extreme heat, fires, floods, and other manifestations of climate change will significantly affect society, the economy, and ecosystems (Markovič and Pecho, 2022).

Climate change has the potential to affect fruit production by increasing temperature, and the occurrence of weather extremes such as torrential rains, hail, or late spring frosts. Assessment of the impact of future climate changes on fruit production should allow for predicting changes in yield and changes in the location of regions suitable for fruit growing. Rising temperatures are already affecting the phenology of many fruit species (Suran, 2022). Fruit production is one of the oldest specialized productions in Slovakia and we encounter cultivation, except for extreme mountain locations, in all regions (Hričovský, 2000). Fruit growing, as a branch of agriculture, is one of the production activities with potentially high production intensity, which makes it possible to achieve profitability of production under good conditions. In the past, the opportunity to use otherwise hard-to-use soil by planting fruit species was valued. In addition, fruit growing has a landscape-forming function. It completes the appearance of the landscape, affects the microclimate, has an anti-erosion function, is a source of food for bees, extensive species provide a living space for birds, etc. (Pintér, 2005).

In the last decades, achieving output was prioritized over sustainability. This system of agriculture has brought environmental degradation, loss of biodiversity, excessive depletion of natural resources, increase in greenhouse gas emissions, etc. One of the concepts that could bring a solution to this problem is sustainable agriculture. It is a form of agriculture that optimally uses the natural environment and integrates it into business management, actively contributes to the quality of the natural environment and has a positive impact on biodiversity, in intensive production it integrates intensive and extensive fruit orchards (Westerin et al., 2018). The modernization of Slovak fruit growing is an important topic for experts at the beginning of the new program period of the Rural Development Program (2021–2027). According to the Fruit Union of the Slovak Republic, to ensure self-sufficiency in the production of its fruit in 2021–2026, 300 ha of new orchards should be planted annually (250 ha of apple trees and 50 ha of other fruit species). The proposed concept envisages planting 1,250 ha of intensive apple orchards and 250 ha of orchards of other fruit until 2026 (Michálek, 2021).

The aim of the presented contribution is the analysis of climatic factors for the sustainability of fruit growing in Slovakia. The most important fruit species in Slovakia in terms of cultivated areas, production and consumption is the apple tree (*Malus domestica*). The contribution is complemented by an analysis of climate change, its impact on the change in the onset of the phenological phase - full flowering (BBCH 65) and the occurrence of frosty days. In the future, this fact will affect the change in the species composition of cultivated fruit plants in some regions of Slovakia.

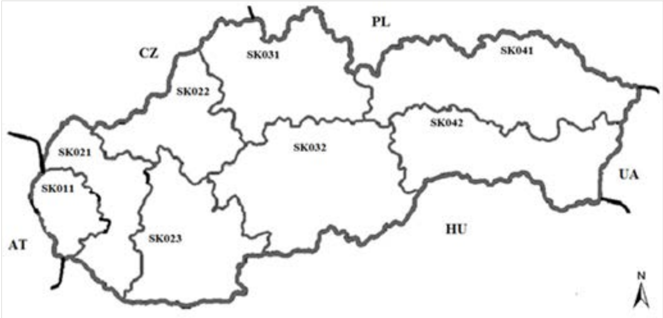
MATERIAL AND METHODS

Input data for the analysis of climatic and phenological factors for the period 1931–1960 were used from the publication Agroclimatic Conditions of the Czechoslovak Republic (Kurpelová et al., 1975), for the years 1961–1990 from the publication Phenological Conditions in Slovakia (Dunajský and Braslavská, 1996) and for years 1991–2020, the data were obtained from the Slovak Hydrometeorological Institute.

Firstly, the climatic and phenological data were processed. The missing values for the entire territory of Slovakia were calculated in ArcGIS Pro (ESRI) using the interpolation method. Several authors compare the suitability of different interpolation methods (Halaj and Zaujec 2023). For the interpolation, the Topo to Raster method uses an iterative finite difference interpolation technique. It is optimized to have the computational efficiency of local interpolation methods such as Inverse Distance Weighted interpolation without the loss of surface continuity of global interpolation methods such as Kriging and Spline (ESRI, 2024). The interpolation was carried out for the periods 1931–1960, 1961–1990 and 1991–2020. After the interpolation, data were reclassified into the categories – the onset of BBCH 65 (full flowering) was divided into three days. The areas above 500 m a.s.l. were excluded, because up to 500 m a.s.l. are areas with optimal conditions and areas with less suitable but satisfactory conditions for growing apple trees. The result is a map compilation, which contains a comparison of all three investigated periods.

Secondly, based on the data, the probability of occurrence of frosts was calculated in the period a) up to the 10th day, b) between the 11th – 20th day and c) over the 21st day from the onset of BBCH 65 for the periods 1961–1990 and 1991–2020. Subsequently, the map of the risk of frost damage to fruit trees for the period 1991 – 2020 was created by an overlapping map of the first flowering (BBCH 60) and the average date of the last frost.

Thirdly, the statistics of growing areas and apple harvesting were processed based on the standardized classification of territorial units in Slovakia, specifically NUTS 3 (Nomenclature of Territorial Units for Statistics). Based on this nomenclature, the territory of Slovakia is divided into 8 regions (Figure 1). Since 2002, fruit orchards have been registered in Slovakia by the Central Agricultural Inspection and Testing Institute (ÚKSUP) and statistically evaluated by the Statistical Office (ŠÚ) of the Slovak Republic.



Legend: SK011–Bratislava, SK021–Trnava, SK022–Trenčín, SK023–Nitra, SK032–Banská Bystrica, SK031–Žilina, SK042–Košice, SK041–Prešov, AT–Austria, HU–Hungary, UA–Ukraine, PL–Poland, CZ–Czechia

Figure 1. Classification of territorial units in Slovakia according to NUTS 3

RESULTS AND DISCUSSION

Climatic conditions

In the period 1931–1960, the warmest month was July. The absolute maximum was measured at the Komárno station (5.7.1950) when the air temperature reached 39.8 °C. The highest monthly average temperature was reached in July 1950 (Štúrovo station – 23,5 °C). On the other hand, the coldest month was January. Another major climatic factor besides temperature is rainfall. This is characterized by a high variability depending on location and altitude. Precipitation values range from 550 to 700 mm in the south to 800-400 mm in the north (Vesecký, 1961).

The period 1961–1990 is characterized by milder winters and cooler summers. The highest average air temperatures were measured in Bratislava, where the average annual temperature was 10.5 °C, the average monthly temperature in January -0.8 °C and in July 20.7 °C. The differences between the Danube and the Eastern Slovakian lowlands can also be seen. The winters in the Eastern Slovakian Lowland are considerably colder than in the Danubian Lowland. The lowest average temperatures were reached at the Lomnický peak station – the annual average of -3.9 °C, in January -11.4 °C and in July 3.6 °C. The average annual rainfall ranged in 530–1200 mm. Lower values of precipitation totals were achieved in lowland areas, while precipitation totals increased with increasing altitude. Daily maximum rainfall is most common in July and October (Kurpelová et al., 1975).

In the last period 1991–2020, all stations show an exponential temperature trend. Temperatures from June to August increased by 1.7–1.9 °C (compared to 1961–1990). The summer period has generally warmed by 1.6 °C. Regarding precipitation, there is a long-term increase in precipitation in some areas of Slovakia. This is a paradox to the increasing number of dry seasons that we are experiencing. There are changes in the long-term average monthly and annual rainfall totals which are in some periods greater than previous standards (SHMÚ, 2022).

Also, in the growing season, the temperature changes. In Hurbanovo station (south) and Oravský Podzámok station (north), the average temperature per growing season increased during the studied periods. However, the 1961–1990 period appears cooler compared to the other two periods, which is caused by colder decade 1971–1980. The temperatures in growing seasons are shown in Table 1.

Table 1. Average air temperature in the growing season (IV-X.)

Station	1931–1960	1961–1990	1991–2020
Hurbanovo	15.60 °C	14.20 °C	17.02 °C
Oravský Podzámok	11.87 °C	11.57 °C	12.89 °C

Phenological conditions

The impact of climate change is also visible at the onset of BBCH 65 (Figure 2), most prominently in the recent period. In the years 1931–1960, this phenophase began in the third decade of April (Danubian Lowland) and in the first decade of May (Eastern Slovakian Lowland). The earliest start date was on average 24.4. at Kamenica nad Hronom station (southern part of the Danubian Lowland), at the latest 23.5. at the Oravský Biely Potok station (northern Slovakia). The period 1961 – 1990 is marked by the cold decade 1971–1980 (Čimo et al. 2020), therefore the average start of BBCH 65 is mainly in the first half of May, except for the Kravany nad Dunajom stations – 27.4. and Malé Kosihy – 30.4. (southern part of the Danubian Lowland). On the contrary, over the last 30 years, the average onset begins already in the second decade of April in the main part of the Danubian Lowland (Košúty station – 18.4.) and in the last decade of April in the Eastern Slovakian Lowland (Bánovce and Ondavou station – 25.4.), and the latest onset in central and northern Slovakia in the second decade of May (Turček station – 15.5). However, if the last 10 years were compared, this onset would be much more significantly accelerated.

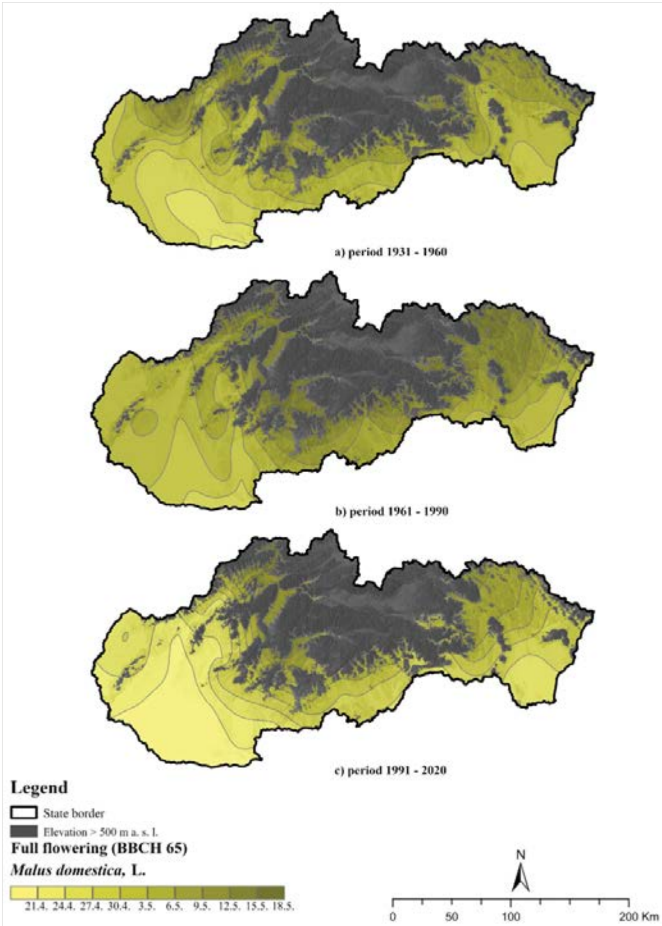


Figure 2. The onset of the phenological phase BBCH 65 for a period a) 1931 – 1960, b) 1961 – 1990 and c) 1991 – 2020

Several authors deal with the issue of changing phenological conditions, which is related to changing climatic conditions. Kalvāne et al. (2021) focused on 17 varieties of *Malus domestica*, finding that the onset of full flowering began around 21 May in the years 2002–2019, while in the period 1959–1967 it was 7 days later. In a study by Wyver et al. (2023) was found that the onset of flowering of Bramley apple trees advanced over the period of their study (due to early spring temperatures and peak flowering dates shifting 6.7 ± 0.9 per 1 °C warming). Stoeckli and Samietz (2015) addressed the change in the phenology of apple trees after decades – the flowering of apple trees between 1960 and 2010 advanced by an average of 3.1 days/decade. From 1981 to 2011, flowering even advanced by an average of 5.1 days/decade. Kamoutsis et al. (2023) focused on the phenology of apple trees in the Region of Central Macedonia. Higher values of the maximum air temperature in Giannitsa caused an earlier occurrence of apple phenophase bud burst, flower bud visible, pink bud stage and full flowering. Kunz and Blanke (2022) focused on the phenological records of apple and pear trees, including flowering, harvest, and leaf fall, and accompanying weather records in the years 1956–1988 and 1989–2017, finding a close correlation between March and April temperature increase and pome fruit flower advancement by 11–14 days.

Occurrence of frosty days

The occurrence of frosts after the onset of the BBCH 65 is for selected stations in Slovakia in Table 2. The probability of occurrence is divided into three categories – up to the 10th day, between the 11th and 20th day and after the 21st day. In the period 1961–1990, the highest probability of occurrence of frost is until the 10th day in the northern part of Slovakia (Spišské Vlachy – 37%, Liptovský Mikuláš – 17%), but the high probability of occurrence of frost is also in the south of Slovakia (Hurbanovo – 30%). In the period 1991–2020, the probability of occurrence of frosts is much higher. In Piešťany (a locality in Danube Hills), the probability is up to 137% (occurrence was 42 times in 30 years per 1st to 10th day). Since average annual temperatures are expected to increase, earlier onsets of individual phenological phases of individual fruit trees, especially flowering, are also likely, which is also related to the threat of spring frosts. We also observed an increase in the occurrence of frosts between the 11th and 20th day in the range of 3–30% depending on the location, while in the period of years, the probability was 3–13%.

According to studies from Poland (Koźmiński et al. 2021; Koźmiński et al. 2023), the occurrence of frosts in the growing season does not change significantly, but in Slovakia it is seen to increase. In Slovakia, not many authors have addressed the impact of frost on fruit trees. They are more focused on forest trees. Škvareninová et al. (2021) explore the occurrence of spring frosts on the flowering of pedunculate oak (*Quercus robur* L.). At altitudes up to 300 m, there is a presumption of more frequent damage to flowers by late spring frosts of strong and very strong intensity. The number of frosts is also reduced by gradual warming from the beginning of April to the end of May. Sitárová et al. (2019) verified the validity of the phenological forecast "On the Three Ice Men the frost kills all flowers" (May 12-14) in the periods 1987-1996 and 2007-2016. Frost days were detected at 6 phenological and climatological stations at 163-725 m asl. Škvareninová et al. (2022) also analysed the occurrence and intensity of frosts during the period around the weather lore "The Ice Saints" on hawthorn (*Crataegus laevigata* (Poir.) DC.) in 1987 – 2016. The risk of late frost damage to flowers is getting highly probable, particularly at 160, 300 and 500 m a.s.l., where the flowering and frosts occur simultaneously. Leštianska et al. (2017) explore the effect of low temperatures on phenological phases in dogwood-oak oak stands (*Corneto-Quercetum*). Spring phenological phases were in strong statistically significant correlation ($P < 0.05$) with minimum temperatures and with amounts of frost days in March and April. Slobodníková et al. (2017) investigated the effect of temperature extremes on the onset of phenological phases of European hazel (*Corylus avellana* L.) and sessile oak (*Quercus petraea* M att.). A strong correlation ($P < 0.05$) was found between the timing of the phenological phases of both tree species and minimum temperatures and the number of frost days in the preceding months.

Table 2. Probability of occurrence of frosts (%) after the onset of the BBCH 65 phenophase (selected stations in Slovakia)

Station	m a.s.l.	1961 - 1990			1991 - 2020		
		<10 day	11-20 day	>21 day	<10 day	11-20 day	>21 day
Gabčíkovo	113	0	0	0	40	13	0
Hurbanovo	115	30	0	0	60	13	0
Piešťany	163	7	0	0	137	13	7
Jaslovské Bohunice	176	0	0	0	70	10	0
Holíč	180	7	7	0	47	3	3
Rimavská Sobota	215	7	0	0	83	10	3
Vígľaš-Pstruša	368	10	0	0	37	17	0
Liptovský Mikuláš	569	17	3	0	47	17	0
Milhostov	105	7	0	0	63	10	0
Orechová	122	20	7	0	43	3	3
Spišské Vlachy	380	37	13	7	80	30	0

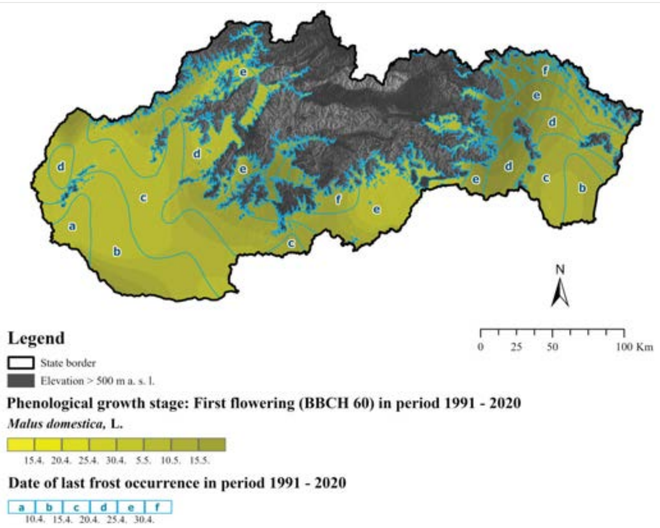


Figure 3. The risk of frost damage to fruit trees for the period 1991 – 2020

Growing fruit trees reduces the occurrence of late frosts. Figure 3 shows the risk of frost damage to fruit trees by overlaying a map of the beginning of flowering (first flowers – BBCH 60) of apple trees (*Malus domestica*, L.) and the average date of the last frost in the period 1991–2020. The map shows areas with the greatest risk of spring frosts, especially in the Danube Lowland, where the average onset of flowering is from April 15 (Kravany nad Dunajom) to April 18 (Trnava) and the average last frost occurred from April 10 to April 20. There is also a risk in the Eastern Slovak Lowland, where flowering begins on April 20 (Bánovce nad Ondavou) and the average last frost occurred from April 15 to April 25.

Therefore, it is necessary to adapt to the current situation with agrotechnical procedures and passive measures, for which we advise the selection of frost-resistant species, the selection of the location, or the application of chemical substances to delay budding. As active measures, is recommend heating the affected area, wrap the plants, or cover them, mix the air, and irrigate (Rehák et al. 2015; Suran 2024).

Cultivation areas and harvest

The development of the acreage of cultivated areas in Slovakia is the result of the direct and indirect effects of environmental factors (ecological and environmental) as well as market factors (supply and demand) and the overall setting of economic activity priorities at the national level. As it is seen from Table 3, in the territory of Slovakia intensively cultivated areas prevail over areas of fruit orchards.

Table 3. Structure of fruit orchards by total and production area in 2023 (ÚKSUP, 2024)

Total area [ha]	Production area [ha]	Distribution of orchards according to intensity [ha]		%
5,794.86	5,406.97	Intensive	4,513.17	83
		Extensive	893.80	17

As can be seen from Table 4, the total area of apple orchards and plantations is decreasing. At the level of individual regions, we see that in the years 2014-2022, the area is continuously decreasing, except for some years when the area increased, but this increase was insignificant.

The total production of fruit in Slovakia changes every year, especially depending on weather conditions, which significantly affect production mainly through frost damage to wood and generative buds, pollination of flowers and the activity of pollinators, fruit growth, the occurrence of diseases and pests, etc. Climate change carries many impacts (change in average monthly/annual temperature, change in the redistribution of precipitation during the growing season of cultivated fruit species). The current situation in fruit growing is unsatisfactory from several points of view (Gálik et al., 2022).

Table 5 shows that the total fruit harvest in Slovakia has been decreasing in recent years. This trend also appears with the most cultivated type of apple tree (except for 2022). For comparison, in 2021 the total production of apples in Slovakia was 29,586 t (Table 5), in Czechia 128,000 t and Hungary 350,000 t. The largest producers were Poland (4,300,000 t) and Italy (2,053,000 t) (Prognosfruit, 2022). Apples are the most popular and most frequently consumed fresh fruit in all EU member countries, except for Spain, where people prefer oranges. However, consumption per capita is decreasing in all EU countries. The consumption of apples per inhabitant in Slovakia decreased in 2021 (11.8 kg) compared to the years 2017 to 2020. Based on a comparison of 165 countries in 2021, the USA ranked highest in apple consumption per capita with 51.9 kg, followed by Hungary with 35.1 kg and Turkey with 30.5 kg (Faostat, 2023).

Table 4. Planted area of fruitful orchards in 2014 – 2022 (ÚKSUP, 2023)

Area	*Malus domestica* [ha]								
	2014	2015	2016	2017	2018	2019	2020	2021	2022
SR	2,557	2,376	2,311	2,179	2,137	2,063	1,804	1,644	1,540
SK011	224	240	248	239	236	263	274	230	251
SK021	420	446	436	397	400	379	377	334	309
SK022	647	631	621	642	642	609	455	445	429
SK023	684	596	588	504	526	465	417	393	362
SK031	38	31	7	6	8	8	13	7	12
SK032	97	87	90	70	73	89	69	72	80
SK041	69	51	30	31	32	32	38	59	30
SK042	376	287	292	288	220	217	162	103	68

Table 5. Total harvest in 2014 – 2022 (ÚKSUP, 2023)

Area	*Malus domestica* [tonnes]								
	2014	2015	2016	2017	2018	2019	2020	2021	2022
SR	48,494	46,250	20,722	32,478	43,929	35,185	28,429	29,586	31,068
SK011	8,073	9,399	8,768	10,931	12,960	12,546	10,791	12,390	13,091
SK021	12,372	11,838	6,422	9,436	10,911	11,031	6,883	7,634	7,817
SK022	14,233	10,007	1,679	4,295	9,534	5,713	5,718	4,789	5,311
SK023	11,973	10,966	3,374	6,936	9,230	5,114	4,342	4,305	3,993
SK031	955	1,011	1	2	12	3	4	10	16
SK032	481	675	150	150	691	363	498	351	690
SK041	157	128	236	59	130	158	96	16	117
SK042	251	2,226	92	669	461	257	98	102	33

CONCLUSION

In the contribution, we focused on the assessment of climatic factors and the associated onset of the BBCH 65 phenological phase, where the onset of flowering in the last period 1991–2020 is visibly earlier than in the past. With this fact, the risk of frost also increases, which is several times higher due to early flowering, especially up to the 10th day from the onset of BBCH 65. Even though it is warming, cold air masses still reach our area in the spring and can cause damage, which also affects the harvest, as can be seen in our analysis. Therefore, in orchards, it is necessary to pay more attention in the spring months and use anti-freeze protection (anti-freeze irrigation, paraffin candles, etc.) and when planting new orchards, use suitable locations and more resistant types of fruit trees. Based on this analysis (climatic and economic factors), it is necessary to focus on sustainable and efficient fruit growing.

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