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CHANGES IN SPRING PHENOLOGY IN APPLE TREE AND ITS RESISTANCE TO LATE FROST UNDER THE CLIMATE CONDITIONS OF STANESTI AREA, ARGES COUNTY, ROMANIA

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Abstract

This paper aimed to analyze the variability of spring phenophases in the apple species, the 'GoldRush' cultivar to analyze the risk of spring frost for apple production in Stănești area of Argeș County (45°13'44"N, 24°50'9"E, altitude 540m), Romania, and the role of phenological acclimatization. The timing of phenological stages is made according to the definitions of the Biologische Bundesanstalt, Bundessortenamt, and CHemical industry (BBCH). Based on Julian day number, on average for 4 years, the phenophases occurred from the 85.54 day of year, marked by "beginning of leaf bud swelling/inflorescence bud swelling" (BBCH 01/51), until 1the 23.36 day of year for phenophase "end of flowering" (BBCH 69). Analyzing the data obtained, they allowed us to assess the temporal trends of development of budding and flowering phenophases and the trends of risks in the light of global warming. The research will be continued in order to analyze a longer period of time and to analyze different cultivars, in order to achieve sustainable and competitive fruit crops.

Key words: *apple, frost resistance, phenology.*

INTRODUCTION

Plant phenology is a fundamental bioindicator of climate change (Cosmulescu et al., 2010; 2018). From a phenological point of view, the main reaction to climate change is considered to be the increase of the duration of vegetation season (Menzel et al., 2002), respectively, an occurence of spring phenophases. Orchards are an important resource for the study of phenology (Cosmulescu et al., 2010). According to Eccel et al. (2009), in the context of global warming, the general trend towards earlier flowering dates of many temperate tree species is likely to result in an increased risk of damage from exposure to frost. Climate accidents such as spring frosts are among the most important causes of yield loss in fruit orchards in temperate regions (Snyder et al., 2005). Like many fruit tree species, the apple is sensitive to spring frosts, especially as the vegetation phenophases are more advanced, newly emerged tissues are highly vulnerable to frost damage (Hoffmann & Rath, 2013). The literature shows that the increase in spring temperatures significantly advances the leaf shedding and flowering (Chuine et al., 2016; Fu et al., 2015). However, this advance could be offset by a delay in interrupting the dormancy due to mild winters, resulting in insufficient cooling requirements (Chuine et al., 2016; Campoy et al., 2011). As a result, the choice of cultivars better adapted to the growing area to cope with these climatic risks is a must. Changes in apple phenology have important implications, and as a result it is necessary to analyze the phenology in different areas of cultivation. Mainly, the optimal areas for cultivation are determined by phenology, and the cultivars can become poorly suited to an area as the climate is changing. One of the three factors that must be considered in order to properly estimate the risk of frost, according to Cannell & Smith (1986), is the likelihood of sub-frost temperatures that are harmful at different stages of bud, leaf and fruit development. The present paper aimed to analyze the variability of some spring phenophases in the apple species, 'GoldRush' cultivar, in order to analyze the risk of spring frost for apple production in the Stănești area of Argeș County, Romania, and the role of phenological acclimatization.

MATERIALS AND METHODS

Plant Material. The study was carried out on the cultivar 'GoldRush' apples in an orchard located in Stănești village, Argeș county, Romania (45°13′44″N, 24°50′9″E, altitude 540 m). 'GoldRush' is a late-maturing yellow apple (*Malus x domestica* Borkh.) with excellent fruit quality and long storage ability combined with field immunity to apple scab incited by *Venturia inaequalis* (Cke.) Wint., a high level of resistance to apple mildew incited by *Podosphaera leucotricha* (Ell & EV.) Salm., and moderate resistance to fire blight incited by *Erwinia amylovora* (Buff.) Winslow (Crosby et al., 1994). A drip irrigation system was used for fertigation purposes. The climate is of the continental temperate type and specific to the high and low hills, the average annual temperature is 10-12°C. The highest values of average monthly temperatures are recorded over the period June-August, while the lowest are in January-February. The rainfall regime in this sector is characteristic of the hilly area, with average annual values of 500-600 mm.

Methods. The timing of the phenological stages according to the definitions of the Biologische Bundesanstalt, Bundessortenamt, and CHemical industry (BBCH). The BBCH scale (Martínez et al., 2019) was used to group reproductive stages. Eleven main growth stages (Table 1) have been described, according to Meier et al. (1994). The plot was periodically visited to observe each of the identified stages. The data obtained were completed with the observations recorded by the camera installed in the experimental plot. Data were recorded simultaneously on all trees (15), once a week from the beginning of March until the first half of May and once every 3 days during the flowering period. The phenology of flowering was followed on the flowering branches of the crown facing north and south. The study for the identification of phenological stages was conducted for four years, over the period 2018-2021. Hourly temperature records over a period of 4 years were used as a reference to analyze the risk of spring frost in apple production in Stănești area and the role of phenological acclimatization. Frost risk was judged by the daily minimum air temperature. For statistical analysis, Microsoft Excel and XLSTAT Pearson Edition version 2014.5.03, Addinsoft and R Core Team (2013) were used.

Table 1. BBCH stages at the apple and their description*

No	BBCH Stage	Description
1	BBCH 01/BBCH 51	Beginning of leaf bud swelling/Inflorescence buds swelling
2	BBCH 03/BBCH 52	End of leaf bud swelling: bud scales light coloured with some parts densely covered by hairs/End of bud swelling: light coloured bud scales visible with parts densely covered by hairs
3	BBCH 07/BBCH 53	Beginning of bud break: first green leaf tips just visible/Bud burst: green leaf tips enclosing flowers visible
4	BBCH 10/BBCH 54	Mouse-ear stage: Green leaf tips 10 mm above the bud scales; first leaves separating/Mouse-ear stage: green leaf tips 10 mm above bud scales; first leaves separating
5	BBCH 15	More leaves unfolded, not yet at full size
6	BBCH 31	Beginning of shoot growth: axes of developing shoots visible
7	BBCH 55	Flower buds visible (still closed)
8	BBCH 57	Pink bud stage: flower petals elongating; sepals slightly open; petals just visible
9	BBCH 60	First flowers open
10	BBCH 65	Full flowering: at least 50% of flowers open, first petals falling
11	BBCH 69	End of flowering: all petals fallen

*Meier et al., 1994

Based on the observations made, the variability of phenological characteristics in 'GoldRush' cultivar was analyzed, using the number of days from January 1 (DOY = day of year) to the landmark stage. Table 2 shows the statistical processing of the data obtained, over four years of observations, regarding the development on eleven phenological growth stages in five growth stages (Table 1). Based on Julian day number, on average for 4 years, the phenophases occurred from the 85.54 day of year, marked by "beginning of leaf bud swelling / inflorescence bud swelling" (BBCH 01/51), until 123.36 day of year for phenophase "end of flowering" (BBCH 69) (Table 2). The coefficient of variability, for the eleven phenophases analyzed, had low values (3.98-6.85%), which highlights a uniformity in terms of their development (Table 2).

Table 2. Descriptive statistics of the start date (day of year; DOY) for the development of the main phenological stages

No	BBCH Stage	Mean	SD	Sample Variance	Minimum	Maximum	Range	Confidence Level (95.0%)	CV%
1	BBCH 01/ 51	85.45	3.69	13.67	80	92	12	2.48	4.31
2	BBCH 03/ 52	88.81	3.54	12.56	83	94	11	2.38	3.98
3	BBCH 07/ 53	92.36	4.61	21.25	84	98	14	3.09	4.99
4	BBCH 10/ 54	97.36	4.84	23.45	88	103	15	3.25	4.97
5	BBCH 15	100.9	4.57	20.89	93	107	14	3.07	4.52
6	BBCH 31	103.18	4.49	20.16	95	109	14	3.01	4.35
7	BBCH 55	102.72	7.04	49.61	93	113	20	4.73	6.85
8	BBCH 57	106.9	5.64	31.89	98	115	17	3.79	5.27
9	BBCH 60	114.36	5.74	33.05	106	123	17	3.86	5.01
10	BBCH 65	118.18	5.61	31.56	109	126	15	3.77	4.74
11	BBCH 69	123.36	5.64	31.85	116	131	15	3.79	4.57

During the four calendar years, the variation limits for the onset of phenophases varied between 11 (BBCH 03/52) and 20 (BBCH 55) days (Table 2). From one year to another, the development period of phenophases changes, in correlation with environmental factors etc. (Table 3).

Table 3. Descriptive statistics of the start date (as Julian day number) for the development of the main phenological stages according to the climatic year

Statistics/ BBCH stage		01/51	03/52	07/53	10/54	15	31	55	57	60	65	69
2018	Mean	91.3	94.3	94.6	99	102.3	103.6	104	106	108	111	118
	SD	2.1	1.5	1.5	2	1.5	1.52	2	2	2	2	2
	Min-max	89-93	93-96	93-96	97-101	101-104	102-105	102-106	104-108	106-110	109-113	116-120
	CV%	2.3	1.6	1.6	2.0	1.5	1.46	1.9	1.8	1.8	1.8	1.7
2019	Mean	81.6	84.3	86	90.3	94.6	97	97.6	99.6	110.3	115	117
	SD	1.5	1.5	2	2.5	1.5	2	1.52	1.52	1.52	1	1
	Min-max	80-83	83-86	84-88	88-93	93-96	95-99	96-99	98-101	109-112	114-116	116-118
	CV%	1.8	1.8	2.3	2.7	1.6	2.1	1.6	1.5	1.4	0.8	0.8
2020	Mean	83.6	88.6	93	99	101.6	104	100	107	116.3	120.3	126.3
	SD	1.5	1.5	2	1	1.5	2	1	1	1.5	1.5	1.5
	Min-max	82-85	87-90	91-95	98-100	100-103	102-106	99-101	106-108	115-118	119-122	125-128
	CV%	1.8	1.7	2.1	1.0	1.5	1.9	1	0.9	1.3	1.3	1.2
2021	Mean	87.6	90.3	97	101	106	107.6	112	114	121.3	124.6	129.6
	SD	1.5	1.5	1	2	1	1.5	1	1	1.52	1.15	1.52
	Min-max	86-89	89-92	96-98	99-103	105-107	106-109	111-113	113-115	120-123	124-126	128-131
	CV%	1.7	1.6	1.0	1.9	0.9	1.4	0.9	0.8	1.2	0.9	1.2

Regarding the number of Julian days required to trigger the "beginning of leaf bud swelling/ inflorescence bud swelling" (BBCH 01/51) phenophases the earliest year was 2019 (DOY = 81.66, range 80-83), followed by 2020 year (DOY = 83.66, range 82-85), 2021 year (DOY = 87.66, range 86-89) and 2018 year (DOY = 91.33, range 89-93). Depending on the climatic conditions, the duration between phenophases was different. The number of days from phenophase "beginning of leaf bud swelling/inflorescence bud swelling" (BBCH 01/51) to "end of flowering" (BBCH 69), differed from year to year, ranging from 26.7 days (year 2018) to 42.7 days (year 2020) (Table 3). The low coefficient of variability (CV%: 0.87-2.77) highlights the uniformity of the observations in the experimental plot (Table

3). Throughout the study, for the 'GoldRush' cultivar, the "first flowers open" phenophase occurred, in average, on 108 DOY (range 106-110) in the year 2018, on 110.3 DOY (range 109-112) in the year 2019, on 116.33 DOY (range 115-118) in the year 2020 and on 121.3 DOY (range 120-123) in the year 2021 (Table 3). The start and end dates of the apple blossom period (ie from the growth stages of BBCH 60 "first open flowers" to BBCH 69 "end of flowering: all fallen petals") were different from year to year. The duration of this period was, in average, 10 days in the year 2018 and 2020, de 6.7 days in the year 2019, and 8.3 days in the year 2021. Linear regression analysis over the four years of the study showed that the duration of flowering decreases with how much later the budding takes place (R^2 = 0.0237, p <0.01; Figure 1), and this is probably due to the higher temperatures that are setting in over time.

The knowledge on the phenology of fruit trees is absolutely essential for the precise programming of horticultural practices, such as pest management, physiological disorders, post-harvest management, and nutrients and water management (Martínez et al., 2019). Frost damage is a major concern in fruit-producing regions (Asakura et al., 2010). The dormant buds of apple trees can withstand low temperatures down to -30°C, but at full bloom, the blossoms are very frost susceptible and freeze with temperatures close to zero.

Since the spring cold resistance of apples depends on the phenophase, we considered 2 periods: (1) beginning of leaf bud swelling/ inflorescence buds swelling (BBCH 01/51); (2) first flowers open (BBCH 60).

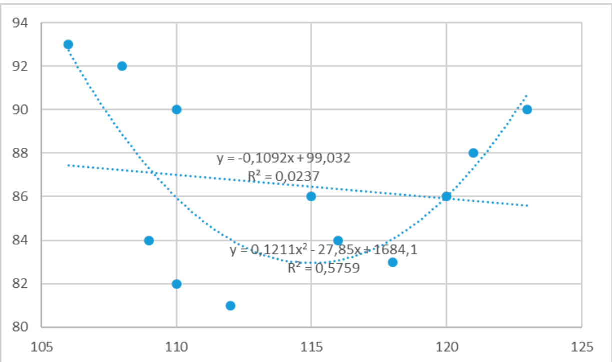

Figure 1. Linear regression between "beginning of leaf bud swelling / inflorescence bud swelling" (BBCH 01/51 and "first open flowers" (BBCH 60) phenophases (DOY)

From a calendar point of view, the "beginning of leaf bud swelling/inflorescence bud swelling" (BBCH 01/51) phenophases took place, depending on the year, between March 20 and April 1. Masaki (2000) believes that during the breaking of buds to the leaves, apples will have the highest risk of frost in future weather conditions. Over the four climate years analyzed, between March 20 and April 1, the minimum recorded temperatures were as follows: -5.2°C in the year 2018, -6.8°C in the year 2019, -7.2°C in the year 2020 and -5.4°C in the year 2021, while the average temperatures of the period varied between 3.02°C (year 2018) and 7.53°C (2019) (Table 4). As a result, they have not affected the buds and fruit production over the analyzed period.

In terms of flowering, apple blossoms are easily damaged by frost and substantial yield losses occur when apple flowering and spring frost events coincide, with a single frost being sufficient to damage the sensitive apple blossom (Rodrigo, 2000). The "first open flower" (BBCH 60) phenophase of the GoldRush apple variety took place at different times of the year, between April 15 and May 2. The flowering period is a crucial process to understand, as it is closely related to air temperature. Early flowering can be explained by the high temperature during the forcing period which induces the appearance of the first flowers in the trees (El Yaacoubi et al., 2019). According to Richardson et al. (1975), during the flowering phase, the risk threshold for apple buds is slightly below -2°C. Regarding the spring frosts and the influence on some phenological stages, based on the predicted data of the sensitive phenophases and the analysis of the minimum temperatures during this interval, the risk of frost was evaluated on an annual basis (Table 4). Over the four climatic years analyzed, between April 15 and May 2, no temperatures below the resistance threshold (-2°C) were recorded. The average temperatures during this period varied between 9.76 and 15.98°C, and the minimum between -1.1°C and 5.2°C (Table 4). As a result, over the four years analyzed, no temperature events were recorded to damage or even kill flower buds. Light frosts result in degradation of fruit quality (Eccel et al., 2009), and the temperature that caused 50% frost damage ranged from -4.25°C to -5.30°C in the red bud stage, and -2.86°C to -3.86°C at the end of flowering, according to Szalay et al. (2019).

The difference between the onset dates of the BBCH60 phenophase over the 4 calendar years was 13.3 days (Table 3). The year-on-year instability of the deviation can be attributed to the unequal temperatures over the period considered, leading to differences between the onset dates of the "first flowers open" phenophase, differences that were more or less pronounced depending on the temperature course to reach the heat requirement (degree hours).

Table 4. Descriptive analysis of temperature during the development of phenophases BBCH 01/51 and BBCH 60

Descriptive statistics/ BBCH stage	Beginning of leaf bud swelling/ inflorescence buds swelling (BBCH 01/51)				First flowers open (BBCH 60)			
	2018	2019	2020	2021	2018	2019	2020	2021
Mean	3.02	7.53	5.35	4.28	15.98	10.02	11.57	9.76
Standard Error	0.16	0.17	0.17	0.15	0.12	0.12	0.13	0.13
Standard Deviation	5.80	6.07	6.16	5.42	5.21	5.28	5.69	5.45
Sample Variance	33.73	36.93	38.03	29.47	27.24	27.89	32.42	29.76
Range	25.5	27.1	26.9	21.9	21.6	24.7	24.3	26.2
Minimum	-5.2	-6.8	-7.2	-5.4	5.2	0.1	-1.1	-0.7
Maximum	20.3	20.3	19.7	16.5	26.8	24.8	23.2	25.5
Sum	3767.2	9375.6	6663.9	5327.3	27618.7	17328.9	20002.6	16874
Count	1244	1244	1244	1244	1728	1728	1728	1728

CONCLUSIONS

Analyzing the data obtained, they allowed us to assess the temporal trends of development of budding and flowering phenophases and the trends of risks in the light of global warming. The time periods when these phenophases occur differ from year to year, and are largely influenced by the temperatures in the period before budding.

Fruit growers operating in similar climatic contexts can choose their cultivars so that, knowing the critical periods, they can solve the risk of frost. The research will be continued in order to analyze a longer period of time and to analyze different assortments, in order to achieve sustainable and competitive fruit crops.

REFERENCES

Asakura, T., Sugiura, H., Sakamoto, D., Sugiura, T. & Gemma, H. (2011). Evaluation of frost risk in apple by modeling changes in critical temperatures with phenology. *Acta Horticulturae*, 919, 65-70

Campoy, J. A., Ruiz, D. & Egea, J. (2011). Dormancy in temperate fruit trees in a global warming context: A review. *Scientia Horticulturae*,130, 357–372.

Chuine, I., Bonhomme, M., Legave, J. -M., García de Cortázar-Atauri, I., Charrier, G. & Lacointe, A. (2016). Can phenological models predict tree phenology accurately in the future? The unrevealed hurdle of endodormancy break. *Global Change Biology*, 22, 3444–3460.

Cosmulescu, S. & Bîrsanu Ionescu, M. (2018). Phenological calendar in some walnut genotypes grown in Romania and its correlations with air temperature. *International Journal of Biometeorology*, 62(11), 2007-2013.

Cosmulescu, S. & Calusaru, F. G. (2020). Influence of temperature on blackthorn (*Prunus spinosa* L.) phenophases in spring season. *Journal of Agricultural Meteorology*, 76 (1), 53-57.

Cosmulescu, S., Baciu, A., Botu, M. & Achim, G. H. (2010). Environmental factors' influence on walnut flowering. *Acta Horticulturae*, 861, 83-88.

Cosmulescu, S., Baciu, A., Cichi, M. & Gruia, M. (2010). The effect of climate changes on phenological phases in plum tree (*Prunus domestica*) in south-western Romania. *South Western Journal of Horticulture, Biology and Environment*, 1(1), 9-20.

Cosmulescu, S., Ştefănescu, D. & Stoenescu, A. M. (2022). Variability of phenological behaviours of wild fruit tree species based on discriminant analysis. *Plants*, 11(1), 45.

Crosby, J. A., Janick, J., Pecknold, P. C., Goffreda, J. C. & Korban, S. S. (1994). Gold Rush'Apple. *HortScience*, 29(7), 827-828.

Eccel, E., Rea, R., Caffarra, A. & Crisci, A. (2009). Risk of spring frost to apple production under future climate scenarios: the role of phenological acclimation. *International Journal of Biometeorology*, 53(3), 273-286.

El Yaacoubi, A., Oukabli, A., Hafidi, M., Farrera, I., Ainane, T., Cherkaoui, S. I. & Legave, J. M. (2019). Validated model for apple flowering prediction in the Mediterranean area in response to temperature variation. *Scientia Horticulturae*, 249, 59-64.

Fu, Y. H., Zhao, H., Piao, S., Peaucelle, M., Peng, S. & Zhou, G. (2015). Declining global warming effects on the phenology of spring leaf unfolding. *Nature*, 526, 104–107.

Hoffmann, H. & Rath, T. (2013). Future bloom and blossom frost risk for *Malus domestica* considering climate model and impact model uncertainties. *PLoS One* 8(10):e75033.

Martínez, R., Legua, P., Martínez-Nicolás, J. J. & Melgarejo, P. (2019). Phenological growth stages of "Pero de Cehegín" (*Malus domestica* Borkh): codification and description according to the BBCH scale. *Scientia Horticulturae*, 246, 826-834.

Masaki, Y. (2020). Future risk of frost on apple trees in Japan. *Climatic Change*, 159(3), 407-422.

Meier, I., Graf, H., Hess, M., Kennel, W., Klose, R., Mappes, D. & Boom van den, T. (1994). Phenological growth stages and indentification keys of pome fruit. Growth stages of mono-and dicotyledonous plants. Berlin: Federal Biological Research Centre for Agriculture and Forestry.

Menzel, A. (2000). Trends in phenological phases in Europe between 1951 and 1996. *International Journal of Biometeorology*, 44, 76-81.

Miranda, C., Bilavcik, A., Chaloupka, R., Dreisiebner-Lanz, S., Gastol, M. & Luedeling, E. (2019). Phenology and critical temperatures. (EIP-AGRI Focus Group Protecting fruit production from frost damage). Report No.: 5. https://ec.europa.eu/eip/agriculture/sites/agri-eip/fles/fg30_mp5_phenology_critical_temperatures.pdf. Accessed 15 Feb 2021.

Richardson, E. A., Ashcroft, G. L., Anderson, J. L., Seeley, S. D., Walker, D. R., Alfaro, J. F., Griffin, R. E. & Keller, J. (1975). Pheno-climatography of selected fruit trees as used in programming sprinkling for bloom delay. Paper No. 75-4053, American Society of Agricultural Engineers, Davis, California, June 22-25.

Rodrigo, J. (2000). Spring frosts in deciduous fruit trees - morphological damage and flower hardiness. *Scientia Horticulturae*, 85(3), 155-173.

Snyder, R. L. & de Melo-Abreu, J. P. (2005). Frost protection: fundamentals, practice and economics Vol. 1. Rome: Food and Agriculture Organization of the United Nations; 2005 (Environment and natural resources series).

Szalay, L., György, Z. & Tóth, M. (2019). Frost hardiness of apple (*Malus domestica*) flowers in different phenological phases. *Scientia Horticulturae*, 253, 309-315.