Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

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EFFECTS OF CLIMATE ON SEASONAL EVENTS IN PERENNIAL HERBS IN TWO EUROPEAN BOTANICAL GARDENS.

Master's thesis in MSc Biology (Ecology, Behaviour, Evolution and Biosystematics)
Supervisor: Vibekke Vange
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Finally, a sincere thank you to the PhenObs team for making it possible to obtain the data needed to produce this thesis. This study would not have been possible without the help and support of these people and groups.

ABSTRACT

Plant phenology is the science of how seasonal cycles are affected by climate and changes in weather. To determine the difference in species in different locations or in changing climatic conditions, certain phenological events are to be observed, such as the initial vegetative growth, young leaves unfolding, flowers open, peak flowering, ripe fruits, and senescence.

In the initial phase of study, the phenological stages of herbaceous species in Ringve Botanical Garden were observed and recorded on a weekly basis from its initial growth to 50 percent senescence of each species. The collected data was compared with the data of the same species from the Botanical Garden of Jena, to find the impact of temperature and other environmental factors on the phenological stages. Later the common species was divided using Raunkiaer's life form to see if the species within the same life form and different groups of life forms showed a similar length of the growing season or not.

The result of the study illustrated that initial growth was early in the Botanical Garden of Jena, but this also led to the quick senescence of species. It was also clear that Ringve Botanical Garden had good flowering phenology among most species. However ripe fruit was seen in very few of them; only some of the species had ripe fruits in Ringve Botanical Garden. However, the length of the growing season among all the species was distinctly different in the same group of growth forms was not distinctly the same.

Keywords:

Plant phenology, Climate change, PhenObs, vegetative phenology, Reproductive phenology, Growth form

ABSTRAKT

Plantefenologi er vitenskapen om hvordan sesongsykluser påvirkes av klima og værendringer. For å bestemme forskjellen i arter på forskjellige steder eller i skiftende klimatiske forhold, må visse fenologiske hendelser observeres, for eksempel den innledende vegetative veksten, unge blader som utfolder seg, blomster åpner, toppblomstring, modne frukter og senescens.

I den innledende studiefasen ble de fenologiske stadiene til urteaktige arter i Ringve botaniske hage observert og registrert på ukentlig basis fra den første veksten til 50 prosent alderdom av hver art. De innsamlede dataene ble sammenlignet med dataene fra den samme arten fra den botaniske hagen i Jena, for å finne innvirkningen av temperatur og andre miljøfaktorer på de fenologiske stadiene. Senere ble den vanlige arten delt opp ved å bruke Raunkiaers livsform for å se om artene innenfor samme livsform og ulike grupper av livsformer viste lik lengde på vekstsesongen eller ikke.

Resultatet av studien illustrerte at den første veksten var tidlig i den botaniske hagen i Jena, men dette førte også til rask alderdom av arter. Det var også tydelig at Ringve botaniske hage hadde god blomstringsfenologi blant de fleste artene. Men moden frukt ble sett hos svært få av dem; bare noen av artene hadde modne frukter i Ringve botaniske hage. Lengden på vekstsesongen blant alle artene var imidlertid tydelig forskjellig i den samme gruppen av vekstformer var ikke tydelig den samme.

Stikkord:

Plantefenologi, Klimaendringer, PhenObs, vegetativ fenologi, Reproduktiv fenologi, Vekstform

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INTRODUCTION

Climate change is a dynamic process of events that affects crucial stages in species-specific phenological circumstances. This has been observed to impact plants' phenology. For example, Ground covered herbs, particularly spring ephemerals, may have a lower annual photosynthetic rate if deciduous forest trees burst their buds earlier (Heberling et al., 2019). This triggers the vegetative phenological stages. While phenology can predict changes in ecological processes, but it is challenging to access data on phenological processes(Piao et al., 2019).

The study of phenology includes examining phenomena reoccurring in plants and animals, as well as the relationship between such phenomena and seasons' changes and climate. Phenology, in other words, refers to studying the annual cycle of plant development (Keller, 2020). In addition, phenological studies examine the timing of biological events.

There has been a rise in interest in the studies of plant phenology in recent decades, and phenological changes are commonly used as measures of global change (Menzel et al., 2006). Phenology is a valuable predictor because it combines climate signals over a long period and is easily calculated (Zhao et al., 2013). Plant phenology changes brought on by warming temperatures are anticipated to impact on plant fitness by changing the reproductive age. For instance, earlier germination due to earlier spring warming may result in a more extended vegetative growth phase (Nord & Lynch, 2009). The possibility that climate change will lead to changes in actual day length for plants has been considered by several studies (Van Dijk & Hautekeete, 2007).

Major phenological events, such as the widely reported spring advancement and autumn postponement (Menzel et al., 2006), have been significantly delayed due to recent climate change. This has resulted in phenological mismatches at all trophic levels (Renner & Zohner, 2018). Such severe phenology shifts brought on by climate change may significantly impact on ecological processes and community structures (Yang & Rudolf, 2010). For instance, due to the various phenological reactions of plants and animals to warming, certain bird species may not reproduce when there is good availability of food (Bailey et al., 2022), or some tree species may produce fewer seeds as a result (Kudo & Ida, 2013).

In Europe, the predictions of increasing warming that have resulted in delays in the start of most seasons have been observed to affect the delay of phenological events of various plant species.

Despite many herbaceous species, trees and shrubs or crops have traditionally been the focus of phenological research, particularly for leaf out and leaf senescence (Chmielewski & Rötzer, 2001; Panchen et al., 2014). The majority of studies, including those involving woody plants (Bucher et al., 2018; Panchen et al., 2014), as opposed to the later phenological stages like the end of flowering, fruiting, and leaf senescence (Panchen et al., 2014; Sporbert et al., 2022).Only a few species of herbaceous plants are the subject of studies that track their entire life cycles (Ettinger et al., 2021).

The growing interest in this field requires interdisciplinary approaches to better research and develop various methods that improve the accuracy of phenology modeling in making predictions for future events. Such as PhenObs, which is a global network of botanical gardens, is spearheading research in studies that link phenological events to changes in climate and its effects on the various plant lifeforms, Primarily focusing on the study of phonology and traits of herbaceous plant species in the botanical gardens (Nordt et al., 2021).

Methods such as collecting species-specific data are resource intensive and dependent on labor and thus cannot be easily obtained at a large scale. Satellite data, on the other hand, can be used over larger areas to make predictions; however, the accuracy has been proven to be limited as it combines multiple species events (Guisan & Thuiller, 2005). Studies have supported other technical approaches, such as the use of mathematical models, which can be efficient in making predictions in phenological studies; however, this approach would require the availability of significant amounts of Data (Menzel et al., 2006). Since closely related taxa typically exhibit similar timing in their life-history events, there is a lot of evidence that evolutionary history can be used to predict patterns in phenology (Panchen et al., 2014; Wolkovich et al., 2013). However, species-specific responses to environmental change exist (Fitchett et al., 2015; Pérez-Ramos et al., 2020).

To better understand and predict the connections between plants and the climate system, it is imperative to have a better grasp of phenology changes, their primary drivers, and ecosystem implications. The last few decades have seen a fast growth in phenology study, which has generated essential data regarding the probable response of ecosystems to climate change. Thus, the study aims to improve our knowledge of the phenological responses of herbaceous species in order to anticipate better effects of climate change on plant populations and communities.

In this study, we will address the following questions: -

(a)How does species' length of growing season differ in between different groups of growth forms and within the same growth form?

(b) How do the phenological phases in the same species respond in two different gardens?

We will test the following hypotheses.

Ø H1: Length of the growing season among Species within the same growth forms and in between different groups of growth forms will differ.

H0: Species within the same growth forms will show the same stretch.

Ø H2: Different phenological phases within a species can respond differently to seasonal events in contrasting gardens.

Ho: All phenological phases within a species respond similarly in contrasting gardens.

METHODS

1.Study Area

The study was conducted in Ringve Botanical Garden, Trondheim. The Ringve Botanical Garden, established in 1973, belongs to the NTNU University Museum. It lies 3 kilometers northeast of the heart of Trondheim and is locally known as Ringve Botaniske Hage. The garden lies within the latitude 63.4346 and longitude 10.3984 and rises 7 meters above sea level. The Ringve estate, now the Ringve Music Museum, is surrounded by decorative plantings and six main plant collections in the 13-hectare garden. It includes an arboretum with northern hemisphere trees and shrubs, a sizeable collection of primula, a Renaissance-style herb garden, a 19th-century English park, and a collection of traditional garden perennials from Central Norway are among the plant collections. The garden is home to approximately 1,000 taxa species of plants and varieties of insects, birds, and animals.

Kart over Ringve botaniske hage

Map of the Botanical Gardens

1 Arboretet The Arboretum
2 Gamlehagen The Traditional Perennials
3 Blomsterlabyrinten The Floral Maze
4 Parken The Park
5 Renessansehagen The Renaissance Garden
6 Primulahagen The Primrose Garden
7 Musikkmuseet The Museum of Music and Musical Instruments
8 Botanisk hages administrasjon The Botanical Gardens administration

Figure 1.Map of Ringve Botanical Garden

2. Data Collection

This observational study was started during the second week of March 2021, as soon as the first species was spotted above ground and completed in October after all the species showed 50% senescence. We used a ground-based phenology observation method to collect our data. The standardized protocol from PhenObs introduced in January 2021 with free accessibility (Nordt et al., 2021) was used to record the data, including the stages like initial growth, young leaves unfolding, Flower open, peak flowering, flowering intensity, ripe fruits, senescence, and senescence intensity. The recording was carried out once a week throughout the recording period.

Following the steps in the protocol, we started the recording as soon as the first appearance of initial growth was seen among the population, and the recording continued until the 50%senescence phase of each species. The phenological stages that should be observed have been chosen because they significantly impact ecosystem functions, services, and trophic interactions and are vital for species performance and reproduction. The phenological stages of around (89) herbaceous species were recorded, and it was decided that the data would be compared with the common species of the botanical garden of Jena. There were 48 common species among the two gardens.

Table 1.An illustration of a full report sheet for a week of monitoring.

S.N	Species	Initial growth	Young leaves unfolding	Flowers open	Peak Flowering	Flowering intensity	Ripe Fruits	Senescence	Senescence intensity	Maintenance	Remarks
1.											
2.											
3.											
4.											
5.											

Table 2. The botanical gardens where plant phenological stages were recorded. Temperature data comes from (YR.no) and (time and date)

Botanical garden	Latitude/Longitude	altitude	Mean annual temperature
Ringve Botanical Garden	63.4483°N, 10.4523°E	121.4 -128ft.	9.8 °C
Botanical Garden of Jena	50°55′N, 11°35′E	150–170ft.	12.8 °C

3.Types of Data

This study includes both primary and secondary data. The primary data on the plant's phenological stages were collected from Ringve Botanical Garden. The secondary phenological data was obtained from the PhenObs team, collected in the botanical garden of Jena, which PhenObs team members collected during the same year, 2021. There were 48 plant species common in between the two gardens.

The phenological data includes different variables starting from Initial vegetative growth (IVG), Young leaves unfolding (YLU), Flowers open (FO), Peak flowering (PF), Flowering intensity (FI), Ripe fruits (RF), senescence and senescence intensity. The intensity of flowering and senescence was recorded in percentage based on the population distribution of each species. The rest of the phenological stages were recorded as 0 for absence and 1 for present. The recording was noted with the date.

4. Data Sorting and Cleaning:

Once the data collection ended, the raw data was cleaned and sorted to eliminate any repetition or mistakes using Excel. After that, the PhenObs team sent us the daylight of the year (DOY) along with the phenological data of the Botanical Garden of Jena for the year 2021. Data was used to make a comparative study between these two gardens. The next step was matching and incorporating the phenological data of common species from two gardens into the same folder. Species like *Reum hybridum, Gentiana subspecies*, and *Helianthemum subspecies* were renamed as *Reum rhabarbarum, Gentiana lutea*, and *Helianthemum nummularium*, respectively, after the visualization of the first analysis. *Humulus lupulus* and *Galega officinalis* were taken off the list since comparing these species in both the gardens did not reveal any informative results. Further, we used Raunkiaer´s life form (Raunkiaer, 1934) to classify plants into different categories to check if the species under the same growth forms show similar timing in phenological stages or vary. The species were categorized as follows,

- Chamaephyte: A plant having buds that are dormant and are between 10 and 50 centimeters above the ground; this category includes tiny shrubs, sub-shrubs, and herbaceous species, e.g., *Vinca sp.*, *Vaccinium spp.*

- Hemicryptophyte: The plant species found in tussocks and rosettes with a growth point that endures harsh seasons as a dormant bud at or near the soil's surface. These could only have basal leaves, just stem leaves, or stem and basal leaves, e.g., *Geum sp., Geranium sp.*,

- Geophyte: any species whose developing phase endures harsh climates as a dormant bud on a subterranean organ like a rhizome, bulb, tuber, or root, e.g., *Galanthus sp.*, *Eranthis sp.*

5. Data Analysis

This study includes observational data from two different locations in Europe, Ringve Botanical Garden which is located at Trondheim, Norway and Botanical Garden of Jena located at Jena, Germany.

The data was analyzed using RStudio (Team, 2022). MS Excel was also used to incorporate phenological data from two gardens, sort them and clean them. The species that were common in both gardens were used for the analysis.

Mean and standard deviation was calculated for each species, including its DOY, according to different growth forms. The results were visualized using ggplot2 to compare the phenological response pattern between two gardens and boxplots to find out the stretch of species among the three different growth forms.

RESULT

This study aimed to determine if there is any difference in the timing of phenological phases' appearance among the same species in two different Botanical gardens and check how the length of the growing season of species differs among the same group of growth forms. During the data collection period, each species' phenological stages were closely observed until the species had 50 percent senescence.

1.Length of Growing Season

The data analysis included the calculation of mean and standard deviation for a stretch of growing season of species in growth forms as summarized in Table 3. The data included all the common species divided into three different growth forms according to Raunkiaer's life form classification.

Table 3. Mean and SD of growth forms for stretches of the growing season.

S. N	Growth forms	Mean	SD
1.	Chamaephytes	138.3636	128.22346
2.	Geophytes	120.8462	71.63781
3.	Hemicryptophytes	156.3750	106.85641

These results were plotted using ggplot2, creating the visualization of the species between growth forms with mean and standard deviation.

Figure 2. Length of the growing season of each species with different growth forms.

The three plots show the length of the growing season in plant species grouped by their growth forms through bar plots with mean and standard deviation (SD) shown as horizontal lines. The three bars were created using ggplot2, one for each growth form, with species names on the x-axis and stretch values on the y-axis. The bars are colored according to growth form and are dodged to show each species separately. Horizontal lines are added to show the mean and SD of stretch values for each growth form, with the mean as a dashed line and the SD as dotted lines in red.

The various species are on the x-axis of each plot, there are the various species, and on the y-axis are the stretch values. The bars are colored in accordance with the plant's growth form and indicate the specific stretch values for each species. As an illustration, the light blue bars in the Chamaephytes plot represent the Chamaephyte species. In contrast, the light orange bars in the Geophytes plot represent Geophyte species, and light green bars in Hemicryptophytes represent Hemicryptophytes species.

Each plot displays numerous horizontal lines in addition to the bars, representing summary statistics for the stretch values within each growth form. The dotted lines show the mean plus or minus one standard deviation of the stretch values, while the dashed line shows the mean stretch value for that growth form.

The data in Table 3 revealed that Hemicryptophytes had the most extended growing season on average (156.3750), followed by Chamaephytes (138.3636) and Geophytes (120.8462). By comparing the bars and summary statistics across the different growth forms, we can see that geophyte species tend to have lower stretch values on average than Chamaephyte and Hemicryptophyte species. Chamaephyte species tend to have intermediate stretch values, while hemicryptophyte species tend to have the highest stretch values on average. In addition, we can see that in each growth form, the stretch values are very different in each growth form, as evidenced by the spread of the bars and the width of the standard deviation lines. Overall, the plot reveals that Chamaephytes and Hemicryptophytes, which have intermediate and high stretch values, respectively, tend to have higher stretch values than those of Geophytes, which are generally lower. It is also notable how each growth form varies from one species to the next, with some having very high stretch values and others having low ones. Different local climatic conditions, soil types, and management techniques, among other things, could cause this result.

A plant's life cycle includes both the vegetative and reproductive phases, which are vital to every plant species. The timing of vegetative growth-related occurrences, such as initial growth, leaf out, and wilting, is called vegetative phenology. On the other hand, reproductive phenology describes when activities like flowering, fruiting, and seed production occur.

2.Vegetative Phenology

Initial Vegetative Growth

Initial vegetative growth is the development of new buds and vegetative shoots above the ground, leaf, or leaf sheath. The graph results in Figure 3 and Figure 4 show that spring started earlier in the Botanical Garden of Jena and recording also started early. Since the population of the same species in a patch was more than one, initial growth continued and was seen for more than one observation (see Figure 15 in appendix).

The result from the graph shows that there was continuous initial growth for several weeks because, in some species, new initial growth was seen among the population of that specific species in several flushes.

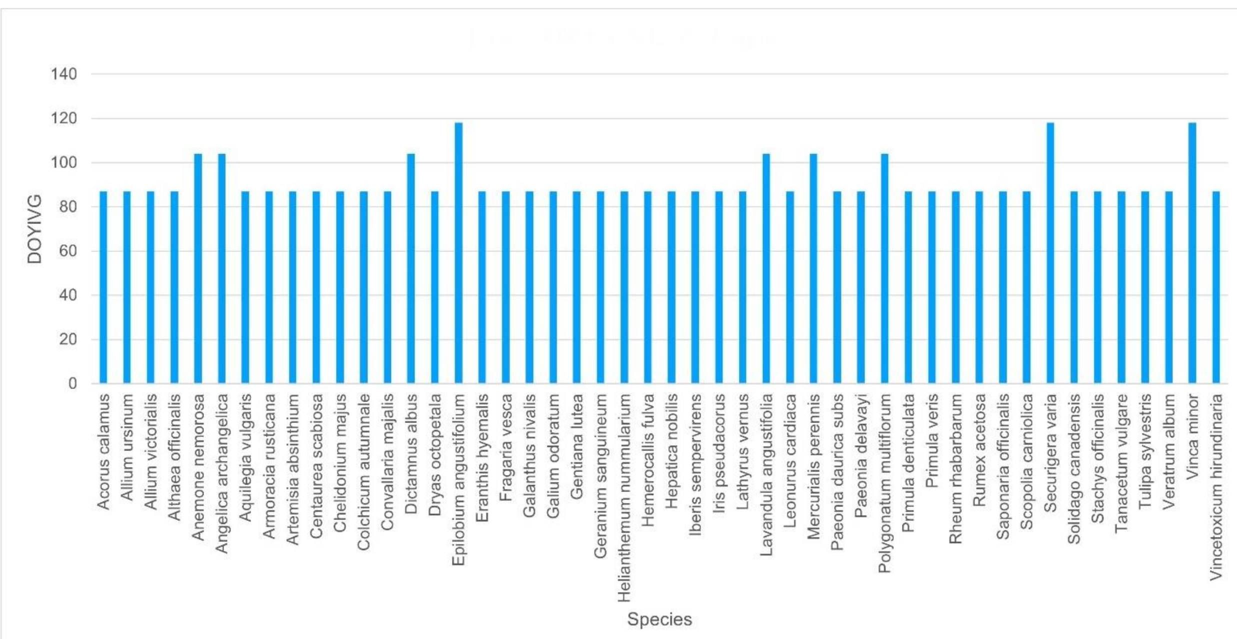

Figure 3.First DOY of IVG (Initial vegetative growth) in Ringve Botanical Garden.

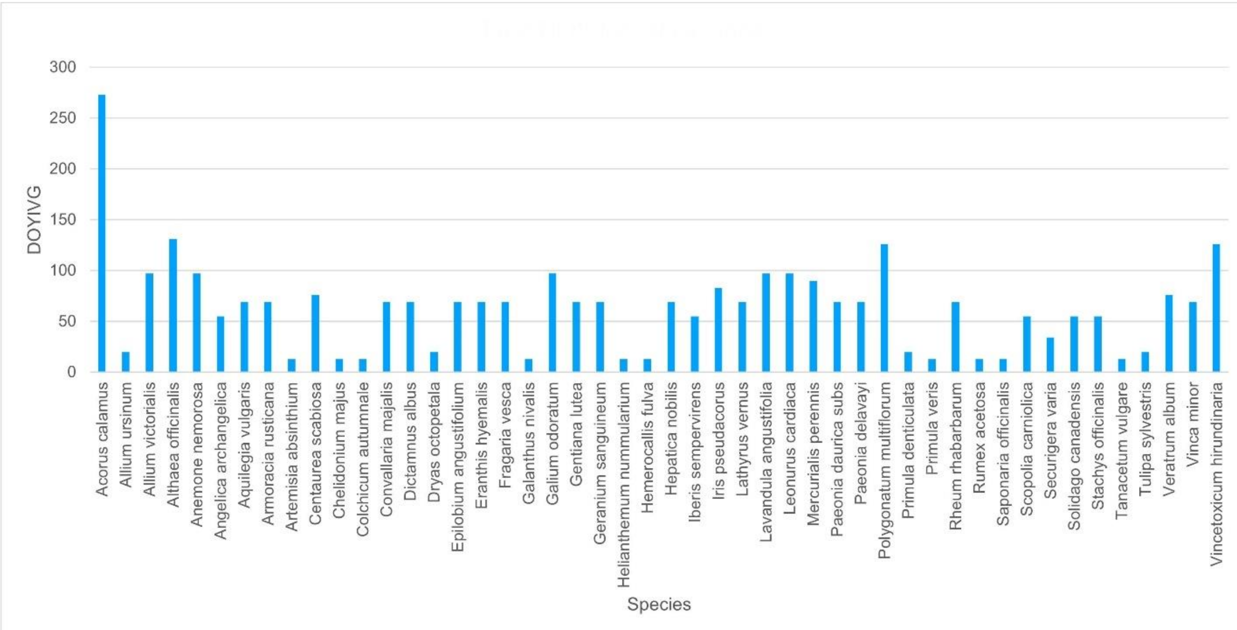

Figure 4. First DOY of IVG (Initial vegetative growth) in Botanical Garden of Jena.

Young Leaves Unfolding

The graph of young leaves unfolding revealed that, in both gardens, this phenological stage is closely related to the initial vegetative growth. It was observed that this phenological stage persisted for a longer period in most of the species in Ringve Botanical Garden as new young leaves kept on emerging for longer periods (see Figure 16 in appendix). Figure 5 and Figure 6 show that most species in the Botanical Garden of Jena had young leaves unfolding comparatively earlier than that of Ringve Botanical Garden. It is also clearly visible in Figure 6 that one of the species, i.e., *Gentiana lutea*, did not have any young leaves unfolding in the Botanical Garden of Jena.

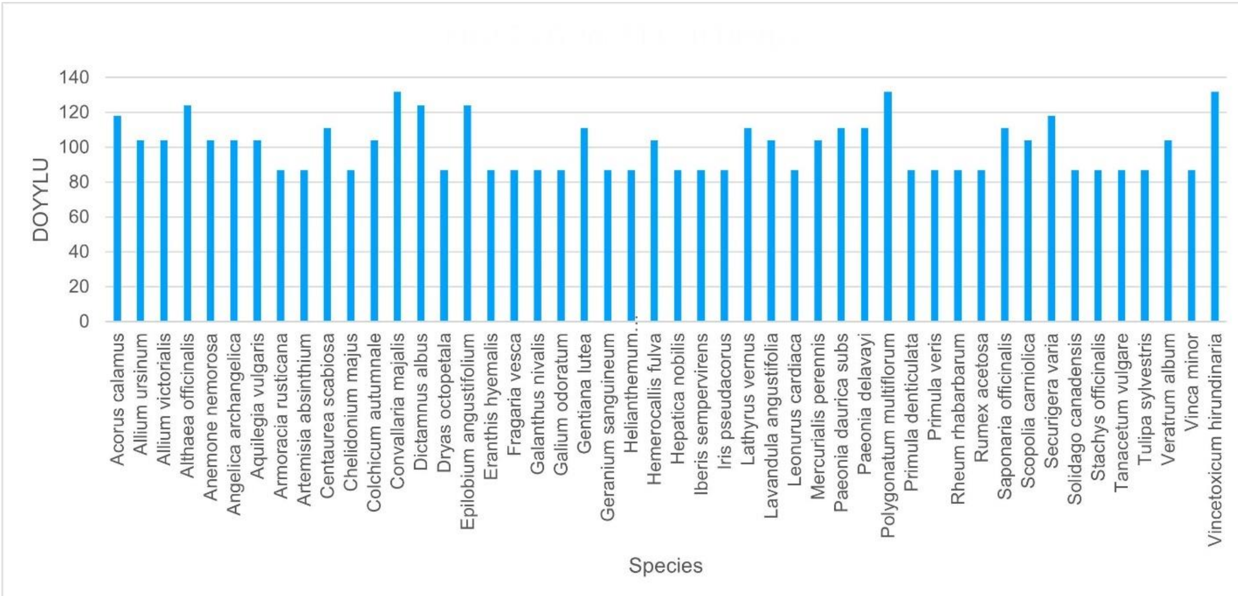

Figure 5. First DOY of YLU (Young leaves unfolding) in Ringve Botanical Garden.

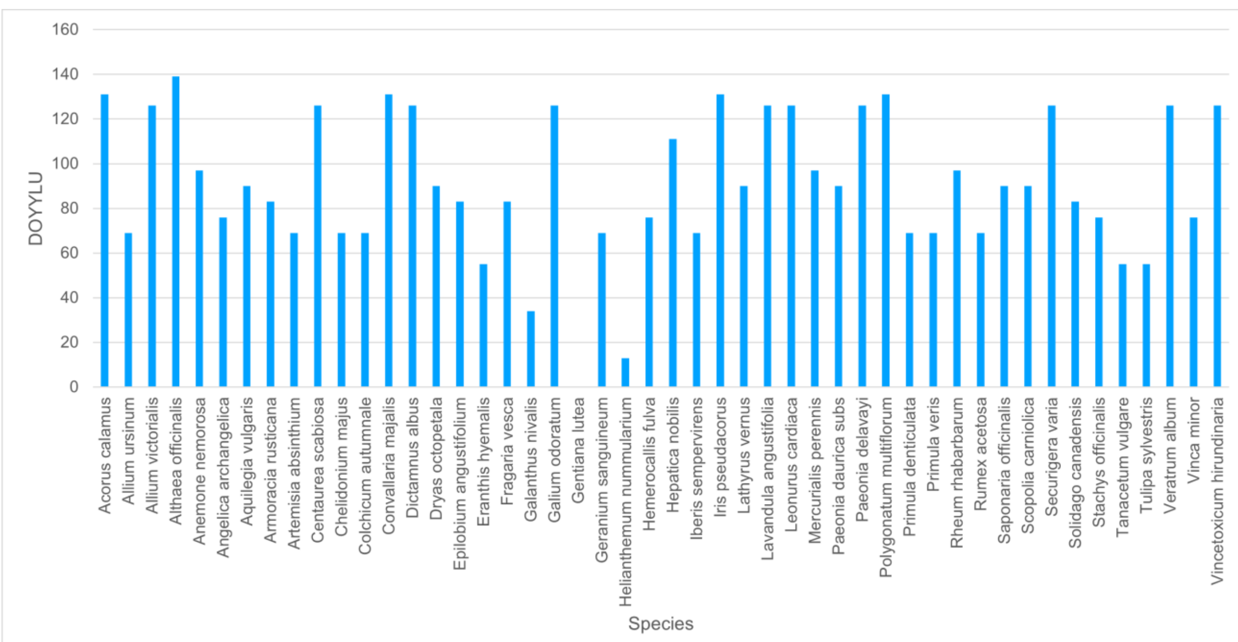

Figure 6.First DOY of YLU (Young leaves unfolding) in Botanical Garden of Jena.

Senescence

The study showed that the senescence among species came earlier in the Botanical Garden of Jena. However, senescence was not observed among *Gentiana lutea* and *Vinca minor* in the Botanical Garden of Jena, and *Allium ursinum* in Ringve Botanical Garden. species in the Botanical Garden of Jena. The earliest DOY for senescence in Ringve Botanical Garden was after DOY 100, whereas in Jena, it was even before DOY 50.

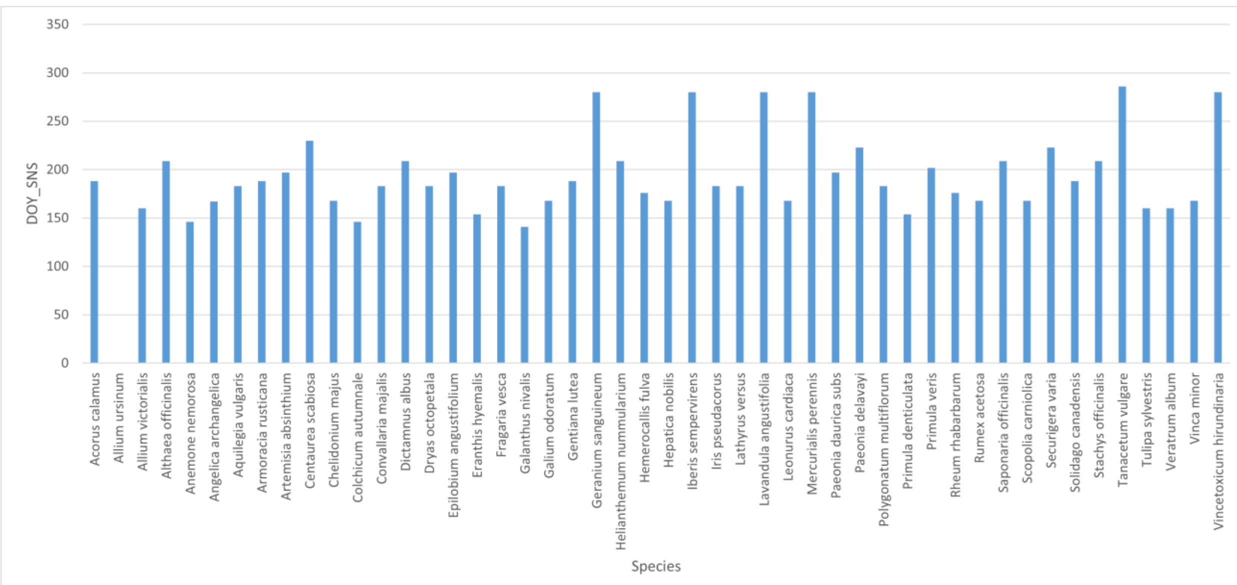

Figure 7.First DOY of SNS (Senescence) in Ringve Botanical Garden.

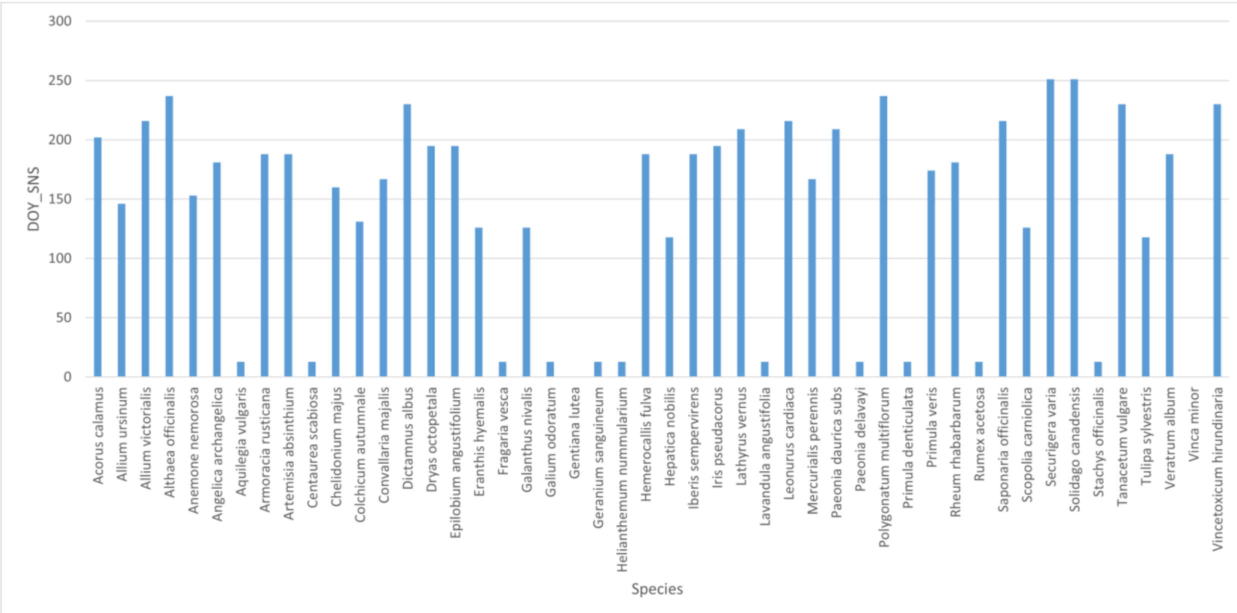

Figure 8.First DOY of SNS (Senescence) in Botanical Garden of Jena.

3. Reproductive Phenology

Flowering Phenology

The result shows that the start of vegetative growth in the Botanical Garden of Jena was earlier than that of Ringve Botanical Garden. Similarly, reproductive phenology, i.e., flowers open, also occurred earlier among many species in the Botanical Garden of Jena compared to Ringve Botanical Garden (see Figure 9 and Figure 10). However, species in Ringve Botanical Garden also had good results for flowering penology.

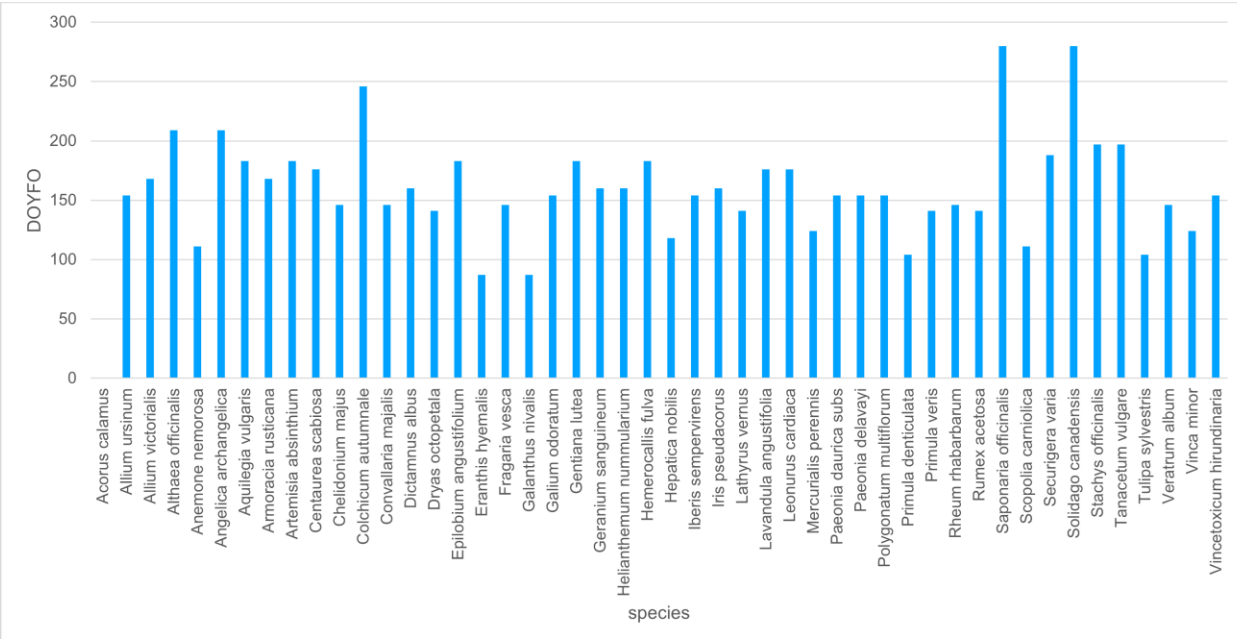

Figure 9.First DOY of FO (Flower open) in Ringve Botanical Garden.

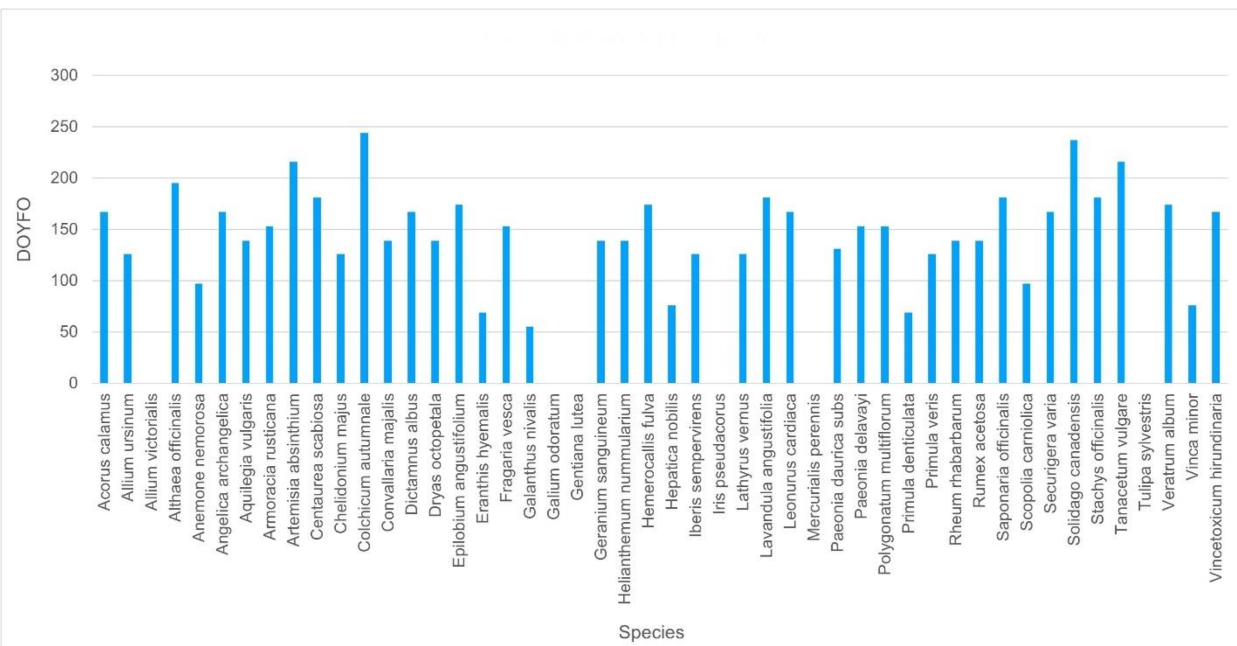

Figure 10.First DOY of FO (Flower open) in Botanical Garden of Jena.

Peak Flowering

The number of species with Peak flowering in Ringve Botanical Garden (see Figure 11) was higher in comparison to that of Jena and flowering intensity was also distinctly seen higher in Ringve Botanical Garden among most of the species (Figure 18 in appendix). The result of Figure 12 showed that about 50 percent of plant species in total of the common species did not have peak flowering in the Botanical Garden of Jena.

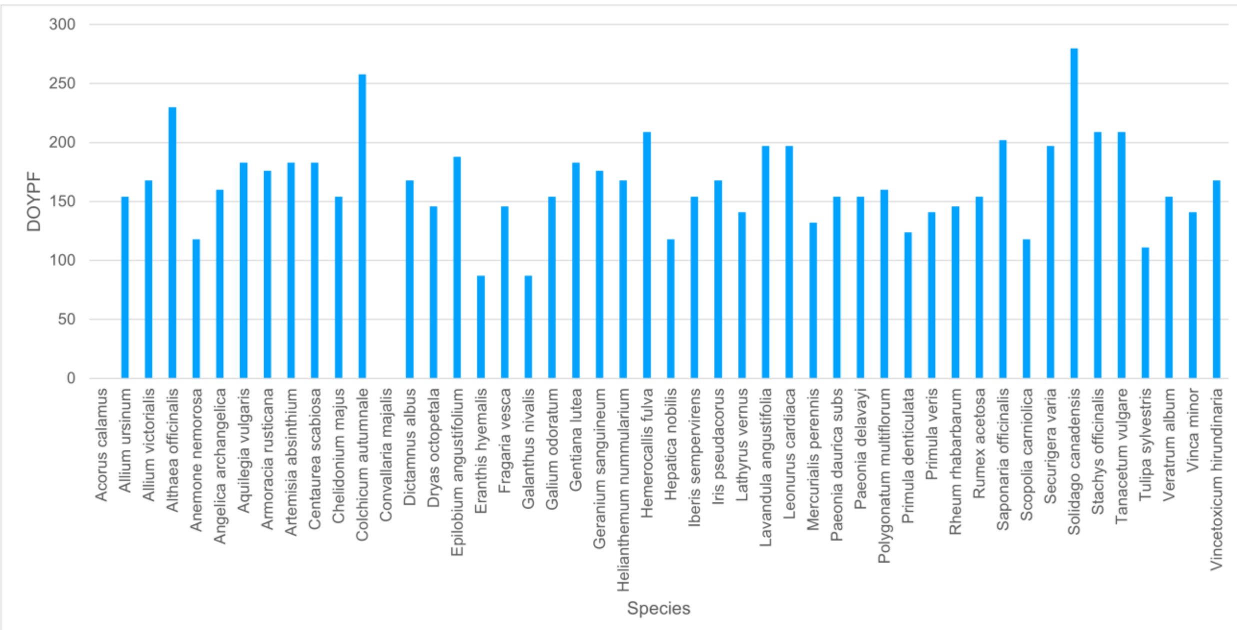

Figure 11.First DOY of PF (Peak flowering) in Ringve Botanical Garden.

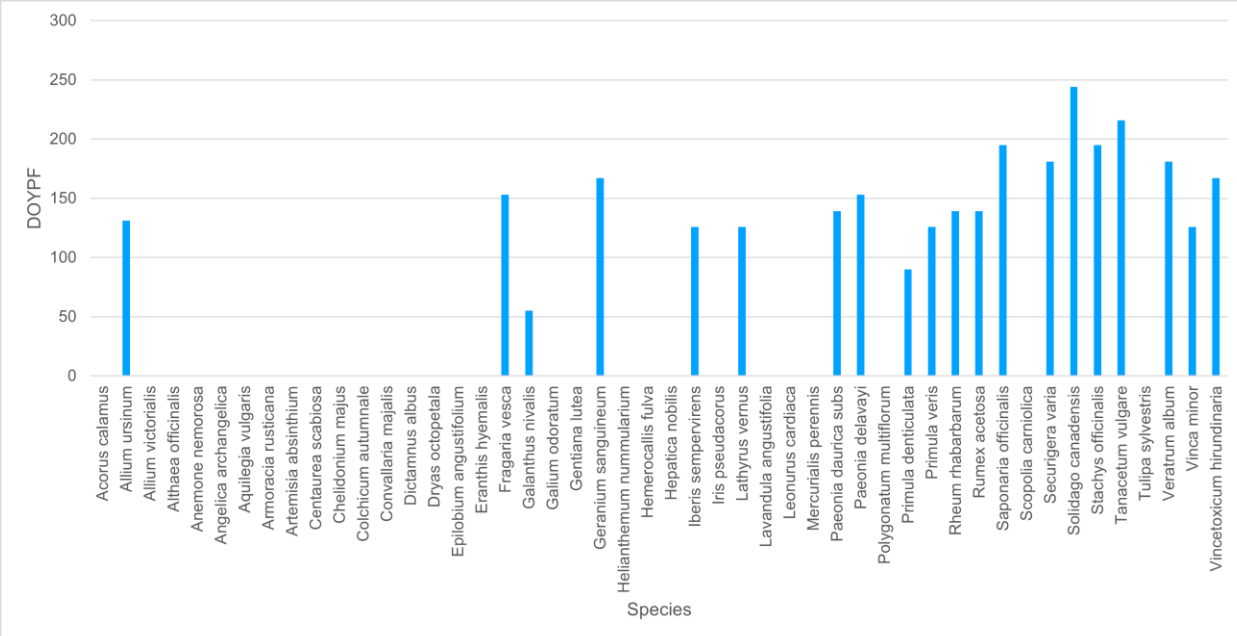

Figure 12.First DOY of PF (Peak Flowering) in Botanical Garden of Jena.

Ripe Fruits

In comparison to Ringve Botanical Garden, the Botanical Garden of Jena had a relatively higher proportion of species with ripe fruits. This study reveals that very few species gave ripe fruits in Ringve Botanical Garden despite having good flowering phenology among these species. In contrast, the Botanical Garden of Jena had many species with ripe fruits.

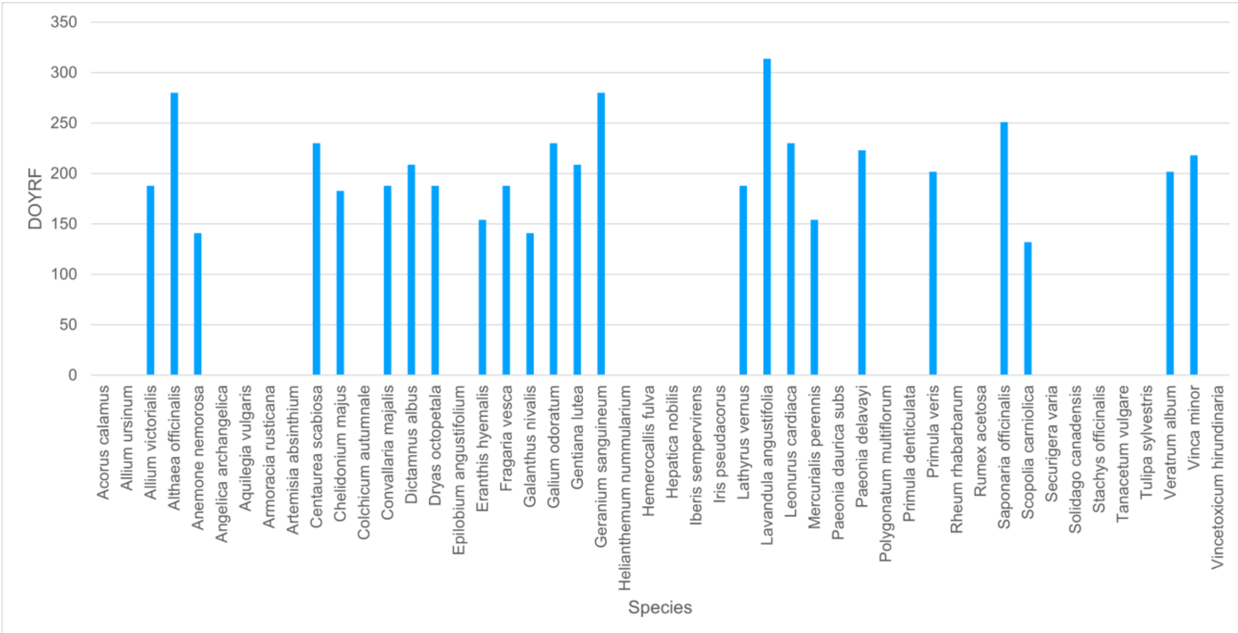

Figure 13.First DOY of RF (Ripe fruits) in Ringve Botanical Garden.

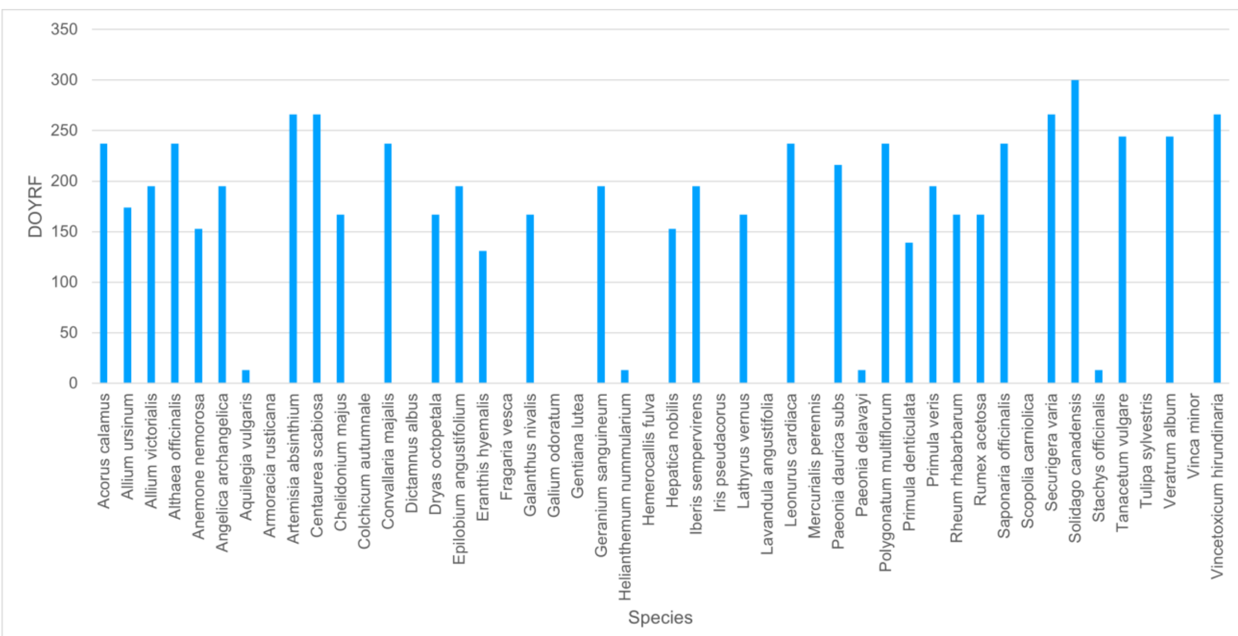

Figure 14.First DOY of RF (Ripe fruits) in Botanical Garden of Jena.

DISCUSSION

This study aimed to examine the difference in the length of the growing season in plant species among the same group of growth form and between the plants in different growth forms and investigate differences in phenological stages among the same species of plants in different gardens. The findings of this study have shown that length of the growing season of species in different growth forms as well as within the same growth form also varies from one another, and there are differences between the timing and duration of phenological phase among the same species in two different botanical gardens (see Figure 2). The result of this study, therefore, rejects the null hypothesis.

1.Length of Growing Season and Growth Forms

The data analysis reveals that chamaephytes and hemicryptophytes tend to have higher stretch values than geophytes, with lower average values. The growing season of geophytes and hemicryptophytes in a Medsupportsan grassland was examined in a study by(Garnier et al., 2004), and it was discovered that the geophytes typically had a shorter growing season than the hemicryptophytes.

The result also showed that the range values within each growth form were significantly different from one other. It was found that growing periods vary according to their site and species, comparing the growth of hemicryptophytes between two grassland areas in Germany (Jentsch et al., 2007). A comparison to a wet, nutrient-rich grassland and a dry, nutrient-poor grassland had a longer growing season for the Hemicryptophyte *Plantago lanceolata*.

2.Differences in Phenological Stages Among the Same Species Located in Different Gardens

A wide range of environmental factors influence plant growth and development, including temperature, daylight, water availability, soil quality, and nutrients. These factors vary widely from place to place, which may lead to differences in the vegetative growth of plant species. According to the findings of this study, phenological stages within the same species can react differently depending on the environment. Different soil types, altitudes, or latitudes, as well as variations in climate, may all contribute to the observed variation. For instance, variations in temperature and day length can influence the timing of phenological events in many species, which are known to be significantly affected by these factors (Dorji et al., 2020). There can also be Indirect effects of other environmental parameters, such as soil moisture, nutrient availability, or atmospheric CO2 concentrations, on plant growth, and resource allocation may also impact phenology (Richardson et al., 2013). Consequently, the observed variations in phenological timing in this study may have been caused by variances in soil composition and differences in altitude and latitude between the two different gardens. As temperature and precipitation also vary systematically with latitude and altitude, these patterns demonstrate the impact of climate gradients on phenology. Warm temperatures in the spring often cause early development to begin, but they can also impact fall senescence by speeding up or slowing it down (Fu et al., 2018).

Vegetative Phenology

It is visibly distinct from this study that the timing of vegetative growth in most of the species was early in the Botanical Garden of Jena compared to Ringve Botanical Garden. According to research on European trees, the timing of budburst and leaf senescence, for instance, differs dramatically between latitudes, with earlier and later phenology at lower and higher latitudes, respectively (Vitasse et al., 2018). The higher mean annual temperature in the Botanical Garden of Jena, as shown in Table 2, could be the probable reason for the early start and early wilting of plant species compared to that of Ringve Botanical Garden. The availability of sunlight, temperature, and moisture can also play a role in determining when and how quickly plants grow and develop (Hatfield & Prueger, 2015) .

Reproductive Phenology

In general, the success of plant reproduction depends on the timing of both flowering and fruiting phenology (Liu et al., 2021). Early flowering and fruiting might help plants avoid resource competition and generate more seeds before the growing season is over. Late flowering and fruiting may enable plants to benefit from later in the season's milder, less demanding circumstances. However, reproductive success may be lowered if the timing of these phenological stages is affected by environmental factors like pollinators or the timing of seed dispersals (Quiroz-Pacheco et al., 2020). This study's result shows good flowering in both the gardens Figure 9 and Figure 10; moreover, the flowering intensity was higher in Ringve botanical garden compared to the Botanical Garden of Jena (see Figure 19 in appendix). The ripe fruits showed better results in the Botanical Garden of Jena (see Figure 20 in appendix). The result for ripe fruits in Ringve Botanical Garden was very weak, which is also clear from the graph in Figure 12, which could be the result of other environmental factors like lack of pollinators in the garden, nutrient deficiency in the soil, herbivores as well as maintenance carried out by gardeners, as few of the stalks were seen to be chewed by herbivores or pruned. Past studies on herbivory showed that damage to plant health caused by herbivores negatively impacts reproduction success and fitness (Boege, 2005; Dominguez & Dirzo, 1994; Koptur et al., 1996; Zvereva & Kozlov, 2014).

CONCLUSIONS

In general, the impact of temperature on plant phenology in oceanic and continental climatic zones may differ due to differences in the seasonal patterns of these factors. This study shows that species in short spring may show good flowering but do not necessarily produce good ripe fruits. The early start of spring may result in the early growth of each phenological stage, which may also lead to earlier senescence or change in the color of leaves which was observed among the species in Jena.

Oceanic climates are characterized by mild temperatures and high precipitation throughout the year. As a result, plant growth and phenology are often driven more by temperature than by water availability. In these climates, warmer temperatures in the spring can lead to earlier leaves unfolding and flowering, while cooler temperatures in the fall can delay leaf senescence and fruit ripening. However, excessive rainfall or waterlogged soils can delay or reduce plant growth and reproduction.

In contrast, continental climates are characterized by greater temperature variability and lower precipitation. Water availability is often the limiting factor for plant growth and phenology in these climates, and temperature becomes a secondary factor. Spring temperatures may have a more limited effect on plant growth and phenology, as moisture stress can prevent plants from taking full advantage of favorable temperatures. In the fall, cooler temperatures may cause earlier leaf senescence and fruit ripening, while warmer temperatures may delay these processes.

The relationship between climate and plant phenology is complex and context-dependent, with important implications for ecosystem dynamics and human well-being. Understanding these relationships across different climatic zones is essential for developing effective strategies to mitigate the impacts of climate change on plant communities and the ecosystems they support.

Given the importance of plant phenology for ecosystem functioning and human well-being, it is essential to continue monitoring and studying how these patterns change over time in response to global environmental changes. Future studies should focus on identifying the specific environmental elements that influence phenological variation in various places and investigating the possible effects of these differences on plant health and the functioning of ecosystems. Monitoring the timing and rate of development of plant phenology in natural ecosystems can provide information about how plants respond to environmental changes and inform conservation strategies for endangered or threatened species.

LIMITATIONS

The study's limitation is that it is based on the data that was collected for a year with no preceding data set to ensure its reliability. It could give better learning and insight into how climate change affects plant phenology if the data were also compared among different years. Herbivores and maintenance carried out in the gardens are other limitations in this study. As some of the stalks were found chopped or chewed.

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APPENDIX

Table 4. Annual Temperature data of Trondheim in 2021.

Location	Month	Highest	Lowest	Average
Ringve Botanical Garden	January	5.8º	-16.7º	-5.4º
	February	11.4º	-20.3º	-4º
	March	10.3º	-7.8º	1.7º
	April	15.8º	-3.6º	2.3º
	May	19.9º	-3.3º	8.1º
	June	24.4º	3.6º	13.2º
	July	29.2º	7.8º	16.3º
	August	23.4º	4.5º	12.1º
	September	17.4º	3.2º	9.9º
	October	16.9º	-0.1º	7º
	November	13.8º	-14º	1.1º
	December	8.9º	-14.5º	-1.6º

Table 5. Annual Temperature data of Jena in 2021.

Location	Month	Highest	Lowest	Average
Botanical Garden of Jena	January	10º	-8º	0º
	February	18º	-22º	1º
	March	23º	0.6º	5º
	April	21º	-3º	5º
	May	26º	1º	11º
	June	32º	5º	19º
	July	28º	8º	18º
	August	28º	6º	16º
	September	27º	4º	15º
	October	22º	-2º	9º
	November	13º	-4º	4º
	December	14º	-11º	2º

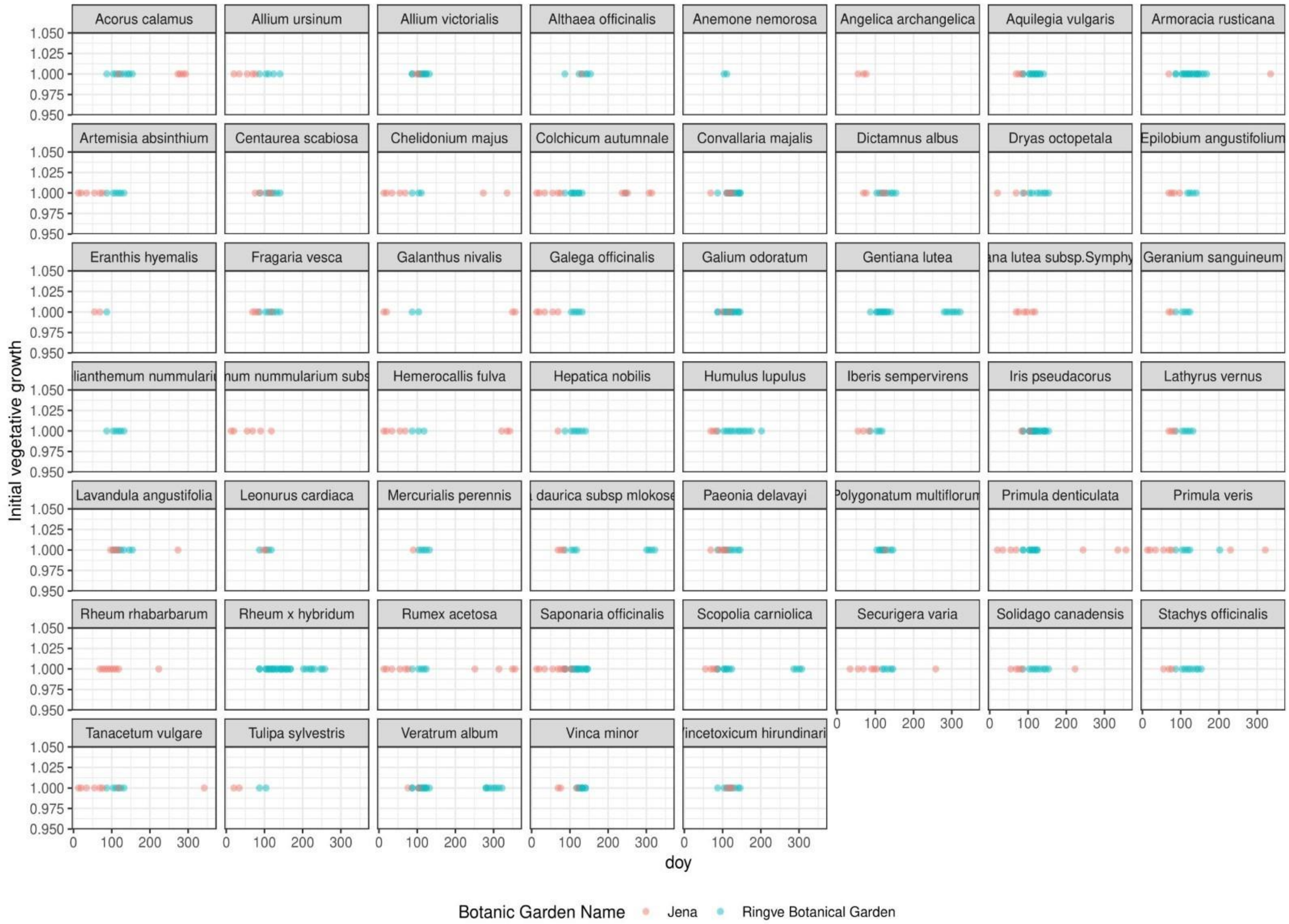

Figure 15. Graph of initial vegetative growth in both the gardens.

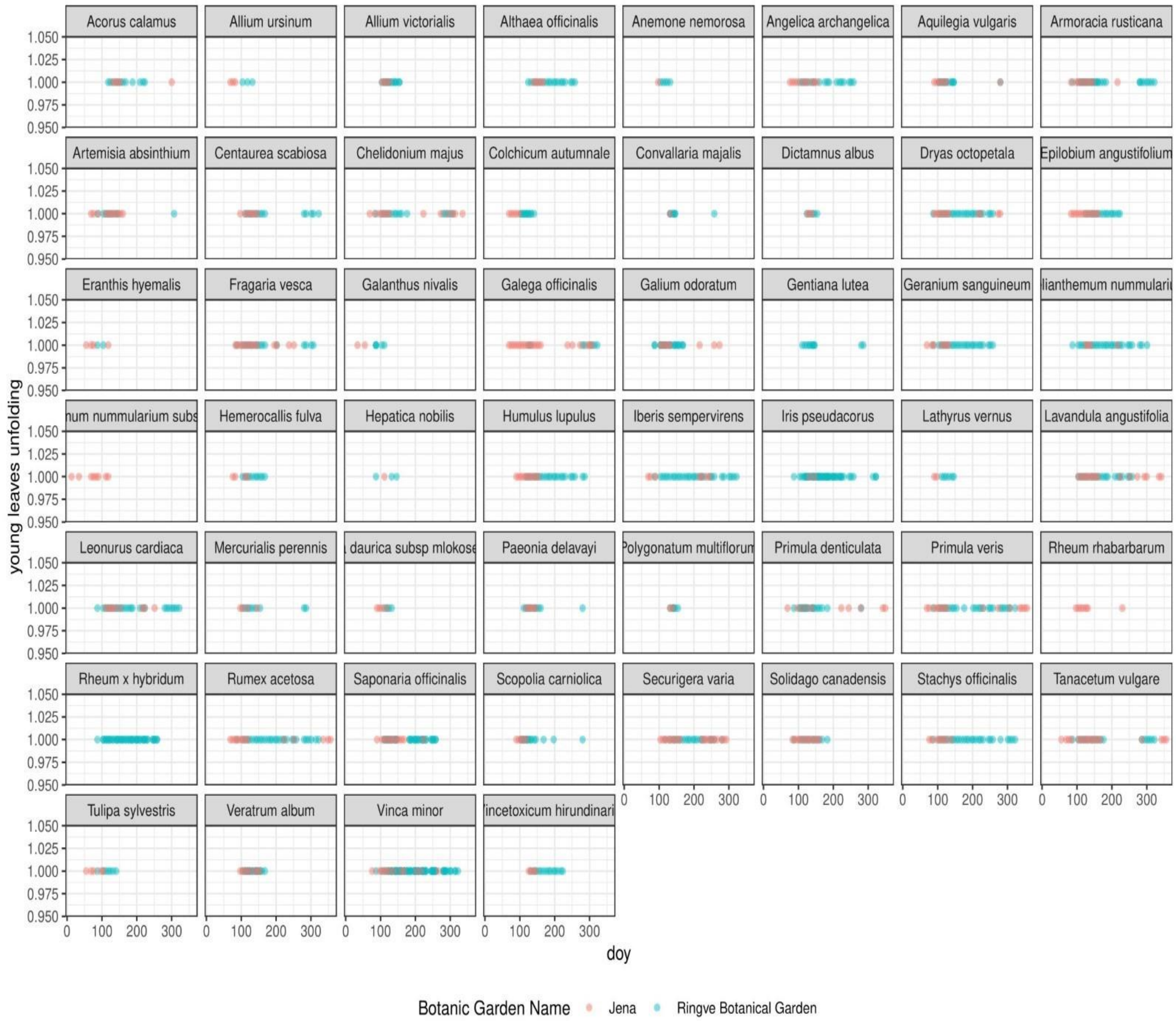

Figure 16. Graph of young leaves unfolding in both the gardens.

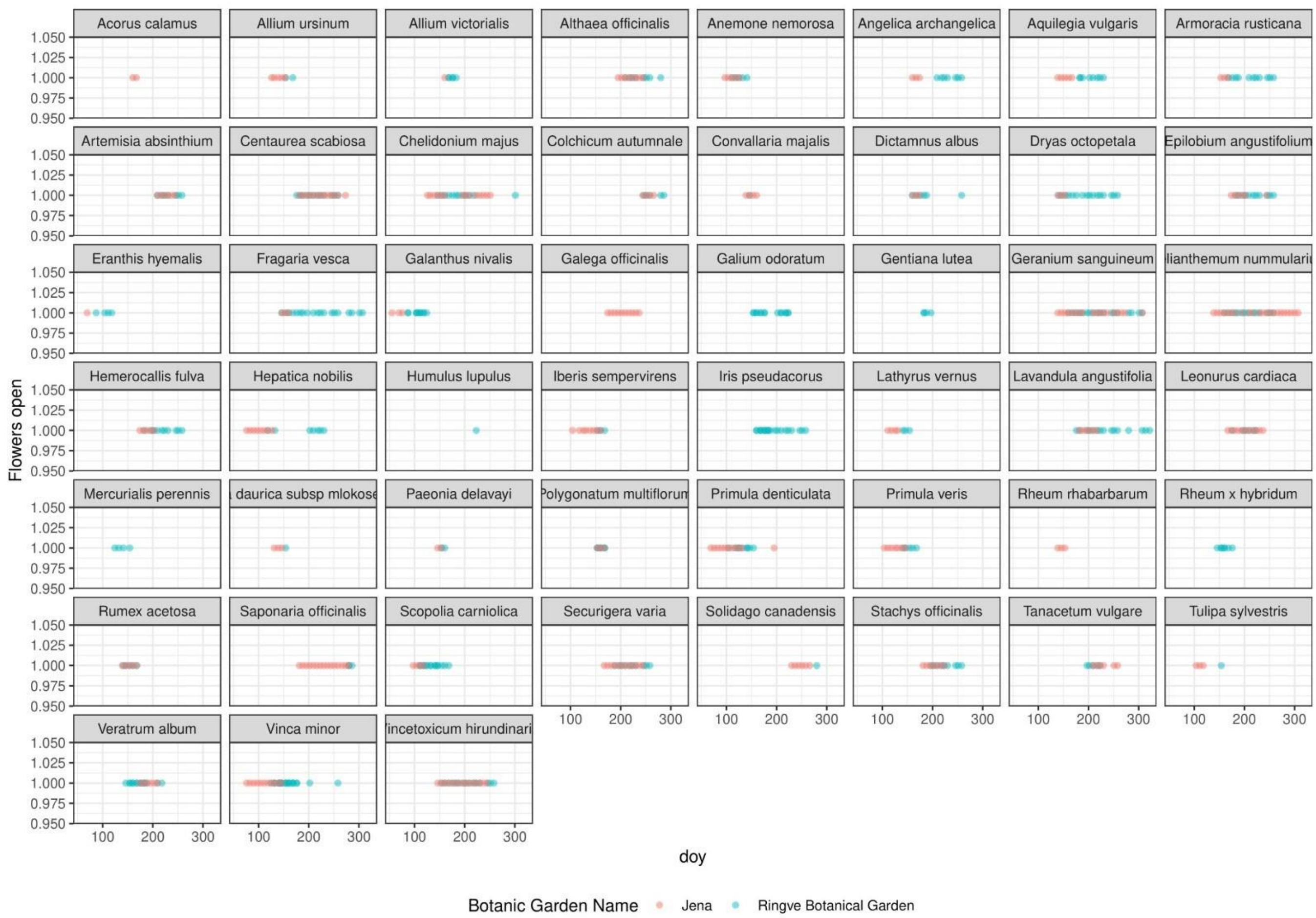

Figure 17.Graph of flowers open in both the gardens.

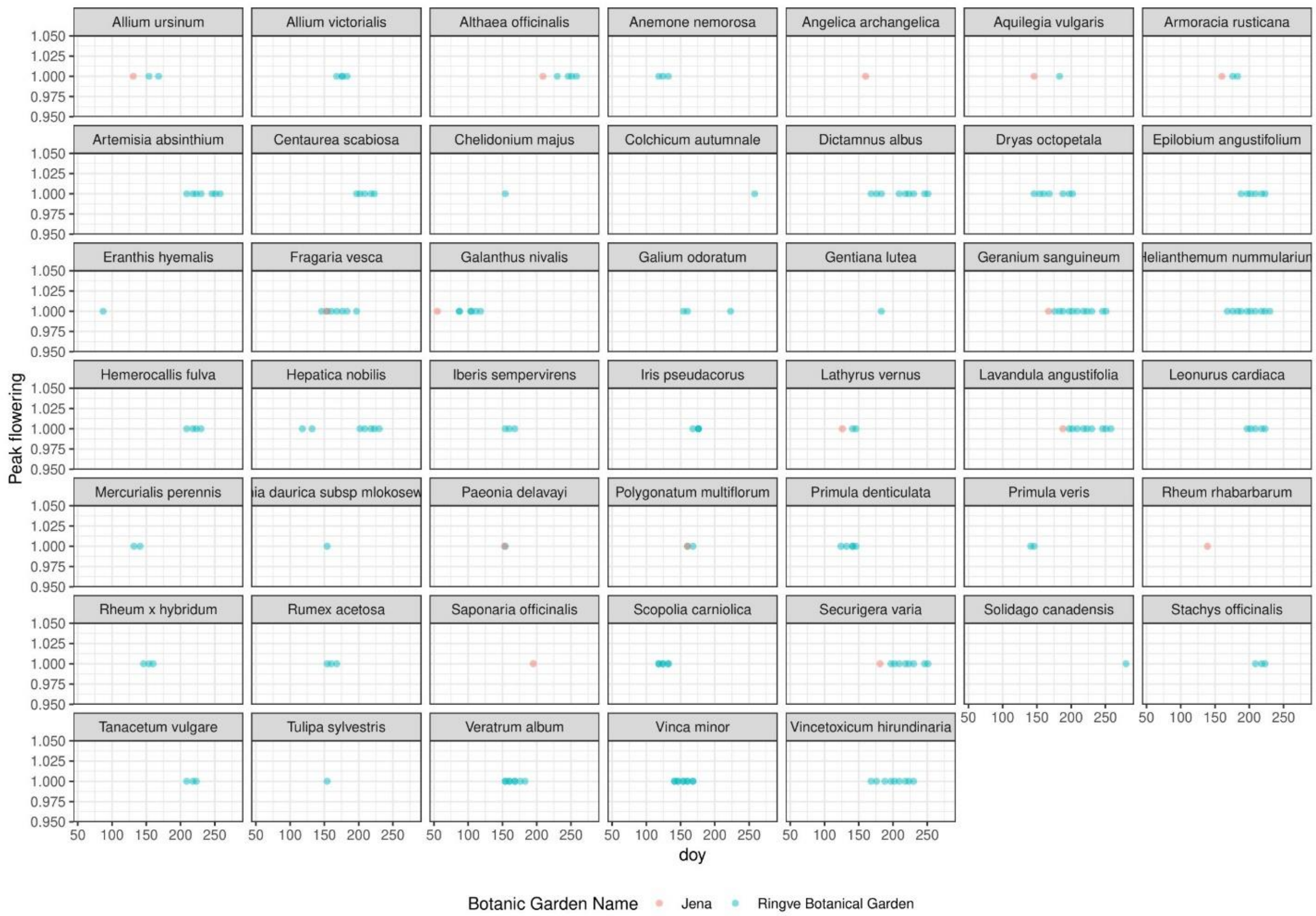

Figure 18.. Graph of Peak flowering in both the gardens.

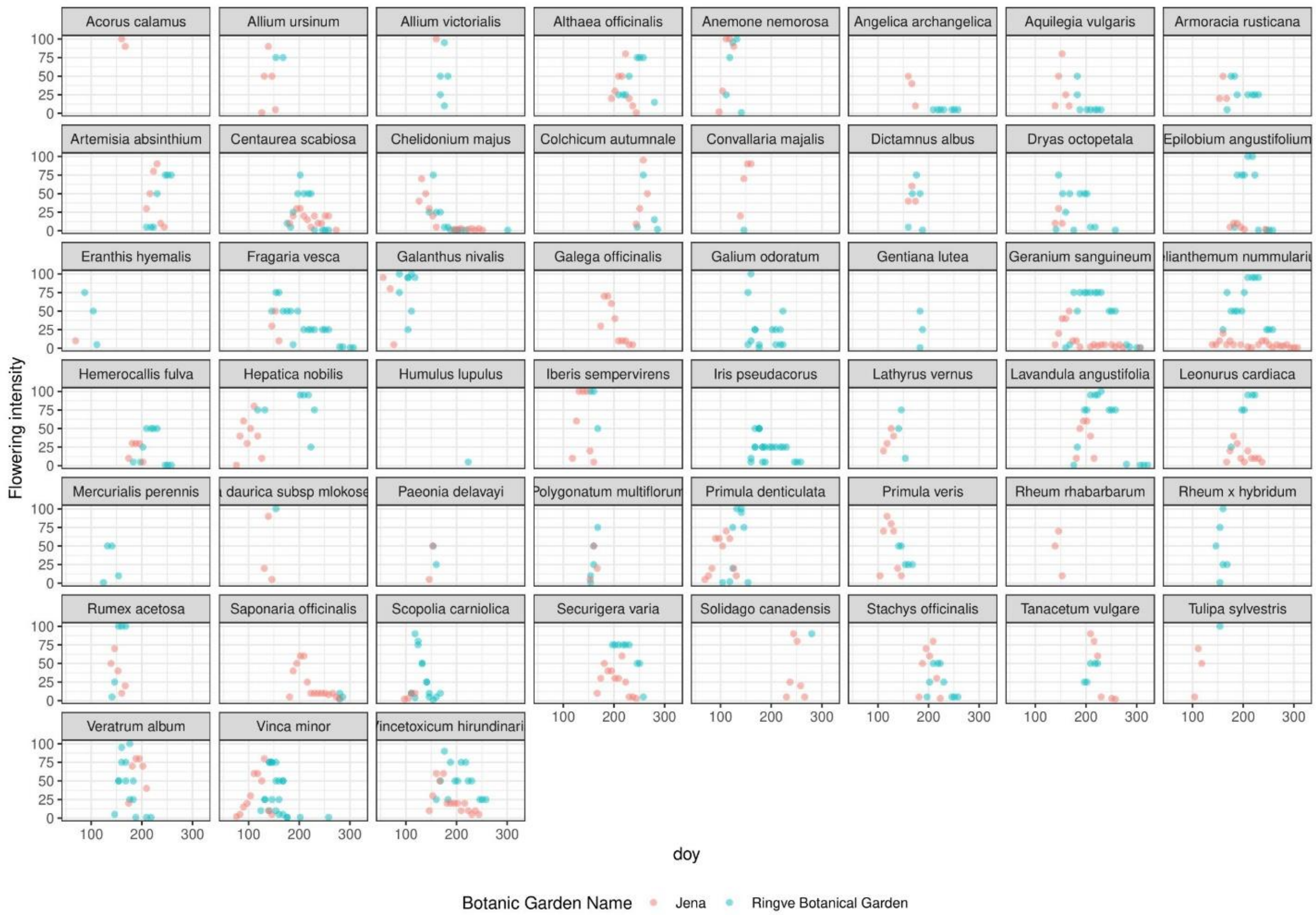

Figure 19.Graph of flowering intensity in both the gardens.

Figure 20.Graph of ripe fruits in both the gardens.

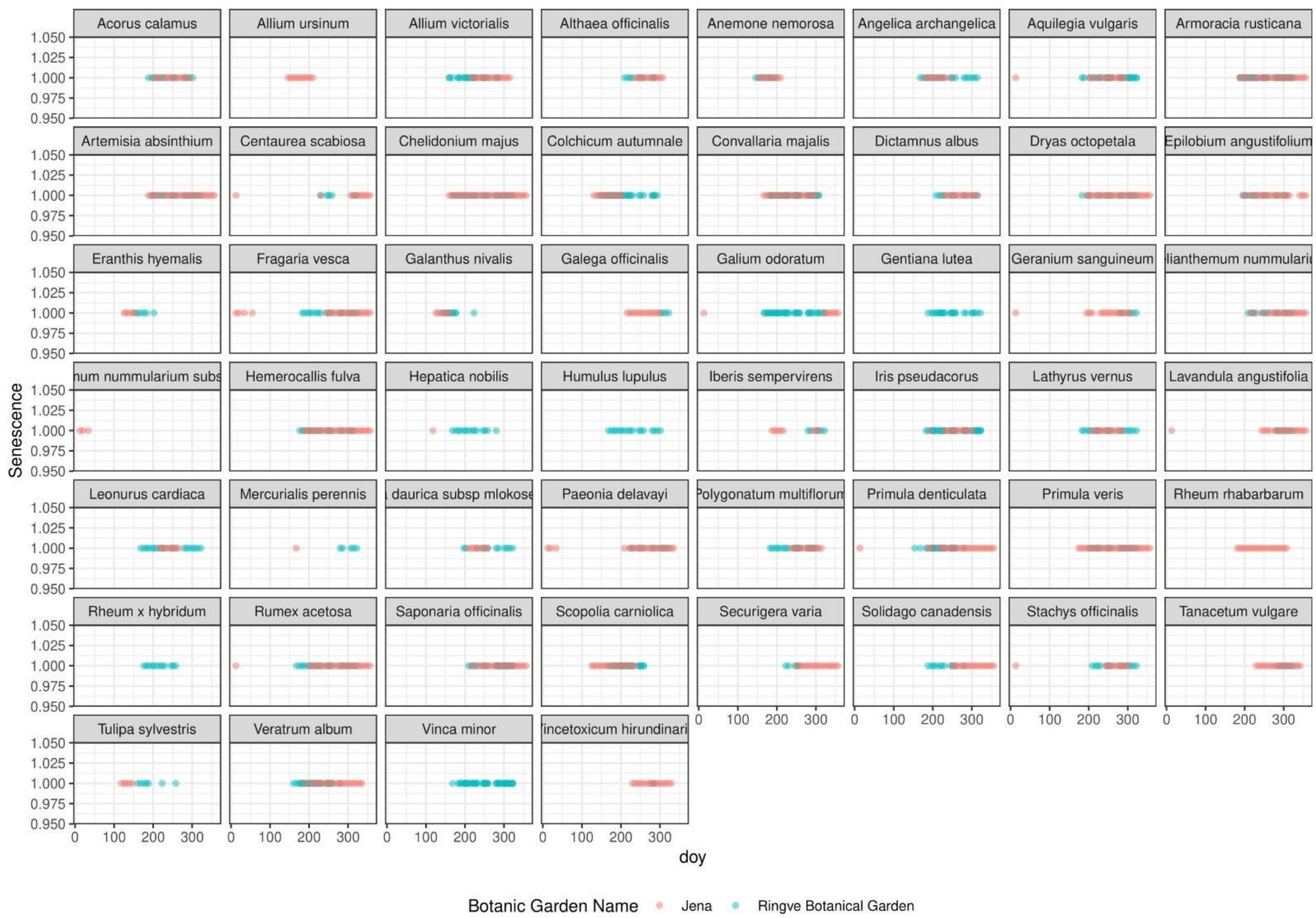

Figure 21.Graph of senescence in both the gardens.

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