INVESTIGATING THE POSSIBILITY OF USING BULBOUS PLANTS IN STRUCTURALLY SUPPORTED GARDENS*

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The goal of this research was to determine the most suitable species of bulbous plants for vertical and rooftop gardens in the context of the temperate climatic zone in Prague. The next issue was to determine how plants respond to individual cardinal directions while growing and how long they stay in bloom. This research focused mainly on plant blooming as this is the most important aesthetic element involved. In the individual years how many plants were in bloom, how long they stayed in bloom, how resilient they were, as well as their total persistence which is the most important factor in future decisions involving utilization of structurally supported gardens were recorded. The family *Narcissus* that thrived best in south facing part of the vertical garden proved to be the most suitable species for both gardens. On contrary, *Scilla siberica* proved to be the worst choice for south-facing gardens, both with respect to the length of bloom and the quantity of plants in bloom. *Muscari armeniacum* reached very balanced results of bloom in all cardinal directions. *Galanthus woronowii* did not show promise to be suited for either locality, and *Crocus* ‚King of Striped' appeared not to be suitable for vertical gardens.

vertical gardens, rooftop gardens, geophytes, persistence, Narcissus

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INTRODUCTION

Nowadays, structurally supported gardens (rooftop and vertical gardens) are an important element utilized in cities (Syumi et al., 2014; Lotfi et al., 2020) due to the undeniable benefits of greenery (Oberndorfer et al., 2007; Pejchal, 2007; Cantor, 2008; Ampim et al., 2010; Krebs et al., 2015; Davis et al., 2016). The main goal of the research was to find a suitable range of bulbs for these extreme conditions, which would support the aesthetic effect of planting, especially in early spring, and which will thrive in these habitats, be persistent and also have a high aesthetic value.

Consequently, primarily plants that stay small and correspondingly have small bulb sizes, are well suited to be included in this research. For example very early species *(Galanthus*), plants that tend to spread easily (*Muscari*), flowers that grow best in full sun and feature large beautiful blossoms (*Narcissus*), bulbous plants that can tolerate semi-shade (*Scilla*), and species that can tolerate low temperatures down to −5 °C while in bloom (*Crocus*) (Vaclavik, 1979; Kresadlova, Vilim, 2004).

In structurally supported gardens there are more difficult (even extreme) growth conditions and the plants in this environment are under the influence of many stress factors. Whether it is a strong wind, frost, extreme sunlight on exposed sides associated with rapid drying of the growth medium, or the action of dust or toxic particles (Minke, 2001). Other common problems are lack of irrigation (Paraskevopoulou et al., 2020) or, conversely, overwetting (Minke, 2001). Temperature instability at the roots can also be a problem, especially in vertical gardens (Pejchal, 2011). Of course, the thickness of the substrate is also limiting (Cermakova, Muzikova, 2009). Bulbs for bulbous plants are storage organs that help plants

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Fig. 1. The Rooftop Garden of the Multi-Faculty Center of Environmental Sciences II

cope with the extreme conditions of gardens on the structure – whether it‘s frost in winter or hot and dry summer (T u r k o v a et al., 1982).

The roof garden located on the building Multi-Faculty Center of Environmental Sciences II at the Czech University of Life Sciences Prague was established in 2015 (Fig. 1). The system of flower beds is treated intensively with corresponding height of substrate, location of automated irrigation, and also range of used plants. Because as early as in 2017 it became obvious that certain species of bulbous plants in the rooftop garden perform worse than the others, in 2018 this experiment was applied also to vertical gardens (Fig. 2). Subsequently, the same types of plants placed into two types of structurally supported gardens at the same time and space were compared. In order to determine the plant response, and as the system was left as a complementary one requiring as little maintenance as possible, the plants remained in the substrate during the dormancy period (summer). This experiment also considered the effect of temperature and amount of rainfall. Temperature plays a dominant role for bulbous plants, particularly for early blooming species, when they start to grow, and according to K r e s a d l o v a , V i l i m (2009), temperature affects the period of flowering as well. The amount of rainfall is also a substantial factor for this research; though both the gardens are equipped with automated irrigation, it is not activated until March in the case of the vertical garden and in April in the case of the rooftop garden. This greatly impacts the life cycle of bulbous plants.

For bulbous plants to grow and survive better in a rooftop garden, irrigation is absolutely necessary. This has also been confirmed by P a r a s k e v o p o u l o u et al. (2020) for non-succulent types of plants. In our climatic zone, the question is how the plants will respond to the period of time after winter, but before the automated irrigation system is activated, and how the plants will handle constant watering during the rest of the year. Bulbous plants in structurally supported gardens should be complemented by such companion plants which will look good for the rest of the year without competing a lot with bulbous plants (Nagase, Dunnett, 2013).

Fig. 2. Experimental Vertical Garden of the Czech University of Life Sciences Prague, Southern Side

Table 1. Bulbous Plants, Vertical (S – South, W – West, N –North, E – East) and Rooftop Garden 2019

Year 2019	Number of Plug Plants					Opened into Blooms					Number of Flowers					Bloom Time				
Plant	S	W	N	E	Rooftop	S	W	N	E	Rooftop	S	W	N	E	Rooftop	S	W	N	E	Rooftop
Narcissus ‚Tête-à-Tête‘ 2018	8	8	8	8	36	7	0	1	0	30	13	0	1	0	34	34	0	14	0	19
Crocus ‚King of Striped‘	8	8	8	8	36	0	0	0	0	10	-	-	-	-		0	0	0	0	14
Muscari armeniacum	20	20	20	20	40	14	10	9	8	40	-	-	-	-		30	35	37	35	30

MATERIALS AND METHODS

The experiment was carried out from February 19, 2019 to May 29, 2019, when the last measurement was made. The beginning of measurements was based on the weather, as there was a lot of snow in early February and the temperatures were lower compared to 2020 (Fig. 3). According to T u r k o v a et al. (1982), the first bulbous plants begin to grow after the chill period is over and warmer temperatures last for three continuous days at least. The experiment lasted until all the observed plants had stopped flowering and after leaves had died down completely. Thanks to warmer weather in 2020 (Fig.3), the experiment began earlier, on February 6, and lasted until May 29. Measurements were taken at least once a week, all data were recorded, and all the respective flowers were photographed. All measurements took place at both sites on the same dates so that subsequent data could be compared. Individual phenological growth stages of all plants were observed, measured, and recorded. For the purposes of this article, attention was focused particularly to the number of blooming plants in the individual years, how long they stayed in bloom, how resilient they were, as well as their total persistence which is the most important factor in future decisions involving the utilization of structurally supported gardens.

The length of bloom was measured in terms of days, in each case for the entire grouping of each species occupying the same space, beginning with the first plant in blossom until the last one has stopped flowering. Also, column (Table 1,2) showing quantity of blossoms was included particularly for Narcissi. Both utilized species have the potential to produce more stems with blooms per one bulb. According to V r e e b u r g , S c h i p p e r (1990), Narcissus ‚Tête-à-Tête‘ can even form multiple blooms on one stem. Therefore, the attention was also focused on this information which was evaluated as average value of the number blooms per one bulb for each species in bloom at the given space. Bulbous species planted in 2018 overwintered for 2 seasons. Bulbs planted in 2019 overwintered 1 season in the experiment.

Research into Bulbous Plants in a Rooftop Garden Multi-Faculty Center of Environmental Sciences II

There are 10 flower beds of different sizes on the roof of the building. In Fall 2018, 112 bulbs total were planted into two selected rooftop flower beds: 36 bulbs of *Narcissus* ‚Tête-à-Tête‘ 2018, 36 pieces

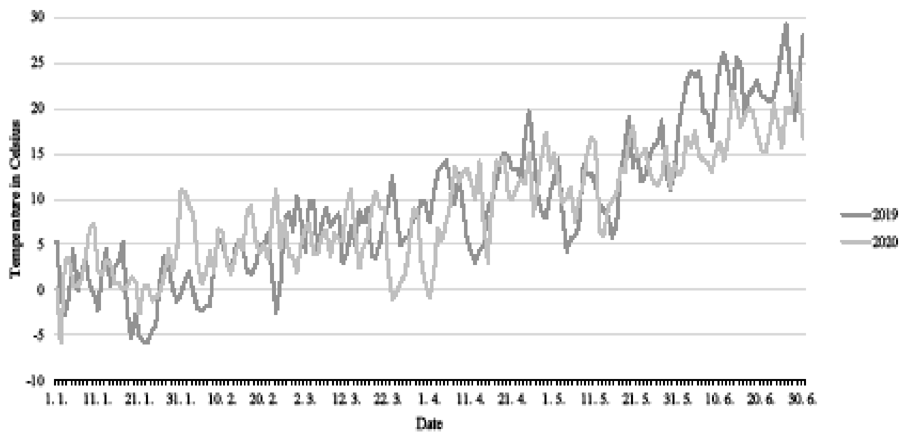

Fig. 3. Average Daily Temperature in 2019 and 2020 (Source: http://meteostanice.agrobiologie.cz/index.php)

Table 2. Bulbous Plants, Vertical (S – South, W – West, N –North, E – East) and Rooftop Garden 2020

Year 2020	Number of Plug Plants					Opened into Blooms					Number of Flowers					Bloom Time				
Plant	S	W	N	E	Rooftop	S	W	N	E	Rooftop	S	W	N	E	Rooftop	S	W	N	E	Rooftop
Narcissus, Tête-à-Tête‘ 2018	8	8	8	8	36	6	0	0	0	28	11	0	0	0	40	36	0	0	0	30
Narcissus, Tête-à-Tête‘ 2019	8	8	8	8	32	8	8	8	8	32	21	27	16	26	38	45	41	19	22	24
Narcissus ‚Jetfire‘	8	8	8	8	32	8	8	8	8	27	10	9	8	10	27	50	41	21	30	19
Muscari armeniacum	20	20	20	20	40	7	10	7	9	20	-	-	-	-	-	24	28	24	29	31
Galanthus woronowii	8	8	8	8	36	2	1	1	0	6	-	-	-	-	-	38	35	25	0	20
Crocus, King of Striped‘	8	8	8	8	36	0	0	0	0	32	-	-	-	-	-	0	0	0	0	19
Scilla siberica	10	10	10	10	40	5	8	7	8	7	-	-	-	-	-	18	41	39	35	31

of *Crocus* ‚King of Striped‘, and 40 pieces of *Muscari armeniacum*. In 2019, 140 bulbs total were planted: 32 pieces of *Narcissus* ‚Tête-à-Tête‘ 2019, 32 pieces of *Narcissus* ‚Jetfire‘, 36 pieces of *Galanthus woronowii*, and 40 pieces of *Scilla siberica*. Each species of one variety was planted in several groupings consisting of one species and at the ideal depth, as according to Kresadlova, Vilim (2009), small bulbs make the best display when planted together in large groupings, rather than as single plantings.

Research into the Bulbous Plants in a Vertical Garden

Similar research was carried out in an experimental cascade vertical garden at the Czech University of Life Sciences Prague. The whole system consists of four free-standing green walls, all of them double-sided. These walls are facing each cardinal direction. Each vertical garden consists of nine rows of troughs with flowers pots (Kunt et al., 2017). In 2018, 144 bulbs total were planted: 32 pieces of *Narcissus* ‚Tête-à-Tête‘ 2018 that were placed into flower beds to complement the grass *Koeleria glauca*, 32 pieces of bulbous plants *Crocus* ‚King of Striped‘ placed with *Saponaria ocymoides* facing south and east and *Campanula poscharskyna* facing north and west. Eighty pieces of *Muscari armeniacum* bulbs were planted to complement *Fragaria vesca*. In Fall 2019, additional 136 bulbs were planted including 32 pieces of *Narcissus* ‚Tête-à-Tête‘ 2019 placed into flower pots to complement the grass *Koeleria glauca*, as in the previous year. Furthermore, three new species were used, including: 32 pieces of *Narcissus* ‚Jetfire‘ placed with the grass *Festuca ovina*, similar to *Narcissus* ‚Tête-à-Tête‘ 2019, 32 pieces of *Galanthus woronowii* planted to complement *Arctostaphylos uva-ursi* facing south and east, and *Lysimachia nummularia* facing north and west. Moreover, 40 pieces of *Scilla siberica* were added to complement *Saponaria ocymoides* facing south and east and *Campanula poscharskyna* facing north and west. The bulbs were planted at a depth of 6 centimeters at the least in order to complement the existing planting area. A specific number of bulbous plants was placed evenly to face each cardinal direction. As regards the bloom time of the individual species, attention was also paid to the individual cardinal directions to evaluate at which cardinal direction the plants stayed in bloom for a longer period and where bloom times were reduced. Subsequently, all the data were summarized and Tables presented in the following chapter were created.

RESULTS

The best interpretation of the results of our research is to analyze them in the individual years. In 2018, bulbs of three varieties of bulbous plants were planted in the vertical and rooftop garden. The measurement was made during the growing season of 2019 and 2020. In fall 2019, three additional species of bulbous plants were planted, with the number of one existing plant being increased. It was decided that a threshold of 50 % of blooming plants in the first growing season and 40 % of blooming plants in the second growing season would be considered satisfactory.

Year 2019

In the vertical garden, only *Muscari armeniacum* qualified for a successful planting, reaching 50 % of flowers in bloom while the species *Narcissus* ‚Tête-à-Tête‘ 2018 only reached 25 %. However, it was found out directly in the said gardens that plants that had begun to develop blossoms in the east, west, and north of the garden had been stolen. Therefore, an additional number of such bulbs was purchased and re-planted in 2019. After the first year, *Narcissus* ‚Tête-à-Tête‘ 2018 and *Muscari armeniacum* were found to be suited for a rooftop garden (see Table 1 and Fig. 4).

Year 2020

The year 2020 was the first growing season for four species (*Narcissus* ‚Tête-à-Tête‘ 2019, *Narcissus* ‚Jetfire‘, *Galanthus woronowii* and *Scilla siberica*). As a satisfactory quantity of 50 percent flowers in bloom was established, and consequently, they had to reach the 50 % threshold of blooming plants in the first growing season to be acknowledged as a promising family. The species *Narcissus* ‚Tête-à-Tête‘ 2019, *Narcissus* ‚Jetfire‘ and *Scilla siberica* reached this threshold in the vertical garden. In the rooftop garden, it was *Narcissus* ‚Tête-à-Tête‘ 2019 and *Narcissus* ‚Jetfire‘ that reached this threshold.

Persistence of the other species was examined for the second year after having survived the second winter; the obligatory threshold was 40 percent of blooming flowers. Only the species *Muscari armeniacum* was determined to be persistent for a green wall, and *Narcissus* ‚Tête-à-Tête‘ 2018, *Muscari armeniacum* and *Crocus* ‚King of Striped‘ for a rooftop garden. Comparing the first and second year, the most appropriate species was *Narcissus* ‚Tête-à-Tête‘ 2018 for both gardens. There was a moderate drop of 6 and 5 per cent in quantity of plants blooming in the second year. The most dramatic drop of 50 percent of blooming plants occurred in *Muscari armeniacum* in the rooftop garden.

Also, the research showed that the length of blooming in a vertical green wall depends on the cardinal direction where the bulbous plants are placed. It was proven that the longest period of bloom for both species of **Narcissus** was south followed by west and east while the shortest time of bloom was in the north. On the contrary, *Scilla siberica* proved to be the worst option for south facing gardens, both with respect to the length of bloom and the quantity of plants in bloom. *Muscari armeniacum* reached very balanced results of bloom in all cardinal directions. Furthermore, it was established that in both types of structurally supported gardens, the flowers bloomed for a longer period of time in 2020. In comparing both types of gardens, the same species were in bloom for a longer time in the vertical garden than in the rooftop one. The exception was *Muscari armeniacum* which reached very balanced results at both locations and in both periods of time (see Table 2 and Fig. 5). As

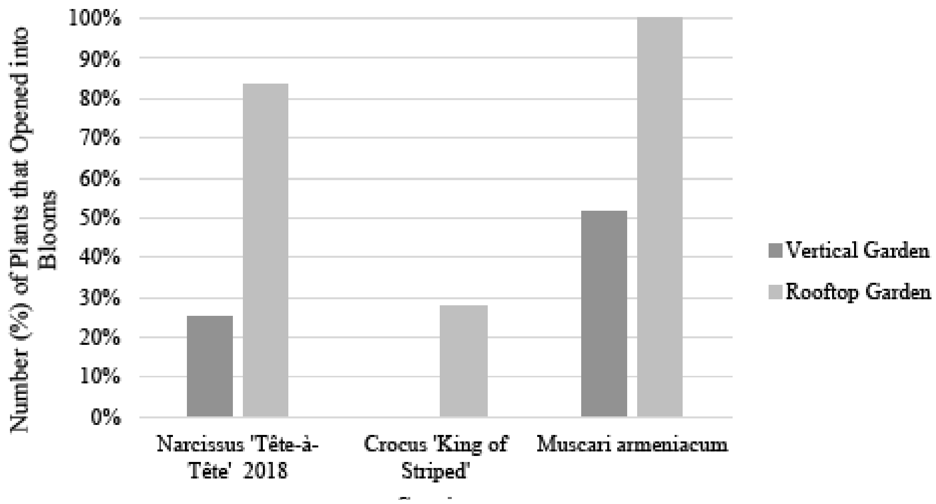

Fig. 4. Number of Bulbous Plants that Opened into Bloom in a Rooftop x Vertical garden 2019

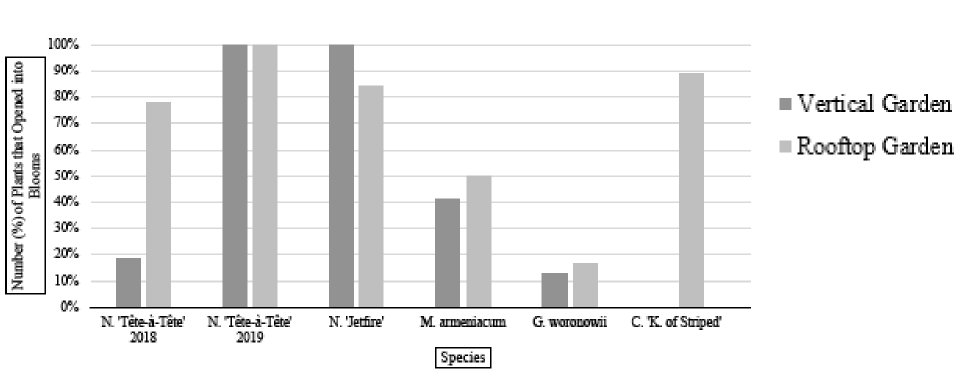

Fig. 5.Number of Bulbous Plants that Opened into Bloom in a Rooftop x Vertical garden 2020

regards *Narcissus* ‚Tête-à-Tête‘, an average number of 2.5 blooms per plant was recorded in the vertical garden while an average number 1.2 blooms per plant was recorded in the rooftop garden. As regards *Narcissus* ‚Jetfire‘, a lower value of 1.2 blooms per plant was reached in the vertical garden and 1 bloom per plant was reached in the rooftop garden.

DISCUSSION

It follows clearly from our experimental results that *Narcissus* is the best suited family in both localities. Wisdom et al. (2019) recommends to plant *Narcissus* ‚Tête-à-Tête‘ as their experiment showed that this species is promising, persistent, and competitive. In our experiment, this assumption proved right also for structurally supported gardens as shown in Fig. 5. As regards Wisdom et al. (2019), who have grown bulbous plants in grass, more than 90 percent of *Narcissus* were in bloom in the first growing season, and less than 50 percent of them were blooming in the second growing season. In our experiment, where the bulbs of *Narcissus* ‚Tête-à-Tête‘ were planted also to complement the grass in a vertical garden, they reached 100 per cent of plants in bloom in the first year (2020). The number of plants remaining from 2019 dropped only by 25 percent in the following year. During both years of our experiment, 80 percent or more of the plants were in bloom in the rooftop garden.

Dinçer et al. (2016) have published in their study that a range of bulbous plants in rooftop gardens and in flower pots was desirable due to their shallow rooting system, low water requirements, and high wind resistance. Nagase, Dunnett (2013) have confirmed this, adding that small bulbous plants are more suitable for rooftop gardens. This assumption proved right only partially, as it was found that, with respect to water consumption, it depends on the bulb species. Based on this experiment, for example, *Crocus* ‚King of Striped‘ appeared to require more moisture to thrive. Zhang et al. (2014) also confirm that non-succulent perennials, including bulbs, irrigation is recommended for proper growth on rooftop gardens.

Though both gardens were equipped with integrated automatic watering systems, these were activated later on when bulbous plants were already growing and in bloom. Before the irrigation system was activated, the plants depended on the amount of rainfall. Fig. 6 shows that daily rainfall was more or less below average in 2019 – before the activation of the irrigation system. The *Crocus* ‚King of Striped‘ plants responded mostly to this fact. According to Vaclavik (1979), such plants are in blossom from March to April, and they suffer from water shortages during the growing season. Given that the automated irrigation system was not activated until the end of March 2019 in the vertical garden, and due to low amounts of rainfall (Fig. 6), the plants only formed leaves, but were unable to form blossoms. At the beginning of February 2019, the rooftop garden was covered by snow, and as the snow melted with an increase in average day temperatures (Fig. 3), it provided at least a partial amount of moisture, and some number of plants grew and blossomed forth. In the next year there was an increase in temperatures and rainfall, and consequently more plants blossomed forth in the rooftop garden. Based on this discovery, it is recommended to grow *Crocus* in earlier watered structurally supported gardens when there is an insufficient amount of rainfall. *Galanthus woronowii* is another example of an early growing plant that cannot tolerate overly dry soil (Vaclavik, 1979; Kresadlova, Vilim 2004). Also, *Galanthus woronowii* did not respond well at all to later watering.

Furthermore, Nagase, Dunnett (2013) also recommended using *Muscari*, as it proved beneficial in a rooftop garden in the United Kingdom because

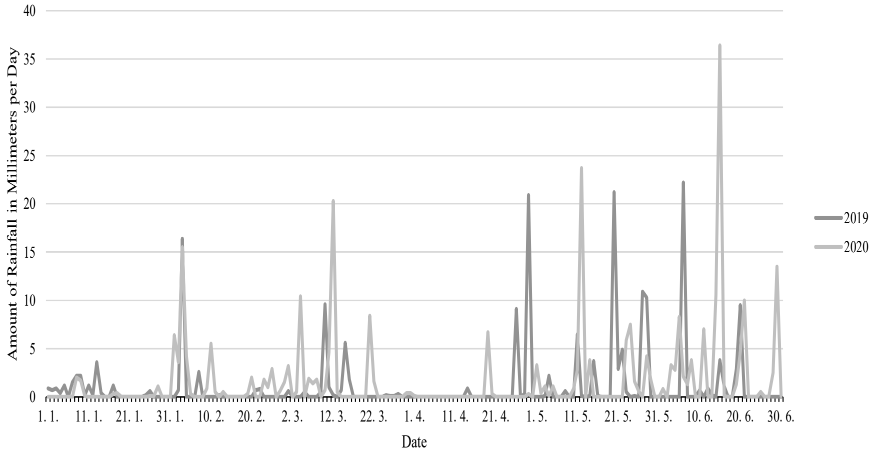

Fig.6. Daily Amount of Rainfall in 2019 and 2020 (Source: http://meteostanice.agrobiologie.cz/index.php)

it propagated quickly. In our experiment, this species showed almost the same results of growing in both locations. However, within the years there were less of such plants. A species not recommended by them for a green roof is *Scilla siberica*. We can agree with this result in case of our rooftop garden; however, this species proved to be suited for a vertical garden. According to Vaclavik (1979), *Scilla siberica* is in blossom from March to April; this was confirmed by our research. Though Fig. 6 shows that there was more rainfall in this period, low numbers of blooming plants in the rooftop garden may have been caused by the irrigation system not being activated until later on. It was more probably the course of daily temperatures during March (Fig. 3) that had a negative impact on plants. Actually, there were two instances when temperatures fell below freezing. This could have had a negative impact on floral buds. Most probably, also *Muscari* were negatively influenced by late activation of the irrigation system in 2020.

Based on their experiment in a rooftop planting, Nagase, Dunnett (2013) deduced that many types of bulbous plants grow better and stay in bloom for a longer time when the bulbs are planted deeper in the soil. According to their experimental results, Erwin, Hensley (2019) agree with Nagase, Dunnett (2013). Erwin, Hensley (2019) had planted bulbous plants at the depth of 5 cm and found that a lot of such plants died. The species of plants utilized in experimental gardens at the Czech University of Life Sciences Prague do not fully correspond to such results. In most cases, the bulbous plants stayed in bloom for a longer time in the vertical garden. Plants inserted into plastic flower pots in such vertical gardens cannot be placed as deep as in the rooftop garden. Still, it might be beneficial for early species of plants placed in such a manner that the substrate in such a small and dark flower pot can warm up earlier than in the rooftop garden. This may have a positive impact on a longer period of the bloom.

It was also confirmed for *Scilla siberica* that vigor and growth depend on cardinal direction where the plants were placed. Given that Kresadlova, Vilim (2004) have stated that family *Scilla* performs best in places where there is semi-shade, we assumed that they would exhibit their worst performance in the south. This assumption was confirmed in our experiment afterwards.

According to Vreeburg, Schipper (1990), *Narcissus* ‚Tête-à-Tête' can have up to several stems with 1 to 3 blooms. In our research, this statement was proven right in both localities involved, with multiflorus plants appearing rather in the vertical garden. On the contrary, there were more instances when species *Narcissus* ‚Jetfire' that should only have one bloom per stem (Huml, 2004) created more stems from one bulb. Consequently, there was an average number of 1.1 blooms per plant. As Vaclavik (1979) stated that *Narcissi* require placement in full sun or in semi-shade, we expected that in the vertical garden it would exhibit its best performance in the warmer south facing location and worst in north facing location. This was confirmed for both species.

As issues appeared that have to be looked at, the research is supposed to continue in the coming years as well. Such issues include: development of persistence of present species, or how the plants would respond to additional watering in months of active growth when the automated irrigation had not been activated, or planting of species that are more drought tolerant. However, such xerophytes would have to cope with irrigation in the rest of the year.

CONCLUSION

Genus *Narcissus* has appeared to be well suited for this purpose, particularly ‚Tête-à-Tête' and ‚Jetfire', the research has affirmed their very good persistence and aesthetic effect both in rooftop and vertical gardens in the temperate climatic zone in Prague. Moreover, it has been proven that such species stay in bloom for the longest period of time in south facing vertical gardens. In this regard, it has also been found that *Scilla siberica* achieved the worth growth in the south, and consequently, we can recommend such plants for other cardinal directions. Contrarily, *Muscari armeniacum* reached very balanced results of growing in the vertical garden (with minor divergences) in all cardinal directions. It follows from our research that the following plants are suitable for the rooftop garden (except for the family *Narcissus*): *Muscari armeniacum* and *Crocus* ‚King of Striped'. For green vertical walls, the following plants may be recommended: *Scilla siberica* and *Muscari armeniacum*. *Galanthus woronowii* have not shown promise to be suited for either application, and *Crocus* ‚King of Striped' does not appear suitable for vertical gardens. Moreover, it has been established that to reach better growth and development of bulbous plants in early Spring when such plants are growing, a hand-operated irrigation system should be used before activation of the automated irrigation system and when there is an insufficient amount of rainfall.

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