Original Article

EVALUATION OF SELECTED ORNAMENTAL ASTERACEAE AS A POLLEN SOURCE FOR URBAN BEES

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Abstract

Offering more floral resources for urban bees can be achieved by growing ornamental bee plants. The aim of the present study was to evaluate selected Asteraceae (*Calendula officinalis* 'Persimmon Beauty' and 'Santana', *Centaurea macrocephala*, *Cosmos sulphureus*, *Dahlia pinnata*, *Tagetes patula*, *Tithonia rotundifolia*, and *Zinnia elegans*) as pollen sources for pollinators. Under urban conditions in Lublin, SE Poland, the investigated plants flowered from late June to the end of October. The mass of pollen produced in florets and capitula was found to be species-related. The highest pollen amounts per 10 florets (10.1 mg) as well as per capitulum (249.7 mg) were found for *C. macrocephala*. The mass of pollen yielded by a single plant depended on both the pollen mass delivered per disk florets and the proportion of disk florets in capitulum, and the flowering abundance of the plants. A single plant of *D. pinnata* and a single plant of *T. rotundifolia* each produced the largest pollen mass. Mean pollen yield per 1m^2 of a plot ranged from 6.2 g (*Z. elegans*) to 60.7 g (*D. pinnata*). Pollen grains are tricolporate, with echinate exine, medium or small in size. They can be categorised as oblatespherical, spherical, and prolatespherical. The principal visitors to *C. macrocephala*, *C. sulphureus*, and *C. officinalis* were honey bees, whereas bumble bees dominated on *T. rotundifolia* and *D. pinnata*. A magnet plant for butterflies was *Z. elegans*. Among the investigated species, *D. pinnata*, *C. macrocephala*, and *T. rotundifolia* were found to be the most valuable sources of pollen flow for managed and wild bees.

Keywords: Asteraceae, bee pasture, pollen production, urban bees

INTRODUCTION

Pollinators provide vital ecosystem services both to crops and wild plant communities (Aguilar et al., 2006; Klein et al., 2007). The primary pollinators of most plants are mainly bees. There is a clear evidence of recent decline in global biodiversity and pollinating insects are no exception (Potts et al., 2010). Land-use change with the loss of floral and nesting resources is generally thought to be the most important contributor to various disturbances in wild bee abundances and species richness (Winfree et al., 2009). However, current studies have shown that cities could be pollinator reservoirs with a higher biodiversity of pollinating insects within them, as compared to the countryside (Goulson et al., 2010; Banaszak-Cibicka & Żmihorski, 2012; Jędrzejewska-Szmek & Zych, 2013). High plant species diversity is characteristic of several urban areas. Plant species richness often increases in cities compared to more natural areas (Grimm et al., 2008). Therefore, urban areas are supportive to wild pollinators. The increase in plant richness in cities happens by using both native and alien ornamental plant species in landscaping and gardening (Acar et al., 2007; McKinney, 2008). But replacement with exotic or alien plants may also be the cause of the changes in insect populations (Stelzer et al., 2010). The usefulness of ornamental species and cultivars requires detailed investigations concerning their flowering biology and availability of floral rewards.

One of the best-represented plant families in urban ecosystems is Asteraceae. Many

Asteraceae have mass flowering, showy inflorescences - capitulum type and floral resources that attract different and abundant pollinators (Käpylä & Niemelä, 1979; Suryanarayana et al., 1992; Bodnarčuk et al., 1993; Wróblewska, 1995, 1997; Wróblewska & Stawiarz 2012 a, b; Denisow et al., 2014). Due to these characteristics, Asteracean species are frequently used to compose flowerbeds in avenues, gardens, squares, and parks. Ornamental Asteraceae are considered particularly important plants for insect visitors (Strzałkowska, 2006; Wróblewska & Stawiarz, 2012 a). Numerous representatives of the Asteraceae family are described as good melliferous plants, providing both nectar and pollen food for insects from early spring to late autumn (Rudnianskaja 1981; Jabłoński, 2000; Ricciardelli d'Albore & Intoppa, 2000; Kołtowski, 2006; Lipiński, 2010).

The aim of the present study was to evaluate eight ornamental Asteraceae species and cultivars as a source of pollen food for pollinating insects under urban conditions. In particular, we investigated (a) flowering phenology and abundance of plants, (b) temporal distribution of the floral resources produced by them, and we estimated (c) the pollen flow. In addition, the spectrum of insect flower-visitors (d) was monitored, and (e) the morphological features of pollen grains from these ornamentals were determined, which may be useful during pollen identification in palynological studies of bee products.

MATERIAL AND METHODS

Study area and species

The investigation was carried out on the experimental plots of the Department of Botany, University of Life Sciences in Lublin, Poland (51°14'N, 22°34'E). The following annuals (A) and perennials (P) were included: *Calendula officinalis* L. 'Persimmon Beauty' (A), *C. officinalis* L. 'Santana' (A), *Centaurea macrocephala* Puschk. ex Willd. (P), *Cosmos sulphureus* Cav. (A), *Dahlia pinnata* Cav. (P/A – a perennial grown as an annual), *Tagetes patula* L. (A), *Tithonia rotundifolia* Mill. S.F. Blake (A) and *Zinnia elegans* Jacq. (A). Most of the studied taxa are native to the New World. Only *Calendula officinalis* is probably of European origin. *Centaurea macrocephala* appears to be native to the Caucasus region and the nearby Anatolia region in Turkey (Wagenitz, 1975). The selected species are easy to grow and highly ornamental and have an extended flowering period.

The study was conducted from 1999 to 2013 but investigations of each taxon were carried out for 3 growing seasons (Fig. 1).

Experimental plots (each of them 2.5m^2) were established on a loess soil with pH 6 - 7 and were fully exposed to the sun. All plants were sown directly into plots. After germination, the seedlings were thinned to obtain the recommended spacing. For each species, plant density (no. plants per 1 m^2) was correlated with plant size: *T. rotundifolia* (2), *C. sulphureus* (6), *D. pinnata* and *C. macrocephala* (7), *Z. elegans* (10), *C. officials* (11), and *T. patula* (20). Fertilisation and plant protection followed the commercial recommendations. Investigations on *Centaurea macrocephala* started the second year after sowing, when fully developed specimens were obtained.

Flowering phenology and abundance

The observations on phenology of flowering were carried out on the species/cultivar level (Dafni, 1992). The flowering onset and flowering termination were recorded to determine the timing and duration of flowering. The florets number per capitulum and the number of the successive order capitula per plant were counted to assess flowering abundance. Then, the total number of inflorescences per plant was determined. In *Dahlia pinnata*, all capitula were counted once, at the end of flowering, as it was impossible to separate the successive order inflorescences without damaging the plants. During vegetation season, counts were made on 6 to 10 plants of each taxon.

Assessment of pollen production and morphology of pollen grains

Total pollen mass available to insects was determined by the modified ether method (Warakomska, 1972). In consecutive years of the study, for each taxon, six samples of 150 mature

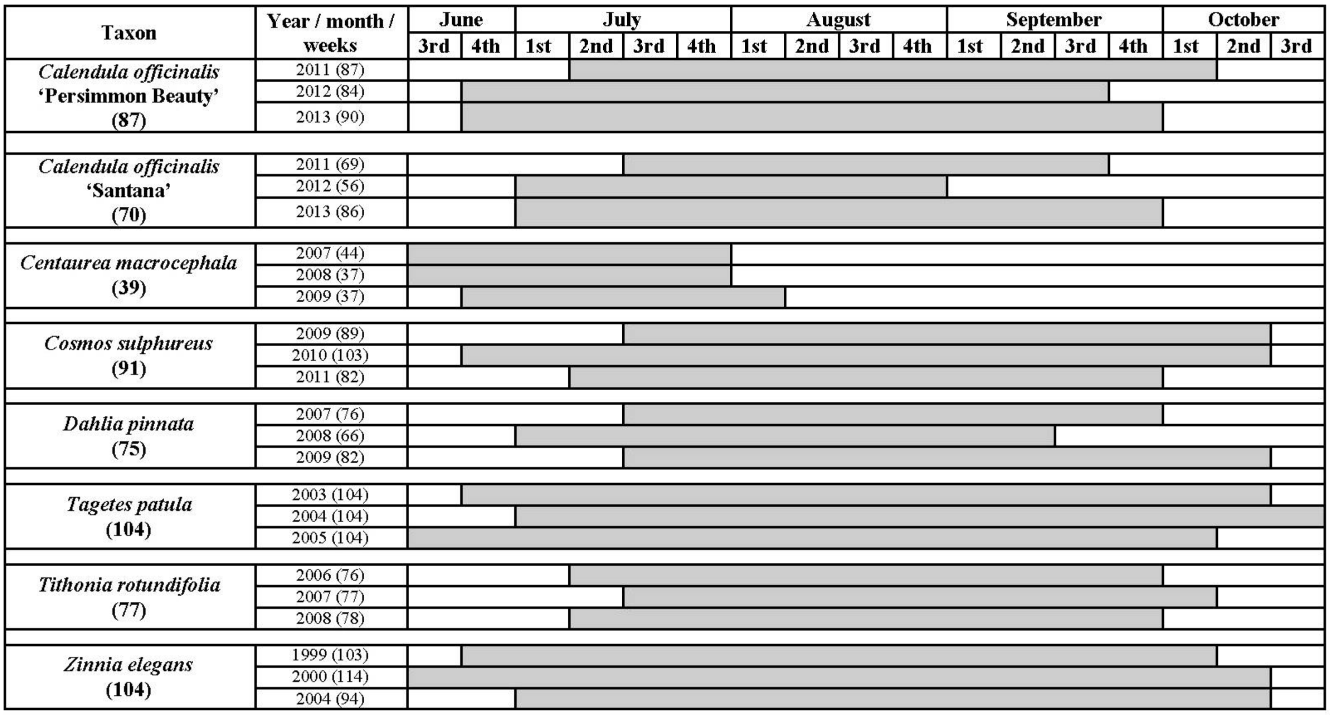

Fig. 1. Flowering period of the studied ornamental Asteraceae. The values in brackets mean the length of blooming in days.

stamen heads from the capitula of successive orders were collected separately. The anthers were removed from randomly chosen flower buds and placed on previously-tarred watch glasses. Samples were then moved in an air dryer (SUP-65G Wamed, Poland) at 30°C to dehisce. Then the pollen grains were first washed from anthers with 70% ethanol, and subsequently - several times with pure ether. The accuracy of the procedure was checked using a binocular microscope. The empty anthers were removed from the watch glasses. Next, the pollen samples were dried and weighted on a balance (WA 34 PRL T A14 MERA-KFM, Poland), allowing a calculation to be made of the mass of air-dried pollen. The results were expressed per 10 florets and then recalculated per capitulum and plant. Moreover, the pollen mass from $1m^2$ of the plot area available to insects was estimated. For this purpose, plant density per $1m^2$ of a plot and the data regarding the average number of capitula on a plant already formed during a given growing season were used.

The dimension of pollen grains (n = 200 per taxon) was determined based on the glycerol-gelatine slides, and using a Nikon Eclipse E600 light microscope at a magnification of 40x15. The length of polar (P) and equatorial (E) axis was measured (Andrejev, 1926) and the shape as the P/E ratio was classified according to Erdtman's recommendations (1954).

Insect visitation

Observations were carried out during one vegetation season for the species studied, with the exception of *T. patula*. Throughout peak blooming, insect foraging activity was monitored. The number of working insects per $1m^2$ of a plot was counted for 5 minutes, six times every 2 hours, from 8:00 to 18:00 (GMT+2 h). Counts were made on 3 days when there was favourable weather. Through observations we noted 5 insect categories: honey bees (*Apis mellifera* L.), bumble bees (*Bombus* spp.), other bees (non-*Apis* and non-*Bombus*), butterflies (Lepidoptera), and all other insects. For each plant species, the relative abundance of these categories was determined. The results were presented as centrograms showing the percentage of individual insects groups working on flowers.

Statystical analysis

Descriptive data are presented as means. Differences between species and cultivars in the number of disk and ray florets per capitulum as well as in the total number of florets per capitulum were tested by means of the Kruskal-Wallis H test, as data could not be normalised with any transformation (Stanisz, 2006). Differences between taxa in the pollen mass produced by florets, capitulum, as well as by one plant, were compared by separate one-way ANOVAs. When significant differences were stated, the ANOVAs were followed by the HSD Tukey test at α=0.05 (Stanisz, 2006). Data analyses were performed with STATISTICA (v.7.1) (StatSoft Poland, Krakow).

RESULTS

Floral phenology and abundance

The flowering season of the studied Asteraceae began in late June and lasted till the middle of July. The time of blooming differed among taxa as well as among the years of study (Fig.1). Plants of *C. macrocephala* were the first to bloom, whereas *D. pinnata* and *T. rotundifolia* were the last to open their inflorescences. Flowering continued for 5 to 16 weeks, depending on species/cultivar. Exceptionally long-lasting flowering was noted for *Z. elegans* and *T. patula* - 104 days, whereas the flowering period of *C. macrocephala* lasted only 39 days.

In annuals, solitary capitula are terminal on the main and side branches of a successive order. Plants of *C. officinalis* (both cultivars) and *Z. elegans* develop inflorescences of the 1st, 2nd and 3rd order. In plants of *C. sulphureus, T. patula* and *T. rotundifolia,* capitula of the 4th order are common. Capitula of the 5th order occur in *T. rotundifolia*. Plants of *C. macrocephala* develop several flowering shoots with a single inflorescence (1st order) at the apex. Remarkably, side branches with capitula of the 2nd order were present. The total number of capitula developed on a plant depended on the plant's growth habitat and on the degree of

Table 1

Flowering abundance of the investigated Asteraceae (for each taxon, the means ± SD from a three-year period are given)

Taxon	Number of:			
	disk florets per capitulum	ray florets per capitulum	all florets per capitulum	capitula per plant
Calendula officinalis 'Persimmon Beauty'	170.9 ± 61.87a (n=54)	155.9 ± 77.7ab (n=54)	326.8 ± 121.91a (n=54)	30.4 ± 11.33 (n=18)
Calendula officinalis 'Santana'	185.9 ± 71.73a (n=54)	199.3 ± 97.05a (n=54)	394.4 ± 142.70a (n=54)	23.3 ± 10.11 (n=18)
Centaurea macrocephala	240.2 ± 64.52a (n=36)	0.00f (n=36)	240.2 ± 64.52a (n=36)	20.1 ± 10.60 (n=30)
Cosmos sulphureus	34.9 ± 6.34c (n=120)	14.6 ± 3.21d (n=120)	49.5 ± 8.55c (n=120)	186.3 ± 103.89 (n=30)
Dahlia pinnata	103.4 ± 26.22b (n=90)	12.5 ± 6.80e (n=90)	115.9 ± 29.66b (n=90)	124.5 ± 58.05 (n=21)
Tagetes patula	37.2 ± 11.97c (n=72)	28.6 ± 11.19c (n=72)	63.1 ± 23.15c (n=72)	64.7 ± 12.97 (n=18)
Tithonia rotundifolia	104.4 ± 14.15b (n=115)	12.0 ± 1.21e (n=115)	115.7 ± 14.98b (n=115)	287.9 ± 117.07 (n=19)
Zinnia elegans	196.7 ± 64.03a (n=90)	67.5 ± 41.39b (n=90)	264.2 ± 96.20a (n=90)	15.3 ± 3.07 (n=21)

The means within columns followed by the same letter are not significantly different at α = 0.05; the Kruskal-Wallis H test was used.

stem branching (Tab. 1). Furthermore, the total number of capitula formed on a plant showed a significant species effect ($H_{7,\ 175}$ = 148.75, P = 0.000). With exception of *C. macrocephala*, the main portion of capitula (and subsequently flowers) was produced by side branches of the 2nd and 3rd order. Lasting of a single inflorescence ranged from 2.1 days (*T. rotundifolia*) to 20 days (*T. patula*).

In a majority of taxa investigated, the capitula consist of peripheral, brightly coloured ray florets and bisexual disk florets. Pollen is yielded only by the disk florets. In the capitula of *C. macrocephala*, there are only disk florets. The number of disk florets per capitulum is species/cultivar-related ($H_{7,\ 631}$ = 516.43, P = 0.000; Tab. 2) and was the highest for *C. macrocephala* (the mean = 240.2). Also, numerous disk florets were produced by *Z. elegans* and both cultivars of *C. officinalis*. The lowest mean values were found for *C. sulphureus* and *T. patula*. The number of ray florets per capitulum as well as the total number of flowers per capitulum also differed significantly among taxa ($H_{7,631}$ = 511.42, P = 0.000 and $H_{7,\ 631}$ = 554.52, P = 0.000, respectively). The proportion of particular types of florets in capitula depended on the taxon. Capitula of *C. macrocephala* consist exclusively of disk florets as it was mentioned above. Disk florets predominated by far, with their percentage standing at 90.2, 89.2, 75.5 and 70.5%, respectively, in *D. pinnata, T. rotundifolia, Z. elegans* and *C. sulphureus*. In the remainder of the taxa studied, the proportion of disk and ray florets were similar to each other.

The blooming and pollen release in flowers proceeds from the periphery towards the central part of the capitulum. The disk florets are protandrous. Anther dehiscence starts at the loose bud stage.

In the studied Asteraceae, pollen forage is provided exclusively by disk florets whose

Table 2

Pollen productivity of the investigated Asteraceae (for each taxon, the means ± SD from a three-year period are given)

Taxon	Mass of pollen per:			
	10 disk florets (mg)	**1 capitulum (mg)**	**1 plant (g)**	**1 m² (g)**
Calendula officinalis 'Persimmon Beauty'	1.72 ± 0.21f (n=54)	29.59 ± 11.52c (n=54)	0.90 ± 0.37c (n=18)	10.32 ± 4.20 (n=18)
Calendula officinalis 'Santana'	1.40 ± 0.31f (n=54)	27.56 ± 10.61cd (n=54)	0.63 ± 0.24c (n=18)	7.16 ± 2.72 (n=18)
Centaurea macrocephala	10.13 ± 1.86a (n=36)	249.66 ± 111.98a (n=36)	5.02 ± 2.63b (n=30)	35.64 ± 18.71 (n=30)
Cosmos sulphureus	3.37 ± 0.58c (n=72)	11.74 ± 2.67de (n=120)	2.11 ± 1.00c (n=30)	13.07 ± 6.18 (n=30)
Dahlia pinnata	7.02 ± 1.65b (n=54)	71.41 ± 19.23b (n=90)	9.05 ± 4.68a (n=21)	60.67 ± 31.3 (n=21)
Tagetes patula	2.59 ± 0.65d (n=72)	9.65 ± 3.56e (n=72)	0.62 ± 0.17c (n=18)	12.47 ± 3.37 (n=18)
Tithonia rotundifolia	3.66 ± 1.06c (n=85)	39.08 ± 10,20c (n=115)	10.91 ± 4.19a (n=19)	22.92 ± 8.80 (n=19)
Zinnia elegans	2.11 ± 0.60d (n=54)	41.07 ± 12.68c (n=21)	0.62 ± 0.16c (n=21)	6.23 ± 1.62 (n=21)

The means within columns followed by the same letter are not significantly different at α = 0.05; the HSD Tukey test was used

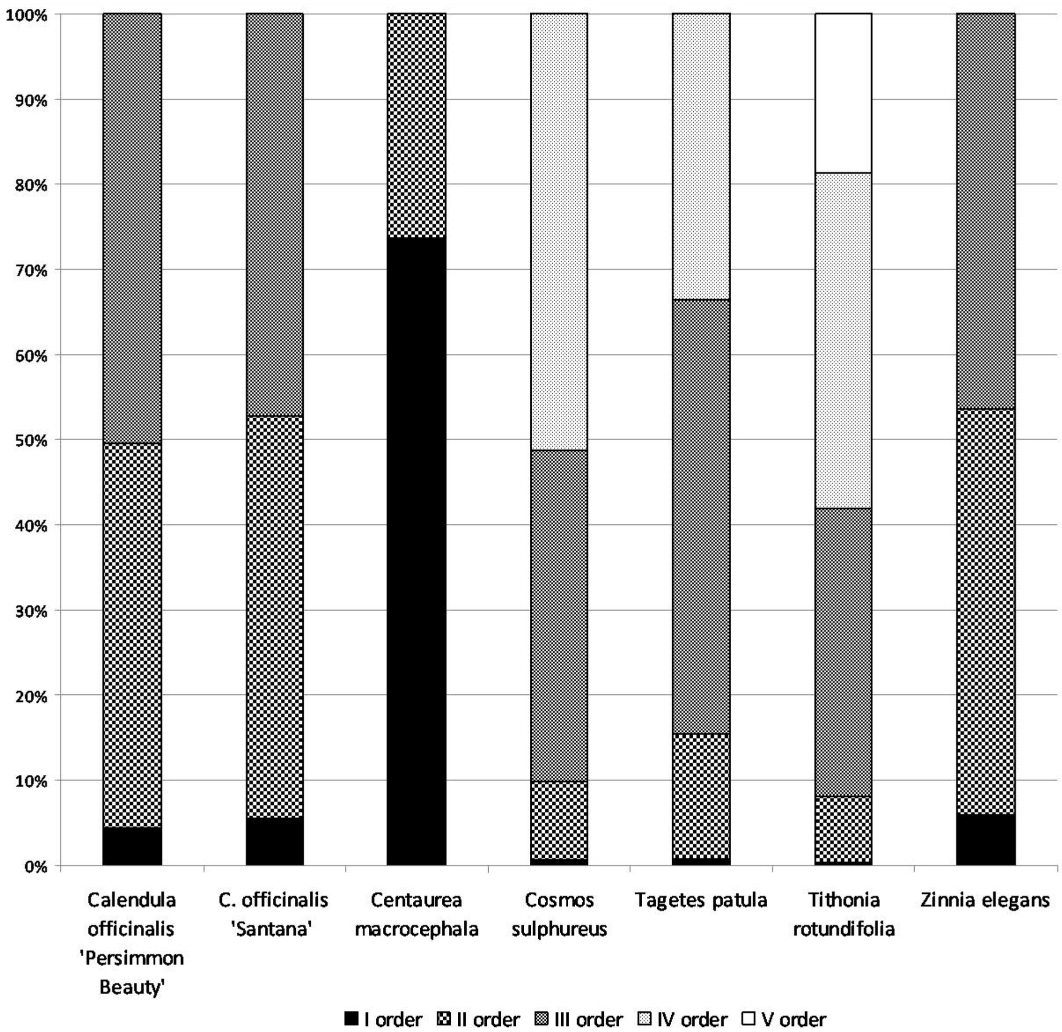

Fig. 2. The consecutive order capitula pollen productivity as a percentage of the total pollen mass delivered by a single plant of the studied Asteraceae. The mean values for three-year periods for each species are given.

Table 3

Dimensions of pollen grains of the examined Asteraceae (μm) (n = 200 pollen grains per taxon)

Taxon	Polar axis (P)		Equatorial axis (E)		Length of spike		Shape index P/E
	range	mean	range	mean	range	mean	
Calendula officinalis 'Persimmon Beauty'	23.09 - 38.68	29.50	22.17 - 42.33	31.19	2.04 - 4.49	3.21	0.94
Calendula officinalis 'Santana'	23.41 - 35.94	29.25	27.92 - 39.93	34.04	2.45 - 6.11	3.94	0.86
Centaurea macrocephala	35.36 - 40.45	37.54	35.70 - 40.59	38.45	-	-	0.98
Cosmos sulphureus	24.37 - 42.70	34.68	23.56 - 41.57	32.63	4.10 - 11.90	7.58	1.06
Dahlia pinnata	28.89 - 36.93	32.38	28.30 - 35.09	32.36	4.09 - 8.77	6.10	1.00
Tagetes patula	29.51 - 34.17	31.69	29.58 - 34.04	32.29	4.03 - 6.08	4.93	0.98
Tithonia rotundifolia	24.04 - 33.11	29.24	22.90 - 31.20	28.01	2.74 - 7.20	4.48	1.04
Zinnia elegans	18.04 - 24.60	14.05	16.40 - 26.24	13.86	1.35 - 1.51	1.45	1.01

anthers are fused together in a tube. After anther dehiscence, the released mature pollen grains are accumulated inside this tube. Insects can forage on the pollen only after it has been pushed outside the staminal tube by the stigmas of the rapidly elongated pistil - secondary pollen presentation (SPP).

Pollen productivity and morphological features of pollen grains

The detailed data concerning pollen production are shown in Table 2. It was found that the studied Asteraceae differed significantly in the mean pollen mass produced by 10 florets ($F_{7,\ 473}$ = 431.01, P = 0.000), capitulum ($F_{7,\ 623}$ = 317.30, P = 0.000), and the plant ($F_{7,\ 167}$ = 57.84, P = 0.000). The highest amount of pollen was produced by 10 florets of *C. macrocephala* - 10.1 mg, on average. The lowest values —less than 2 mg/10 florets— were found for the *C. officinalis* cultivars. Almost 250 mg of pollen were obtained from one capitulum of *C. macrocephala*, whereas for *T. patula* the mean value was only 9.7 mg. Another good pollen producer was *D. pinnata*, with an average pollen mass per 10 florets and capitulum of 7.0 mg and 71.4 mg, respectively.

The mass of pollen yielded by a single plant depended on both the pollen mass delivered per disk florets and the disk florets' proportion in inflorescences, and the flowering abundance of the plants (Tables 1 and 2). The contribution of the consecutive order capitula in the total mass of pollen produced by a single plant is shown in Fig. 2. Generally, the highest proportion of pollen was produced by the 2nd and 3rd order capitula. In our study, we found that for *C. sulphureus*, *T. rotundifolia*, and *T. patula*, the contribution of the 4th order inflorescences was also significant and exceeded 30% of total pollen mass obtained from a single plant. The largest pollen mass was produced by a single plant of *D. pinnata* and *T. rotundifolia* (Table 2). The mean pollen yield per 1m^2 of a plot ranged from 6.2 g (*Z. elegans*) to 60.7 g (*D. pinnata*).

Pollen grains of the studied Asteraceae are tricolporate, with echinate exine. Only in *C. macrocephala*, are the spines extremely short. For this reason, these spines are difficult or even unrecognisable under light microscope. Some morphological characteristics of pollen grains are presented in Table 3 and in Fig. 3 a - h. Based on the P/E ratio values, they can be classified into 3 shapes: (a) oblatespherical (0.86 - 0.98) - both cultivars of *C. officinalis*, *C. macrocephala*, *T. patula*; (b) spherical (1.0) in *D. pinnata*, and (c) prolatespherical (1.01 - 1.06) - *C. sulphureus*, *T. rotundifolia*, *Z. elegans*. The biggest pollen grains are those of *C. macrocephala*, in which the average length of the polar and equatorial axis was 37.54 μm and 38.45 μm, respectively. The smallest pollen grains were those of *Z. elegans*, with the relevant lengths of 14.05 μm and 13.86 μm. The average length of the spines differed among the species and varied from 1.45 to 7.58 μm (Table 3).

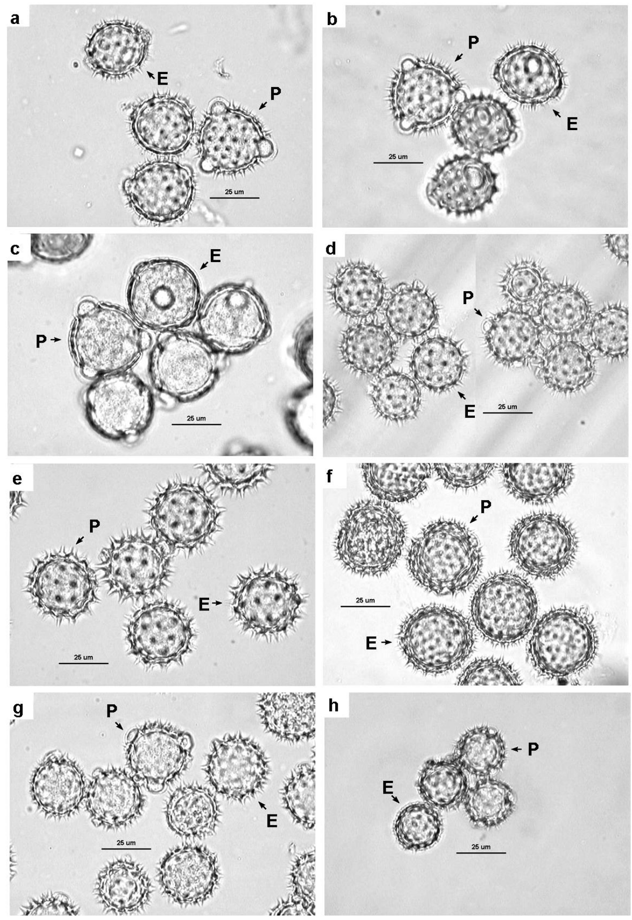

Fig. 3. Light micrographs of Asteraceae pollen grains: a) Calendula officinalis 'Persimmon Beauty', b) C. officinalis 'Santana', c) Centaurea macrocephala, d) Cosmos sulphureus, e) Dahlia pinnata, f) Tagetes patula, g) Tithonia rotundifolia, h) Zinnia elegans. Abbrev. P – polar view, E – equatorial view.

Insect visitation

Under good weather conditions insects visited flowers of the investigated species throughout the day. Peak visiting activity was between 12:00 and 16:00. For *C. macrocephala*, the second peak of insect visitation was noted at 17:00. The principal visitors foraging on flowers of the studied species were *Hymenoptera* (Fig. 4). Honey bees were the most common on *C. macrocephala* and *C. sulphureus*, comprising over 50% of all insects working on their flowers and they dominated on the capitula of *C. officinalis*. Bumble bees were principal visitors to *T. rotundifolia* (72.8%) and *D. pinnata* (45.3%). In contrast, they were completely absent on *C. officinalis*. Although no regular monitoring was carried out on *T. patula* flowers, both honey bees and bumble bees were observed foraging on them. The relative abundance of other wild bees ranged from a total lack - 0% (*T. rotundifolia*) to 30.7% (*C. officinalis*). Flowers of *Z. elegans* were eagerly visited by butterflies, comprising 41.1% of all insect visitors. At a peak of forage activity, the mean number of all insects working per 1m^2 of a plot differed considerably among plant taxa. Flowers of *C. officinalis*, *Z. elegans*, and *C. macrocephala* were the most visited (14, 14, and 12 insects per 1m^2 of a plot, respectively) whereas the lowest number of visitors was noted for *T. rotundifolia* – 4.3 insects per 1m^2 of a plot, on average.

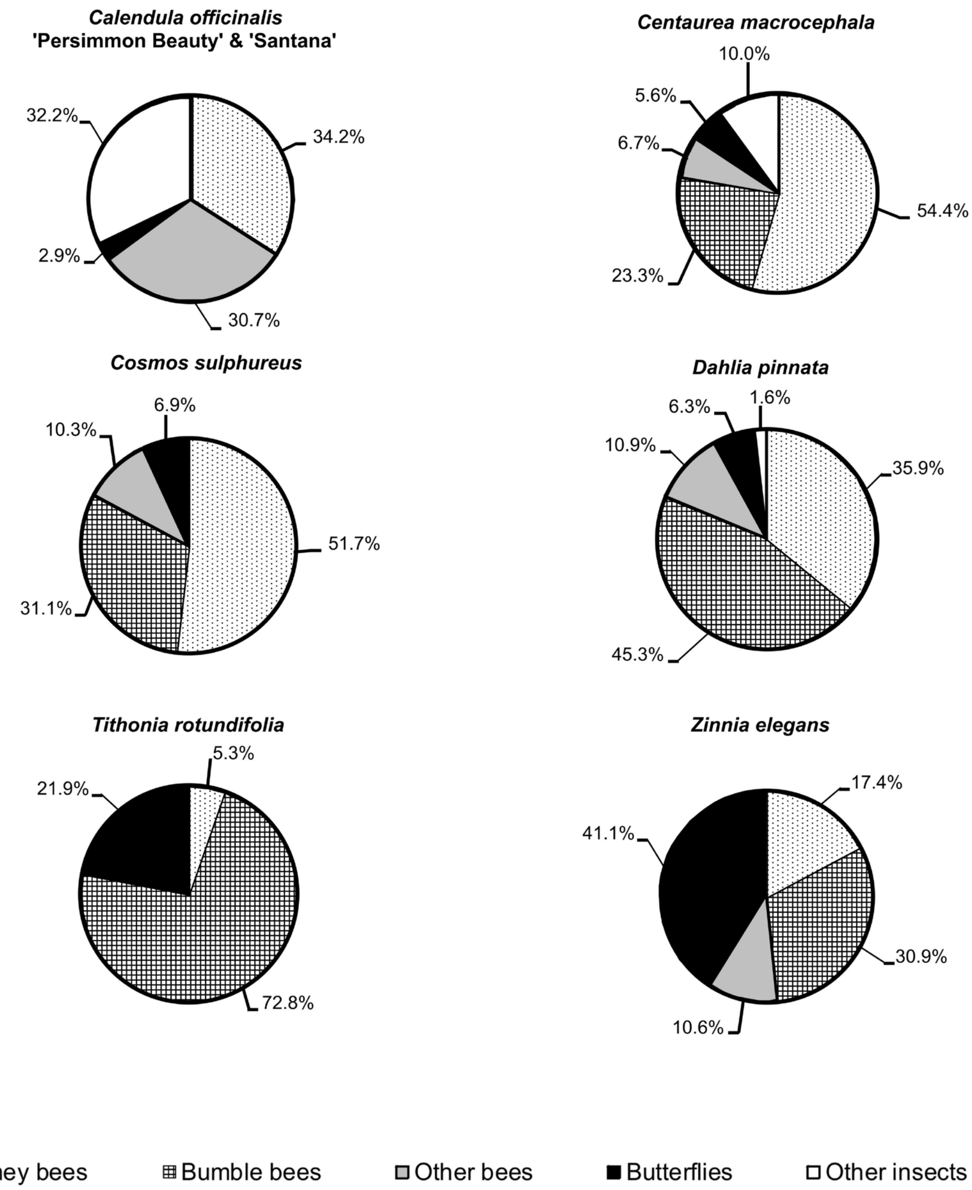

Fig. 4. Relative abundance of the groups of insect flower-visitors to the Asteraceae studied (means are given, n = 54 counts).

It was observed, that bees foraging on *C.macrocephala, C. officinalis, C. sulphureus*, and *D.pinnata* formed yellow, golden-yellow or orange pollen loads. The presence of pollen grains from these species in collected pollen loads was confirmed by pollen analysis (unpubl. data).

DISCUSSION

Offering more floral resources for urban bees can be achieved by encouraging the growing of ornamental bee plants in gardening, landscaping, and for sustainability (Matteson et al. 2008). Ornamental plants are not often thought to be good bee plants because they are not always conspicuous pollen or nectar resources (Jabłoński, 1997; Lipiński, 2010). However, many of them are suitable for bees that visit them eagerly. Ornamentals with different flowering periods, if intensively managed, produce floral resources that are more consistently available to insect visitors, even in times of drought (Steiner et al., 2010). Ornamental plants grown in cities exhibit a large botanical diversity. The family that shows numerous bee plant representatives is the Asteraceae (e.g., Jabłoński, 1997; Kołtowski, 2006; Lipiński, 2010).

Under the urban conditions of south-eastern Poland, the Asteraceae we studied are summer to autumn flowering ornamentals. If planted in gardens, parks or along avenues, these plants can provide pollen from late June until the 3rd week of October, during the period of foraging activity of various groups of visiting insects. Many species from the Asteraceae family are recognised as valuable late-season forage plants providing winter stores (Kołtowski, 2006; Strzałkowska, 2006; Denisow, 2011). Also, the majority of the taxa under study can supply their floral visitors until autumn frosts.

In all the observed plants, the onset and length of blooming depended on the weather conditions during the growing seasons. The influence of meteorological factors on the onset, duration, and abundance of flowering has been reported for many plant species, both in natural and urban habitats (e.g., Masierowska, 2006; Stawiarz & Wróblewska 2012 a, Denisow et al. 2014).

As described earlier, in the studied Asteraceae, pollen forage is provided exclusively by disk florets whose anthers are fused together in a tube. After anthers dehisce, the released, mature pollen grains are accumulated inside this tube. Insects can forage on the pollen only after it has been pushed outside the staminal tube by the stigmas of the rapidly elongated pistil - secondary pollen presentation (SPP). This mechanism of pollen presentation is typical for representatives of Asteraceae (Yeo, 2012) and has been observed e.g., in *Solidago* x *hybrida* (Strzałkowska, 2006), *Ligularia* (Wróblewska & Stawiarz, 2012 a), *Arctium* (Wróblewska & Stawiarz, 2012 b), and *Centaura* species (Denisow et al., 2014).

Pollen grains of the studied taxa are characteristically echinate in exine ornamentation. They are medium or small in size. According to Erdtman's classification (1954), pollen grains with dimensions within a range of 25-50 μm are included in the group of medium-sized grains. The mean shape index (P/E) ranged between 0.86 and 1.06. Based on the shape index, we categorised the pollen grains of examined taxa into three groups: oblatespherical, spherical, and prolatespherical. Jafari & Ghanbarian (2007) described four shape groups of pollen grains in the Asteraceae: spherical, prolatespherical, subprolate, and prolate.

There are no previously published research results on pollen productivity and pollen yield of the studied Asteraceae. Their flowers offered substantial pollen reward to visiting insects but significant differences among taxa were stated. The highest pollen amounts per 10 florets (10.1 mg) as well as per capitulum (249.7 mg) were found for *C. macrocephala*. The mean pollen mass per ten *C. macrocephala* flowers was 5-fold higher than that for both *C. officinalis* cultivars. The mass of pollen produced is a highly genetic-dependent trait and can vary greatly among species, cultivars, and varieties (Denisow, 2011; Wróblewska & Stawiarz, 2012 a, 2012 b). According to Warakomska (1972), the amount of pollen produced by a given number of flowers depends on the number of anthers in flowers, and also on the size of the pollen sacs. The size is correlated with the mass of archesporium, which is influenced by weather conditions during flower bud formation (Andrejev, 1926).

The mass of pollen yielded per plant and per unit area was directly related to the abundance of blooming, especially to the number of capitula formed on a plant and plant density per area unit. The main portion of capitula (and flowers) was produced by branches of the 2^{nd} and higher order. The bigger contribution of higher-order flowering units to the total number of flowers produced on a plant was previously noted in Asteraceae (Wróblewska et al., 1993; Wróblewska, 1995).

When the pollen yields per plant and per area unit are taken under consideration, the best pollen producers are *D. pinnata, C. macrocephala*, and *T. rotundifolia.* These plants may provide from 60.7 g·m^{-2} to 22.9 g·m^{-2} of pollen and can be placed among the good pollen-yielding plants. According to Jabłoński (1997), flowers of *Dahlia variabilis* supply bees with substantial amounts of nectar and pollen. The pollen production values for *C. macrocephala* (35.6 g·m^{-2}) in the present study, were higher than those established for *Centaurea scabiosa* (28.3 g·m^{-2}) (Denisow, 2006) or the ornamentals *C. montana*, *C. mollis*, and *C. dealbata* (6.81 g·m^{-2}, 5.85 g·m^{-2} and 7.92 g·m^{-2}, respectively) (Denisow et al., 2014). A fair pollen source was from the plants of *C. sulphureus.* Insects visiting its flowers may collect 13.1 g pollen per 1 m^2 of canopy. Additionally, this species does not seem to be highly invasive (http://www.cabi.org/isc/datasheet/12041). The lowest amounts of pollen (less than 1g per plant and up to 10 g·m^{-2}) were provided by *C. officinalis*, *T. patula*, and *Z. elegans*. Also, Jabłoński (1997) estimated the beekeeping value of these species as medium to poor.

In ornamental Asteraceae, the nectar and easily accessible pollen reward welcome an array of insect visitors. The number of insects visiting the inflorescences of the studied species increased in the early afternoon hours; when pollen release intensified. The majority of visitors to *C. macrocephala*, *C. sulphureus*, and *C. officinalis* were honey bees, whereas bumble bees dominated on the capitula of *T. rotundifolia* and *D. pinnata.* According to Garbuzov & Ratnieks (2014), bumble bees were the most numerous foragers on different *Dahlia* cultivars. Magnet flowers for butterflies appeared to be those of *Z. elegans*. Also, Matteson & Langelotto (2011) observed in New York City, USA, that butterflies comprised 10.6% of all visitors to *Z. elegans*. Presumably, both the florets morphology and characteristics of the floral rewards offered, e.g. nectar composition (Carlson & Harms, 2006) and starch content in pollen (Denisow, 2011), influenced visitors preferences. The colour and number of ray florets may also impact the frequency of insect visitors. All these characteristics require additional study for the ornamentals investigated. The main visitors to the studied flowers were polylectic bees. Several urban bee surveys indicate that generalist bee species with broad tolerance are favoured in urban areas (Matteson & Langelotto, 2011; Banaszak-Cibicka & Żmihorski, 2012); however the persistence of specialist species is also possible (Jędrzejewska-Szmek & Zych, 2013).

The interest shown by the insects in the forage as well as formation of pollen loads (*C. macrocephala, C. officinalis, C. sulphureus*, *D. pinnata*) provide evidence of the attraction held by those plants for both domesticated and wild bees. It is further corroborated by the data by Ostrowska (unpubl. data), Coffey & Breen (1997), and Bilisik et al. (2008), which demonstrated formation of pollen loads or high frequency of the pollen of *Dahlia*, *Cosmos*, and *Centaurea* spp. in pollen load samples. According to Antonini et al. (2006), pollen of *C. sulphureus* is eagerly collected by the wild bee *Melipona quadrifasciata* (Apinae). Furthermore, *C. officinalis*, *C. sulphureus*, *Tagetes* spp., and *Z. elegans* were listed among ornamental flowers abundantly visited by bees within the urban gardens of New York City, USA (Matteson & Langelotto, 2011). Omoloye & Akinsola (2006) reported that *Tithonia diversifolia* supplies food for *A. mellifera adansonii* in Nigeria.

Several studies suggest increasing the use of native plants to conserve wildlife in urban areas (Fussel & Corbet, 1992; McKinney, 2002;

Tallamy, 2007) but the vegetation of these areas reflect human preferences and needs. Ornamentals with long flowering periods and abundant flowers may also represent profitable resources of pollen and nectar and can be intensively exploited by bees. Among the species investigated in our study, *D. pinnata*, *C. macrocephala*, and *T. rotundifolia* are the most valuable sources of pollen food for managed and wild Hymenoptera. Under the climatic conditions of SE Poland, these species support the floral resources for urban pollinators from summer till autumn frosts. Additionally, they tend not to invade undisturbed areas.

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