URBAN BEES BENEFIT FROM A NATIVE FOREST SPECIES GROWN IN A CITY ENVIRONMENT- A CASE STUDY OF *GERANIUM PHAEUM* L.

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Abstract

This two-year study tested whether urban bees benefit from the forest perennial *Geranium phaeum* L. replanted from natural stands to an urban environment. The flowering abundance and phenology, spectrum of insect visitors, nectar and pollen production, and the energetic value of nectar were investigated in Lublin, SE Poland. The apiarian value of *G. phaeum* was studied for the first time. The species bloomed abundantly from late April to early June and can be regarded as a valuable spring food resource for urban bees, mainly bumblebees, which accounted for >50% of all visits in both years of study. Bees collected mainly nectar. The highest daily pollen and nectar sugar amount offered by a plant reached 73.7 mg and 36.5 mg, respectively, with the caloric value of nectar of 146 cal. The estimated mean sugar yield, caloric value of nectar and pollen yield $\cdot \text{m}^{-2}$ were 1.7 mg, 6.9 kcal, and 3.4 mg, respectively. The current study confirms the advantage of using native plants in urban landscaping and proves their positive role in strengthening both wild and managed bee populations in cities. The finding that wild plants translocated from the natural habitat can develop a self-sustaining population in the urban environment and establish beneficial relationships with urban bees is of interest in terms of the conservation of both native plants and pollinators.

Keywords: bee pasture, biodiversity conservation, native plant, nectar, pollen, urban pollinators

INTRODUCTION

Rapid urbanization, one of the main characteristics of the recent 21st century, has led to radical changes in the habitat structure and loss of flora and fauna species. However, cities can support a high diversity of many plants and animals, and urban habitats are indicated to be promising in the restitution of pollinator richness and abundance (e.g. Hall et al., 2017; Wenzel et al., 2020). Bees play a crucial role in pollination in both natural and human-altered habitats (Klein et al., 2007; Potts et al., 2010). Support for urban pollinators, including bees, requires a proper strategy in the planning and management of urban green infrastructure to enhance floral resources as well as nesting and hibernation resources (Baldock, 2020).

Urban areas are a patchwork of different land uses and ecological habitats (Niemelä et al.,

2011). This creates a possibility to incorporate plants of various origins, environmental demands, and cultivation status into local floral resources. So far, a characteristic feature of urban landscape has been the high level of non-native and exotic plant species (Pickett et al., 2011; Staab et al., 2020). However, there is the threat that alien species may escape from cultivation and compete with native ones (van Kleunen et al., 2018), so a wider use of native plants as a nectar and pollen source for urban pollinators is recommended (Threlfall et al., 2017; Rollings & Goulson, 2019). As shown by Salisbury et al. (2015), urban gardens can be enhanced as a pollinator habitat by planting a variety of flowering plants biased towards native and near-native species.

The usefulness of plants for pollinators requires detailed studies on their blooming biology (Fisogni et al., 2020) and pollen/nectar availabil-

ity and quality (Garbuzov & Ratnieks, 2014; Tew et al., 2021). Knowledge of these traits is crucial for designing a “bee-friendly” urban greenspace (Stange et al., 2017). Moreover, native plants used in urban greenery must perform well in such specific environmental conditions as urban warming, increased water stress and pollution (Pickett et al., 2011). When grown in urban greenery, their aesthetic value should be taken under consideration as well.

This study aimed to evaluate the native *Geranium phaeum* L. (Geraniaceae) as a food source for urban bees. More specifically, (i) the flowering phenology and abundance, (ii) the nectar and pollen production, and (iii) the spectrum of urban insect visitors were assessed. Nectar is the main bee reward in other *Geranium* species (Masierowska et al., 2018), and its both quantitative and qualitative characteristics were investigated in the current study. With *G. phaeum* as a model species, this study was focused on an attempt to test whether honeybees and wild bees benefit from floral rewards offered by the forest plant grown in an urban environment.

Geranium phaeum is native to South and Central Europe. In Poland, it is a rare species, occurring in the Carpathian and Sudety foreland, north Małopolska, and Lublin Highlands with isolated localities in lowlands (Zajac, 1996). The natural habitat of *G. phaeum* includes forests, wood margins, and moist mountain meadows (Rutkowski, 2006). The species is characteristic of riverside montane alder forest *Alnetum incanae* (Matuszkiewicz, 2008). *Geranium phaeum* also grows in stable meadows and disturbed areas. The species and its cultivars are recommended for planting in parks, gardens and perennial flower meadows (Marcinkowski, 2002).

According to literature, *G. phaeum* flowers are visited by bees and dipterans (Knuth, 1908; Fiz et al., 2008). However, their attractiveness to bees has never been evaluated in detail. Moreover, to the best of my knowledge, this is the first study of an established city population originated directly from wild specimens replanted from natural stands.

MATERIAL AND METHODS

Study site and plant species

The study was conducted in Lublin, SE Poland (51°16'N, 22°30'E; 200 m a.s.l.), in 2015-2016. The local climate is classified as humid continental (Dfb) (Köppen, 1948). The investigation was conducted on a population of *G. phaeum* grown in the UMCS Botanical Garden, where it was established from specimens brought from natural stands in the Bieszczady Mountains in 1975-1976. The plant patches grow on loess soil in partial shade, under a tree layer comprising *Tilia cordata* Mill., *Acer pseudoplatanus* L., and *Fagus sylvatica* L. and a shrub layer consisting of *Sambucus nigra* L., *Frangula alnus* Mill., *Cornus mas* L., and *Staphylea pinnata* L.

Geranium phaeum is an 80 cm tall rhizomatous, clump-forming perennial. It has dark reddish-brown flowers, 18-22 mm in diameter, clustered in 2-flowered cymes growing from the consecutive nodes of basal shoots. Its protandrous perfect and actinomorphic flowers consist of five free sepals, five free petals, ten stamens in two whorls, and one pistil with a five-lobed stigma (Knuth, 1908). Nectar is secreted by five external nectaries located at the stamen base (Konarska & Masierowska, 2020).

Flowering records and insect visitation monitoring

The onset and termination of blooming were recorded and the length of the flowering period was determined. The abundance of flowering was expressed as the number of flowers · m⁻² of patch area. This number was estimated by multiplying the number of shoots developed per m² of patch (n=11 patches in each year of study) and the mean number of flowers · shoot⁻¹. The number of shoots per year on which flowers were counted is shown in Tab. 1. Additionally, in 2015 the flowering pattern of a plant was examined. To this end, five specimens were randomly chosen and marked. When their blooming started, the number of open flowers (in the ♀ and ♂ phases and their sum) on each plant was counted every day (at the very beginning) and later every 3-5 days

Table 1.
Time and abundance of flowering of *Geranium phaeum* in the years of study, Lublin SE Poland

Year	Flowering period (days)	No. of flowering stems · m ⁻² of a patch*	No. of flowers:*	
			flowering stem ⁻¹	m ⁻² of a patch (thous.)
2015	27 April-8 June (43)	120.6 ^a ± 42.1 (11)	16.5 ^b ± 4.7 (113)	2.0 ^a ± 0.8 (11)
2016	29 April-31 May (33)	65.3 ^b ± 12.8 (11)	21.3 ^a ± 7.1 (140)	1.6 ^a ± 0.3 (11)
mean	(38)	92.9 ± 41.5 (22)	19.2 ± 6.6 (253)	1.8 ± 0.6 (22)

*Means ± SD (number of samples) are given. Means in columns with the same letter do not differ significantly in the years of study (the Kolmogorov-Smirnov test, $p > 0.1$)

until blooming terminated. In 2015-2016, during the peak blooming of the plants, the spectrum of insect visitors and the number of their visits to *G. phaeum* flowers were noted. Five-minute observations were made every hour from 10.00 to 16.00 (GMT + 2 hrs) for 2-3 days in sunny and non-windy weather. The observations were performed in 4-5 marked areas, each sized 0.2 m².

Assessment of floral rewards

To determine nectar production, the cymes with flower buds on randomly selected 20-30 shoots were marked (two to four cymes on each shoot). The shoots were isolated with tulle isolators (mesh size <1 mm) to exclude insect visits. Samples were then collected on the fourth day of isolation, as preliminary observations exhibited a 3-4 day life span of *G. phaeum* flower. Accumulated nectar was sampled separately from the ♂ and ♀ phase flowers in 2015. In 2016, it was gathered only from the ♀ phase flowers, which was enough to compare nectar production in *G. phaeum* with other *Geranium* species. The nectar was extracted using glass microcapillaries and its amount was measured (in mg) with the use of a WPS-36 analytical balance (RADWAG, Radom, Poland). A single sample contained nectar from two to twelve flowers. The number of samples per each year is shown in Tab. 2 and Fig. 3. The nectar sugar concentration (% w/w) was measured with the RL-4 refractometer (PZO, Warsaw Poland). The nectar sugar amount · flower⁻¹ (mg) was calculated

based on the nectar amount and nectar sugar concentration (Jabłoński, 2002). Additionally, the high-performance liquid chromatography technique with a refractometric detector (HPLC-RI) was used to determine sugars contents in the nectar from the flowers in both phases. The analysis was carried out on the Shimadzu HPLC system (Phenomenex Inc., Torrance, CA, USA). The various sugars were identified through the comparison of individual sugar retention times of the reference and the analyzed solution. The quantitative assays were conducted using the external standard method comparing the peak surfaces of these sugars. The results (g/100 g) were recalculated into the sucrose (S) to hexose (fructose F + glucose G) ratio r (Baker & Baker, 1983). The amount of pollen available to insects was determined with the use of the protocol described in previous studies on *Geranium* species (Masierowska et al., 2018). Six samples were collected each year and a single sample contained 100 mature stamens. The results were expressed in mg of pollen · flower⁻¹. In 2015, the temporal distribution of the nectar sugar amount, the caloric value of nectar, and the pollen amount offered to insects by a single plant (n=5) were estimated. The daily nectar sugar amount was calculated as a sum of the sugar amount secreted in nectar of the ♂ and ♀ phase flowers open on a plant on the census day. The caloric value of nectar (= energy amount, in cal) was calculated through the multiplication of this sum and the energetic value of 1 mg sugar =

Table 2.
Nectar and pollen reward of *Geranium phaeum* available to flower visitors in 2015-2016, Lublin,
SE Poland

Year	Nectar amount · flower ⁻¹ (mg)*	Nectar sugar concentration (% w/w)*	Nectar sugar amount:*		Caloric value of nectar · m ⁻² of patch (cal)	Pollen amount:	
			flower ⁻¹ (mg)	m ⁻² of patch (g)		flower ⁻¹ (mg)	m ⁻² of patch (g)
2015	1.6 ^b ± 1.3 (14)	36.6 ^b ± 11.2 (14)	0.5 ^b ± 0.3 (14)	1.0 ^b ± 0.4 (11)	4.0 ^b ± 1.6 (11)	2.0 ^a ± 0.1 (6)	4.0 ^a ± 1.5 (11)
2016	2.9 ^a ± 1.0 (16)	53.1 ^a ± 7.4 (16)	1.6 ^a ± 0.6 (16)	2.5 ^a ± 0.3 (11)	9.9 ^a ± 2.0 (11)	1.7 ^b ± 0.2 (6)	2.7 ^b ± 0.6 (11)
mean	2.3 ± 1.4 (30)	45.4 ± 12.5 (30)	1.1 ± 0.7 (30)	1.7 ± 0.9 (22)	6.9 ± 3.5 (22)	1.9 ± 0.2 (12)	3.4 ± 1.3 (22)

* Nectar accumulated in the ♀ phase flower

Untransformed data are presented. Means ± SD (number of samples) are given. Means in columns followed by different letters differ significantly between years of study (HSD Tukey test, $p < .05$)

4 cal (Dafni, 1992). The daily pollen amount was based on the number of open ♂ phase flowers on a plant and the pollen amount · flower⁻¹.

Moreover, the sugar and pollen yield · m⁻² of patch area (g) as well as the nectar caloric value · m⁻² of patch (kcal) were estimated. To this aim, data of the mean number of flowers · m⁻² of patch, the mean nectar sugar amount · ♀ phase flower⁻¹, and the pollen amount · flower⁻¹ were used. The caloric value of nectar was calculated by multiplying the sugar yield · m⁻² of patch area and energetic value of 1 mg sugar. The between-year variation in the sugar content, nectar caloric value, and pollen yield was analyzed with the yields calculated for eleven plots each year.

Data analyses

Seasonal differences in the number of flowers · shoot⁻¹, number of shoots · m⁻², and number of flowers · m⁻² were tested with the Kolmogorov-Smirnov test. One-way ANOVA was applied to check the differences in nectar amount, nectar sugar concentration, nectar sugar amount · flower⁻¹, nectar sugar yield · m⁻², nectar caloric value · m⁻², pollen amount · flower⁻¹, and pollen yield · m⁻² between the years of the study. The percentage values of the nectar sugar concentration were transformed by arcsines. When

significant differences were found, the ANOVA was followed by the HSD Tukey test. All analyses were performed at $\alpha = .05$, using STATISTICA v.13.3 (StatSoft Poland, Cracow).

RESULTS

The data on the seasonal flowering period and abundance are shown in Tab. 1. In the climatic conditions of Lublin, *G. phaeum* began to flower in late April and lasted until the first week of June. The species bloomed over one month in both years of the study (Tab. 1). The length of blooming was affected by prevailing weather conditions during the flowering period, especially in May. In 2015, this month was warm as usual (the mean air temperature 13.3°C vs. the multiyear mean of 13°C) but was extremely wet, with precipitation twice higher than the multiyear value of 60.7 mm (Biuletyn PSHM, 2015), and the plants bloomed for up to forty-three days. In May 2016 the mean air temperature exceeded the multiyear mean value by 1.3°C and the precipitation sum accounted for only 58% of the standard rate (Biuletyn PSHM, 2016), and the warm and dry weather shortened the species flowering period by ten days, compared to 2015.

Fig. 1. Mean daily number of open flowers on *G. phaeum* plant (n=5) in 2015, Lublin, SE Poland.

Fig. 2. Insect visits expressed as the percentage of total visits to the flowers of *G. phaeum* recorded in a particular study year and groups of flower visitors in Lublin, SE Poland. Numbers in brackets show the number of censuses

The mean number of shoots $\cdot m^{-2}$ of patch and

the mean number of flowers $\cdot shoot^{-1}$ differed significantly between the growing seasons

(Kolmogorov-Smirnov test; $df=1$, $p<.01$ and $p<.001$, respectively). In 2015, the number of shoots per area unit was 1.9-fold higher than in 2016; simultaneously, the number of flowers produced by a shoot was 1.3-fold lower. Finally, in 2015, the mean number of flowers $\cdot m^{-2}$ of patch was higher than in 2016 (Tab. 1), but the difference was not significant (Kolmogorov-Smirnov test; $df=1$, $p>.01$).

The number of shoots $\cdot plant^{-1}$ ranged from five to thirty-five. A single plant bloomed four weeks, with a peak in the second and third week after first flower opening. Usually, the daily number of ♂ phase flowers exceeded that of ♀ phase flowers (Fig. 1).

The observations revealed the presence of honeybees, bumblebees, solitary bees,

Fig. 3. Effect of floral phases on nectar traits in *G. phaeum*. Mean values for 2015 season are given (n = number of samples). Vertical whiskers indicate SD and the same letters next to the mean indicate no statistically significant differences for a given trait between floral phases (HSD Tukey's test, $p < .05$).

Fig. 4. Mean nectar sugar amount, caloric value of nectar and pollen amount delivered daily by *G. phaeum* plant (n=5) in 2015, Lublin, SE Poland. Vertical whiskers show SD

and dipterans from the Syrphidae family foraging on the *G. phaeum* flowers. In total, 580 insect visits were noted over the two years of study. The main visitor activity was observed between 12.00 and 16.00. The proportion of insect groups visiting the flowers in the years of the study is shown in Fig. 2. Bees accounted for more than 94% of all visits. In both growing seasons, bumblebees were the principal flower visitors to *G. phaeum* (>50% of all visits). Solitary bees, abundant in 2015, were not observed in 2016, whereas hoverflies were present only in 2016 (Fig. 2). Bees collected both nectar and pollen from the flowers but were more interested in the nectar reward. Hoverflies ingested pollen directly from anthers.

Nectar production in the protandrous *G. phaeum* flowers depended on floral phases (Fig. 3). Despite no significant differences were found for the nectar amount and concentration ($F_{1,29} = 0.84$, $p = .40$ and $F_{1,29} = 0.87$, $p = .77$, respectively), the ♀ phase flowers produced smaller amounts of nectar with a higher concentration of nectar

sugars in comparison with the ♂ phase flowers. Therefore, the amounts of nectar sugars from the ♂ and ♀ phase flowers did not differ significantly ($F_{1, 29}=2.26$, $p=.14$). (Fig. 3). Generally, a moderate to high nectar concentration reaching up to 63.4% was recorded. In the nectar, the presence of only sucrose, fructose, and glucose was detected. The nectar was sucrose-rich in both floral phases with the r ratio =0.8-0.9. The qualitative characteristics of the nectar produced by the ♀ phase flowers in the years of the study (mean values and number of samples) are shown in Tab. 2. All the parameters of the mean nectar amount, nectar sugar concentration and nectar sugar amount · flower⁻¹ differed significantly between the growing seasons ($F_{1, 28}=10.06$, $p<.01$; $F_{1, 28}=23.21$, $p<.01$, and $F_{1, 28}=33.60$, $p<.01$, respectively) and were higher in 2016 than in 2015. In contrast to nectar, the mean pollen amount · flower⁻¹ was significantly higher in 2015 ($F_{1, 30}=21.84$, $p=.02$) (Tab. 2).

The daily distribution of the nectar sugar amount, energetic value of nectar and pollen amount available to insects throughout blooming of a single plant are presented in Fig. 4. One plant supplied floral visitors with at least 177.2 mg of sugar secreted in nectar with a caloric value of 708.8 cal and 382.1 mg of pollen in total. The richest floral rewards were noted in the second week of blooming, when the mean daily portion of nectar sugars varied from 24.2 to 34.5 mg with the energetic value accounting for 51% of its total amount and the mean daily pollen amount was up to 72.7 mg (Fig. 4).

In 2015, the estimated mean sugar nectar yield · m⁻² of patch and the mean caloric value of nectar were both 2.5-fold higher than those calculated for 2016 ($F_{1, 20}=7.22$, $p<.001$ and $F_{1, 20}=57.22$, $p<.001$, respectively). Conversely, the estimated mean pollen yield · m⁻² of patch was significantly 1.5-fold higher in 2015 ($F_{1, 20}=6.58$, $p=.02$) (Tab. 2).

DISCUSSION

In response to the growing recognition of ecosystem services by urban pollinators, the policy is aimed at the expansion of urban green

infrastructure and improvement of food pasture for pollinating entomofauna (Lepczyk et al., 2017; Fischer et al., 2018). To benefit pollinators, also in the context of urban agriculture and beekeeping activities, the planting of native plants in urban greenery is recommended (Pardee & Philipott, 2014; Fukase & Simons, 2016; Daniels et al., 2020). Native wildflower species grown in cities quickly establish themselves and tolerate urban stressors (Bretzel et al., 2016). They are also relatively easy to care for and require little maintenance (Younis et al., 2010). Supplementing floral resources with native plants facilitates the conservation of native pollinators, including wild bees (Pardee & Philipott, 2014), which often prefer these plants over alien species (Urbanowicz et al., 2020 and references herein). Indeed, a dominant and permanent presence of bumblebees on *G. phaeum* flowers observed in this study proves such preferences. Planting native plants also aids the conservation of other native species by contributing to the overall genetic diversity and maintaining gene flow between remnant populations (Whelan et al., 2006). Moreover, native plants are less likely to be invasive or become weeds in comparison to alien species (Isaacs et al., 2009).

When selected wild plants for a landscape, it is important to understand the conditions required by the plant growing in its natural habitat and thus its potential to accommodate to the urban environment. An ecologically beneficial urban landscape should be designed using plant species that are suitable for a broad spectrum of environmental conditions (Younis et al., 2010). The studied *G. phaeum*, mainly attributed to forest habitats, grows also in meadows and disturbed areas (Rutkowski, 2006), which indicates the wide ecological amplitude of this taxon. In this study, *G. phaeum* grew vigorously under trees, tolerating both light and moisture deficiency. This species can compete with the natural understorey vegetation in urban green spaces, which benefit a broad array of biodiversity, including bees (Threlfall et al., 2017).

In Lublin, *G. phaeum* is a spring flowering plant that provides nectar and pollen from late April to early June. It may be important for urban

social and solitary bees, as many of them are very active in urban habitats in spring (Hicks et al., 2016) and seek flowers to satisfy their high nutritional demands (Dicks et al., 2015; Moquet et al., 2015).

The studied species produced thousands of flowers per area unit. The blooming was continuous and lasted over one month. Abundant, continuous, and long flowering is of great value when plant attractiveness to visiting insects is considered and extends the food supply (Willmer, 2011). It also matters when not only environmental but also aesthetic factors must be addressed before planting. The blooming abundance of *G. phaeum* differed significantly in the years of the study. Seasonal differences in flowering abundance have been reported for many species grown in urban habitats; they were mainly attributed to meteorological factors (e.g. Masierowska et al., 2018, Dmitruk et al., 2021).

G. phaeum flowers provide visitors with both nectar and pollen. Visiting bees were more interested in collecting nectar, although insects gathering pollen were noted as well. This agrees with observations made by Warakomska (unpublished data) in a natural habitat of *G. phaeum*. Studies conducted on other *Geranium* species (Jabłoński & Kołtowski, 2002; Masierowska et al., 2018) also showed bees' preference to collect nectar from their flowers.

As earlier reported by Konarska & Masierowska (2020), the nectar production in *G. phaeum* is gender-biased towards the female phase. Such pattern of nectar distribution has been assumed to influence female reproduction success in a plant (Antoń et al., 2017). In this study, the daily number of open ♂ flowers on a plant exceeded that of ♀ flowers. Sometimes, ♂ and ♀ phase flowers on a plant are in particular spatial relationships, which may be related to nectar reward (Willmer, 2011) and pollinator directionality (e.g. Fisogni et al., 2011). In *G. phaeum*, a ♀ phase flower with more concentrated nectar usually occurs with a ♂ phase flower producing less concentrated nectar in the same cyme or in cymes located just below the ♂ flowers. This pattern may keep bees working on both types

of flowers and thus influence pollen transport between them. Bumblebees and honeybees, i.e. the main flower visitors in the studied species, show tendency to move upwardly from more to less rewarding flowers. If insects forage first on ♀ phase flowers and then move to ♂ phase flowers, the chance of self-pollen transfer between flowers is minimized (Fisogni et al., 2011). Thus, the gender-biased nectar production with sexual segregation in *G. phaeum* should be considered as a trait promoting out-crossing while avoiding geitonogamy.

According to the classification proposed by Baker & Baker (1983), the nectar in *G. phaeum* is sucrose-rich with the sucrose/hexose ratio above 0.8 but below 0.99. Percival (1961) found that *Geranium* species have both sucrose-dominant and hexose-dominant nectars. High-sucrose nectars are preferred by larger and long-tongued bees (Percival, 1961; Southwick et al., 1981; Baker & Baker, 1983) and, indeed, bumblebees and honeybees were the main visitors foraging on *G. phaeum*. Honeybees, bumblebees and wild bees from the Halictidae and Megachilidae families were noted as principal visitors to *G. phaeum* both in natural habitats and on cultivated plants (Knuth, 1908; Fiz et al., 2008, Zych, personal inf.). In this study, solitary bees were present only in 2015, whereas hoverflies were only observed in 2016. Dipterans foraging on *G. phaeum* flowers were previously reported by Fiz et al. (2008). Significant year-to-year differences in the composition of flower visitors assemblage to the plant have been found in many studies (Burkle & Alarcón, 2011 and references herein). The size of the insect population, which can dramatically vary between years, probably plays a large role in this phenomenon. Moreover, insects might shift their foraging when their preferred resource is rare or absent (Burkle & Alarcón, 2011). The different weather conditions in May 2015 and 2016 may have influenced both the abundance of solitary bees and hoverflies and the floral resources in the study area and thus modified the visitors' assemblage to the *G. phaeum* flowers.

Plants provide visiting insects with energy

resources, predominantly in the form of nectar. The mean nectar-sugar quantity secreted in the nectar accumulated in the ♀ phase *G. phaeum* flowers - 1.1 mg (equal to life-time production) was not very high but in the range of values obtained for *G. pratense* - 0.2-2.5 mg (Demianowicz et al., 1963) and higher than the value found for *G. sanguineum* - 0.8 mg (Masierowska et al., 2018). Both these native species are regarded as good nectariferous plants. However, the value was lower than in *G. sylvaticum*, i.e. another native forest species, whose flowers secreted 2.6-8.8 mg of total sugar in nectar (Jabłoński & Kołtowski, 2002). Similarly to other *Geranium* species, *G. phaeum* provides nectar with a moderate to high percent of sugars (Jabłoński & Kołtowski, 2002, Masierowska et al., 2018), which is very attractive for bees, as they prefer nectar with a sugar content of 30-55% (Willmer, 2011). Nectar with its carbohydrates is the main energy source for bees foraging on *G. phaeum* flowers. An adult honeybee worker requires about 4 mg of sugars per day for survival (Heinrich, 1975; Brodschneider & Crailsheim, 2010); hence, a single plant of *G. phaeum*, offering 24.2-36.5 mg of total sugars in nectar daily in peak flowering, can feed ~6-9 honeybees during a day. The relevant daily caloric value of nectar (96.8-146 cal) is equal to honeybee's energy output for a 2.5-3.7-hour flight, corresponding to energy use of $385 \text{ cal g}^{-1} \text{ h}^{-1}$, similar to that of flying bumblebees (Heinrich, 1985).

Pollen is essential in a bee's diet as the main source of proteins, lipids, fatty acids, vitamins and minerals (Brodschneider & Crailsheim, 2010). The amount of pollen · flower⁻¹ in *G. phaeum* was high and equal to that reported for the flowers of *G. platypetalum* (1.9 mg) but lower than in *G. sanguineum* (2.3 mg) (Masierowska et al., 2018). In peak flowering, a single *G. phaeum* plant provided from 39.9 to 73.7 mg of pollen daily. This is sufficient to satisfy the nutritional requirements of 10-17 honeybees, as one insect consumes on average 3.4-4.3 mg pollen per day (Brodschneider & Crailsheim, 2010). However, hymenopterans were less interested in using the *G. phaeum* pollen than dipterans. Probably,

the protein and/or starch content in the pollen influences the preference of the flower-visitors, but additional studies are necessary to prove this assumption.

The estimated sugar yield · m⁻² patch of the studied species ranged from 1.0 to 2.5 g. It is lower than in *G. sylvaticum* (3.8-11.9 g) (Jabłoński & Kołtowski, 2002) but still in the range of values reported for *G. pratense* (2.2-12.2 g) - a very good melliferous plant (Demianowicz et al., 1963). The mean estimated pollen yield · m⁻² of *G. phaeum* (3.4 g) was similar to that of *G. platypetalum* (3.3 g) and higher than that of *G. sanguineum* (2.5 g) (Masierowska et al., 2018). The mean estimated energetic value of nectar provided by 1 m² of the *G. phaeum* patch throughout the flowering period was 6.9 kcal. To produce 125 kg of honey, a honeybee colony collects nectar with the total energetic input of ~13 200 kcal (Southwick & Pimentel, 1981). Therefore, the energetic value of nectar gathered from 1 m² patch of the studied species can be recalculated to ~0.07 kg of honey. Moreover, the 3-m² *G. phaeum* patch is sufficient to establish a bumblebee colony of five workers (if bumblebees feed on this species alone), as queens require up to 50 mg of sugar and 6 g of pollen to produce such a colony (Rotheray et al., 2017).

A considerable difference in year-to-year nectar and pollen resources per area unit was recorded in this study. It was associated mainly with the differences in nectar and pollen production per flower, which can be partly attributed to the variable weather conditions. The influence of external factors on floral reward production in *Geranium* species was previously reported by Masierowska et al. (2018). Some of them secrete nectar abundantly and regularly only under high air humidity and air temperature. However, the cloudy and rainy weather in May 2015 contributed to the reduction of nectar production in the *G. phaeum* flowers to a greater extent than the dry weather in May 2016. Concurrently, the prolonged drought and extreme air temperatures may have resulted in the decreased quantity of produced pollen in 2016 (see Dmitruk et al., 2021).

In conclusion, the recent study demonstrates that the native plant *G. phaeum* introduced directly from the natural habitat can develop a vigorous population in the specific urban environment and establish beneficial relationships with urban pollinators, including wild and managed bees. This provides a step forward in understanding the role and contribution of native plants for biodiversity conservation. The studied species can be regarded as a valuable melliferous plant although, at the flower level, it is a medium nectar producer. Nevertheless, due to the abundant and long flowering, *G. phaeum* can enrich urban bee pastures and improve bee nutrition in spring. In particular, this plant can be useful for bumblebee colonies and should be planted to strengthen their populations in cities. Finally, biodiversity conservation strategies for bees in urban areas might benefit from listing rewarding native plants of different habitats among 'pollinator-friendly' species recommended in urban landscaping.

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