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Article

Trends in the Phenology of Climber Roses under Changing Climate Conditions in Mazovia Lowland in Central Europe

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Abstract: The genetic pool of valuable old ornamental cultivars and their in situ maintenance may be threated by climate change. Meanwhile, the ornamental plants like roses make up an important share of both gardens and urban green spaces, where they are particularly vulnerable to multistress growth conditions. The aim of this research was to evaluate the effect of changing climatic conditions on growth and flowering of 11 historic climber roses through long-term studies (2000-2017) conducted in Central Europe. The evaluation of plants consisted of assessment of frost damage and the timing of early phenological stages (starting of bud break, leaf unfolding) as well as gathering data on beginning, fullness and end of flowering and its abundance. Frost damage was not recorded in any year only in ‘Mme Plantier’, and did not occur for any cultivar after the winter in the years 2007, 2008, and 2014. Only a little damage to one-year shoots was recorded after the winter in the years 2015-2017. Frost damage to ‘Alberic Barbier’, ‘Albertine’, ‘Chaplin's Pink Climber’, ‘Orange Triumph clg’ and ‘Venusta Pendula’ led to pruning to ground level in every year excluding those listed above. Frost damage of once blooming roses limited their flowering; however, the many-year data-sets showed a trend for decreased frost damage and improved abundance of flowering, and these results can be interpreted as a response to the increase of average air temperature. The timing of bud breaking and leaf development in all climber roses was strictly correlated with average air temperature in the dormancy period. The reactions of climber roses to weather conditions confirmed the influence of climatic changes on ornamental crop plants in Central Europe, introducing the potential possibility for the wider application of climber roses, but without certainty of flowering every year.

Keywords: Central Europe, climate warming, flowering, frost damage, genetic variability, historical roses, climber roses, seasonality, spring phenology, winter hardiness

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1. Introduction

The genus *Rosa* belongs to the most diverse ornamental plants with exceptionally rich selection of cultivars [1,2,3] and has been a significant crop plant in many fields of human life for thousands years, used for edible, cosmetic and medicinal purposes [4]. The biodiversity and different origins of groups, cultivars and varieties of roses cause variation in their cultivation requirements and ornamental features. Most historical once-blooming climber roses originate from species from Asia bred and grown in habitats of West Europe with mild winters, e.g. *Rosa luciae* Franch. & Rochebr. (syn. *R. wichuraiana* Crép.), *R. moschata* Herrm., *R. multiflora* Thunb. [1,2]. However, the limited knowledge is available, how climate change will impact the future cultivation limiting their ornamental value. The most of research focus on wild species and crop plants, the ornamental cultivars are rather overlooked. Meanwhile, the ornamental plants make up an important share of both gardens and urban green spaces, where they are particularly vulnerable to multistress growth conditions.

Climber roses can vine up on supports without the typical growth habit of trailing, scandent stems or runners, but have long flexible shoots with prickles, thanks to which they climb the supports and fix to them impermanently [1,2]. The spectacularly decorative climbing roses are planted traditionally in parks as well as narrow streets with limited space for greenery, e.g. courtyards, squares, estate greenery, café gardens, where the vertical surface is especially important and developable [2,5]. However, most research focuses on trees, which are especially valuable to cities due to climate change [6], rather than on old ornamental plants of minor practical use. However, shrubs and vines, including roses, should be used in places where there is not enough space for the optimal growth of trees [7] and in particularly representative locations, cramped and congested old towns, and historical gardens [2,5,8].

Ornamental plants are important especially for urban greenery and amateur home gardens [5,8,9]. Places located in large cities tend to warm faster than non-urbanized areas due to the heat island effect [10]. When it comes to changes in phenology stages, the influence of temperature, light and precipitation seem to be stronger factors than the effects of gas pollution [11].

Research about the phenology of both wild and cultivated plants is important for biology as well as meteorological, agricultural and botanical sciences [12–15]. Changes in plant phenology are a considerable biological effect in nature, affecting a lot of taxa in various geographical regions [14–20]. They are caused by climatic features [12,14,15,18,20,21] and influence e.g. the life cycle of pollinators and herbivores [18,22] and bud dormancy [20]. Climate changes affect also on the phenology or changeability of seasonal biological events of trees [23]. These changes in phenology are more consistent and clear in direction and magnitude in spring compared to summer and autumn [16,18,24–26]. It is predicted that numerous species will no longer be able to exist in their current sites due to lack of tolerance to envinomental changes, e.g. air temperature, water stress, competition with other plant species, the presence of herbivores, as a result of climatic changes [27,28]. Similar problems concern cultivated plants, where changes in climate as well as extreme weather and climate events adversely affect crop production and plant cultivation [14,15,29]. Most research concerns crops plants and their productivity but not the conservation of old ornamental plants and their genetic pool. This problem raises particular concerns due to climatic changes. The evaluation of the evolutionary potential of phenological events with climate change have significance for understanding of the environmental cues and agro-ecosystem processes [30]. On the other hand, the many of plants may be find as sufficiently heterogeneous to envolve and adapt that will profit from higher temperatures and longer growing seasons [19].

Botanical gardens have conducted standard long-term phenological observations of many plant taxa in collections of native and alien plants, limiting the factors affecting the results [10]. Climate factors (temperature, precipitation, light) seem to be less ambiguous agents in affecting the phenology of plants than factors such as gas pollution [11].

The conducted research is significant for biodiversity maintenance of cultivated ornamental plants and broadening knowledge about their use. Because of high breeding progress, old cultivars are significantly inactive, leading to so-called genetic erosion, which has resulted in the current narrow range in the gene pool [31–34]. The intensive search for, and introduction of, new ornamental plants [9,35] deepens problems with maintaining genotypes of valuable old cultivars and brings with it the possibility of introducing other new invasive species [36,37].

More than 1000 taxa were collected in the National Collection of Rose Cultivars in the Polish Academy of Sciences Botanical Garden – Center for Biological Diversity Conservation in Powsin. Among them, more than 200 taxa of different origin are historical roses that were known and cultivated before the year 1945. The chosen cultivars were observed in relation to their winter hardiness, growth and flowering, and ornamental value [8,38–45]. Maintaining plant collections, including crops and ornamentals, is an important task for botanical gardens, due to the need to preserve biodiversity [10].

The aim of this research was to analyse 11 historical cultivars of once-blooming climber roses across a long-term period in relation to changing climate conditions in Mazovia, Central Europe, focusing on their ornamental values related to chosen phenology phases. Their response in selected phenological events and their interrelationship were observed. An assessment of their frost resistance, growth and flowering as well as ornamental value could encourage the proper selection of cultivars for specific places. Additionally, this research could contribute to the maintenance of biodiversity of the genetic pool of old garden roses and help implement the provisions of the Convention on Biological Diversity (CBD) drawn up in Rio de Janeiro on 5th June, 1992.

2. MATERIALS AND METHODS

2.1. Plant material

Eleven historical cultivars of once-blooming climber roses derived from various species and growing in the National Collection of Rose Cultivars of the Polish Academy of Sciences Botanical Garden – Center for Biological Diversity Conservation in Powsin were chosen for observation in the period of 2000-2017 (Table 1). These cultivars are distinguished by their high decorative value [1,2,8] and were commercially available.

Table 1. The climber roses selected for research and grown in the Polish Academy of Sciences Botanical Garden CBDC in Powsin and their origin (Krüssmann 1974, Gustavsson 1999).

Cultivar	Breeder / Introduction	Group	Number of shrubs	Year of planting	Height of support (m)
'Albéric Barbier'	Barbier Frères & Compagnie, France 1900	Hybrid Wichurana	3	2009	2.4
'Albertine'	Barbier Frères & Compagnie, France before 1921	Hybrid Wichurana	3	2002	2.0
'Chaplin's Pink Climber'	Chaplin Bros., Ltd, United Kingdom 1928	Hybrid Wichurana	3	1999	2.4
'Dr Robert Huey'	George C. Thomas, USA 1914	Hybrid Wichurana	7	1998	no
'Duc de Constantin'	Soupert & Notting, Luxembourg 1857	Ayrshire / H. Multiflora, / H. Sempervirens	3	2009	2.0
'Gerbe Rose'	Frédéric Fauque, France 1904	H. Wichurana	8	2004	2.0
'Mme Plantier'	Plantier, France 1835	Alba / Noisette/ H. Moschata	5	2002	no
'Orange Triumph cl.'	Mathias Leenders, Netherlands 1945	Polyantha / H. Multiflora	3	2003	2.0
'Paul's Scarlet Climber'	William Paul & Son, United Kingdom 1915	H. Wichurana / H. Multiflora	3	1998	2.0
'Venusta Pendula'	Unknown, before 1873	Ayrshire / H. Arvensis	3	2008	2.0
'Zéphirine Drouhin'	Bizot, France 1868	Bourbon / H. Pendulina	4	1998	2.0

All the cultivars were budded on rootstocks (*Rosa canina* L.) and planted as one-year shrubs in optimal spacing and cultivation conditions. The height of supports is given in Table 1. The shrubs were cared for according to standard cultivation methods for roses. The pruning took place twice a year, every spring and summer after flowering. The shrubs were fertilized with 'Azofoska' (4-6 kg/m^2, Grupa Inco S.A., Poland) after spring pruning. The bedding was not watered, excluding the first year after planting the shrubs. Every late autumn, the bases of shrubs were hilled up with bark (20-30 cm). The shrubs were sprayed against pests and fungal diseases three times per year: in May, July and October according to the plant protection program in force.

2.2. *Evaluation of climber rose*

The climber roses were evaluated from the year of planting to the end of 2017 (Table 1).

The degree of frost damage was noted every spring according to a 0-7 point valuation scale developed in the Botanical Garden for rose research [38-45], as below:

0 – plants without frost damage;
1 – buds develop, but darkened vascular bundles on stem cross-section;
2 – buds on stem frost-damaged;
3 – the tips of one-year-old shoot frosted;
4 – one-year-old shoots overall frosted or solely their base living;
5 – two-year-old and older shoots frosted;
6 – all the shoots frosted to the ground surface;
7 – shrubs frosted, without young shoots.

The chosen phenological stages were recorded according to the basic principles of the BBCH (Biologische Bundesortenamt, CHemische Industrie) scale [13,46] after winter dormancy or the resting period (BBCH scale 00) from the beginning of bud break to flowering, according to chosen points of the BBCH scale described for cultivated roses [12]. Moreover, because only two characteristic early initial stages in phenology development were selected (07 and 11), the following time intervals were determined and used to present the results of observations:

- 07 – starting of bud break, first leaf tips appears, were compiled into decades, i.g., MI– 1-10 March; MII – 11-20 March; MIII – 21-31 March; AI – 1-10 April; AII – 11-20 April; AIII – 21-30 April;
- 11 – the first light green and/or bronze leaves pair develops, not yet at full size, were compiled into decades, i.g., MI– 1-10 March; MII – 11-20 March; MIII – 21-31 March; AI – 1-10 April; AII – 11-20 April; AIII – 21-30 April; M – after 30 April);
- 60 601 – start of flowering (ca. 10% opened flowers);
- 63 605 – full of flowering ($\geq$ 50% opened flowers);
- 69 609 – final of flowering (after all petals shedding) (Figure 1).

Evaluation of the phenological stages BBCH 07 and 11 was conducted on the middle part of one-year shoots before spring pruning. When the shoots were strong but frost damaged the live part of the shoots were used for evaluation.

The timing of the beginning of flowering stages (Figure 1a) is presented in the Results section for days starting from the 25th May.

Flowering abundance was evaluated every year in the period of 2000-2017, according to a 0-5 point scale used in the Botanical Garden for rose research [38-45], where:

- 0 – plants fail to bloom;
- 1 – a few poor inflorescences on shoot;
- 2 – $\leq$ 5 inflorescences on 1 m of shoot, weak flowering;
- 3 – 3-10 flowers in inflorescences, average flowering;
- 4 – > 5 inflorescences on 1 m of shoot, abundant and long flowering;
- 5 – abundant and long flowering, the inflorescences densely placed on the plant (Figure 1b).

The height of the plants was noted in spring after pruning and at the end of the vegetation season (last days of October). However, the height of plants is not equal to the length of their shoots and also depends on the height of supports, as noted in Table 1.

2.3. *Statistical analysis*

Analysis of variance (one-way ANOVA), and Duncan's Honest Significant Difference test (HSD) were performed to set up the significance of differences among cultivars and years of observations for the means ($p \leq 0.05$) obtained for frost damage, bud break (BBCH 07), leaf development

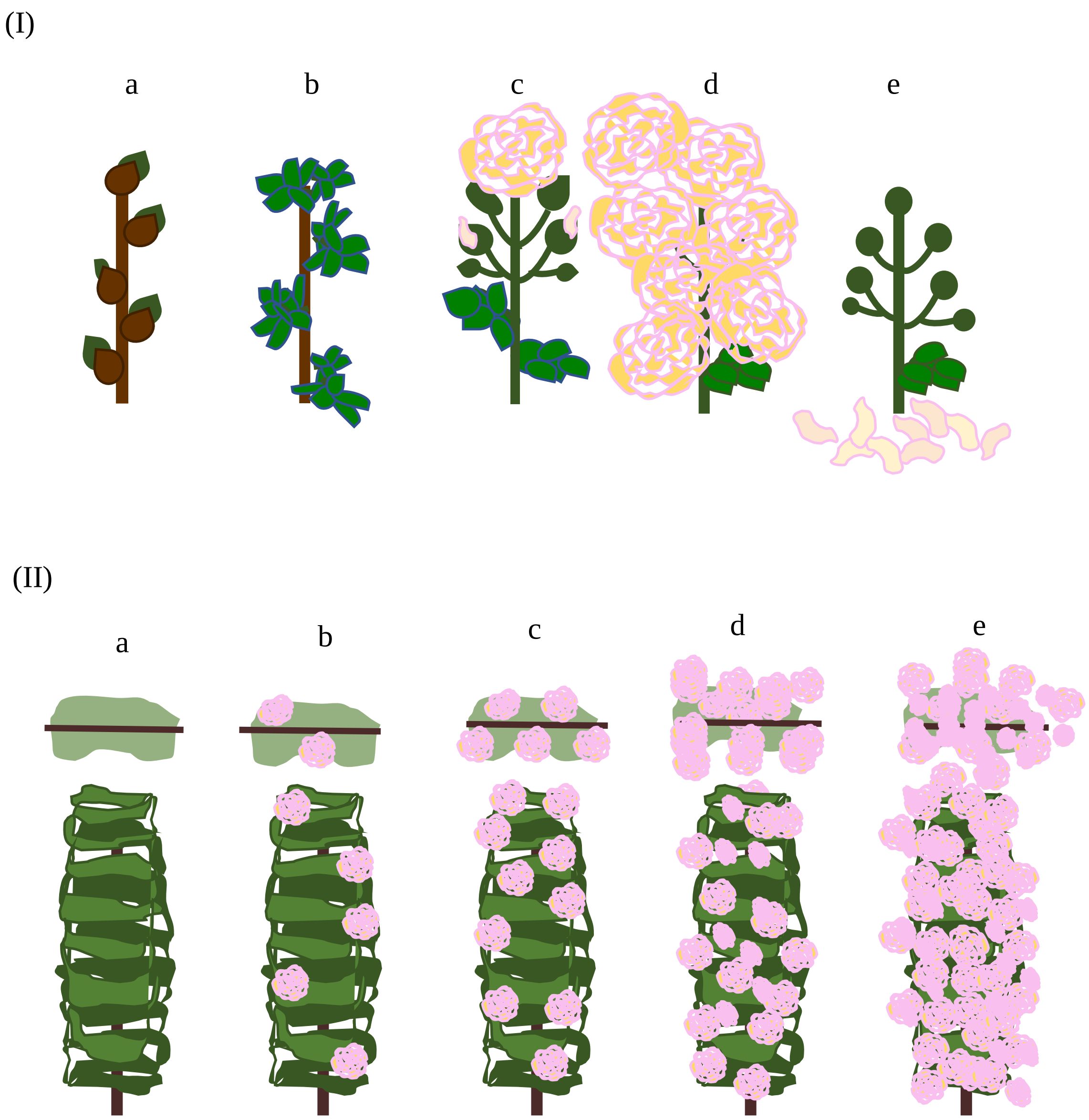

Figure 1. The chosen phenology stages (1) and abundance of flowering on a scale 0-5 in climber roses (2). (1), where: a – BBCH 07 – starting of bud break, first leaf tips appears; b – BBCH 11 – the first light green and/or bronze leaves pair develops, not yet at full size; c – BBCH 60 601 – start of flowering (about 10% of flowers open); d – BBCH 63 605 – full of flowering (at least 50% of flowers open); e – BBCH 69 609 – final of flowering (after all petals shedding); (2), where: a - 0 – plants fail to bloom; b - 1 – a few poor inflorescences on shoot; c - 2 – < 5 inflorescences on 1 m of shoot, weak flowering; d - 3 – with 3-10 flowers in inflorescences, average flowering; e - 4 – > 5 inflorescences on 1 m of shoot, abundant and long flowering; f - 5 – abundant and long flowering, the inflorescences densely placed on the plant.

(BBCH 11), the date of the start and its abundance of flowering. The STATISTICA 10 (StatSoft, Cracow, Poland) software was used.

Additionally, correlation analyses were performed to examine:

- the interconnections of frost damage, bud break (BBCH 07), leaf development (BBCH 11), the date of the start of flowering (BBCH 60 601) and its abundance. Pearson's correlation coefficient (SPSS software, IBM Statistics) was used for all the cultivars separately;
- the association between average monthly temperature and frost damage, bud break (BBCH 07), leaf development (BBCH 11), the date of the start of flowering (BBCH 60 601) and its abundance for each month from October to April, and all months together for selected seasons (2005/2006, 2009/2010, 2015/2016) with a long and frosty autumn-winter-spring period (STATISTICA 10 software, StatSoft, Cracow, Poland);
- the correlations between minimum air temperature throughout the month and frost damage (STATISTICA 10 software, StatSoft, Cracow, Poland).

2.4. Assessment of weather conditions in Polish Academy of Sciences Botanical Garden - Center for Biological Diversity Conservation in Powsin in view of elements of climate change in Poland

The Polish Academy of Sciences Botanical Garden – Center for Biological Diversity Conservation in Powsin is located on the outskirts of Warsaw (Poland, 52.6°N, 20.5°E) in the Middle Vistula mesoregion. The area was separated from the Warsaw Plain by a high fluvial terrace at the border of a post-glacial plateau [47]. Warsaw, together with the Mazovia region, lies in USDA hardiness zone 6B (minimal average temperatures -20.6°C – -17.8°C) [48].

The increase of temperature is clearly visible when observing the long-term average. For this purpose, data measured between 1973-2017 in the Warsaw-Okęcie meteorological station, 10 km from PAS Botanical Garden, was provided. The linear trend with R-square values of linear regression [49] conducted for average, maximal and minimal monthly temperatures in the years 1973-2017, which exposes the climate warming of the region, is presented in Figure 2a. The minimal, maximal and average air temperature has risen by an estimated ca 1.5°C over the past 44 years (Figure 2a). The climatic changes manifested by the increase of average air temperature were smaller in PAS Botanical Garden CBDC in Powsin (R2=0.1028) (Figure 3).

The increase of temperature is connected with a longer growing season in autumn [50]. As Krużel *et al*. [50] inform, in the years 2001-2009 the growing season in Poland extended by eight days, wherein it was longer in the northwest (231-335) and shorter in the east (196-200). The growing season in the years 1981-2010 (216-220 days) was three days longer than in 1971-2000 in Warsaw, Poland [50]. Also, the date of last spring frost noted for six meteorological stations in Poland were reported statistically significant earlier from 1.6 to 3.5 days per decade in the years 1961-2020, noted as consecutive days of the year. However, the last spring frost occurred 7-14 days earlier in the years 1991-2020 [51]. Although the climate warming is connected with the decreasing the total number of frost days per year and caused also extension of growing season, the number of the days with the days with minimum temperature < 0 °C on many areas on Nothern Hemisphere at latitudes greater than 30° N [52].

Additionally, the precipitation measured in Warsaw-Okęcie meteorological station using polynomial trend line estimation with R-square values of multiple regression [49] is shown in Figure 2 b. The course of precipitation in the years 2000-2017, based on measurements carried out in the PAS Botanical Garden CBDC, is designated in Figure 4. However, a tendency for an increase in the sum of precipitation was observed in both stations in recent years (Figures 2b and 4). A disadvantageous phenomenon was observed in the sum of precipitation in early spring (March, April) and late autumn (October, November) in the Botanical Garden (Figure 4a). Long-lasting high snow cover occurred in the seasons of 2009/2010, 2010/2011 and 2011/2012.

Adverse weather conditions were observed in the Botanical Garden from October to April of some seasons e.g. 2002/2003 and 2005/2006 (Figure 4a, Figure Suppl. 1). The lowest minimal temperatures were measured in January (2003: -22.0ºC, 2009: -22.5°C, 2010: -25.0°C, 2013: -15.1°C, 2014:

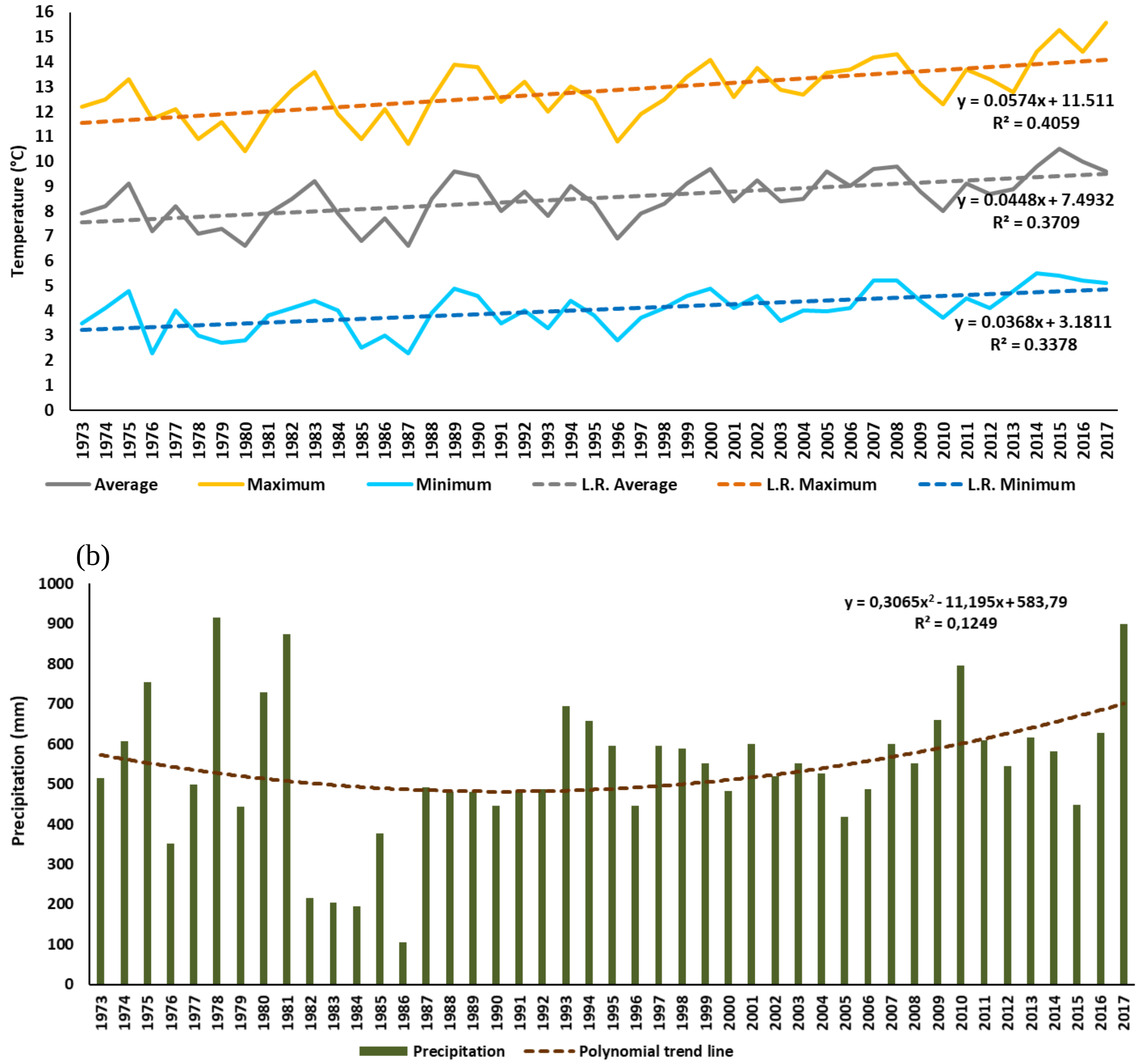

Figure 2. The means of monthly temperatures (average, minimal, maximal) (a) (Monder, 2021) and precipitation (b) in the years 1973-2017 noted at the Warsaw-Okęcie meteorological station (within 10 km from PAS Botanical Garden) with the linear (a) or polynomial (b) trend line.

-17.0°C, 2016: -18.4°C), February (2011: -18.1°C, 2012: -26.0°C) and March (2013: -14.2°C) (Figure 2-4). The course of weather conditions in the autumn-winter-spring period was also adverse, with e.g. a sudden increase of temperature in spring (2003, 2013, 2016), a decrease of 24-hour temperature below zero in the last days of December or in January (2002, 2009, 2010, 2012, 2014), low minimum temperatures at the end of February or in March (2005/2006, 2011/2012, 2013/2014), high amplitudes of 24-hour temperature occurring for a period of a few days in winter (2002/2003, 2014/2015, 2015/2016) and in April (2010-2016), and prolonged frost periods (2002/2003, 2005/2006, 2011/2012, 2012/2013) followed by fast spring warming (2010, 2012, 2013, 2014, 2017) (Figure Suppl. 1).

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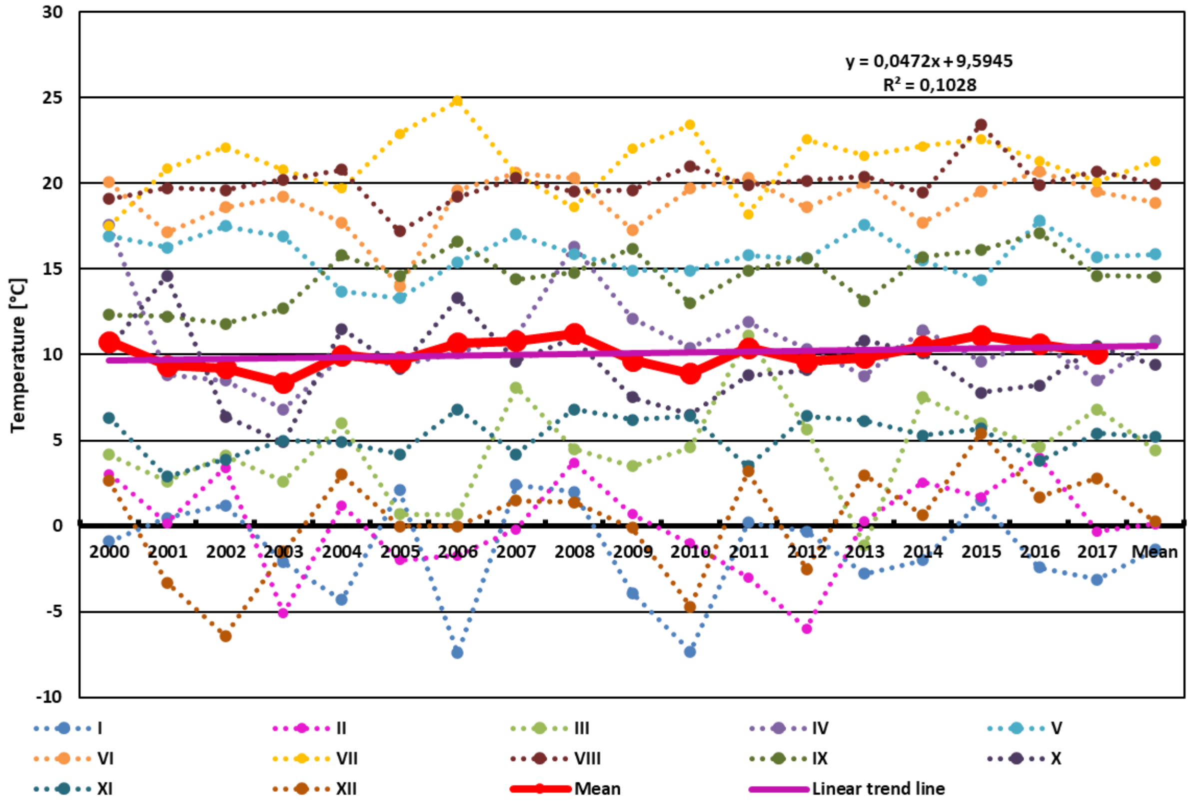

Figure 3. The means of monthly and yearly air temperatures (°C) in the years 2000-2017, measured in the PAS Botanical Garden CBDC in Powsin, and the linear trend line of increase of the average yearly temperature in this period (Monder, 2021).

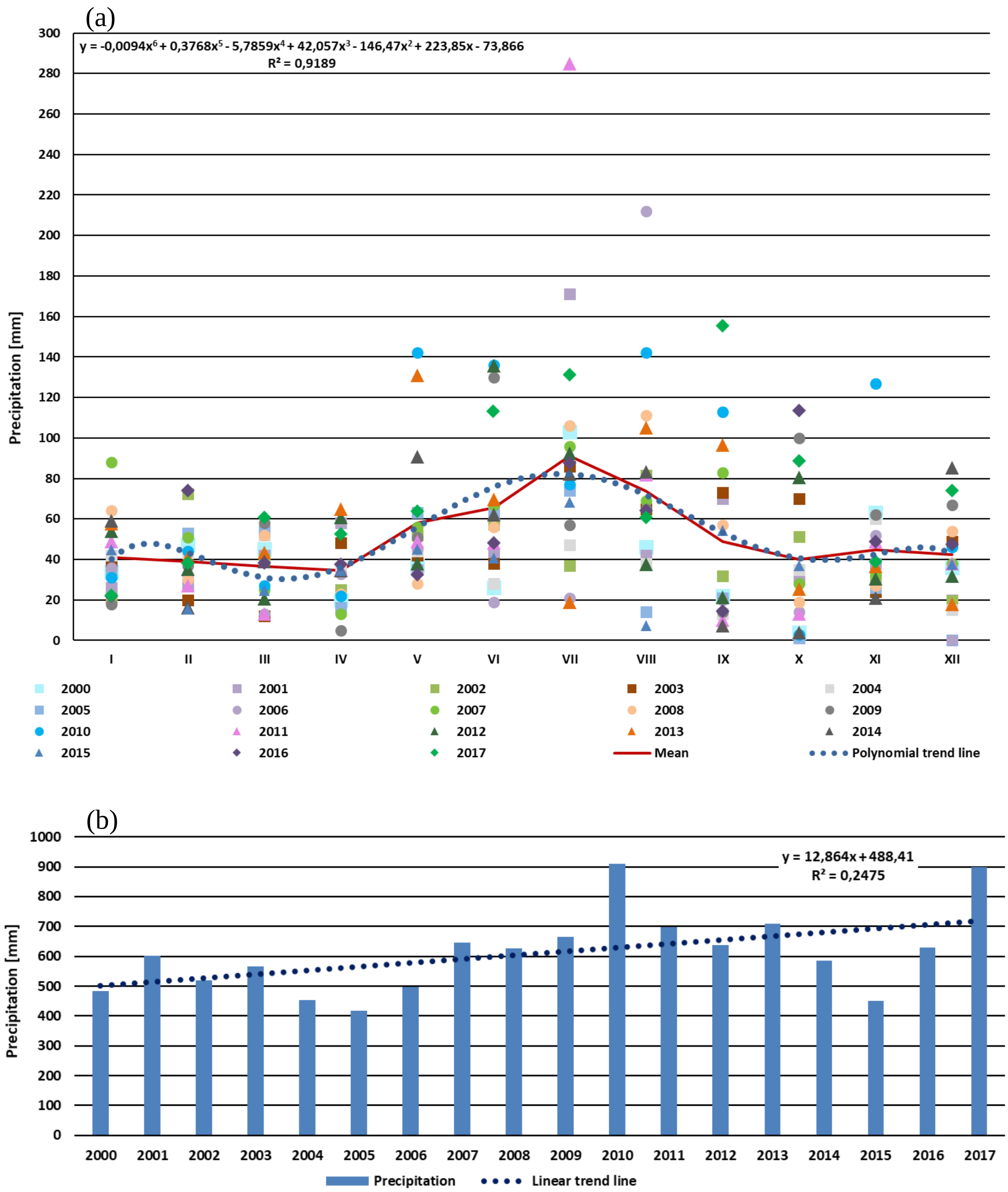

Figure 4. The sum of monthly precipitation (a) (Monder, 2021) and means for years (b) [mm] in the years 2000-2017, measured in the PAS Botanical Garden CBDC in Powsin, with the trend lines.

3. Results

3.1. Growth of plants

The growth of plants was uneven in subsequent vegetation seasons and often did not reach the maximum height provided by the support (Table 1, Figure 5). The necessity of low spring pruning of frozen shoots after frosty winters limited the roses' height in the current season and delayed the possible height of most rose cultivars, e.g. 'Chaplin's Pink climber', 'Orange Triumph', 'Paul's Scarlet Climber', whose low-cut 4-9 year old plants nevertheless grew taller than 2-4 year old 'Zéphirine Drouhin' plants. The rose plants of all cultivars, regardless of age, reached their maximum in the years 2014-2017 with an early spring, long summer and autumn, and mild winter. The climber roses reached their maximum height 3 years after planting ('Alberic Barbier', 'Albertine', 'Chaplin's Pink Climber', 'Dr Robert Huey', 'Duc de Constantin', 'Orange Triumph clg', 'Venusta Pendula') or a few years later ('Chaplin's Pink Climber', 'Dr Robert Huey' 'Gerbe Rose', 'Mme Plantier', 'Paul Scarlet Climber', 'Zéphirine Drouhin') (Figure 5).

The necessity of pruning the shoots after severe winters contributed to their limited growth and height by the end of the year (Figure 5). It was observed that in the years 2014, 2015, 2016 and 2017, with early spring, long autumn and simultaneously mild winter (Figure 3), and therefore a long growing season, the shrubs were 50-100 cm taller than before, regardless of their age (Figure 5).

3.2. Frost damage in climber roses

The frost damage varied in scale for different years and cultivars; however, none of the plants suffered complete frost damage (no signs of regeneration) (Figure 6). 'Mme Plantier' was the only cultivar without frost damage in any year. Low frost damage in all remaining cultivars of climbers was observed after the mild winter seasons of 2006/2007, 2007/2008, and 2013/2014. Short-term (1-2 day) drops in minimal temperature exceeding -20°C (2002/2003; 2005/2006, 2009/2010, 2010/2011, 2011/2012) or a few days of long-term minimal temperature not exceeding -20°C (2012/2013) caused significant frost damage (5-6 points). In the seasons from 2014/2015 to 2016/2017 minimal temperatures below -20°C were not recorded, the frost damage in shrubs had been evaluated at 1-3 points and was limited to darkened vascular bundles on shoots or dying one-year shoot tips (Figure 6).

Considering all the years of observation, low frost resistance was typical for 'Dr Robert Huey' and 'Duc de Constantin' in contrast to 'Alberic Barbier', 'Albertine', 'Chaplin's Pink Climber', 'Orange Triumph clg', and 'Venusta Pendula' (Figure 6). The frost damage to 'Alberic Barbier', 'Albertine', 'Chaplin's Pink Climber', 'Orange Triumph clg', 'Venusta Pendula' after the winter seasons 2000-2006 and 2009-2013 resulted in shoots completely dying out to the ground level, darkened vascular bundles on shoots or darkening buds. The buds that began growth on damaged shoots in March and April died out in May. The shoots were damaged to the ground surface (5 and 6 points on the scale) and the shrubs were pruned low. 'Dr Robert Huey', 'Duc de Constantin', 'Gerbe Rose' and 'Paul's Scarlet Climber' also required strong pruning after the winter season in 2000-2006 and 2009-2013 (Figure 6, Table 2).

Correlation analysis of the climber roses for frost damage showed a strict relationship between average monthly temperature and values of frost damage in all cultivars. The decreasing of average temperature in October, January and February correlated with an increase of frost damage in eight out of 11 cultivars ('Alberic Barbier', 'Albertine', 'Chaplin's Pink Climber', 'Gerbe Rose', 'Orange Triumph clg', 'Paul's Scarlet Climber', 'Venusta Pendula', 'Zephirine Drouhin') (Table 2) with a high tendency to frost damage (Figure 6), while the decreasing of average temperature in November, January, February, and March had the same effect on the remaining three cultivars ('Mme Plantier', 'Duc de Constantin', 'Dr Robert de Huey') (Table 2) with a lower tendency to frost damage (Figure 6). Increased average temperatures in December and April also correlated with an increase in frost damage in 'Mme Plantier', 'Duc de Constantin' and 'Dr Robert de Huey'. Decreasing the average air temperature in the following month caused higher frost damage (Table 2), but a decrease of low minimum temperature was significant only in December and March (Table 3).

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Figure 5. The height (cm) of climber roses after spring pruning (green) and at the end of October (orange) in following years.

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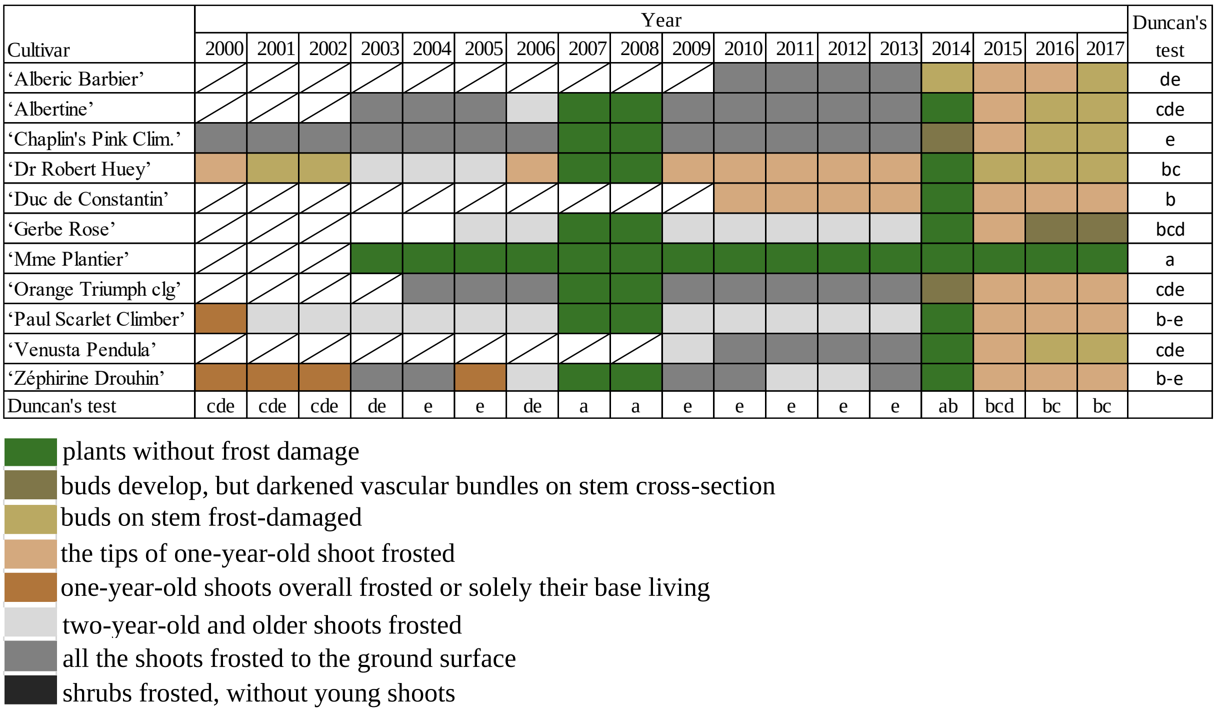

Figure 6. Frost damage of climber roses evaluated in valuation scale. Means with the same letter are not significantly different between cultivars (vertically) and years (horizontally) at p ≤ 0.05 in Duncan's range test.

Table 2. The effect of correlations between frost damage of climber roses and average monthly air temperature (2005/2006, 2009/2010, 2015/2016).

Cultivar	SD	Month						
		October	November	December	January	February	March	April
'Alberic Barbier'	1.15	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
'Albertine'	0.58	-0.941***	0.809**	-0.992***	-0.488	-0.320	0.999***	-0.914***
'Chaplin's P. Clim.'	1.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*
'Dr Robert Huey'	0.58	0.179	-0.914***	0.604*	-0.512*	-0.660**	-0.543*	0.808**
'Duc de Constantin'	1.15	0.179	-0.914***	0.604*	-0.512*	-0.660**	-0.543*	0.808**
'Gerbe Rose'	0.58	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
'Mme Plantier'	0.58	0.179	-0.914***	0.604**	-0.512*	-0.660**	-0.543*	0.808**
'Orange Triumph clg'	1.73	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
'Paul Scarlet Clim.'	1.15	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
'Venusta Pendula'	1.73	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
'Zéphirine Drouhin'	1.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*

Note: The correlations are significant at p<0.05, marked: *0.500-0.599 – restrained; **0.600-0.899 – high; ***>0.9 – very high

Table 3. The effect of correlations between frost damage of climber roses and minimum monthly air temperatures (2005/2006, 2009/2010, 2015/2016).

Cultivar	SD	Month						
		October	November	December	January	February	March	April
‘Alberic Barbier’	2.66	-0.097	-0.175	-0.554*	-0.240	-0.216	-0.644**	-0.186
‘Albertine’	2.63	-0.087	-0.202	-0.521*	-0.207	-0.223	-0.633**	-0.211
‘Chaplin's P. Clim.’	2.69	-0.027	-0.155	-0.515*	-0.309	-0.232	-0.667**	-0.205
‘Dr Robert Huey’	1.75	-0.142	-0.016	-0.476	-0.434	-0.022	-0.367	-0.010
‘Duc de Constantin’	1.93	-0.067	-0.041	-0.500*	-0.160	0.043	-0.117	0.174
‘Gerbe Rose’	2.27	-0.100	-0.118	-0.527*	-0.385	-0.264	-0.725**	-0.137
‘Mme Plantier’	1.57	0.403	-0.190	0.248	0.034	0.038	-0.245	-0.059
‘Orange Triumph clg’	2.74	-0.107	-0.133	-0.522*	-0.315	-0.263	-0.734**	-0.285
‘Paul Scarlet Clim.’	2.17	-0.098	-0.070	-0.520*	-0.426	-0.241	-0.730**	-0.222
‘Venusta Pendula’	2.68	-0.070	-0.163	-0.544*	-0.279	-0.262	-0.696**	-0.251
‘Zéphirine Drouhin’	2.36	-0.060	-0.157	0.083	-0.009	0.215	-0.153	-0.078

Note: The correlations are significant at $p<0.05$, marked: *0.500-0.599 – restrained; **0.600-0.899 – high; ***>0.9 – very high

3.3. Early phenological stages and growth of climber roses

The date of early phenological stages – bud breaking and leaf development – varied from year to year depending on the temperature range in winter and spring as well as on the cultivar (Figures 7 and 8, Tables 4 and 5).

The start of bud break, when the first leaf tips were visible (BBCH 07), occurred from the first days of March to the last days of April. It occurred first in ‘Orange Triumph clg’, ‘Gerbe Rose’, ‘Mme Plantier’, ‘Dr Robert Huey’, and ‘Venusta Pendula’. Bud break was observed last in ‘Alberic Barbier’, ‘Albertine’, ‘Chaplin's Pink Clim.’, and ‘Zéphirine Drouhin’ (Figure 7).

For most cultivars, the first two leaf were developed (BBCH 11) 10-20 days later each year from the end of March to the first days of May. Leaves were first to unfold in ‘Gerbe Rose’, ‘Mme Plantier’, ‘Dr Robert Huey’, ‘Orange Triumph clg’, ‘Paul Scarlet Climber’, and ‘Venusta Pendula’. The cultivars observed to unfold leaves the last were ‘Alberic Barbier’, ‘Albertine’, and also ‘Duc de Constantin’ (Figure 8).

The correlation analysis of the climber roses for the timing of bud break and leaf unfolding showed a strict relationship with the average temperature in winter and early spring months in all cultivars (Tables 4 and 5). The increase of average temperature in March and its decrease in April were correlated with a later date of leaf unfolding in ‘Venusta Pendula’ and ‘Zéphirine Drouhin’, in contrary to the decrease of average temperature in March and its increase in April in ‘Chaplin's Pink Climber’, ‘Duc de Constantin’, ‘Mme Plantier’, which inhibited the leaves’ unfolding (Table 5).

3.4. Flowering of climber roses

The first abundant flowering in once-blooming climber roses appeared 3-4 years after planting. The flowerings of climber roses were limited or plants did not bloom (Figures 9 and 10) in years after severe winters (Figures 4 and Suppl. 1), when the shoots were shortened to the ground or almost to it (frost-damage 5-6 in scale), especially in 1-3 year old plants (Figure 5).

The flowering began a few days later in years that followed severe winter and necessary low pruning, and a few days earlier in years after mild winter and early spring. An early start of flowering characterised ‘Gerbe Rose’, ‘Venusta Pendula’, ‘Zéphirine Drouhin’, while ‘Chaplin’s Pink Climber’ and ‘Orange Trimph clg’ began to flower later. However, the flowering period elongated a few days after severe winter and shorter in years after mild winter – 2006, 2010, 2015, 2016 (Figures 9 and 10).

Correlation analysis of the climber roses for the period of flowering showed a strict relationship with the average temperature in winter (January, February) for all cultivars excluding ‘Albertine’. The decrease (‘Gerbe Rose’, ‘Orange Triumph clg’, ‘Paul’s Scarlet Climber’, ‘Zéphirine Drouhin’) or increase (‘Chaplin's Pink Climber’, ‘Duc de Constantin’, ‘Dr Robert Huey’, ‘Venusta Pendula’) of the average

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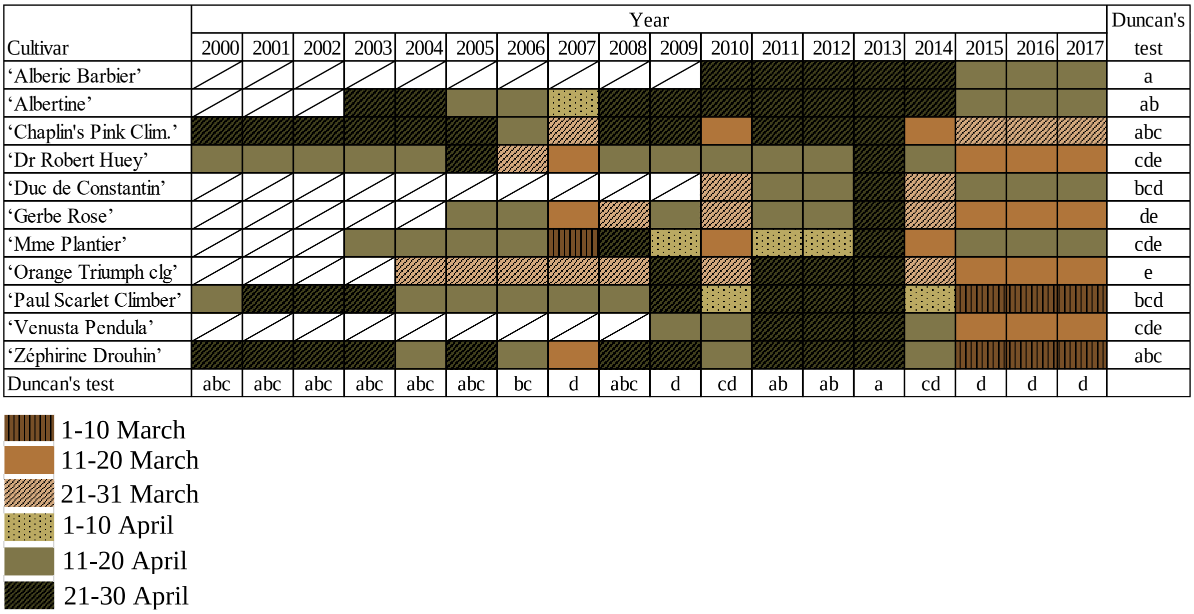

Figure 7. Time frame when starting of bud break and first leaf tips appears [BBCH 07] on unpruned shoots in climber roses. Means with the same letter are not significantly different between cultivars (vertically) and years (horizontally) at $p \leq 0.05$ in Duncan's range test.

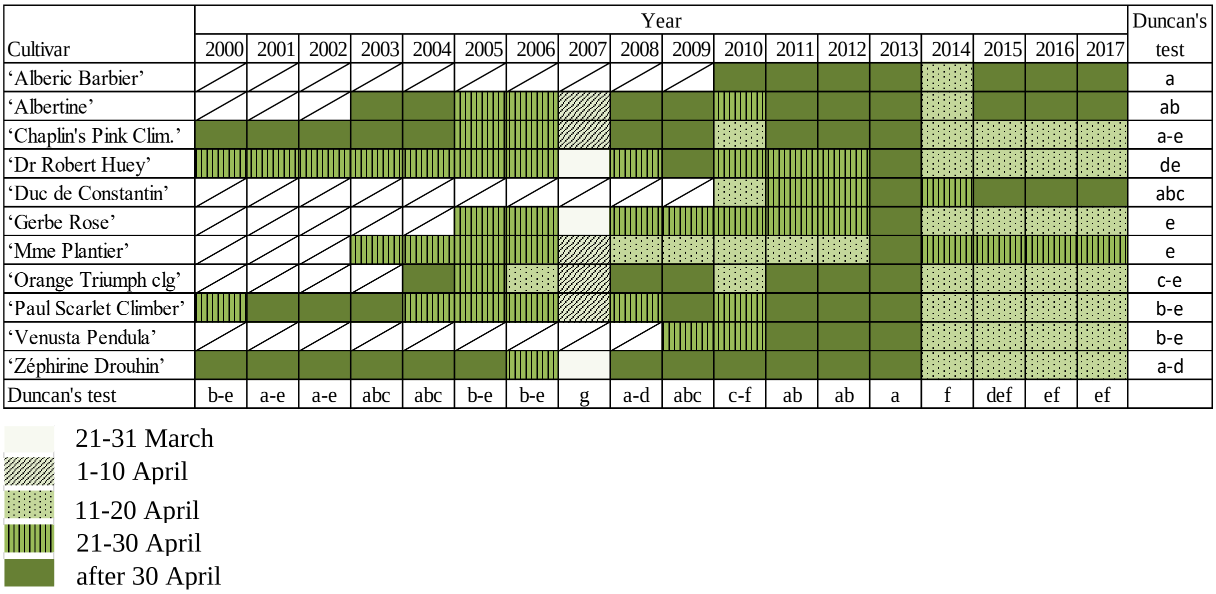

Figure 8. Time frame when the first light green and/or bronze leaves pair develops, not yet at full size [BBCH 11] on unpruned shoots of climber roses. Means with the same letter are not significantly different between cultivars (vertically) and years (horizontally) at $p \leq 0.05$ in Duncan's range test.

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Table 4. The effect of correlations between average monthly air temperature (2005/2006, 2009/2010, 2015/2016) and the term of bud break with visible first leaf tips (BBCH 07) in climber roses.

Cultivar	SD	Month						
		October	November	December	January	February	March	April
‘Alberic Barbier’	5.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*
‘Albertine’	0.58	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Chaplin's P. Clim.’	15.28	0.491	-0.996***	0.832**	-0.202	-0.378	-0.788**	0.956***
‘Dr Robert Huey’	15.28	-0.998	0.572*	-0.897**	-0.747	-0.613**	0.927***	-0.731**
‘Duc de Constantin’	10.00	0.984***	-0.407	0.797**	0.859**	0.751**	-0.840**	0.589*
‘Gerbe Rose’	15.28	-0.153	-0.730**	0.310	-0.765**	-0.870**	-0.238	0.571*
‘Mme Plantier’	17.32	0.941***	-0.809**	0.992***	0.488	0.320	-0.999***	0.914***
‘Orange Triumph clg’	5.77	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Paul Scarlet Climber’	15.28	-0.932***	0.227	-0.668**	-0.940***	-0.862**	0.722**	-0.426
‘Venusta Pendula’	15.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*
‘Zéphirine Drouhin’	23.09	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106

Note: The correlations are significant at p<0.05, marked: *0.500-0.599 – restrained; **0.600-0.899 – high; ***>0.9 – very high.

Table 5. The effect of correlations between average monthly air temperature (2005/2006, 2009/2010, 2015/2016)) and period of the first leaf pair unfolding (BBCH 11) in climber roses.

Cultivar	SD	Month						
		October	November	December	January	February	March	April
‘Alberic Barbier’	0.58	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Albertine’	5.77	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Chaplin's P. Clim.’	5.77	0.179	-0.914***	0.604**	-0.512*	-0.660**	-0.543*	0.808**
‘Dr Robert Huey’	5.77	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Duc de Constantin’	10.00	0.984***	-0.407	0.797***	0.859**	0.751**	-0.840**	0.589*
‘Gerbe Rose’	5.77	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Mme Plantier’	5.77	0.941***	-0.809**	0.992***	0.488	0.320	-0.999***	0.914***
‘Orange Triumph clg’	0.58	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Paul Scarlet Clim.’	5.77	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106
‘Venusta Pendula’	5.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*
‘Zéphirine Drouhin’	10.00	-0.984***	0.407	-0.797**	-0.859**	-0.751**	0.840**	-0.589*

Note: The correlations are significant at p<0.05, marked:: *0.500-0.599 – restrained; **0.600-0.899 – high; ***>0.9 – very high.

Table 6. The effect of correlations between average monthly air temperature (2005/2006, 2009/2010, 2015/2016) and the start of the flowering period (BBCH 60 601) in climber roses.

Cultivar	SD	Month						
		October	November	December	January	February	March	April
‘Alberic Barbier’	6.93	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Albertine’	7.64	-0.491	0.996***	-0.832**	0.202	0.378	0.788**	-0.956***
‘Chaplin's P. Clim.’	14.43	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Dr Robert Huey’	5.77	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Duc de Constantin’	8.66	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Gerbe Rose’	6.03	-0.426	-0.508*	0.029	-0.915***	-0.974***	0.045	0.316
‘Mme Plantier’	4.73	-0.034	-0.807**	0.422	-0.682***	-0.804**	-0.353	0.665**
‘Orange Triumph clg’	14.43	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Paul Scarlet Clim.’	12.58	-0.443	-0.491	0.010	-0.923***	-0.978***	0.064	0.298
‘Venusta Pendula’	0.58	0.763**	0.104	0.388	0.998***	0.981***	-0.455	0.106
‘Zéph. Drouhin’	5.20	-0.763**	-0.104	-0.388	-0.998***	-0.981***	0.455	-0.106

Note: The correlations are significant at p<0.05, marked:*0.500-0.599 – restrained; **0.600-0.899 – high; ***>0.9 – very high.

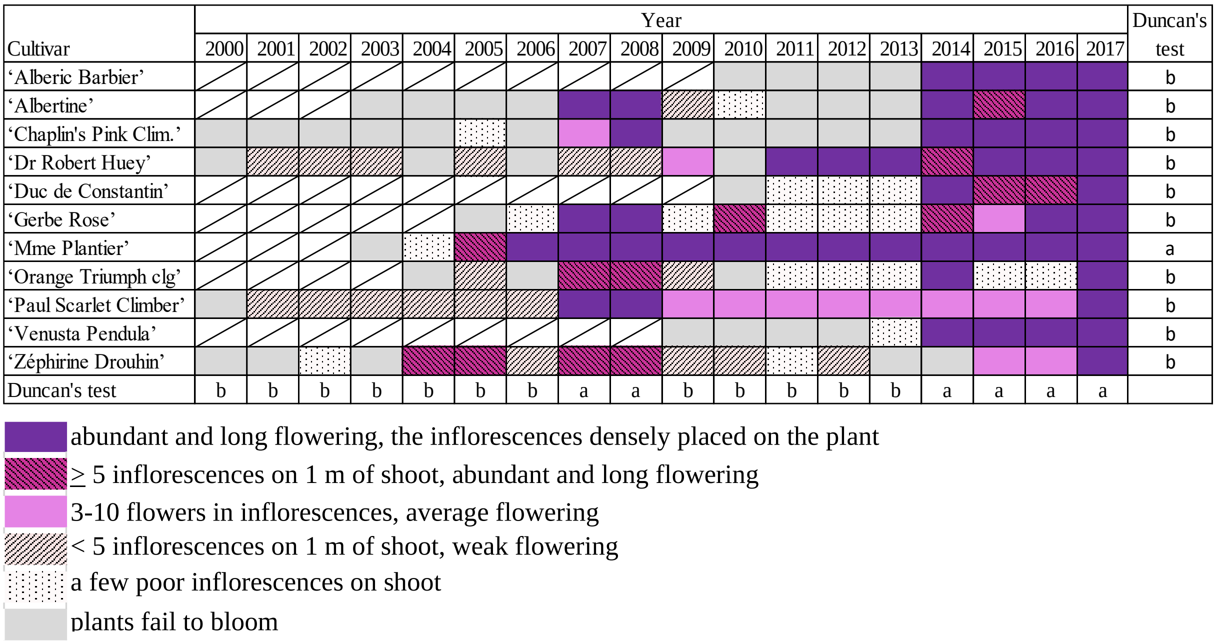

Figure 9. The flowering in climber roses evaluated according to the valuation scale: 0 – plants fail to bloom; 1 – a few poor inflorescences on shoot; 2 – < 5 inflorescences on 1 m of shoot, weak flowering; 3 – with 3-10 flowers in inflorescences, average flowering; 4 – > 5 inflorescences on 1 m of shoot, abundant and long flowering; 5 – abundant and long flowering, the inflorescences densely placed on the plant. Means with the same letter are not significantly different between cultivars (vertically) and years (horizontally) at $p \leq 0.05$ in Duncan's range test.

temperature in January and February were correlated with a later period of flowering. The increase in average temperature in November and March and its decrease in December and April showed a correlation with later flowering in 'Albertine' (Table 6).

3.5. The association of frost damage, early phenology stages and abundance of flowering

Correlation analysis conducted for all cultivars taken together showed strict connections between valued parameters. Delayed bud break, leaf development, beginning of flowering and also a decrease of flower abundance were correlated with stronger frost damage. The plants that were late to break buds and fold leaves started flowering later and exhibited lower abundance (Tables 7).

The correlations for each cultivar taken separately were variable. Increased frost damage was correlated with delayed bud break and leaf development as well as decreased abundance of flowering in all cultivars excluding 'Mme Plantier'. Delayed bud break correlated with late leaf development in all cultivars, excluding 'Alberic Barbier', and with late beginning of flowering in all cultivars excluding 'Dr Robert Huey' and 'Mme Plantier'. Decreasing abundance of flowering was correlated with delayed bud breaking in all cultivars and with delayed leaf development in 'Alberic Barbier', 'Alberine', 'Chaplin's Pink Climber', 'Gerbe Rose', 'Mme Plantier', 'Orange Triumph', 'Venusta Pendula', and 'Zéphirine Drouhin' (Table 8).

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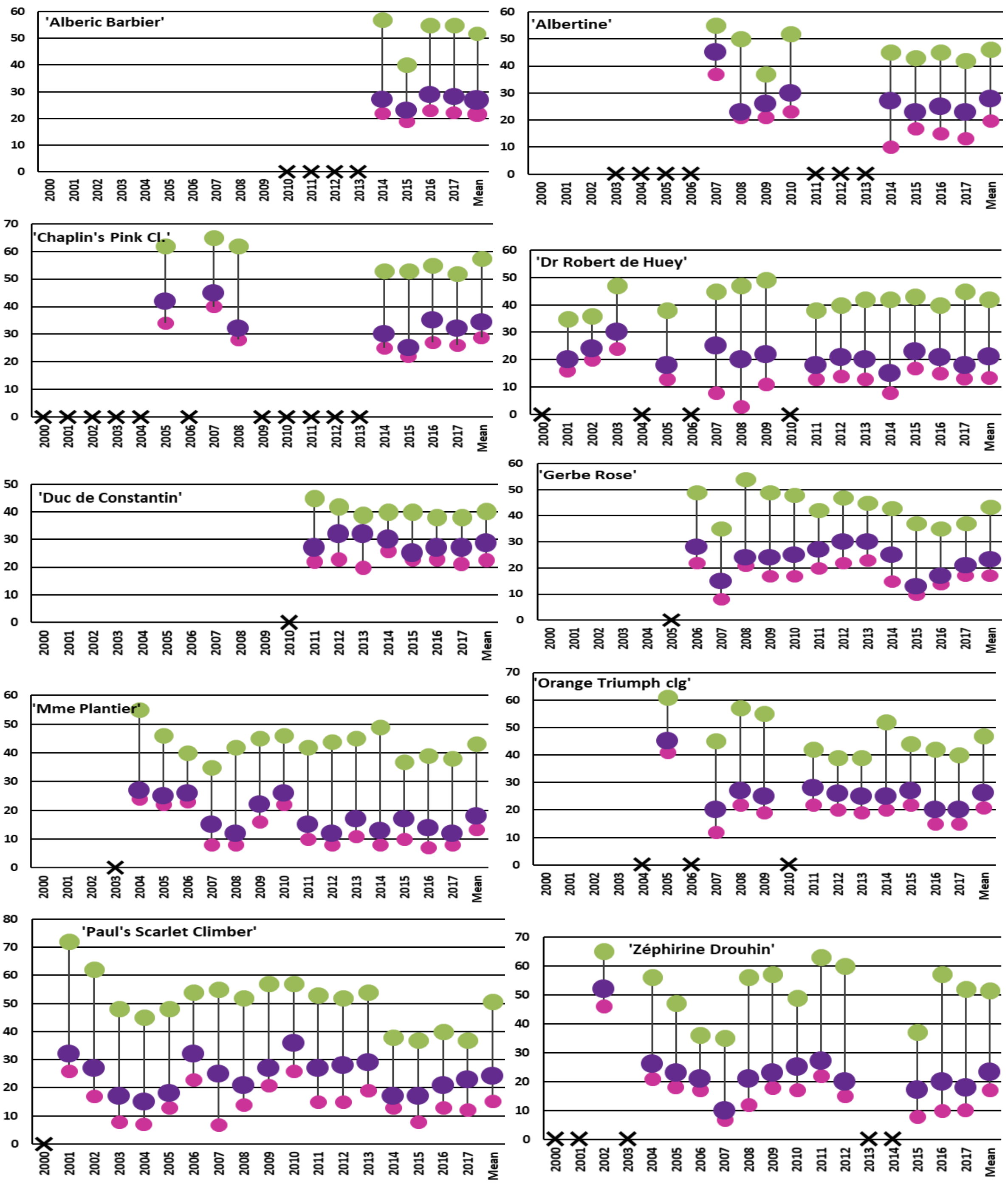

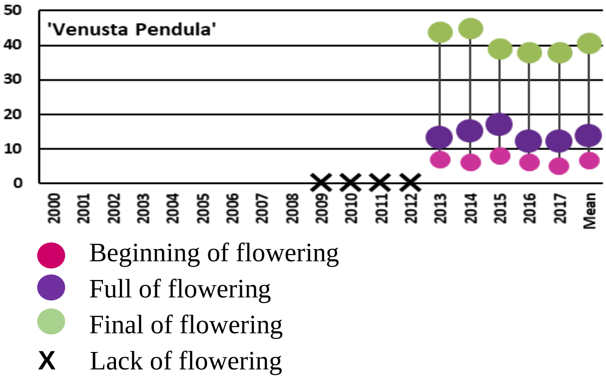

Cultivar	Beginning of Flowering	Full of Flowering	End of Flowering
‘Alberic Barbier’	b	bc	b
‘Albertine’	bc	b	cd
‘Chaplin's Pink Clim.’	a	a	a
‘Dr Robert Huey’	e	ef	e
‘Duc de Constantin’	b	b	e
‘Gerbe Rose’	cd	de	cde
‘Mme Plantier’	e	f	de
‘Orange Triumph	b	bcd	c
‘Paul Scarlet Climber’	de	de	b
‘Venusta Pendula’	f	g	e
‘Zéphirine Drouhin’	cd	de	b

Figure 10. The beginning of flowering (BBCH 60 601), full flowering (BBCH 63 605) and its end (BBCH 69 609) in climber roses in the years 2000-2017. The numbers on the Y-ray indicate fallowed days where 1st day start at the 25th May. Different letters marked significant differences between cultivars, in respect Duncan’s test ($\alpha = 0.05$).

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Table 7. Correlations matrix between frost damage, early phenology stages, beginning and abundance of flowering in climber roses for all cultivars taken together (‘Alberic Barbier’, ‘Albertine’, ‘Chaplin's Pink Climber’, ‘Dr Robert Huey’, ‘Duc de Constantin’, ‘Gerbe Rose’, ‘Mme Plantier’, ‘Orange Triumph clg’, ‘Paul Scarlet Climber’, ‘Venusta Pendula’, ‘Zéphirine Drouhin’).

Variable	Bud Break	Leaf Development	Frost Damage	Beginning of Flowering	Abundance of Flowering
For all Cultivars					
Leaf Development	0.759****	1.000			
Frost Damage	0.410**	0.548***	1.000		
Beginning of Flowering	0.210*	0.359**	0.288*	1.000	
Abundance of Flowering	-0.432**	-0.403**	-0.733****	0.220*	1.000

Note: The correlations are significant at α= 0.01; marked: *0.100-0.299 – low; **0.300-0.499 – restrained; ***0.500-0.699 – high; ****0.700-0.899 – very high; *****≥0.900 – almost full.

Table 8. Correlations matrices between frost damage, early phenology stages, beginning and abundance of flowering in climber roses for: ‘Alberic Barbier’, ‘Albertine’, ‘Chaplin's Pink Climber’, ‘Dr Robert Huey’, ‘Duc de Constantin’, ‘Gerbe Rose’, ‘Mme Plantier’, ‘Orange Triumph clg’

Variable	Bud Break	Leaf Development	Frost Damage	Beginning of Flowering	Abundance of Flowering
‘Alberic Barbier’					
Leaf Development	-0.293*	1.000			
Frost Damage	0.687***	0.476**	1.000		
Beginning of Flowering	0.122*	0.178*	-0.066	1.000	
Abundance of Flowering	-0.775****	-0.378**	-0.980*****	0.001	1.000
‘Albertine’					
Leaf Development	0.520***	1.000			
Frost Damage	0.440**	0.462**	1.000		
Beginning of Flowering	0.380**	0.330**	0.291*	1.000	
Abundance of Flowering	-0.429**	-0.429**	-0.933*****	-0.243*	1.000
‘Chaplin's Pink Climber’					
Leaf Development	0,924*****	1.000			
Frost Damage	0.591***	0.638***	1.000		
Beginning of Flowering	0.291*	0.329**	0.406**	1.000	
Abundanceof Flowering	-0.641***	-0.639***	-0.908*****	-0.063	1.000
‘Dr Robert Huey’					
Leaf Development	0.740****	1.000			
Frost Damage	0.373**	0.423**	1.000		
Beginning of Flowering	0.056	-0.084	0.471**	1.000	
Abundance of Flowering	-0.138*	0.251*	-0.357**	-0.111*	1.000
‘Duc de Constantin’					
Leaf Development	0.747****	1.000			
Frost Damage	0.619***	0.204*	1.000		
Beginning of Flowering	0.147*	-0.450**	0.078	1.000	
Abundance of Flowering	-0.073	0.569***	-0.465**	-0.776****	1.000
‘Gerbe Rose’					
Leaf Development	0.756****	1.000			
Frost Damage	0.787****	0.694***	1.000		
Beginning of Flowering	0.527***	0.741****	0.221*	1.000	
Abundance of Flowering	-0.907*****	-0.631***	-0.866****	-0.258*	1.000
‘Mme Plantier’					
Leaf Development	0.626***	1.000			
Frost Damage	Nd	Nd	1.000		
Beginning of Flowering	-0.032	0.097	Nd	1.000	
Abundance of Flowering	-0.222*	-0.244*	Nd	-0.278*	1.000
‘Orange Triumph clg’					
Leaf Development	0.713****	1.000			
Frost Damage	0.513***	0.472**	1.000		
Beginning of Flowering	0.107*	0.457**	0.530***	1.000	
Abundance of Flowering	-0.510***	-0.456**	-0.858****	-0.342**	1.000

Note: The correlations are significant at α= 0.01; marked: *0.100-0.299 – low; **0.300-0.499 –restrained; ***0.500–0.699 – high; ****0.700-0.899 – very high; *****≥0.900 – almost full. Nd – The variable takes constant values.

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Table 9. Correlations matrices between frost damage, early phenology stages, beginning and abundance of flowering in climber roses: 'Paul Scarlet Climber', 'Venusta Pendula', 'Zéphirine Drouhin'.

Variable	Bud Break	Leaf Development	Frost Damage	Beginning of Flowering	Abundance of Flowering
'Paul Scarlet Climber'					
Leaf Development	0.716****	1.000			
Frost Damage	0.355**	0.735****	1.000		
Beginning of Flowering	0.395**	-0.444**	0.386**	1.000	
Abundance of Flowering	-0.321**	0.525***	-0.613***	-0.225*	1.000
'Venusta Pendula'					
Leaf Development	0.847****	1.000			
Frost Damage	0.635***	0.882****	1.000		
Beginning of Flowering	0.103*	0.200*	0.325**	1.000	
Abundance of Flowering	-0.816****	-0.881****	-0.920*****	-0.146*	1.000
'Zéphirine Drouhin'					
Leaf Development	0.823****	1.000			
Frost Damage	0.394**	0.660***	1.000		
Beginning of Flowering	0.591***	0.537***	0.335**	1.000	
Abundance of Flowering	-0.560***	-0.391**	-0.298*	-0.295*	1.000

Note: The correlations are significant at α= 0.01; marked: *0.100-0.299 – low; **0.300-0.499 –restrained; ***0.500-0.699 – high; ****0.700-0.899 – very high; *****≥0.900 – almost full.

4. Discussion

Phenological observations of plants are useful for the examination of the effects of climate change, but cultivated ornamentals are rarely taken into consideration. The most interesting features are frost damage, flowering abundance and the timing of flowering.

The most important factors limiting the cultivation of plants are frost resistance [38,41] and the ability to grow in changeable climate [25,45,53].

A significant additional criterion for the use of species as ornamental plants is their ornamental potential and value [54]. The basic value of climber roses is growth and flowering abundance in present and following seasons [45,55,56]. Most taxa of historical climber roses flower on one-year old and older shoots [1,2,38], which could limit their ornamental value in adverse climatic conditions during which rose shoots freeze. The once-blooming climber rose cultivars presented in this research flower on 2-year and older shoots, and their ornamental value is limited particularly by frost damage.

This research showed that autumn-winter-spring conditions determined their overwintering and consequently frost damage to shoots (Tables 2 and 3, Figure 4) as well as the necessary height of pruning (Figure 5). Frost damage has a dominant role not only in terms of the period of flowering and its abundance but also the period of bud break and leaf development (Tables 6-10). The observation in Polen showed the lenghtening of the growing season by a few days [50]. However, as indicated the research of [52], the number of the days with minimum temperature below 0°C may increase. This suggests, that earlier terms of early phenological events (starting of bud break, leaf unfolding) in roses could lead in future to shoots damage by spring frost caused lack of flowering or low its abundance.

The studied varieties originated in Asia and were grown in a warmer climate with milder winters [1,2], which suggests insufficient resistance to negative temperature. The many years of observation of growth and flowering of chosen groups of rose cultivars were conducted in PAS Botanical Garden CBDC in Powsin [38-44]. The climber roses observed in this research had different responses to winter conditions depending on their origin. 'Mme Plantier' did not experience frost damage every year, unlike most varieties of the Alba group, e.g. 'Celestial', 'Hurdals', 'Maiden's Blush' [38]; the Gallica group [44]; or the Spinosissima group, e.g. 'Aïcha', 'Elegans', 'Frühlingsduft', 'Frühlingsgold', 'Poppius', 'Stanwell Perpetual' [40] and most old and modern cultivars of Rugosa-Hybrids, e.g. 'Agnes', 'Belle Poitevine', 'F.J. Grootendorst', 'Frau Dagmar Hastrup', 'Rugeaux du Japon' [42,43] that were observed in the same climate conditions in PAS Botanical Garden CBDC in Powsin. Strong frost damage after winter was observed in cultivars of Hybrid Wichurana: 'Alberic Barbier', 'Albertine', 'Chaplin's Pink Climber', 'Orange Triumph clg', and 'Zéphirine Drouhin' (Figures 6). Their winter hardiness can be compared with ground cover roses, but they bloom continuously throughout the season and also in spring, quickly regenerating frosted shoots [39,41]. Older plants experience lower frost damage than the younger, which was also visible in their level of abundance of flowering (Figures 6 and 10). The abundance of flowering was always lower on the scale after substantial winter damage and the necessity of strong pruning (Figure 5). In the case of repeat-flowering rose cultivars, ornamental value depended on regenerative abilities after frost damage and also the height to which pruning was necessary [39,41]. In once-flowering roses, the shoots were damaged to the ground surface (Figure 6), and low pruned shrubs did not flower, or there were only a few flowers on old parts of the shoots of 'Dr Robert Huey', 'Duc de Constantin', 'Gerbe Rose' and 'Paul's Scarlet Climber' after winter seasons between 2000-2006 and 2009-2013 (Figure 9). Moreover, the length of the flowering period in several rose climber ('Albertine', 'Gerbe Rose', 'Mme Plantier', 'Orange Triumph', 'Paul's Scarlet Climber') tended to shorten between 2015 and 2017 years compared to the pre-2015 period. Such a response may support the hypothesis [57], that climate warming may cause significant reduction of the lenght of flowering period in plants. The term of biginning of blooming seems to be less sensitive on climate warming [57].

However, complete frost damage (without signs of regeneration) was not recorded, and the rose plants pruned to the ground grew intensively until autumn (Figure 5). Woody plants of the temperate zone can survive the winter thanks to bud dormancy and cold hardiness [20,58], a process which could be disrupted by climate changes, as in the case of *Vitis* [20,59]. Winter hardiness can be connected with the prolongation of the growing season [50] as well as hardening and dehardening [20], because the decrease of low minimum temperature was only correlated with higher frost damage in December and March (Table 3). Low temperatures in April caused increased frost damage in 'Albertine', 'Chaplin's Pink Climber' and 'Zéphirine Drouhin'. In contrast, the frost damage increased for more frost resistant climbers ('Dr Robert Huey, 'Duc de Constantin', 'Mme Plantier') when the temperature decreased in March and then rapidly increased in April (Figure 3, Table 2). Moreover, low rainfall in late autumn and early spring (Figure 4) can exacerbate frost damage of green, primarily one-year shoots due to the phenomenon of physiological drought [60].

Climate warming, accompanied by temporal amendments in average temperature and also other variables, exerts an effect on phenology [25,61] by influencing temperature values [53] and photoperiods [62]. Previous research in *Vaccinum membranaceum* showed, that greater advances in phenology are likely to be notherly and higher altitude regions of North America [63]. Spring phenology stages such as leaf unfolding and blooming have been shown to mainly advance, some by a few weeks, with median increase of 4–5 days per degree Celsius. Autumn traits, e.g., leaf colouring or leaf drop, have typically become delayed, though with more changeability than spring events. Amendments in terms of summer phenological stages have been stirred [18]. These results were similarly confirmed by Zheng [26] in nine woody species where the start dates of spring and summer phenophases occurred earlier with time, while the beginning of autumn and winter phenology stages were delayed. The terms of flowering depend on weather conditions such as chilling and heating in early blooming almonds [64]. In this research, bud break (BBCH 07) in climber roses occurred earlier every next year except after frosty winters, when it would take place later. Bud break and leaf development (BBCH 11) in climber rose cultivars showed strict correlations with average monthly temperature in the autumn-winter-spring period in all cultivars (Tables 4 and 5), but they were also different depending on the origin of the cultivar (Figures 7 and 8). Similar relations between weather conditions and origin were observed in other groups of roses, e.g. the Spinosissima group [40], Rugosa-Hybrids [42,43], Gallica-Hybrids [44] and also rambler roses [45]. This relationship was especially relevant to the first phenological stages: bud breaking and leaf development (BBCH 07 and 11) and the period of initial flowering (BBCH 60 601) (Figures 6, 7 and 8). It was also observed gene expression and identified gene candidates connected with the processes dormancy and flowering in flower buds of almond cultivars [*Prunus dulcis* (Mill.) D.A. Webb]. The informations of this research can be used by the breeding programs of new cultivars by a climate change in temperate regions [59].

The *Rosaceae* fruit trees like apricot are flowering earlier than roses. However, the research on apricot in UK showed, that blooming time was associated with changes in air temperature during

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effective chilling and warming periods in spring, with warming interval chilling caused the blooming delays by 4.82 d °C^{-1}, while warming during heat accumulation was connected with flowering advances by 9.85 d °C^{-1}. However, apricot blooming term remained relatively unaltered notwithstanding significant temperature rise. It may mean a decrease of frost risk for early spring blooming crops, e.g. apricot [65]. The simiraly phenomena for early phenolohgical stages were observed in roses. The timing of leaf unfolding in climber roses was similar in the following years, but in the years 2014-2016, this phenological stage appeared earlier by one or two points in the scale. Both a longer growing season and higher total monthly temperature in March can result in earlier flowering (Figure 3). The changing timings of flowering in the years 2000-2012 in ground cover, Rugosa Hybrid, Gallica Hybrid and Spinosissima roses in PAS Botanical Garden were similar [38,40,41,42,44]. Nonetheless, in the research of Włodarczyk and Perzanowska [55] on repeat-flowering climbing roses conducted across three years of observations (2004-2006), high temperatures (above 20°C) in 2006 caused the flowering period to shorten. Moreover, the break between the first and the fallowed flowering in the season sustained longer than in previous years [55]. In the research of Włodarczyk [56], 10 cultivars of repeat-flowering modern shrub roses began to flowering no later than in the first ten days of June in the years 2005-2010, irrespective of the frost damage of shoots in winter. In this research, the timing of blooming in climber roses differed by a few days from timings shown after three different autumn-winter-spring seasons (Figure 10).

The height of shrubs was determined to a large extent by supports, and the plants' maximum height was measured in autumn. The climbers reached their maximal height after 3-5 years (Figure 5), in contrast to the ground cover roses, where the shrubs reached their maximum height after two years of growth [39]. The climber can grow higher in warmer parts of Europe, where it also flowers reliably every year thanks to mild winters [1,2]. Additionally, the observed historical rambler [40,45] and climber are characterized by strong vigour and growth (Figure 5) compared with modern cultivars [55]. There is only perfunctory information in the literature related to phenology as well as the timing or duration of the flowering period of old rose cultivars. It should be considered that in the long period of observations the weather conditions were variable (Figures 1, 2, 3 and Suppl. 1), and this may be the primary reason behind the high changeability in terms of phenology stages shown in this research.

CONCLUSIONS

Resistance to changing climate conditions is a basic criterion of choosing rose taxa, and long-term observations suggest wide adaptability to the changing climate in the Mazovian Lowland. Recent milder winters in Mazovian Lowland encourage the cultivation of less frost-hardy plants, including climber roses. The increase of air temperature during the autumn-winter-spring period in the last few years of observations (2013-2017) showed lower frost damage and higher abundance of flowering than in previous years (2000-2006 and 2009-2013). The air temperature in October and November likewise had an effect on frost damage and was probably connected with their hardening. Strong frost damage necessitated low pruning, however the roses regenerated quickly. Nevertheless, despite the plants' growth, this treatment did interfere with blooming in the year of pruning. The research also showed especially changes in observed early phenology stages: bud breaking and leaf development, and their strict connections with autumn-winter-spring conditions. However, the climber roses have probably natural ability to adapt in warming climate because of their origin (Table 1) and also tradition of cultivation for many years in west and southern Europe.

Climber roses are a valuable proposal for the available assortment of vines, and preserving their biodiversity and genetic pool as historical ornamental plants may be becoming easier. Their maintenance in cultivation is connected with adaptation to changing climate conditions. The research confirmed that these roses can be successfully cultivated in Central Europe, although they may prove unreliable in terms of flowering after frosty winters. The cultivars most tolerant to adverse climatic conditions and reliable in flowering were 'Mme Plantier' and 'Paul Scarlet Climber'. Propably, it will be also properly proposal in changing and warming climate conditions including urban areas.

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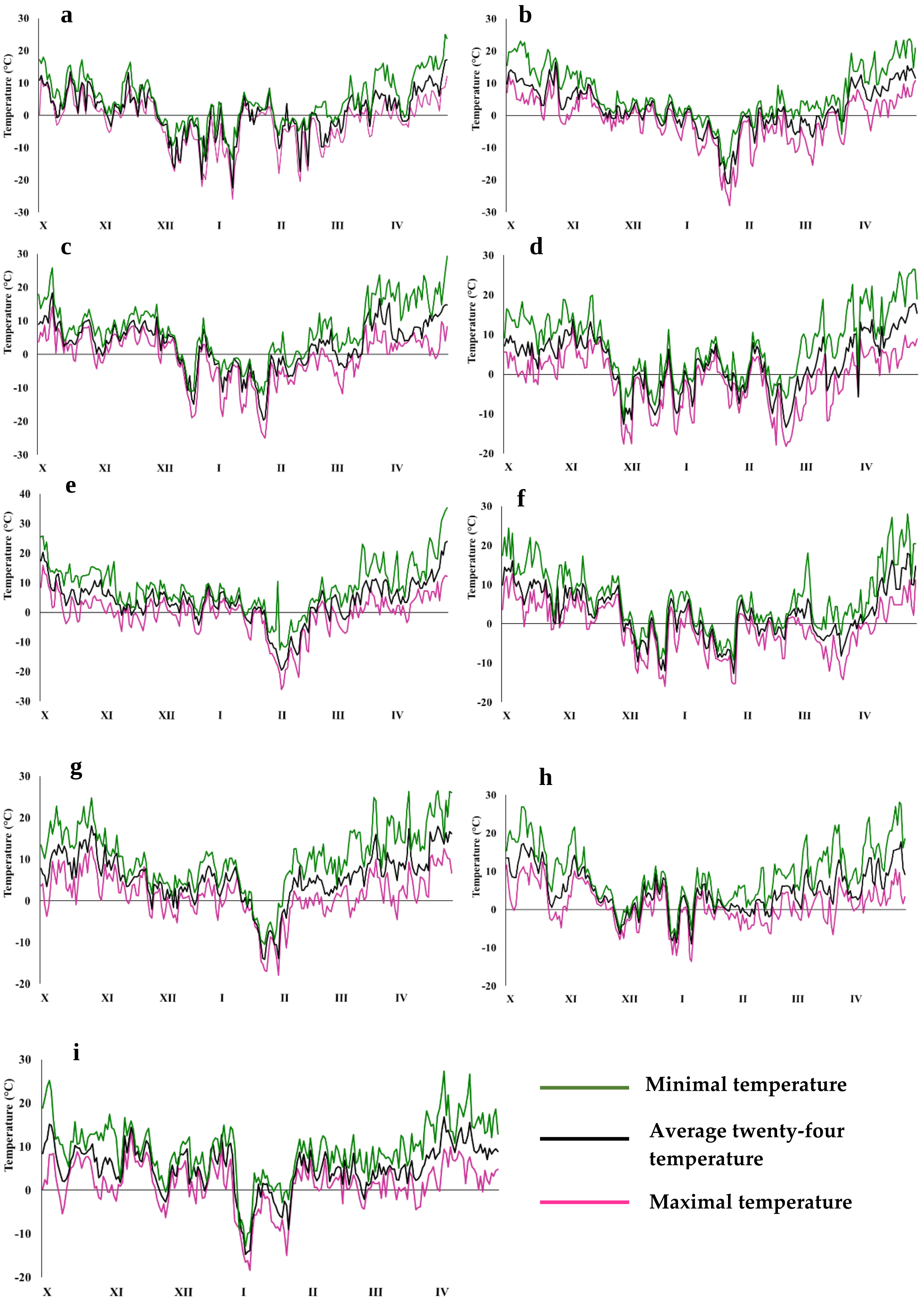

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Figure Suppl. 1. The minimal (purple line), average twenty-four (black line) and maximal (green line) air temperature from October to April for the seasons: 2002/2003 (a), 2005/2006 (b) and 2009/2010 (c), 2010/2011 (d), 2011/2012 (e) and 2012/2013 (f), 2013/2014 (g), 2014/2015 (h), 2015/2016 (i) (Monder, 2021).