Scientific Papers. Series B, Horticulture. Vol. LXIX, No. 2, 2025
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

DYNAMICS OF CLIMATIC ACCIDENTS DURING PEACH, APRICOT, AND CHERRY DORMANCY AND FIRST GROWTH STAGES IN THE LAST 20 YEARS IN ROMANIA

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Abstract

The paper analyzes the impact of climate change on the 20-year frequency of climatic accidents and the intensity of damage to apricot, peach, and sweet cherry flower buds in the continental climate of Romania. There was a rise from 2004 to 2023 in winter minimum temperature and mean temperature, especially in February, March, and April. Between 2004 and 2023, climatic accidents were registered in Romania in 14 years during the dormancy or in the first growth stages, i.e. damages caused by late frosts in 9 years, in three years (2006, 2010, and 2012) frosts below the hardiness limit of some fruit species causing damages during dormancy, and also in three years (2004, 2015, and 2016) bud damages caused by thermal oscillation in the dormant season (35-40°C in only 2-7 days). In 7 of the 20 analyzed years, the damages caused to the flower buds of some cultivars were major. Although until 2016, damages caused by frosts and thermal fluctuations in the dormancy season prevailed, since 2017, in six out of seven years, the damages were caused only by late frosts.

Key words*: winter minimum temperature, late frost, thermal winter oscillations, flower buds.*

INTRODUCTION

Since the climate strongly restricts fruit species' distribution and productivity (Chitu et al., 2016), plants have developed a series of strategies to adapt and deal with less favourable or even adverse environments over time. Such adaptation in the case of temperate species was the temporal distribution of development and growth phases, under the control of environmental factors such as photoperiodicity, solar radiation intensity, temperature, soil, and water (Sherman & Beckman, 2003). Among them, temperature controlled physiological processes during the vegetative season, dormancy during the winter, and vegetation onset (Łysiak & Szot, 2023).

Changing world patterns of climate, with seasonally uneven warming reported in Europe, characterized by winter and spring months warming twice faster compared to summer or autumn months (Zohner & Renner, 2019), could results in a redistribution of fruit species, but also, through phenology shifting (Zohner & Renner, 2019). The resizing of the vegetative growth season may expose them to certain conditions of stress/climatic accidents with repercussions on yield quality.

Global warming had different and even opposite consequences depending on the geographical area (Kopecka et al., 2023), from the increase of thermal and radiative stress, the insufficient accumulation of cold hours during dormancy, followed by the start of uneven vegetation, or contrarily, more rapid chilling accumulation correlated to early vegetation onset, the increase (or sometimes the reduction) in the frequency and intensity of climatic accidents such as early autumn frosts or, on the contrary, frosts late spring (Zahradníček et al., 2023).

In temperate zones, under the influence of environmental signals, fruit species enter

dormancy, when cold hardiness develops through gradual exposure to freezing temperatures as a plant's strategy to protect its meristematic tissues (Hermawaty et al., 2024). Depending on the moment in the rest period and exposure to freezing temperatures, the tissues of the trunk, branches, and flower buds acquired different degrees of cold hardiness, and the heating episodes during the winter could result in dormancy offset (Moran & Ginakes, 2024). During warm spells, cambium was found to be the most vulnerable to loss of cold hardiness (especially in S or SW trunk exposures), and almost as sensitive was the phloem. At the same time, xylem damage was very rarely reported (Moran et al., 2021). Endo-dormant floral buds had the highest cold hardiness at the opposite pole (Moran & Ginakes, 2024).

Therefore, a time characterized by higher-than-normal temperatures during winter could stimulate the activity of some plant tissues, leading to their hydration and loss of hardiness (Chitu et al., 2014). In these conditions, the subsequent decrease in temperature, or rather the restoration of normal climatic conditions, led to serious consequences because, if floral buds damage was only reflected on the fruit yield of the year in which it occurs, damage to the trunk, even if it was not severe enough to kill the trees, could have long-term effects (Sheppard et al., 2016) as once a tree was damaged, wounds were vulnerable to fungal and insect attack (Houghton et al., 2024).

Secondly, the milder winters lately have created the conditions for the species' need for cold to be fulfilled as early as December in the last decade. After completing the necessary cold (endo-dormancy), the plants enter eco-dormancy, which is controlled by the air temperature. In this phase, at least six consecutive days with temperatures above the basal limit of the phenophase, which is species/cultivar-specific, were required for vegetation onset (Łysiak & Szot, 2023).

The sensitivity to negative temperature of fruit species increased with the advancement of the phenological stages, and late frosts were frequently recorded during the bud-break period or flowering. The intensity of the damage resulted from the intersection between the level of sensitivity to negative temperatures of the floral organs and the size of the reduction in air temperature below their frost resistance limit. Regarding the reproductive structures, stigma, style, and the flower stalk/peduncle in high mountain plants were the most frost-susceptible (Neuner et al., 2013).

Sweet cherry occupied the third place (as surface) in Romania, after apple and plum, while apricot and peach were placed in the 5th and 6th positions (unpublished data). Sweet cherry frequently found favourable conditions except for the mountainous areas, especially in the NE, SE, and S areas. The maximum thermal suitability for the peach was concentrated in the SE and S, and the apricot encountered in the NE, E, SE, and S even more favourable conditions than sweet cherry and peach. Previous studies indicated that in Romania, orchards frequently dealt with late spring frosts, and their effects became more and more severe due to the spring phenological advance (Chitu et al., 2016; Florea et al., 2019). Starting from these observations, the present study aims to analyse the damage recorded in Romania's peach, apricot, and sweet cherry orchards during temperature deviation from normal in the winter-spring period.

MATERIALS AND METHODS

The study was carried out in the experimental field of Research Institute for Fruit Growing Pitesti (RIFG), Arges county (Maracineni, Southern part of Romania, 44°53’56” N, 24°51’35” E) and in other eight Research Stations and orchards located in Baneasa (Bucharest, in S-SE, in the Romanian Plain; 44°30’05” N, 26°04’13” E) and Moara Domneasca (44°29’45” N, 26°15’09” E), Constanta (Valul lui Traian, in South-East; 44°10’03” N, 28°29’31” E), Bistrita (in North, in the Transylvania Plateau; 47°10’01” N, 24°29’50” E), Iasi (in North-East; 47°13’29” N, 27°09’41” E), Dabuleni (Dolj, in South; 43°47’48” N, 24°03’47” E), Valcea (in the hilly area of the Southern Carpathians, 45°08’26” N 24°22’01” E), Voinesti (Dambovita, in the Southern area of the Southern Carpathians, 45°04’58” N, 25°14’22” E), Targu Jiu (Gorj, in the area of the Getic Subcarpathians; 45°02’26” N, 23°18’58” E), Falticeni (Suceava, in North-East; 47°27’08” N, 26°17’39” E), and Cenad-Timis (in East; 46°06’03” N, 20°35’35” E).

A phenological stage database consisting of observations made for sweet cherry, peach, and apricot cultivars grown in the above-mentioned field trials and in different orchards from Romania was used, i.e., bud swelling (51 BBCH), bud burst (53 BBCH), beginning of flowering (61 BBCH), end of flowering (69 BBCH), and young fruit (71 BBCH).

For temperature dynamics, the weather data were determined in a fenced meteorological platform, 25 m × 25 m, at 44º53'53.42'' North, 24º52'03.55'' East, and an altitude of 287 m a.s.l, during 2004-2023, from an automatic weather station, WatchDog 900ET, from Spectrum Technologies Inc., USA. From December 1 to May 31, the weather variable used was air temperature, which was measured at 10-minute intervals by sensors in the automatic weather station.

Starting from the multiannual (1969-2022) database, temperatures (minimum, maximum, and mean) multiannual averages in the Pitesti-Maracineni area were calculated, and their evolution was studied starting from 2004 for the next 20 years. Winter low temperatures and late frost events, especially those preceded by an unusual increase in temperature related to trees' phenology and frequency, were presented. To appreciate the low temperature impact intensity on sweet cherry, peach, and apricot, orchard and laboratory observations were performed, i.e., damages on S or SW exposure of the trunk and of the fruit buds, flowers, and young fruits, following the protocol proposed by Larsen (2009). The negative critical temperatures for fruit species, below which damage to the fruit buds/flowers/fruits was considered to occur, were those presented by Muray's (2020) study.

Linear regression equations and their statistical coefficients have been calculated for temperatures and phenological data with MS Office EXCEL and IBM SPSS Statistics version 20 software. Therefore, the trend of the decadal averages of the minimum and maximum temperatures, as well as the differences between the maximum and minimum temperatures of two successive pentads during the 2004-2023 winter and spring months and the evolution of the species' first four phenological stages, were presented and discussed.

RESULTS AND DISCUSSIONS

Temperature trends 2004-2023

To observe the amplitude and frequency of temperature oscillations during the wintertime in the Pitesti-Maracineni area, the decadal trends of the minimum and maximum temperatures in the December-May interval were analysed (Figure 1). As presented, there were wide oscillations, especially of the maximum temperature trends between December and the second decade of March, followed by a much lower value of trends until the end of May. The maximum temperature showed an increasing trend in most of the analysed decades, interrupted by a decrease in the first decade of December and stagnation or a very slight decrease in the second decade of January, but also after the second decade of March. Significant is the upward trend of 3.2°C per decade in mid-February. This was an early warning signal because rising temperatures can stimulate the vegetation onset, especially with the warm end of February and the beginning of March, or it could just activate the cambium, exposing the trunk of the trees to further normal low temperatures during winter.

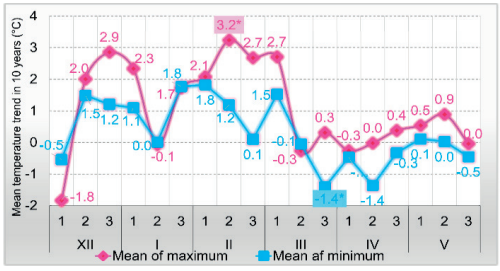

Figure 1. Decadal trends of minimum and maximum temperatures in Pitesti-Arges (Maracineni) in the December-May interval (2004-2023)

The minimum temperature oscillations were smaller than the maximum temperature in the first half of the analysed interval. The minimum temperature also increased in December, January, February, and the first decade of March. However, a slight cooling tendency was still observed in early December, followed by stagnation in January's second decade and March's third decade.

This warming trend may contribute to the earlier accumulation of cold hours during deep dormancy, making the species sensitive to subsequent temperature increases above the basal threshold. Thus, the onset of vegetation could occur. The consequences are fruit bud damage, especially since, as the graph indicates, in the third decade of March there is a significant decrease in air minimum temperature of 1.4°C per decade, followed by a second minimum temperature decrease in mid-April, when the sweet cherry are usually at least in bloom, peach at BBCH 69, and apricot even more advanced.

Increases in maximum temperature during the winter in conditions of a stagnant minimum (if not even in a slight decrease) could reduce the frost resistance of the trees and have more serious effects, as the thermal amplitudes can even reach 35-40°C in Pitesti - Arges (Maracineni). As a result of maximum and minimum temperatures trends (sometimes even opposite), a significant increase in the frequency and amplitude of thermal oscillations occurred in the analysed December-February period.

The warming of the winter (by increasing the maximum temperature in February and early March), determined a general tendency of earlier occurrence of flower and fruit development phenology accentuated for early stages (especially BBCH 51) and more temperate (with a small and insignificant slope) for the beginning and end of flowering (BBCH 61 and 69).

In sweet cherry ('Gemersdorf' cultivar, Figure 2), a significant advance of almost 10 days per decade was registered for vegetation onset (BBCH 51).

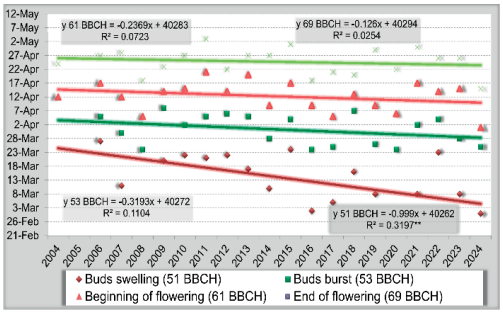

Figure 2. Linear relationships between the time to onset date (TOD) of the four phenology stages and the year of study for the 'Germersdorf' sweet cherry cv. (Pitesti, 2004-2024)

At the same time, bud breaking, beginning and end of flowering were not significantly delayed, and the advance recorded for the three phenophases was low (three days, 2 days, and one day, respectively).

For peach ('Filip' cv., Figure 3) a greater phenological advance was registered compared to the cherry, very significant for BBCH 51 (almost 12 days per decade), distinctly significant in the case of BBCH 53 (10 days per decade) and also very significant for BBCH 69 (9 days per decade). Still, the beginning of flowering (BBCH 61) showed a non-significant tendency to produce earlier by 5 days per decade, probably because this thermophilic species finds unfavourable conditions in the second decade of March, while in April it is still uncertain from a climatic point of view.

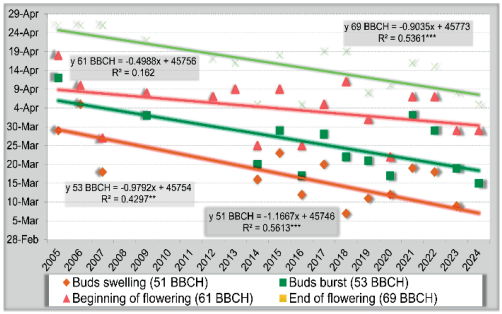

Figure 3. Linear relationships between the time to onset date (TOD) of the four phenology stages and the year of study for 'Filip' peach cv. (Constanta, 2005-2024)

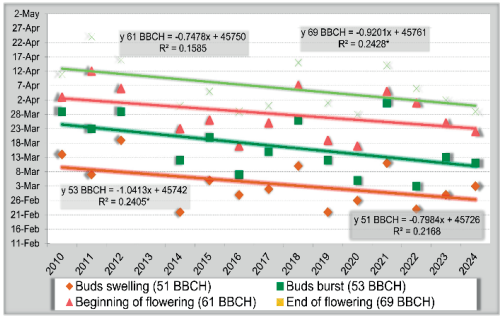

Figure 4. Linear relationships between the time to onset date (TOD) of the four phenology stages and the year of study for 'Elmar' apricot cv. (Constanta, 2010-2024)

The trends of the four phenological phases of the apricot (Figure 4) are somewhat similar. However, their statistical significance differs, as only BBCH 53 and 69 showed significant

advances of 10 and 9 days, respectively. Although there was a trend towards the earlier occurrence of BBCH 51 and 61, on the background of temperatures with wide oscillations from one year to another, the advance of 8 and 7 days was insignificant, respectively.

Analysis of climatic accidents from 2004 to 2023

2004

In 2004, the highest mean air temperature in the second pentad of the last 35 years was recorded (12.9°C, February 6), when the maximum air temperature reached 18.3°C on February 6 and 18.6°C on February 7. These very high temperatures, although they did not cause bud swelling, contributed to a decrease in the trees' frost resistance. After only 6-7 days, on February 13, the average air temperatures dropped to -13.4°C (0.3% probability to register a lower temperature in the third pentad). The minimum temperature decreased to -21.7°C (0.1% probability to register a lower temperature). As a result of these exceptional phenomena, the fruit buds of peach and apricot froze (99.5% and 99.8% damage, respectively). Peach vegetative buds also froze at the top of the crown (53%) but mostly at the base of the crown (100%) (Chitu et al., 2004).

2006

January 2006 differed significantly from the previous months by very low temperature, close to the absolute minimum of the area (-24.4°C, recorded on January 13 and 17, 1985). The coldest interval was January 24-26, when the minimum temperature dropped below -20°C. On the 24th, -23.3°C was recorded in the air, the second lowest value after the station's absolute minimum of -24.4°C. If the absolute minimum occurred in the middle of the month, the lowest minimum air temperatures since January 2006 were recorded in the third decade. Therefore, the air temperature of -23.3°C was the lowest value in the third decade of January in the last 38 years (1969-2006) and led to 83% flower bud damage in sweet cherry (Budan et al., 2006).

2008

In 2008, after high temperatures in February and March, which hastened the vegetation onset, very low minimum temperatures appeared in the sixth pentad of March, culminating with -5.6°C in the morning of March 27. The sudden drop in the minimum air temperature occurred after three days with very high average and maximum temperatures (daily P≤85%) for this period (the maximum on March 23 was 19°C, on the 24th 19.1°C and the 25th 17.6°C), with intense sunshine and very low atmospheric humidity of 34-35% (daily P≤3-4%). Although sweet cherry was not in bloom (advanced bud breaking, 55 BBCH single flower buds visible, still closed, borne on short stalks, green scales slightly open), the ovules were affected (Chitu et al., 2010), and up to 96% of sweet cherry yield was compromised in Pitesti.

2009

As a result of very low temperatures (-3.4 to -6.0°C) in the last decade of April 2009, in many areas of the country, damages caused by late frosts on flowers, young fruits, and shoots of most fruit tree species were observed. Thus, after March 30, in Pitesti-Arges (Maracineni), the maximum air temperature rose to over 15°C in 21 days out of 24 and to over 20°C in 11 days, with a maximum of 23.9°C. In the same interval, the minimum temperatures did not drop below 1.2°C; in 9 days out of 24, they were higher than 6°C.

On the night of April 23 in Pitesti-Arges (Maracineni), although the temperature in the weather shelter only dropped to -1.7°C, outside the shelter, at the frost sensors, it decreased to -3.4°C (at 2 m from the ground) on dry bulb and to -4.2°C on a wet bulb. Sweet cherry flowers (falling petals, 66 BBCH) were massively affected (100%). In Baneasa-Bucharest (-2°C air temperature, -4°C soil surface temperature), damage to young fruits (70 BBCH) reached 40% in cherry, 70% in peach, and even 95% in apricot. In Constanta (-3°C in the air and -6°C on the surface of the soil), damage to young fruits (70 BBCH) in sweet cherry rose to 35%, in peach it was 85%, while apricot was affected in a slightly lower proportion of 80%. In Falticeni-Suceava (-2.5°C in the air and -4.2°C on the ground), the damage recorded to the sweet cherry (67 BBCH) was 48%.

2010

In Pitesti-Arges (Maracineni), after a first half of January 2010 warmer than normal (minimum

temperature probabilities of up to 95% and in 9 days out of 20 of over 80%), starting from January 21, temperatures dropped suddenly. They remained at this level for 8 days. The coldest period was reported on the 25th at 5 a.m., when the temperature outside the meteorological shield dropped to -23.9°C, being only 0.5°C higher than the absolute minimum of the station, -24.4°C, and in the shelter to -22.6°C. On January 25 and 26, the air temperature outside the meteorological shelter remained below -20°C for almost 24 hours. Under these conditions, the losses in the sweet cherry orchard (00 BBCH, Figure 5) rose to 73% (Budan et al., 2010).

Figure 5. Low winter temperature damages the tree trunk and flower buds (2020)

2012

As a result of very low temperatures in January and February 2012, frost damage to the vegetative and generative organs of tree species was reported in many areas of the country. In Pitesti-Arges (Maracineni), the lowest air temperatures were recorded in a short period: the first cold wave between January 29 and February 2 (with minimums between -17.5 and -20.1°C) and the second between February 9 and 11, 2012, with even lower temperatures (minimums between -18.1 and -23.4°C), while the temperature recorded at the surface of the snow layer dropped down to -27.1°C. Among the 9 locations analysed, the highest temperatures in the two intervals were recorded in Constanta (-17.4°C and -17.6°C), and the lowest in the second cold wave in Dabuleni-Dolj and Falticeni-Suceava (-27°C).

The calculation of the probability of occurrence of very low air temperatures in February in Pitesti-Arges (Maracineni) indicated that the value of -23.4°C represented the lowest temperature recorded in the last 44 years (the absolute minimum of February so far was -22.1°C, recorded on February 14, 1985). Phenologically, the species had accumulated the necessary chilling and were going through eco-dormancy. However, even under these conditions, the damage produced at Pitesti by the low temperatures reached the maximum threshold of 100% for some sweet cherry and peach cultivars. Damage was recorded in the orchard by affected fruit buds of up to 100% in cherry, 46.4% in apricot, and especially in peach, where the losses were (100%).

The frosts at the end of January and the first decade of February 2012 caused the greatest damage to peach and apricot species in the Dabuleni-Dolj area (minimums of -24.3°C on January 31 and -27.0°C on February 1) by freezing all fruit buds and annual branches. In Baneasa-Bucharest (minimum of -22°C on January 29 and -24°C on February 9), for the same species, flower buds were affected in maximum percentages of 92%, and the damage to the annual branches rose to 35%.

2014

Due to the warming trend of November 2014, which favoured the accumulation of more than 900 chilling hours (between 0°C and 7°C) by the end of December, severe tree stunting may have occurred at the end of December 2014. In the last decade of December 2014, the minimum negative temperatures of the day varied between -0.6°C and -5.0°C, with the absolute minimum of -20°C on December 31. Even if the negative temperatures were maintained in the first decade of January **2015**, reaching the absolute minimum of -19.6°C on January 8, they did not affect the flower buds, while the species were in deep rest on that date. Warm periods in December, followed by a drop in temperature at the end of December and beginning of January, were also recorded in other regions of the country. However, no damage was reported, as the trees were still in vegetative rest.

In the southeast of the country, in Constanta, the minimums of -10.4°C in the third decade of December 2014 and -16.1°C in the first decade of January 2015 were preceded by maxima of 12.2°C and 16.0°C in the last two decades of December 2014. Under these conditions, damage that reached 14% in apricot and 15% in the peach was recorded (both species being at that time in the early phenophase of bud swelling, 51 BBCH).

2016

2016 started after a warm autumn, with maximums of up to 22.1°C. The first and last decade of December 2015 were characterized by high temperatures, with maximums of up to 16.4°C and 19.7°C, respectively, and were followed by a sudden drop in temperature to minimum values from -10.1°C to -14.9°C between 29 December 2015 and 5 January 2016. At the end of December, over 900 chilling hours had been accumulated, so that between January 11 and 14, a slight warming with maximums of 9.1-13.8°C, followed by a second wave of low temperatures between -11.8°C and -17.3°C between January 17 and 25, made the trees strongly susceptible. Maximum damage recorded for eco-dormant species rose to 35% in peach, 50% in apricot, and 73% in cherry.

Subsequently, the warm February 2nd and 3rd decades (with maximum rising to 22.2°C) and the first March decade (with a maximum of 17.3°C) were followed by a thermal decline on March 17 to -4.2°C. Since phenological, at that time the peach and apricot were at the stage of pink petals, and the cherry at bud breaking (53 BBCH), following that frost episode, additional damages of 35% were recorded for the cherry, 60% for the peach, and 95% for the apricot.

2017

In Pitesti-Arges (Maracineni), the low temperatures of January 2017 (negative average and minimum values down to -21.3°C) and the close-to-normal February from a thermal point of view were followed by a marked warming in March (with maximums up to 24°C) and in the first half of April (maximum of 22.6°C), which determined a phenological advance of the species and exposed them as a result of the effects of frost late from the last pentad of April. The phenological stage of the three species, young fruit, made them susceptible to damage in a percentage of 10% at the drop in temperature starting from the threshold of -2.2°C and 90% at 3.9°C.

The first exposure was on April 21, when temperatures were below -2.2°C (the 10% damage threshold) and the absolute minimum dropped to -3.2°C. The next exposure to critical temperatures for the species was on April 22, when the minimum reached -4.2°C (outside the radiation shield), exceeding the 90% damage threshold (3.9°C).

Sweet cherry, in a very advanced phenological phase of young fruit (70 BBCH), was very intensely affected in Voinesti-Dambovita (-4.3ºC, 95% frozen fruits) and in Pitesti-Arges (Maracineni, Figure 6), where the percentage of damaged fruits rose to 91%, but very little in Baneasa-Bucharest (-1°C) and Iasi (-0.5°C), except 'Regina' cv. with 85% affected flowers. The damage recorded in the peach was also very high due to the high sensitivity of young fruit to frosts. In Valcea, peach yield was totally compromised, and in Pitesti-Arges (Maracineni), the damage was lower (84%). Without data from Constanta, the lowest damages were registered in Iasi (65%). In the same phenophase of young fruit (70 BBCH), the apricot was totally affected in Voinesti-Dambovita and Valcea. Apricot damages rose to 80% in Baneasa and exceeded 85% in Iasi.

Figure 6. Ice on flowers and young fruits, in the morning of April 21, 2017, in Pitesti-Arges (Maracineni)

2018

In 2018, the interval with very high temperatures (average, maximum, and minimum) that started on the first days of February was interrupted for 5 days between February 25 and March 1, when the lowest minimum temperatures of the winter 2017-2018 were reported. In these circumstances, a single climate accident with significant negative effects from the beginning of the growing season was recorded. In Pitesti-Arges (Maracineni), on March 1, a record minimum temperature for March in the last 50 years of climatological observations was registered, i.e., -19.8ºC (-24ºC outside the radiation shield), a temperature by 0.3ºC lower than the absolute minimum of the month (1969-2017).

The greatest damage recorded during this period occurred in the apricot and peach orchards, which were in the phenophase of bud swelling (51 BBCH), respectively, at the onset of bud swelling, and in the cherry, which, similar to the peach, was also at the onset of bud swelling.
The damage reported in the northeast of the country, in Iasi, for apricot rose to 85% of fruit buds affected, while for peach the damage was only 20%. In the southeast, in Constanta, as a result of the frost on March 1 (-13.3ºC) and the glaze ice (-5.7ºC) on March 19-20, fruit bud damages of 30% in peach and 52% in apricot were found. In the south, at Dabuleni-Dolj, the percentages of fruit buds affected by the frosts between February 27 and March 2 (-17.6ºC) rose to 80% for apricot and 10% for peach. In Pitesti-Arges (Maracineni, -24ºC outside the radiation shield on March 1), for peach, the maximum percentage of affected fruit buds was 59%, and for sweet-cherry it reached 42% due to the frost.

2019

In 2019, the warm period in February (with highs rising to 19.2ºC) and March (highs of 23.6ºC) favoured a phenological advance in both March and April, months in which three episodes of late frost occurred.
The first such event was recorded on March 28, when in Pitesti and Constanta the peach and cherry were in the budding phenophase (53 BBCH, -3.9ºC), and the apricot in the flowering phase (BBCH 65, -2.7ºC). The very low temperatures since the morning of March 28, 2019 (below -5ºC, and even -7.3ºC in Targu Mures and -6.4ºC in Jimbolia), recorded in other localities in Transilvania, but also in Banat, which fell below the critical temperatures of the phenophases experienced by the species, could affect, locally, the flowers of the apricot species and the peach and cherry fruit buds. On March 29, the second event had a lower impact on the trees, with the recorded minimums dropping only to -4.9°C (at Targu Mures).
The subsequent increase in temperature favoured the phenological advance. Thus, in the first week of April, in Constanta, the peach and the cherry were in the phenophase of flowering (63 BBCH), and the apricot was going through the end of flowering (69 BBCH). Between April 3 and 7, very low minimum temperatures were recorded in Constanta, from -4.1ºC on April 3, to -5.1ºC in the morning of April 6. Under these conditions, damages of 96% to peach flowers were estimated. In apricot, the damage was maximum (with 100% frozen flowers), and in cherry, 65% of the flowers were affected by frost.
Temperatures below the critical thresholds of the current phenophase were recorded in the morning of April 4 in other localities in the south-eastern area of Romania (especially in Tulcea -4.3ºC and Grivita -4.1ºC).

2020

The first months of 2020 were characterized by above-normal average temperatures, especially February and March. This warm period stimulated the start of vegetation and determined a phenological advance of the species (14 days for cherry in the Pitesti area). In the South and East of Romania, starting on March 16 and ending on April 7, there were five waves of late frosts with temperatures below the minimum critical thresholds (10% damage) of the current phenophases, for almost all fruit tree species. In many cases, even critical thresholds were reached for damage of more than 90% of floral organs. The event was seconded in the south and east of Romania, by a drop in temperatures in March to -7.1°C, followed in April by a thermal decline to -3.9°C.
In the first such frost (March 16-17), the temperatures dropped below the threshold of 10% damage to the cherry (53 BBCH) and to the peach in the pink button phenophase (57 BBCH), even exceeding the temperature of -4.4°C (the thermal threshold for 10% damage to the apricot in the white button stage, 57 BBCH). The minimum temperature exceeded -6.2ºC (March 16), dropping to -7.1ºC on March 17.
The damage caused by the first wave of late frosts on March 16 and 17 was accentuated by the fact that they followed two weeks of exceptionally high temperatures (higher than 90% probabilities on 9 days out of 14. During this interval the highs culminated in 23.3ºC on March 13 (99% probability, higher values occurring only once in 100 of years), so that after 3 days the temperatures drop to -6.2ºC and the next day to -7.1ºC (3% probability, lower

values being registered only once every 33 years), the thermal oscillation being 30.4ºC.
The warm period from March until March 21, between March 26 and 30, and daily highs of up to 17.1 ºC, favoured the phenological evolution. On top of these conditions, during the first 7 days of April, there was a period with minimums lower than the damage thresholds due to late frosts in the three species. Thus, on April 1, the minimum dropped to -5ºC (2% probability, lower values once every 50 years), on April 3 to -4.2ºC (≤3% probability), and on April 7 to -4.0ºC (≤2% probability).
The peach from Pitesti in the pink button phenophase in mid-March and flowering between April 1 and 7 was insignificantly affected (2-3%) by the low temperatures. The cherry tree, very advanced phenologically, 53 BBCH in the middle of March (2 weeks earlier than the multiannual average), when in standard years the flower buds were barely swollen and at the beginning of flowering on April 7 (April 15 being the average date of this phenophase), recorded heavy damage of more than 90% affected flowers.
In Iasi (-4.9ºC on March 16 and -3.0ºC on March 17, 95.5% damage was reported to the apricot in full bloom (65 BBCH), 39.5% to the peach (pink button), and 56.7% to the cherry (swelling buds, 51 BBCH). In Falticeni-Suceava (-5.0ºC on March 16, respectively -3.0ºC on March 17), damage to the cherry species (bud swelling, 51 BBCH) was 15.0%. In Voinești-Dambovita (-2.3ºC on March 16 and -4.3ºC on March 17), 20.0% damage was reported to cherry (swelling buds), 95% to apricot (full bloom), and 25% to peach (beginning to bloom). In Bistrita, the minimum temperature of -3.8ºC recorded on the night of April 15 - 16 was below the threshold for damage to fruit buds, and major damage was recorded to cherry trees (100%).

2022

The warm period in the first two months of 2022 (average temperature of 3°C above normal in January and 4.6°C in February) preceded the temperature drop in March to lows of -9.3°C and then -3.8°C in April. A first frost episode occurred between March 9 and 20, which culminated with lows of -9.3°C (March 12), exceeding the 10% damage threshold for cherry (in the advanced swelling phenophase) and peach (red calyx) as well as the 90% damage threshold for peach (pink button) and apricot (white button).
Between March 21 and April 3, there followed a similarly warm period, with maximum temperatures between 11.8 and 22.1°C, followed by the second episode of frost, which consisted of a drop in temperatures on April 4 and 5 to a minimum of -3.8°C, when the phenophases passed were white button for cherry and beginning of flowering in the case of peach and apricot, the species being therefore susceptible to damage in proportion to 10%.
A third wave of high temperatures was recorded between April 6 and 17 (with maximums between 10.8°C and 24.1°C in the Maracineni Arges area), followed by the third episode of frost, in which there was a drop in temperature between April 18 and 20, in the phenophase of petal fall in cherry and young fruit in peach and apricot. This episode was reported only in certain regions of the country. -2.0°C was reported in Bistrita and Iasi on April 19, which did not cause damage. In Botosani, -5.8°C was recorded on April 18 and -3.0°C on April 20, with damage of 40% to the cherry in full bloom and 50% to the peach and apricot in the young fruit stage.
In Pitesti-Arges (Maracineni), the losses of fruit buds/flowers in the cherry species were 52% due to the first two periods of frost. In Baneasa, at the Baneasa Experimental Base, the losses were 30% in apricot (young fruit) and 55% in cherry (petal fall). At the Moara Domneasca Experimental Base, the losses were 80% for apricot (young fruit), 28% for peach (young fruit), and 12% for cherry (full bloom). In Iasi (-2.0°C), the losses were 40% for cherry (full bloom), 50% for apricot and peach (young fruit). In the southern area of Botosani County and the northern area of Iasi County (-5.8°C), cherry losses (full bloom) were maximum (100%). At Targu Jiu (-3.0°C on April 21), it affected the cherry (full bloom) insignificantly. In Voinesti (-1.8°C), the loss of flowers was 25% for cherry (the beginning of flowering). In Bistrita, no damage was recorded under a minimum of -2.0 degrees for the same species (cherry) (white bud and beginning of flowering).

2023

2023 started very warm (average monthly temperature almost 5°C higher than usual). Moreover, increases in the average temperature were also recorded in the other months that preceded the flowering. Except the warming in the first eight days of January (with maximum between 10.4°C and 20.3°C), and the 18-21 January interval (maximum of 16.2°C), temperatures favourable for the vegetation onset (over 10°C) were recorded starting from the second half of February almost every day, simultaneously with the decline of the negative temperatures. In March, in 24 of the first 30 days, the maximum temperature was 10.3-21.7°C, encouraging the start of the vegetation.

By lowering the minimums on March 30 to -6°C (temperature measured outside the radiation shield) and the persistence for about an hour of temperatures below -5.5°C, the limit temperatures for 10% damage to cherry trees in advanced swelling, and even the limit temperature for a percentage of 90% damage to flowering peach, were exceeded. In these conditions, relative to the limit of frost resistance of the fruit organs (Muray, 2020), the apricot, at the petals fall, was even more affected than the peach and sweet cherry. In Pitesti-Arges (Maracineni), fruit bud/flower losses rose over 85% in the sweet-cherry orchard (61 BBCH) and peach (65 BBCH-full bloom).

In Baneasa-Bucharest (-5.0°C on March 30) the damage was maximum on sweet-cherry (BBCH 61) and apricot, and when exposed to -5.3°C (Moara Domneasca-Bucharest), the cherry lost 50% of its buds (green bud), the peach 90% (65 BBCH full bloom), and the apricot 100%. In Bistrița (-4.3°C/March 29, -5.9°C/March 30), cherry losses were 80% (green button). In Constanța (-4.0 degrees/March 30), damage to cherry (white button) was 40%, to peach (blooming) 64%, and to apricot (petal shaking) reached 72%. In Iasi (-2.0 degrees/March 28 and 29), damage was lower for peach (16%, at flowering), compared to apricot (30% at the end of flowering). In Voinesti-Dambovita (-6.8 degrees/March 30), 25% of the cherry buds were affected (advanced swelling/bud breaking). In the east of the country (Cenad-Timis, -4.2 degrees dry bulb/-5.6 degrees Wet bulb), the damage rose to 50% for cherry (flowering onset), and in peach and apricot, the losses were maximum (full bloom).

CONCLUSIONS

The impact of climate change on 20 frequencies of climatic accidents and damage intensity to apricot, peach, and sweet cherry flower buds in the continental climate of Romania was analysed. In 20 years of study, 14 climate accidents occurred, all preceded by warmer periods compared to normal. Out of the 14 events discussed, nine were damages caused by late frosts. Six occurred during the dormancy period: three (2006, 2010, and 2012) of them were frosts below the hardiness limit of some fruit tree species causing damages during dormancy and in other three (2004, 2015, and 2016) bud damages were reported, caused in the dormant season by very high thermal oscillation (of 35-40°C) in only 2-7 days. Among the six accidents during the dormancy (4 in January and 2 in February), in five the air temperature dropped below -20 degrees, and in 3 it was even lower than -23 (and one of them occurred in February, when -27 degrees were recorded on the snow surface). Two of the winter low temperatures were preceded by a rapid temperature drop of 39.2°C in 7 days (2015) and 34.6°C in 3 days (2016). Of the 9 late frosts, seven occurred in March (the lowest temperature was -20.4°C/March 1, 2018, 51 BBCH) and five in April (with a minimum of -5.8°C/April 18-21, 2022). The most damaging event was the late frost of April 21-22, 2017 (70 BBCH), when fruit yield was compromised for all three studied species. An alarm signal could be raised because there was a statistically guaranteed trend of warming in February (and therefore earlier stimulation of vegetation onset). However, the temperature remained the same in the following two months or decreased slightly. Therefore, the danger of late frosts will increase in the future in Romania, which requires the judicious choice of species and cultivars suitable for each pedoclimatic condition and the timely adoption of adequate frost protection measures.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Romanian Ministry of Agriculture and Rural Development. It was financed from Project 'Updating the suitability of Romania for fruit species to climate changes', Project Number ADER 6.3.3/2023, and Project 'The use of autonomous energy systems for digitalization of technological sequences specific to precision fruit growing', Project Number ADER 6.3.23/2023.

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