Original Research Article

Phenology of apple cultivars with different chilling requirements

ABSTRACT

Under mild climate conditions where chilling requirements are not met, the different phenological stages tend to extend and vary according to the year and chill intensity. Knowledge on the phenological stages becomes important for the management of some cultural practices such as fruit thinning and phytosanitary treatments. The phenology of six apple cultivars with different chilling requirements was studied for a period of 20 years. The method employed made it possible to analyze the evolution of the different phenological stages, allowing the chronological determination of their development. The results suggest adaptability of the different cultivars in the same region, highlighting the influence of environmental factors. The duration of the different phenological stages varied according to the chilling requirements of each cultivar, being directly influenced by climatic factors.

Keywords: Malus domestica. climate variability. phenological stages. chilling requirement.

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1. INTRODUCTION

Under mild climate conditions where chill needs are not met, phenological stages tend to extend and vary according to the year and chill intensity. Fruit production is directly influenced by flowering time, which is a highly heritable trait greatly affected by how a genotype perceives its environment [1, 2, 3]. The evolution of the phenological stages of apple, during the vegetative phase, beginning of bud breaking, full flowering, fruit development and maturation, as well as yield and production quality, can be observed visually and are influenced by climatic conditions [4]. Apple flowers are largely self-incompatible, so cultivars that flower in a synchronized manner are required to ensure adequate cross-pollination [5]. Commercial apple cultivars have a flowering cycle that extends from a week to a month depending on the cultivar and environmental conditions. Knowledge on the phenological stages becomes important for the management of some cultural practices such as fruit thinning, phytosanitary treatments and nutrition. Among the factors that influence apple phenology, the ones which stand out are chill needs of the cultivar, degree days and rootstock. These phenological changes have been widely studied and classified according to their development from dormancy to fruiting [6, 7, 8]. Despite the long history of phenological observations, the term “phenology” appeared in 1949 [9]. In regions with a mild climate where the chill needs of the cultivar are not met to exit dormancy, there may be a series of anomalies in the phenological stages and development of apple [10, 11, 12, 13]. According to Saraiva[14], the study of phenology is based on observations and measurements of a number of plant organs in a given period. This is an essential element in assessing the adaptability of a species to certain environmental conditions. Phenology has been associated with environmental factors such as precipitation, temperature, and photoperiod [15].

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The climate of the southern region of Brazil is distinct from the climates of the temperate regions in the center of origin of the main apple species (Caucasus and eastern China) and also distinct from those in the main areas where this fruit tree is cultivated [16]. When the chilling requirements of temperate climate fruit trees are not fully met, they exhibit some anomalies such as lower percentage of bud breaking and flowering, as well as a prolonged and uneven flowering period [17]. Such uneven flowering causes plants to show several phenological stages at the same time, hindering cultural practices, in addition to resulting in a lower and low-quality production at the end of the production cycle [17]. Knowledge of phenology and thermal requirements is a necessity in apple cultivation, as it allows the rationalization of cultural practices and the estimation of probable harvest dates. Therefore, studies on the phenological behavior of different cultivars in several cycles are necessary, since different accumulations of chilling hours are observed in different years and may advance or delay apple flowering, according to the chilling requirements of each cultivar. The occurrence of frosts during flowering or effective fruiting can affect production, whereas late flowering is less affected, so it is important to know the phenological stages of apple [18]. The amount of accumulated chill is very important for the adaptation of temperate climate fruit trees, due to the influence of chill on the exit from dormancy [19, 20]. After a long period of cold during the winter, high temperatures in the early spring of the subsequent season promote final development and flowering [21, 22]. However, these studies on the interaction between environmental conditions and genotypes require a number of years of research, and some cultural practices may also affect phenology. At the physiological level, harvest load, growth dynamics, genotype, plant architecture, bearing habit (regular or biennial), and temperature affect the time and rate of flower initiation in apple [23, 24, 25, 26, 27, 28, 29, 30]. High temperatures during pre-flowering and flowering can shorten the flowering period [31]. The phenological stages most observed in the field are the beginning of bud breaking, beginning of full flowering and end of flowering, which are important to define phytosanitary treatments, cultural practices such as thinning, and to predict early harvest. The objective of this study was to evaluate the phenological development of six apple cultivars in a historical series under the climatic conditions of Southern Brazil.

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2. MATERIAL AND METHODS

The experiment was carried out in an experimental orchard located in the municipality of Caçador, SC, Brazil (26º46'S latitude, 51º W longitude, 960 m altitude), belonging to the EPAGRI Experimental Station – Caçador, SC. The climate of this region is characterized as temperate, constantly humid, with mild summers, classified as Cfb according to Köppen's classification. The soil of the orchard under study is classified as a Nitossolo Bruno distrófico (Ultisol) (Embrapa, 2006). The average annual rainfall is 1,670 mm and the average relative humidity is 78% (Ciram/Epagri). The average chilling accumulation during the autumn-winter period, according to the modified North Carolina model [32] is 1,058 chilling units on average.

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The phenology of six apple cultivars with different chilling requirements was evaluated for a period of 19 years during the cycles from 2000 to 2019. The method to determine the evolution of the different phenological stages was visual, allowing the chronological determination of their development (Figure 1). To determine the phenology, the evaluation consisted of determining the dates of occurrence of the following stages: green tip (C-C3); beginning of bud breaking; beginning, full and end of flowering; and beginning and end of harvest for each cultivar. The beginning of bud breaking was considered when 50% of the reproductive buds had 1.3 cm of green tip; beginning of flowering was considered when the plants had 10% of open flowers; full flowering was considered when more than 70% of flowers were open; and end of flowering was determined when 90% of the flowers had their petals falling.

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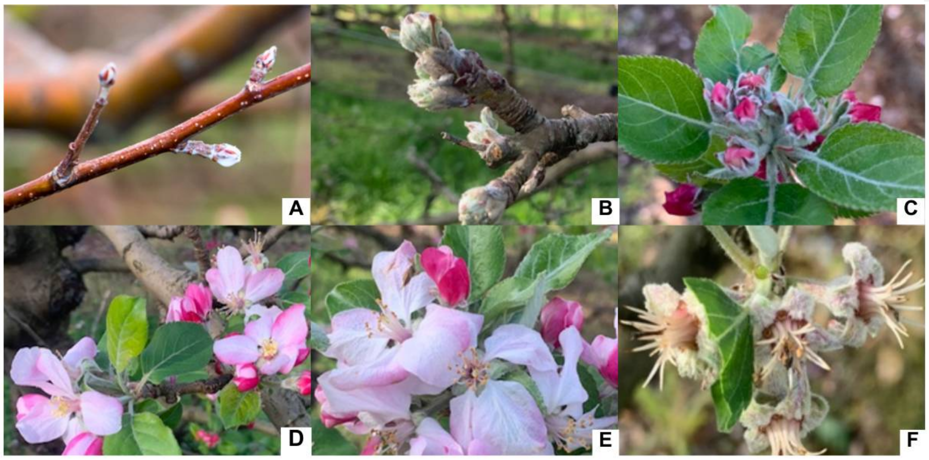

Figure 1 – Phenological stages of apple. A: Silver tip (B); B: Green tip (C-C3); C: Pink; D: Beginning of flowering; E: Full flowering; F: Petal fall.

Data of chilling units according to the Modified North Carolina model [32], chilling hours below 7.2 ºC, during the period of phenological evaluations, and degree days with base temperature of 10 ºC were collected (Figure 2). The cultivars studied were 'Condesa' (low chilling requirement), 'Imperatriz', 'Baronesa' and 'Fred Hough' (medium chilling requirement) and 'Gala' and 'Fuji Suprema' (high chilling requirement). The orchard used has a planting density of 2,500 plants per hectare, all cultivars are grafted on the M-9 rootstock and trained to the central leader system. Orchard management practices followed the technical recommendations of the production system [33]. To overcome dormancy, the dormancy breaking treatment was performed with a mixture of mineral oil and hydrogenated cyanamide in all seasons studied. Phenological development was evaluated twice a week from the C-C3 stage until the end of flowering and the beginning and end of fruit harvest. The cultivars were studied separately and were not considered causes of variation. The results compare the adaptive capacity of different cultivars in the same region and the influence of environmental factors.

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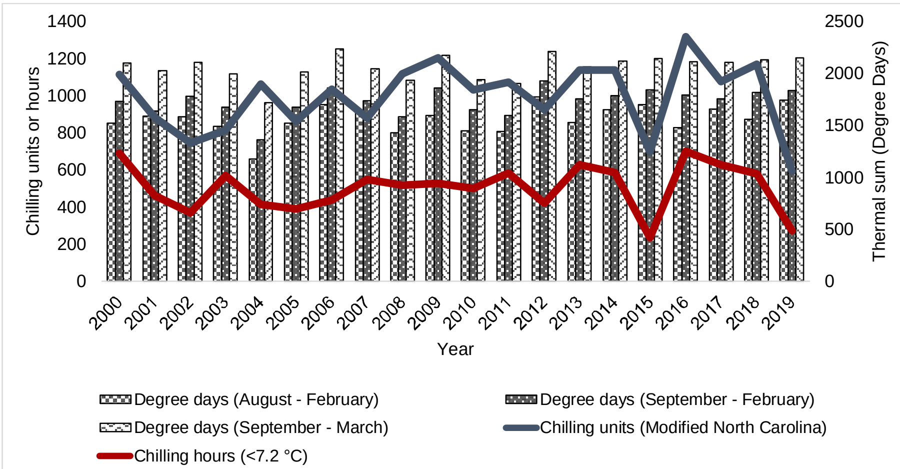

Figure 2 – Chilling units according to the modified North Carolina model, chilling hours below 7.2 °C and degree days in different periods in the years 2000 to 2019. Caçador, SC, Brazil, 2023.

3. RESULTS AND DISCUSSION

The different phenological stages varied according to the chilling requirements of the cultivar. Within the same cultivar, the phenological stages tend to advance in years with greater chill intensity (Figures 3 to 8 and Tables 1 and 2). The cv. 'Condesa', the one with the lowest chilling requirement, showed a variation in the beginning of bud breaking and flowering concentrated in August, but with great variability according to the year. In turn, the cultivars 'Imperatriz', 'Fred Hough' and 'Baronesa', with medium chilling requirement, concentrated their flowering in September and the first half of October, and the cultivars with highest chilling requirement, 'Gala' and 'Fuji Suprema', concentrated their flowering in October. These results demonstrate that the cultivars with lower chilling requirements have their bud breaking and flowering earlier than those with medium and high chilling requirement, showing that the chilling requirement of the cultivar influences the times for the beginning of bud breaking and flowering. Within the same cultivar, there were variations in the different phenological stages according to the years, which also had great variability in terms of the amount of chill, showing that the variation of the phenological stages is linked to climatic factors. According to Putti et al. [34], the greater the number of chilling units during dormancy, the shorter the time and the need for thermal units for the sprouting of apple buds. According to the climatic conditions observed, the average air temperature recorded from dormancy break to bud breaking is influenced by temperature, and the increase in temperature in the period following the dormancy breaking treatment accelerates bud breaking [35]. Full flowering in cv. 'Gala' was very variable according to the year, with a difference of up to 34 days among the sequences of the years (Figure 6). This also occurred in the other cultivars, regardless of the chilling requirement, which indicates that climatic variables influence the flowering date. The number of days from the beginning to the end of flowering also showed great variability between the years, regardless of the cultivar, with no evident correlation with the chilling units or chilling hours (Table 1). However, there are several factors that affect apple phenology, including the rootstock, training system, arching of the branches, time of application of bud break inducers, cultivar, environmental conditions and type of fruiting structure [4]. It is worth pointing out that there are differences in the phenological behavior of apple trees when cultivated under conditions that do not meet their

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chill needs. Under these conditions, chemical treatment needs to be applied to induce bud breaking and flowering, and the post-treatment temperatures influence the beginning of bud breaking and flowering. The increase in temperature during the days following the dormancy breaking treatment accelerates bud breaking, while lower temperatures prolong the period and consequently delay flowering [35]. This may explain why there was no correlation between the date of the phenological stages and chilling units or hours for the different cultivars studied. The year 2000/2001, one of those with the highest chilling units and hours (Figure 2), was among the years with the longest delay in the beginning of bud breaking for the cultivars studied (Figures 3 to 8).

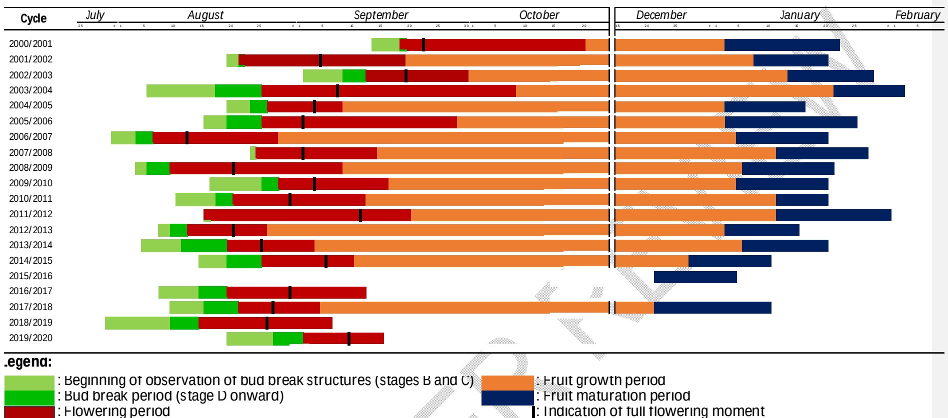

Figure 3 – Date and duration of the main phenological events that occurred from stage C (Green tip C-C3) until the fruit harvest of the apple cultivar ‘Condesa’. Caçador, SC, Brazil, 2023.

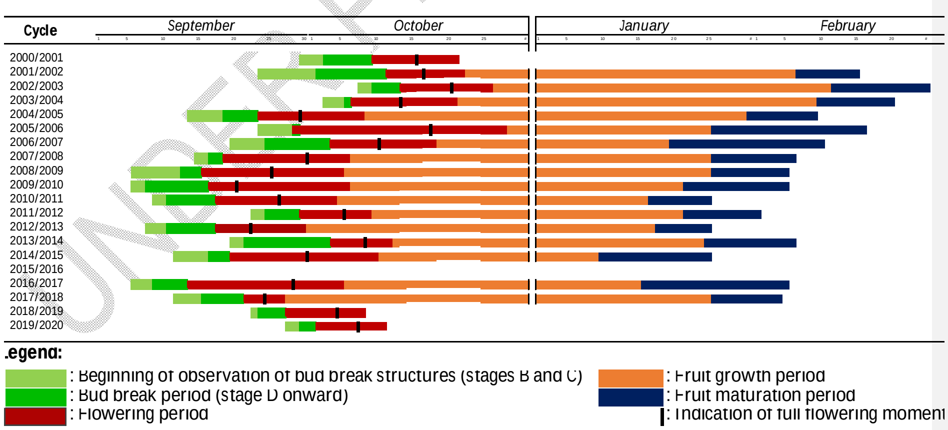

Figure 4 – Date and duration of the main phenological events that occurred from stage C (Green tip) until the fruit harvest of the apple cultivar ‘Imperatriz’. Caçador, SC, Brazil, 2023.

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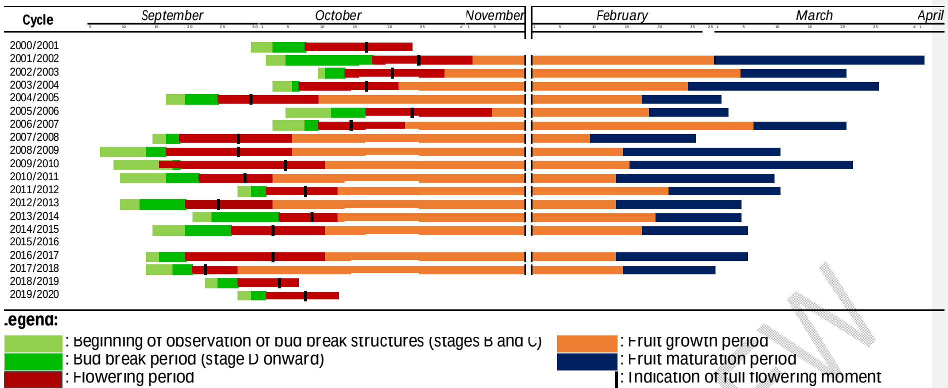

Figure 5 – Date and duration of the main phenological events that occurred from stage C (Green tip) until the fruit harvest of the apple cultivar 'Fred Hough'. Caçador, SC, Brazil, 2023.

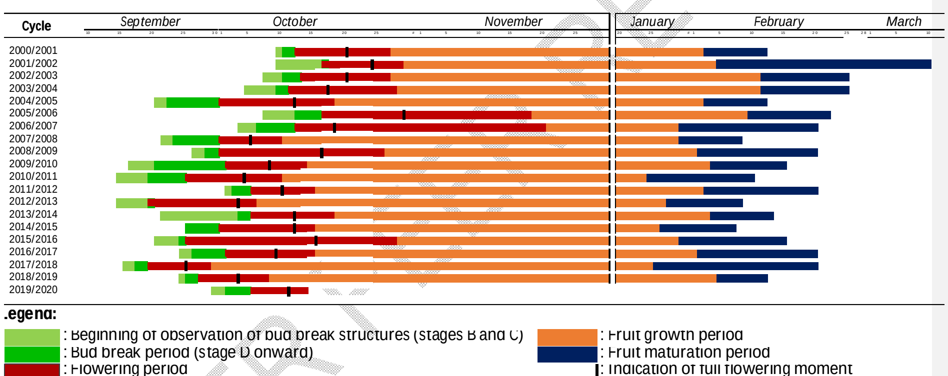

Figure 6 – Date and duration of the main phenological events that occurred from stage C (Green tip) until the fruit harvest of the apple cultivar 'Gala'. Caçador, SC, Brazil, 2023.

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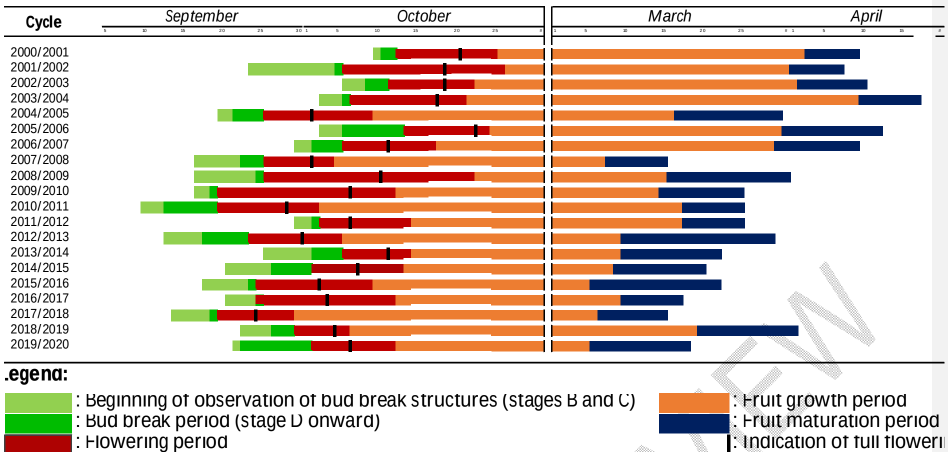

Figure 7 – Date and duration of the main phenological events that occurred from stage C (Green tip) until the fruit harvest of the apple cultivar 'Fuji Suprema'. Caçador, SC, Brazil, 2023.

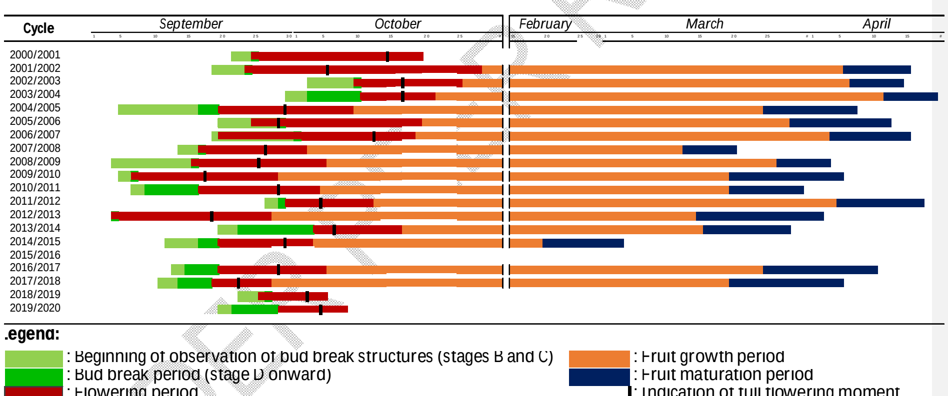

Figure 8 – Date and duration of the main phenological events that occurred from stage C (Green tip) until the fruit harvest of the apple cultivar 'Baronesa'. Caçador, SC, Brazil, 2023.

The flowering period (beginning to end) varied according to the year and the cultivar, but there was no relationship between the chilling requirement of the cultivar and the number of days from the beginning to the end of flowering (Table 1). There was a great variability between the years in the flowering period, as seen in the 'Gala' cultivar, whose flowering period ranged from nine to 38 days, with an average of 17 days. Among the cultivars, the average of the different years ranged from 13.4 days to 21.6 days. A more concentrated flowering period becomes more advantageous due to the uniformity of maturation, less need for labor and greater efficiency of thinners; however, the probability that flowers will be pollinated in a longer flowering period becomes higher, especially under adverse conditions to pollination, impairing the work of bees [35].

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Table 1 – Number of days from the beginning of flowering to the end of flowering in several apple cultivars. Caçador, SC, Brazil, 2023.

Year	'Condesa'	'Imperatriz'	'Fred Hough'	'Baronesa'	'Gala'	'Fuji Suprema'
2000	22	-	15	25	14	22
2001	27	10	13	34	12	27
2002	17	12	14	15	13	17
2003	34	14	14	10	16	34
2004	11	14	14	19	17	11
2005	32	29	17	24	32	32
2006	21	14	12	28	38	21
2007	19	17	16	15	9	19
2008	28	19	18	19	25	28
2009	19	19	24	20	12	19
2010	19	16	10	17	14	19
2011	35	9	10	12	9	35
2012	12	12	12	23	16	12
2013	13	8	8	12	12	13
2014	14	20	13	13	19	14
2015	-	-	-	-	-	-
2016	22	21	20	15	13	22
2017	12	7	6	8	9	12
2018	21	10	8	9	10	21
2019	33	9	10	9	-	33
Mean	**21.6**	**14.4**	**13.4**	**17.2**	**17.0**	**21.6**

Considering the period from full flowering to the beginning of harvest, in days, there was a great variation between cultivars and within the same cultivar between years, which may be related to maximum and minimum daily temperatures (Table 2). Among the cultivars, those with the latest harvest were the ones with the longest cycle, namely 'Baronesa' and 'Fuji Suprema', with an average of 176.8 and 161.5 days, respectively. For the other cultivars, the average cycle duration was 114.6 days for 'Gala', 113.7 days for 'Imperatriz', 124.3 days for 'Condesa' and 135.5 days for 'Fred Hough'. Variability was high within the different years, as in the case of 'Fuji Suprema', whose cycle ranged from 150 to 175 days, i.e., 25 days. The individual study of each period is extremely important, as it can provide direct evidence and specific information about which events, such as climate variations and changes, may influence [35]. There was a reduction of up to 25 days in the case of 'Fuji Suprema', but it was observed that the degree days also showed great variability between the years, influencing the cycle of the cultivars. Despite that, the index of degree days from full flowering is appropriate for possible calculations of the period from flowering to fruit maturity, which requires the monitoring of degree days during the cycle.

Table 2 – Number of days from full flowering to the beginning of fruit maturation of several apple cultivars. Caçador, SC, Brazil, 2023.

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Year	'Condesa'	'Imperatriz'	'Fred Hough'	'Baronesa'	'Gala'	'Fuji Suprema'
2000	116	114	131	171	116	165
2001	126	114	128	184	104	165
2002	117	115	136	173	115	166
2003	136	120	132	178	118	175
2004	122	124	142	177	114	167
2005	123	108	119	182	104	160
2006	115	102	144	174	105	170
2007	132	118	136	168	117	154

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2008	138	123	141	183	109	157
2009	124	124	135	184	119	150
2010	134	113	139	173	113	171
2011	122	109	138	183	116	163
2012	136	118	143	178	117	162
2013	134	109	135	161	115	150
2014	114	102	139	178	107	153
2015	-	-	-	-	-	-
2016	113	110	135	178	116	158
2017	115	124	146	179	123	165
2018	124	104	139	174	125	167
2019	120	110	118	181	125	152
Mean	**124.3**	**113.7**	**135.5**	**176.8**	**114.6**	**161.5**

4. CONCLUSION

The different phenological stages vary with the year and the cultivar, being influenced by climatic variables and cultural practices such as the budbreak induction treatment.

Cultivars with low chilling requirement show advance in the beginning of bud breaking and flowering compared to cultivars with higher chilling requirement.

The number of days from the beginning of flowering to the end of flowering varied with the years, but did not correlate with chilling units or chilling hours.

REFERENCES

Comment [HK8]: Check and change the reference style as per requirement of the journal's guideline.

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1. CELTON, J.-M. et al. Deciphering the genetic determinism of bud phenology in apple progenies: A new insight into chilling and heat requirement effects on flowering dates and positional candidate genes. New Phytologist. 2011;192:378-392. https://doi.org/10.1111/j.1469-8137.2011.03823.x.

2. GOTTSCHALK, C.; VAN NOCKER, S. Diversity in seasonal bloom time and floral development among apple species and hybrids. Journal of the American Society for Horticultural Science, 2013;138:367-374.

3. HAUAGGE, R.; CUMMINS, J. N. Phenotypic variation of length of bud dormancy in apple cultivars and related Malus species. Journal of the American Society for Horticultural Science, 1991;116:100-106.

4. PETRI, J.L.; HAWERROTH, F.J.; LEITE, G.B.; COUTO, M.; FRANCESCATTO, P. Apple phenology in subtropical climate conditions. In: ZHANG, X. (Ed.). Phenology and climate change. Rijeka (Croácia): InTech, 2012:195-216

5. Ramírez F, Davenport TL.. Apple pollination: A review. Scientia Hortic. 2013;162:188–203. https://doi.org/10.1016/j.scienta.2013.08.007

UNDER PEER REVIEW

6. Fujisawa, M.; Kobayashi, K. Apple (Malus pumila var. domestica) phenology is advancing due to rising air temperature in northern Japan. Global Change Biology, Oxford, 2010;16:2651-2660.

7. Guédon, Y.;Legave, J.M. Analyzing the time-course variation of apple and pear tree dates of flowering stages in global warming context. Ecological Modelling, Amsterdam, 2008;219:189-100.
8. Oliveira, I.V.M.; Lopes, P.R.C.; Silva-Matos, R.R.S.; Cavalcante, I.H.L. Fenologia da macieira cv. 'Condesa' no Vale do São Francisco. Revista Ciências Agrarias, Belém, 2013;36:23-30.
9. Demarée, G. R.; Rutishauser, T. Origins of the word "phenology" . Eos Transactions American Coeo physical union. Doi 10.1029, 2009.
10. Skinner, J. E.. Delayed foliation. Deciduous Fruit Grower, 1964;4:195-197. Isnn 0302-7074.
11. Saure, M.C... Dormancy release in deciduous fruit trees. Horticultural Review, 1985;7:.239-299. Isnn 0163-7851

12. PETRI, J.L.; PALLADINI, L.A.; SHUCK, E.; DUCROQUET, J.H.H.J.; MATOS, C.S. Dormência e indução da brotação de fruteiras de clima temperado. Florianópolis: EPAGRI, 1996.110p.

13. PETRI, J.L.; LEITE, G.B. Consequences of Insufficient Winter Chilling on Apple Tree Bud-break. Acta Horticulturae, 2004;662:53-60.

14. Saraiva, I.. Fenologia das Pomóideas. Frutos, 72/73, 1976:25-44.

15. Bullock, S.H.; Solis-Magallanes, J.A.. Phenology of canopy trees of tropical deciduous forest in México. Biotropica, 1990;22:384-395.

16. PETRI, J. L.; HAWERROTH, F. J.; FAZIO, G.; FRANCESCATTO, P.; LEITE, G. B. Advances in fruit crop propagation in Brazil and worldwide-apple trees. Revista Brasileira de Fruticultura, 2019;41:e-004,

17. PASA, M. D. S.; FELIPPETO, J.; NAVA, G.; SILVA, C. P. D.; BRIGHENTI, A. F.; CIOTTA, M. N. Performance of 'Fuji Suprema' apple trees treated with budbreak promoters, in São Joaquim-SC. Revista Brasileira de Fruticultura, 2018;40:e325.
18. GARIGLIO, N.; MENDOW, M.; WEBER, M.; FAVARO, M. A.; GONZALEZ-ROSSIA, D.; PILATTI, R. A. Phenology and reproductive traits of peaches and nectarines in central-east Argentina. Revista Scientia Agricola, 2009;66:757-763,.
19. EREZ, A.; FAUST, M.; LINE, M. Chang in water status in peach buds on induction, development and release from dormancy. Scientia Horticulturae, 1998;73:111-123,.
20. DENNIS JR, F. G. Dormancy: Manifestations and causes. In: Handbook of plant and crop physiology. CRC Press, 2001:183-202.
21. Labuschagne IF, Louw JH, Schmidt K, Sadie A.. Genetic variation in chilling requirement in apple progeny. J Am Soc Hortic Sci. 2002;127(4):663–672. https://doi.org/10.21273/JASHS.127.4.663.
22. Powell LE. The chilling requirement in apple and its role in regulating time of flowering in spring in cold-winter climates. Acta Hortic. (179):129–140. https://doi.org/10.17660/actahortic. 1986:179.10.
23. BELHASSINE, F. et al. A genotype-specific architectural and physiological profile is involved in the flowering regularity of apple trees. Tree Physiology, 2022;42(11):2306-2318. https://doi.org/10.1093/treephys/tpac073.

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24. GOTTSCHALK, C.; VAN NOCKER, S. Diversity in seasonal bloom time and floral development among apple species and hybrids. Journal of the American Society for Horticultural Science, 2013;138(5):367-374,.
25. GUITTON, B.; KELNER, J. J.; VELASCO, R.; GARDINER, S. E.; CHAGNE, D.; COSTES, E. Genetic control of biennial bearing in apple. Journal of experimental botany, 2012;63:131-149,.
26. HABERMAN, A.; ACKERMAN, M.; CRANE, O.; KELNER, J. J.; COSTES E.; SAMACH, A. Different flowering response to various fruit loads in apple cultivars correlates with degree of transcript reaccumulation of a TFL 1-encoding gene. The Plant Journal, 2016;87(2):161-173.
27. HANKE, M-V.; FLACHOWSKY, H.; PEIL, A.; HÄTTASCH, C. No flower no fruit—genetic potentials to trigger flowering in fruit trees. Genes Genomes Genomics, 2007;1:1-20.
28. HEIDE, O. M.; RIVERO, R.; SØNSTEBY, A. 2020. Temperature control of shoot growth and floral initiation in apple (Malus x domestica Borkh.). CABI Agriculture and Bioscience, 2020;1(1):1-15.
29. KOFLER, J.; MILYAEV, A.; CAPEZZONE, F.; STOJNI, S.; MICIC, N. High crop load and low temperature delay the onset of bud initiation in apple. Scientific Reports, 2019;9:17986.
30. KOFLER, J.; MILYAEV, A.; W€URTZ, B.; PFANNSTIEL, J.; FLACHOWSKY, H.; W€UNSCHE, J. N. Proteomic differences in apple spur buds from high and non-cropping trees during floral initiation. Journal of proteomics, 2022;253:104459,.
31. BERNAD, D. Characterization of Some Self-compatible Almonds. II. Flower Phenology and Morphology. HortScience, 1995;30(2):321,.
32. EBERT, A.; PETRI, J. L.; BENDER, R. J.; BRAGA, H. J. First experiences with chill units models is southern Brazil. Acta Horticulturae, The Hague, 1986;184:9-96.
33. SEZERINO, A. A. (Org.). Sistema de produção para a cultura da macieira em Santa Catarina. Florianópolis: Epagri, 2018:136. (Epagri. Sistema de Produção 50)
34. PUTTI, G. L.; PETRI, J. L. Estádios fenológicos da macieira nas cultivares Gala, Fuji e Golden Delicious. AgropecuáriaCatarinense, 2002;15(3):22-25.

35. FRANCESCATTO, P.; PETRI, J.L.; RACSKO, J.; COUTO, M.; SILVA, A. L. Avaliação fenológica das diferentes estruturas de frutificação das macieiras 'Gala' e 'Fuji' na região de Caçador-SC. Revista Brasileira de Fruticultura, 2015;37(4):913-923.

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