Characteristics of blooming, pollen production, and insect visitors of *Polemonium caeruleum* L. – a species with a potential to enrich pollinator-friendly urban habitats

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Abstract

Mosaic structure of urban green areas is regarded as favorable for pollinating insects. Ornamental plants can provide food resources to pollinators and may thus be used to create pollinator-friendly habitats. However, detailed data on forage quantity and quality is required for the selection of the most valuable plant species. In this paper, blooming biology, pollen production, and insect visitors of two forms (blue-flower and white-flower) of *Polemonium caeruleum* were studied in the period of 2012–2014 in Lublin, SE Poland. Both forms bloomed from mid-May until mid-June. The average mass of pollen produced in a single flower was 1.57 mg and 1.39 mg in blue-flower and white-flower forms, respectively. On average, the blue-flower form produced 7.74 g of pollen/m², while the white-flower form yielded 6.54 g of pollen/m². Both forms attracted mainly honey bees and solitary bees. *Polemonium caeruleum* can be considered a good source of pollen for honey bees and wild insect pollinators and should be propagated in urban pollinator-friendly arrangements.

Keywords

blooming; ornamental plants; pollen production; forage flora; insect visitors; honey bee; solitary bees

Introduction

The traits of floral rewards, i.e., nectar and pollen, are regarded as crucial factors shaping plant–insect visitor interactions [1–3]. Nectar is an aqueous solution of sugars (up to 75%) and other less abundant compounds (amino acids, inorganic ions, proteins) and is considered a main source of energy for pollinating insects [4,5]. Pollen is the main source of proteins, and it contains lipids, sterols, vitamins as well [6–8]. Pollen macro-, oligo-, and microelements are important components of stoichiometrically balanced pollinator diet [9].

Over the last decades, insect pollinator species richness and abundance have declined [10–13]. Although this phenomenon is complex, several reasons for pollinator decrease have been identified: pathogens and diseases [14,15], intensification of agricultural production and application of pesticides [16,17], habitat fragmentation [18], and the shortage of floral food resources [19–21]. One of the initiatives suggested for mitigating pollinator failure is improvement of floral food resources, both in agricultural [19,22,23] and urban areas [24–26].

Towns and cities have a mosaic structure of landscape which is regarded as beneficial for pollinating insects [27,28]. Urban recreational green areas (e.g., parks, private gardens,
green roofs) contribute to the diversity of floral food resources for pollinators [29–32]. Nectariferous and polleniferous flora also occurs in ruderal sites [33], road verges [26,34], and along railway embankments [35]. Urban greenery can be supplemented with forage flora species in order to create pollinator-friendly habitats [24,26,36,37]. In modern urban landscape design, a trade-off between aesthetic value and ecosystem services of plant species is desired. Ornamental plants can provide insect pollinators with considerable amounts of pollen and nectar sugars [29,31,38]. However, some ornamental plants are unattractive to native pollinators or they produce a very small amount of forage for the pollinators [39,40]. For the improvement of bee pastures, detailed data on blooming biology as well as on nectar and pollen quantity and quality is necessary in order to select the plant species most valuable for this purpose [29,38,41].

The aim of this study was to investigate blooming biology of Polemonium caeruleum and to evaluate the quantity of the pollen offered to insect visitors. In particular, I investigated (i) blooming time, diurnal pattern, and blooming abundance, (ii) pollen production, and (iii) the spectrum of insect visitors on P. caeruleum.

Material and methods

Study species and study area

Polemonium caeruleum L. (Polemoniaceae) is a perennial herbaceous species distributed in the temperate climate of the Northern Hemisphere. In Poland, P. caeruleum is a glacial relict and naturally occurs in damp meadows, mainly in the northeastern part of the country. The plant is listed as vulnerable in the Red list of plants and fungi in Poland [42]. Polemonium caeruleum grows up to 1.2 m tall and produces campanulate flowers with corollas ca. 3 cm in diameter, grouped in cymes [43]. It is listed as a melliferous plant [44,45]. Because of its high aesthetic value, the species is popular in garden arrangements [46].

The study was carried out in the period of 2012–2014. Two forms of P. caeruleum (one with blue flowers and one with white flowers) were grown on experimental plots in the suburban area of Lublin, SE Poland (51°16' N, 22°30' E). The plots were established in 2010 (six plants per 1 m²) on loess soil (pH 6.0–7.0) and were fully exposed to the sun.

Blooming biology and insect visitors

The onset and duration of the successive stages of blooming were recorded according to the protocol described by Denisow [47]. The phenological phases were established as follows: the beginning of blooming was determined when ca. 10% of flowers started to bloom, the full blooming phase when ca. 70% of flowers were in bloom, and the end of blooming when ca. 80% of flowers fell off. Flower life-span and the duration of pollen presentation (from the first anther dehiscence until all the anthers were empty) were observed in 20 marked flowers. Flower life-span was defined as the period of time between flower opening and wilting of the corolla. In order to assess blooming abundance, the number of flowers per inflorescence (n = 30) and the number of inflorescences per plant (n = 10) were counted. Insect activity and diurnal pattern of blooming were investigated following the method described by Czarnecka and Denisow [48]. Newly opened flowers were counted, and foraging insects were observed for 3 consecutive days at 1-hour intervals (from 6 a.m. to 8 p.m., Eastern European Time) in the areas of 1 m². During each observation (5 min), the diversity and abundance of insect visitors were recorded.

Pollen production and viability

The mass of produced pollen was estimated at the full blooming stage according to the ether/ethanol method described by Denisow [33]. Mature, unopened anthers of
20 flowers, (in five replications) were inserted into glass containers of known weight. The containers with anthers were placed into a dryer (ELCON CI 65) at 33°C for 7 days. Dried anthers were weighed, and their mass was used as the estimator of anther size [49,50]. Diethyl ether (1–3 mL) and 70% ethanol (2–8 mL, two–three times) were used to rinse pollen from the anthers. The accuracy of the process was checked with a stereoscopic microscope. The mass of the produced pollen was calculated per flower (mg), per inflorescence (mg), and per 1 m² (g). The viability of pollen grains was tested for each flower form and study season. Fresh pollen from three–four randomly chosen flowers of different individuals was collected at the full blooming stage and acetcarmine-stained slides were prepared. Pollen grains (n = 100 per flower form per year, in triplicate) were observed under a light microscope (LM Nikon Eclipse E-200). Red stained pollen grains were considered to be viable, while deformed and unstained ones were considered to be sterile [49].

Weather conditions

Meteorological data were collected from a local weather station. Mean air temperature and precipitation were compared to long-term data (1951–2010) (Tab. 1). In April 2013, a long-lasting snow layer was recorded. In May 2012 and 2013, mean air temperatures were 1.5–1.6 °C higher than the long-term norm, while in the same month in 2014 the air temperature was close to the norm. In May 2012, extremely low precipitation was recorded (ca. 50% lower than the long-term data), while in May 2013 and 2014, heavy rainfalls occurred (precipitation ca. 2 and 4 times higher than the long-term norm, respectively). Compared to the long-term norm mean, in June 2013, 1.4°C higher air temperature and 1.5 times higher precipitation were recorded.

Data analysis

Prior to the analyses, the collected data were tested for normality. For the number of flowers per inflorescence, log transformation was applied, and for pollen viability, reflected natural logarithm transformation was applied. One-way ANOVA was used to test the significance of differences between all the analyzed features. Whenever applicable, means were compared post hoc by Tukey’s HSD test at α = 0.05 [51]. STATISTICA software ver. 9.0 (StatSoft Poland) was applied to perform the analyses. Data are presented as mean ±SD (standard deviation).

Results

The blooming seasons of P. caeruleum began in the middle or late May and lasted until mid-June (Fig. 1). Generally, the time and duration of blooming was similar between study seasons and only slight differences (1–2 days) were found between the forms of P. caeruleum. Flower life-span was 3.6 ±0.5 days. The duration of pollen presentation was 1.4 ±0.4 days. No statistically significant differences were found in flower life-span or duration of pollen presentation between study seasons or flower forms. The flowers opened between 6 a.m. and 5 p.m. (GMT +2 h; Fig. 2). The most intensive flower openings were observed between 8 a.m. and 1 p.m., when ca. 75% of the daily installment of flowers were opening.

The number of flowers per inflorescence did not exhibit significant differences neither between flower forms [F(2, 177) = 0.0382, p = 0.845] nor between study seasons.
The number of inflorescences per plant was also independent of the flower form \( F(2, 57) = 0.331, p = 0.570 \) and year \( F(2, 57) = 0.225, p = 0.780 \). Consequently, the number of flowers per shoot was consistent in different flower forms and years of study.

The size of the anthers (expressed as the dry mass of anthers) did not differ significantly between flower forms \( F(2, 27) = 1.447, p = 0.239 \); Tab. 3]. However, this trait was found to be year dependent \( F(2, 27) = 123.171, p < 0.001 \), and 80–95% higher values were calculated for 2014 than for 2012 or 2013. The mass of pollen per flower was not variable between flower forms \( F(2, 27) = 0.940, p = 0.341 \), but significant year-to-year disparities were found \( F(2, 27) = 100.291, p < 0.001 \). In general, viability of pollen grains was high (>85%), and I recorded a significant year effect for this trait \( F(2, 176) = 7.7117, p = 0.001 \).

Among insect visitors, mainly honey bees and solitary bees were observed (Fig. 3). \textit{Apis mellifera} workers collected both pollen and nectar and formed bright yellow pollen loads on their legs. Honey bees predominated in both forms of flowers, making up 66–72% of the total number of recorded insects. Single visits by bumblebees were noted. Solitary bees visited flowers of \textit{P. caeruleum} most intensively from the morning till midday, while the frequency of \textit{Apis mellifera} visits peaked in the afternoon (Fig. 2).
Under the climatic conditions in Poland, *P. caeruleum* bloomed in late spring. This period is considered to be critical for the survival of honey bee colonies because in urban-adjacent agricultural areas, seasonal gaps in food resources were recorded [19,52,53]. Contrasting weather patterns occurred between the study seasons. However, only slight differences were noted for the onset (up to 6-day disparities) and duration of blooming (maximal 5-day disparity between study seasons) in *P. caeruleum*, while in other spring-blooming species, high disparities in blooming initiation and duration were observed [38,54,55]. The results of this study suggest that *P. caeruleum* provides constant food resources from mid-May to mid-June; however, long-term studies are necessary in order to confirm this assumption.

In this study, anthesis of individual flowers lasted 3.6 ±0.5 days. A much longer flower life-span (7.2 ±1.3 days) was observed by Zych et al. [43]. It is known that flower life-span depends on meteorological...
factors (i.e., air temperature and humidity) and on whether or not it was pollinated [47,54].

Significant differences were found in anther size and mass of pollen per flower between flowers collected in different years, with the highest values calculated for 2014 when heavy rainfalls were recorded during the blooming period of *P. caeruleum*. As demonstrated by other authors, abiotic conditions, especially precipitation, can strongly affect pollen production [54,56,57].

Flowers of *P. caeruleum* enrich pollinator food resources with pollen and nectar. A single *P. caeruleum* flower produced on average 1.48 mg of pollen and mean pollen yield was 7.14 g/m² (means across study seasons and flower forms). Similar mass of pollen per unit area was calculated for ornamental *Centaurea* spp. by Denisow [38], who considered the species as high pollen-yielding. This indicated that *P. caeruleum* can be a valuable source of pollen. Pollen viability was high regardless of the flower form or study season. Viable pollen grains were found to be preferred by some groups of pollinating insects [58–60], and the high number of pollen grains with protoplasts can be regarded as a predictor of the quality of pollen reward [38]. Although nectar production was not assessed in this study, *P. caeruleum* is considered as a valuable source of nectar [45]. As reported by Wróblewska et al. [61], pollen grains of *Polemonium* were found in multifloral honeys from northeastern Poland. According to Kołtowski [45], one flower can produce up to 1.6 mg of nectar sugars. Similar results were obtained by Chwil [44] who calculated nectar sugar concentration at 29–52% and nectar sugar mass at 1.1–1.8 mg/flower.

Flowers of *P. caeruleum* do not seem to exhibit any morphological adaptations towards being pollinated by particular species/guild of insects. Pollen is easily available, and nectar can be collected by both short- and long-tongued insect visitors [43,44]. However, in this study, mainly honey bees and solitary bees were observed foraging on the flowers of *P. caeruleum*. According to the nomenclature suggested by Ollerton [62], flowers of *P. caeruleum* can be regarded as phenotypical generalists but given that one guild of insect visitors greatly predominated in this study, the species might be considered as a functional specialist. On the contrary, Zych et al. [43] recorded that 39 insect species (including members of Hymenoptera, Diptera, Coleoptera, Lepidoptera, and Heteroptera) visited the flowers of *P. caeruleum*. Nonetheless, bumblebees predominated, making up ca. 50% of all insect visitors. Results obtained by Ostrowiecka et al. [63] confirmed that insect visitor assemblages may vary greatly between the populations of *P. caeruleum* (honey bees or sawflies predominated, depending on the study population). Moreover, insect behavior (frequency and duration of visits, number of visited flowers) is also population-dependent. Given that the spectrum of insect visitors is highly dependent on geographical context, it can be concluded that *P. caeruleum* is more functionally generalized at the species level than at the population level [62].

In conclusion, *P. caeruleum* can be considered as a good source of pollen. The results obtained in this study can contribute to the list of plant species suitable for urban bee-friendly arrangements. Moreover, because of its attractiveness for honey bee and wild pollinators, *P. caeruleum* should be recommended when planning insect-friendly urban arrangements.

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Kwitnienie, wydajność pyłkowa i oblot kwiatów *Polemonium caeruleum* przez owady zapylające

**Streszczenie**

W latach 2012–2014 na terenie Lublina badano biologię kwitnienia, produkcję pyłku i oblot przez owady zapylające kwiaty wielosiłu błękitnego (*Polemonium caeruleum*) ze zróżnicowaniem na okazy o kwiatach niebieskich i białych. Kwiaty obu form kwitły od połowy maja do połowy czerwca. Średnia masa pyłku produkowanego w kwiecie wynosiła 1,57 mg i 1,39 mg, a masa pyłku w przeliczeniu na 1 m² 7,74 mg i 6,54 mg odpowiednio dla formy niebieskiej i białej. Obie formy były odwiedzane głównie przez pszczołę miodną i pszczoły samotnice. Wielosił błękitny jest dobrym źródłem pożytku pyłkowego dla pszczoły miodnej i dzikich zapylaczy. Z tego względu powinien być propagowany w miejskich nasadzeniach.