Acta Agrobotanica

DOI: 10.5586/aa.1795

Publication history
Received: 2019-09-12
Accepted: 2019-11-08
Published: 2019-12-31

Handling editor
Marcin Zych, Faculty of Biology, University of Warsaw, Poland

Funding
This work was financially supported by the Ministry of Science and Higher Education of Poland as part of the statutory activities of the Department of Botany and Plant Physiology, University of Life Sciences in Lublin, Poland.

Competing interests
No competing interests have been declared.

Citation
Bożek M. Characteristics of blooming, pollen production, and insect visitors of *Polemonium caeruleum* L. – a species with a potential to enrich pollinator-friendly urban habitats. Acta Agrobot. 2019;72(4):1795. https://doi.org/10.5586/aa.1795

ORIGINAL RESEARCH PAPER

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

Małgorzata Bożek*

Department of Botany and Plant Physiology, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland

* Email: malgorzata.bozek@up.lublin.pl

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/m^2, while the white-flower form yielded 6.54 g of pollen/m^2. 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 m^2) 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 m^2. 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 CL 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 m^2 (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 acetocarmine-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].

Tab. 1 Mean monthly air temperature and precipitation before and during the blooming of *Polemonium caeruleum* in the period of 2012–2014 compared to the long-term data for Lublin, SE Poland.

Month	Year 2012	2013	2014	1951–2010
Temperature in °C				
March	4.1	−2.5	6.0	1.4
April	9.2	7.9	9.7	7.8
May	14.7	14.8	13.4	13.2
June	16.8	17.8	15.6	16.4
Precipitation in mm				
March	27.4	54.7	42.9	32.9
April	31.3	46.4	53.7	41.5
May	34.0	105.6	239.9	60.3
June	68.1	113.1	76.8	69.6

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 $\alpha = 0.05$ [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

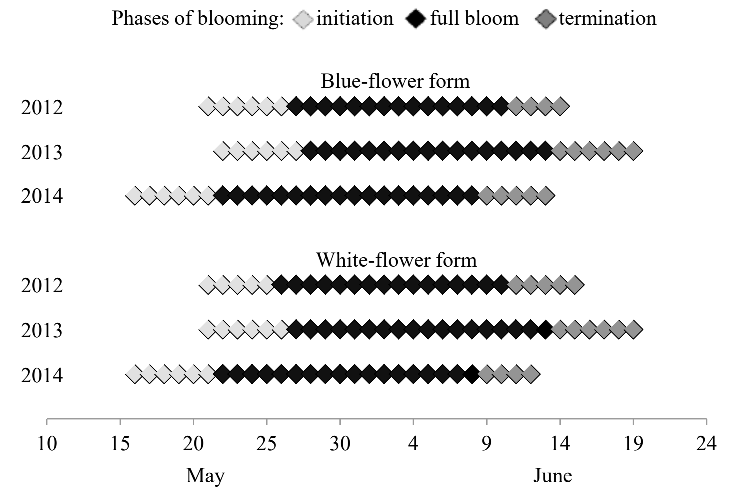

Fig. 1 Blooming phenology of *Polemonium caeruleum* in the period of 2012–2014, Lublin, SE Poland.

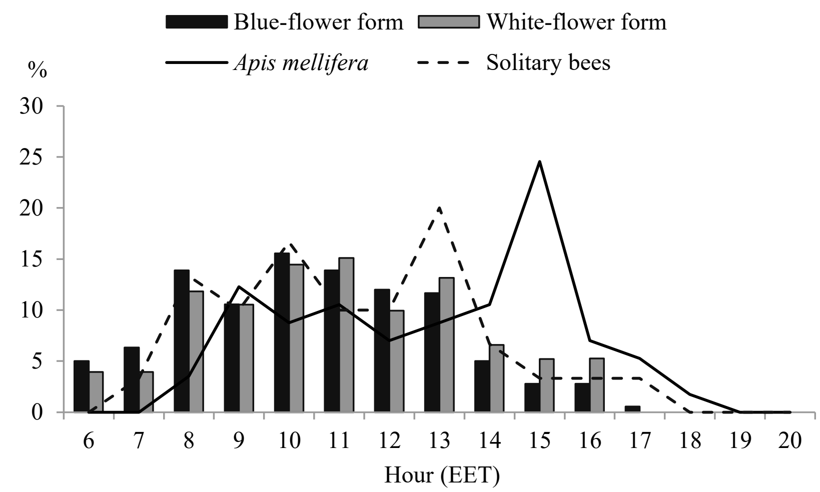

Fig. 2 Diurnal pattern of blooming in two forms of *Polemonium caeruleum* expressed as the number of flowers opened at 1-h intervals in relation to the total number of flowers opened during the day and the diurnal activity of insect visitors observed in Lublin, SE Poland. Data represent means calculated from 2012–2014; EET – Eastern European Time.

[$F(2, 177) = 2.1465$, $p = 0.119$; Tab. 2]. 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). *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 *P. caeruleum* most intensively from the morning till midday, while the frequency of *Apis mellifera* visits peaked in the afternoon (Fig. 2).

Tab. 2 Blooming abundance in two forms of *Polemonium caeruleum* in the period of 2012–2014, Lublin, SE Poland.

Form	Year	Number of flowers per inflorescence		Number of inflorescences per plant		Number of flowers per plant	
		Mean	±*SD*	Mean	±*SD*	Mean	±*SD*
Blue-flower	2012	94.1 [a]	55.1	8.0 [a]	1.7	753.1 [a]	440.8
	2013	87.5 [a]	37.9	8.8 [a]	2.3	770.0 [a]	333.3
	2014	102.3 [a]	58.0	8.6 [a]	1.4	880.1 [a]	499.0
	Mean	94.7 [A]		8.5 [A]		801.0 [A]	
White-flower	2012	100.4 [a]	72.2	8.0 [a]	1.4	803.0 [a]	577.2
	2013	81.2 [a]	42.1	8.3 [a]	1.9	682.1 [a]	353.2
	2014	107.4 [a]	53.9	7.8 [a]	1.3	837.5 [a]	53.9
	Mean	96.3 [A]		8.1 [A]		773.9 [A]	

ANOVA procedures were performed separately for each analyzed feature. Means with the same lowercase letter do not differ significantly between years of study, while means followed by the same uppercase letter do not differ significantly between flower forms at α = 0.05 based on Tukey's HSD test. Untransformed data are presented in the table. *SD* – standard deviation.

Tab. 3 Mass of dry anthers, mass of pollen, and pollen viability in two forms of *Polemonium caeruleum* in the period of 2012–2014.

Form	Year	Dry mass of anthers per flower (mg)		Mass of pollen per flower (mg)		Pollen viability (%)		Mass of pollen per 1 m² (g)
		Mean	±*SD*	Mean	±*SD*	Mean	±*SD*	
Blue-flower	2012	2.03 [a]	0.03	1.15 [a]	0.08	95.9 [b]	1.4	5.20
	2013	1.97 [a]	0.05	1.18 [a]	0.04	94.8 [b]	2.1	5.45
	2014	3.84 [b]	0.22	2.38 [b]	0.18	89.6 [a]	4.8	12.57
	Mean	2.61 [A]		1.57 [A]		93.4 [A]		7.74
White-flower	2012	1.89 [a]	0.06	1.02 [a]	0.06	85.4 [a]	4.6	4.91
	2013	1.81 [a]	0.06	1.26 [a]	0.06	95.8 [b]	3.1	5.16
	2014	3.11 [b]	0.06	1.90 [b]	0.04	88.1 [a]	6.6	9.55
	Mean	2.27 [A]		1.39 [A]		89.8 [A]		6.54

ANOVA procedures were performed separately for each analyzed feature. Means with the same lowercase letter do not differ significantly between years of study, while means followed by the same uppercase letter do not differ significantly between flower forms at α = 0.05 based on Tukey's HSD test. Untransformed data are presented in the table. *SD* – standard deviation.

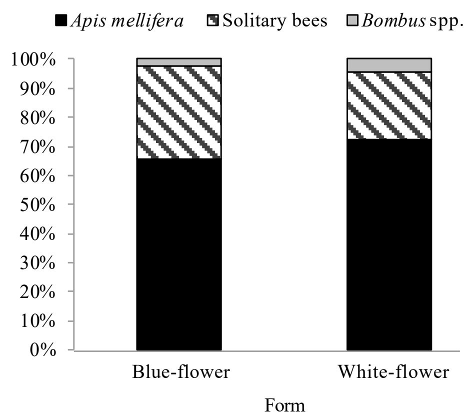

Fig. 3 Percentages of insect taxa visiting two forms of *Polemonium caeruleum* investigated in Lublin, SE Poland. Data from the period of 2012–2014 are shown.

Discussion

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/m^2 (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.

References

1. Somme L, Vanderplanck M, Michez D, Lombaerde I, Moerman R, Wathelet B, et al. Pollen and nectar quality drive the major and minor floral choices of bumble bees. Apidologie. 2015;46(1):92–106. https://doi.org/10.1007/s13592-014-0307-0

2. Gardener MC, Gillman MP. The taste of nectar – a neglected area of pollination ecology. Oikos. 2002;98(3):552–557. https://doi.org/10.1034/j.1600-0706.2002.980322.x

3. Kriesell L, Hilpert A, Leonhardt SD. Different but the same: bumblebee species collect pollen of different plant sources but similar amino acid profiles. Apidologie. 2017;48(1):102–116. https://doi.org/10.1007/s13592-016-0454-6

4. Nicolson SW, Thornburg RW. Nectar chemistry. In: Nicolson SW, Nepi M,

Pacini E, editors. Nectaries and nectar. Dordrecht: Springer; 2007. p. 215–264. https://doi.org/10.1007/978-1-4020-5937-7_5

5. Antoń S, Komoń-Janczara E, Denisow B. Floral nectary, nectar production dynamics and chemical composition in five nocturnal *Oenothera* species (Onagraceae) in relation to floral visitors. Planta. 2017;246(6):1051–1067. https://doi.org/10.1007/s00425-017-2748-y
6. Nicolson SW. Bee food: the chemistry and nutritional value of nectar, pollen and mixtures of the two. African Zoology. 2011;46(2):197–204. https://doi.org/10.1080/15627020.2011.11407495
7. Weiner CN, Hilpert A, Werner M, Linsenmair KE, Blüthgen N. Pollen amino acids and flower specialisation in solitary bees. Apidologie. 2010;41(4):476–487. https://doi.org/10.1051/apido/2009083
8. Ischebeck T. Lipids in pollen – they are different. Biochim Biophys Acta Mol Cell Biol Lipids. 2016;1861(9):1315–1328. https://doi.org/10.1016/j.bbalip.2016.03.023
9. Filipiak M, Kuszewska K, Asselman M, Denisow B, Stawiarz E, Woyciechowski M, et al. Ecological stoichiometry of the honeybee: pollen diversity and adequate species composition are needed to mitigate limitations imposed on the growth and development of bees by pollen quality. PLoS One. 2017;12(8):e0183236. https://doi.org/10.1371/journal.pone.0183236
10. Rhodes CJ. Pollinator decline – an ecological calamity in the making? Sci Prog. 2018;101(2):121–160. https://doi.org/10.3184/003685018X15202512854527
11. Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF, et al. Patterns of widespread decline in North American bumble bees. Proc Natl Acad Sci USA. 2011;108(2):662–667. https://doi.org/10.1073/pnas.1014743108
12. Aizen MA, Garibaldi LA, Cunningham SA, Klein AM. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Ann Bot. 2009;103(9):1579–1588. https://doi.org/10.1093/aob/mcp076
13. Kevan PG, Phillips TP. The economic impacts of pollinator declines: an approach to assessing the consequences. Ecol Soc. 2001;5(1):8. https://doi.org/10.5751/ES-00272-050108
14. Fürst MA, McMahon DP, Osborne JL, Paxton RJ, Brown MJF. Disease associations between honeybees and bumblebees as a threat to wild pollinators. Nature. 2014;506(7488):364. https://doi.org/10.1038/nature12977
15. Cavigli I, Daughenbaugh KF, Martin M, Lerch M, Banner K, Garcia E, et al. Pathogen prevalence and abundance in honey bee colonies involved in almond pollination. Apidologie. 2016;47(2):251–266. https://doi.org/10.1007/s13592-015-0395-5
16. Dudley N, Attwood SJ, Goulson D, Jarvis D, Bharucha ZP, Pretty J. How should conservationists respond to pesticides as a driver of biodiversity loss in agroecosystems? Biol Conserv. 2017;209:449–453. https://doi.org/10.1016/j.biocon.2017.03.012
17. Dance C, Botías C, Goulson D. The combined effects of a monotonous diet and exposure to thiamethoxam on the performance of bumblebee micro-colonies. Ecotoxicol Environ Saf. 2017;139:194–201. https://doi.org/10.1016/j.ecoenv.2017.01.041
18. Xiao Y, Li X, Cao Y, Dong M. The diverse effects of habitat fragmentation on plant–pollinator interactions. Plant Ecol. 2016;217(7):857–868. https://doi.org/10.1007/s11258-016-0608-7
19. Jachuła J, Denisow B, Wrzesień M. Validation of floral food resources for pollinators in agricultural landscape in SE Poland. J Sci Food Agric. 2018;98(7):2672–2680. https://doi.org/10.1002/jsfa.8761
20. Ouvrard P, Jacquemart AL. Agri-environment schemes targeting farmland bird populations also provide food for pollinating insects. Agric For Entomol. 2018;20(4):558–574. https://doi.org/10.1111/afe.12289
21. Wrzesień M, Jachuła J, Denisow B. Railway embankments – refuge areas for food flora, and pollinators in agricultural landscape. J Apic Sci. 2016;60(1):97–110. https://doi.org/10.1515/JAS-2016-0004
22. Wratten SD, Gillespie M, Decourtye A, Mader E, Desneux N. Pollinator habitat enhancement: benefits to other ecosystem services. Agric Ecosyst Environ. 2012;159:112–122. https://doi.org/10.1016/j.agee.2012.06.020
23. Decourtye A, Mader E, Desneux N. Landscape enhancement of floral resources for honey bees in agro-ecosystems. Apidologie. 2010;41(3):264–277. https://doi.org/10.1051/apido/2010024

24. Davis AY, Lonsdorf EV, Shierk CR, Matteson KC, Taylor JR, Lovell ST, et al. Enhancing pollination supply in an urban ecosystem through landscape modifications. Landsc Urban Plan. 2017;162:157–166. https://doi.org/10.1016/j.landurbplan.2017.02.011
25. Turo KJ, Gardiner MM. From potential to practical: conserving bees in urban public green spaces. Front Ecol Environ. 2019;17(3):167–175. https://doi.org/10.1002/fee.2015
26. O'Sullivan OS, Holt AR, Warren PH, Evans KL. Optimising UK urban road verge contributions to biodiversity and ecosystem services with cost-effective management. J Environ Manage. 2017;191:162–171. https://doi.org/10.1016/j.jenvman.2016.12.062
27. Banaszak-Cibicka W, Ratyńska H, Dylewski Ł. Features of urban green space favourable for large and diverse bee populations (Hymenoptera: Apoidea: Apiformes). Urban For Urban Green. 2016;20:448–452. https://doi.org/10.1016/j.ufug.2016.10.015
28. Michołap P, Sikora A, Kelm M, Sikora M. Variability of bumblebee communities (Apidae, Bombini) in urban green areas. Urban Ecosyst. 2017;20(6):1339–1345. https://doi.org/10.1007/s11252-017-0686-x
29. Wróblewska A, Stawiarz E, Masierowska M. Evaluation of selected ornamental Asteraceae as a pollen source for urban bees. J Apic Sci. 2016;60(2):179–191. https://doi.org/10.1515/JAS-2016-0031
30. Jachuła J, Denisow B, Strzałkowska-Abramek M. Floral reward and insect visitors in six ornamental *Lonicera* species-plants suitable for urban bee-friendly gardens. Urban For Urban Green. 2019;44:126390. https://doi.org/10.1016/j.ufug.2019.126390
31. Masierowska M, Stawiarz E, Rozwałka R. Perennial ground cover plants as floral resources for urban pollinators: a case of *Geranium* species. Urban For Urban Green. 2018;32:185–194. https://doi.org/10.1016/j.ufug.2018.03.018
32. van Mechelen C, van Meerbeek K, Dutoit T, Hermy M. Functional diversity as a framework for novel ecosystem design: the example of extensive green roofs. Landsc Urban Plan. 2015;136:165–173. https://doi.org/10.1016/j.landurbplan.2014.11.022
33. Denisow B. Pollen production of selected ruderal plant species in the Lublin area. Lublin: University of Life Sciences Press; 2011.
34. Somme L, Moquet L, Quinet M, Vanderplanck M, Michez D, Lognay G, et al. Food in a row: urban trees offer valuable floral resources to pollinating insects. Urban Ecosyst. 2016;19(3):1149–1161. https://doi.org/10.1007/s11252-016-0555-z
35. Wrzesień M, Denisow B, Mamchur Z, Chuba M, Resler I. Composition and structure of the flora in intra-urban railway areas. Acta Agrobot. 2016;69(3):1666. https://doi.org/10.5586/aa.1666
36. Shwartz A, Turbé A, Simon L, Julliard R. Enhancing urban biodiversity and its influence on city-dwellers: an experiment. Biol Conserv. 2014;171:82–90. https://doi.org/10.1016/j.biocon.2014.01.009
37. Salisbury A, Armitage J, Bostock H, Perry J, Tatchell M, Thompson K. Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? J Appl Ecol. 2015;52(5):1156–1164. https://doi.org/10.1111/1365-2664.12499
38. Denisow B, Strzałkowska-Abramek M, Bożek M, Jeżak A. Ornamental representatives of the genus *Centaurea* L. as a pollen source for bee friendly gardens. J Apic Sci. 2014;58(2):49–58. https://doi.org/10.2478/jas-2014-0016
39. Denisow B, Strzałkowska-Abramek M. Characteristics of blooming and pollen in flowers of two *Syringa* species (f. Oleaceae). Acta Agrobot. 2013;66(4):65–72. https://doi.org/10.5586/aa.2013.052
40. Strzałkowska-Abramek M. Nectar and pollen production in ornamental cultivars of *Prunus serrulata* (Rosaceae). Folia Hortic. 2019;31(1):205–212. https://doi.org/10.2478/fhort-2019-0015
41. Masierowska M. Floral reward and insect visitation in ornamental deutzias (*Deutzia* spp.), Saxifragaceae sensu lato. J Apic Res. 2006;45(1):13–19. https://doi.org/10.1080/00218839.2006.11101306
42. Zarzycki K, Szeląg Z. Red list of the vascular plants in Poland. In: Mirek Z, Zarzycki K, Wojewoda W, Szeląg Z, editors. Red list of plants and fungi in Poland. Cracow: W. Szafer Institute of Botany, Polish Academy of Sciences; 2006. p. 9–20.
43. Zych M, Stpiczyńska M, Roguz K. Reproductive biology of the red list species *Polemonium caeruleum* (Polemoniaceae). Bot J Linn Soc. 2013;173(1):92–107. https://doi.org/10.1111/boj.12071
44. Chwil M. The structure of some floral elements and the nectar production

rate of *Polemonium caeruleum* L. Acta Agrobot. 2010;63(2):25–32. https://doi.org/10.5586/aa.2010.029

45. Kołtowski Z. Wielki atlas roślin miododajnych [The great atlas of melliferous plants]. Warsaw: Publishing Enterprise Rzeczpospolita; 2006.
46. Borgen L, Guldahl AS. Great-granny's garden: a living archive and a sensory garden. Biodivers Conserv. 2011;20(2):441–449. https://doi.org/10.1007/s10531-010-9931-9
47. Denisow B. Pollen production, flowering and insect visits on *Euphorbia cyparissias* L. and *Euphorbia virgultosa* Klok. J Apic Res. 2009;48(1):50–59. https://doi.org/10.3896/IBRA.1.48.1.11
48. Czarnecka B, Denisow B. Floral biology of *Senecio macrophyllus* M. BIEB. (Asteraceae), a rare Central European steppe plant. Acta Soc Bot Pol. 2014;83(1):17–27. https://doi.org/10.5586/asbp.2014.002
49. Denisow B, Wrzesień M. The habitat effect on the diversity of pollen resources in several *Campanula* spp. – an implication for pollinator conservation. J Apic Res. 2015;54(1):62–71. https://doi.org/10.1080/00218839.2015.1030243
50. Denisow B, Wrzesień M, Cwener A. Pollination and floral biology of *Adonis vernalis* L. (Ranunculaceae) – a case study of threatened species. Acta Soc Bot Pol. 2014;83(1):29–37. https://doi.org/10.5586/asbp.2014.001
51. Stanisz A. Przystępny kurs statystyki w oparciu o program STATISTICA PL na przykładach z medycyny. Kraków: StatSoft Polska; 1998.
52. Ziaja M, Denisow B, Wrzesień M, Wójcik T. Availability of food resources for pollinators in three types of lowland meadows. J Apic Res. 2018;57(4):467–478. https://doi.org/10.1080/00218839.2018.1454293
53. Wrzesień M, Denisow B. The share of nectariferous and polleniferous taxons in chosen patches of thermophilous grasslands of the Lublin Upland. Acta Agrobot. 2006;59(1):213–221. https://doi.org/10.5586/aa.2006.021
54. Denisow B, Strzałkowska-Abramek M, Bożek M, Jeżak A. Early spring nectar and pollen and insect visitor behavior in two *Corydalis* species (Papaveraceae). J Apic Sci. 2014;58(1):93–102. https://doi.org/10.2478/jas-2014-0009
55. Denisow B, Antoń S, Wrzesień M. Morphology of *Anemone sylvestris* L. flower (Ranunculaceae). Acta Bot Croat. 2016;75(1):74–80. https://doi.org/10.1515/botcro-2016-0009
56. Strzałkowska-Abramek M, Tymoszuk K, Jachuła J, Bożek M. Nectar and pollen production in *Arabis procurrens* Waldst. & Kit. and *Iberis sempervirens* L. (Brassicaceae). Acta Agrobot. 2016;69(1):1656. https://doi.org/10.5586/aa.1656
57. Denisow B, Wrzesień M. The study of blooming and pollen efficiency of *Adonis vernalis* L. in xerothermic plant communities. J Apic Sci. 2006;50(1):25–32.
58. Roulston TH, Cane JH, Buchmann SL. What governs protein content of pollen: pollinator preferences, pollen–pistil interactions, or phylogeny? Ecol Monogr. 2000;70(4):617–643. https://doi.org/10.1890/0012-9615(2000)070[0617:WGPCOP]2.0.CO;2
59. Rader R, Edwards W, Westcott DA, Cunningham SA, Howlett BG. Pollen transport differs among bees and flies in a human-modified landscape. Divers Distrib. 2011;17(3):519–529. https://doi.org/10.1111/j.1472-4642.2011.00757.x
60. Robertson AW, Mountjoy C, Faulkner BE, Roberts MV, Macnair MR. Bumble bee selection of *Mimulus guttatus* flowers: the effects of pollen quality and reward depletion. Ecology. 1999;80(8):2594–2606. https://doi.org/10.1890/0012-9658(1999)080[2594:BBSOMG]2.0.CO;2
61. Wróblewska A, Warakomska Z, Koter M. Pollen analysis of bee products from the north-eastern Poland. J Api Sci. 2006;50(1):71–83.
62. Ollerton J, Killick A, Lamborn E, Watts S, Whiston M. Multiple meanings and modes: on the many ways to be a generalist flower. Taxon. 2007;56(3):717–728. https://doi.org/10.2307/25065856
63. Ostrowiecka B, Brzosko E, Jermakowicz E, Wróblewska A, Mirski P, Roguz K, et al. Breeding system variability, pollination biology, and reproductive success of rare *Polemonium caeruleum* L. in NE Poland. Acta Agrobot. 2017;70(1):1709. https://doi.org/10.5586/aa.1709

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 m^2 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.