

BLOOMING AND POLLEN PRODUCTION OF SEVERAL REPRESENTATIVES OF THE GENUS *Centaurea* L.

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S u m m a r y

Investigations on the flowering time and pollen efficiency of three *Centaurea* species were conducted in the years 2002 – 2004. The study included *Centaurea cyanus* L. – cornflower and *C. scabiosa* L. – greater knapweed which grew in the districts of Sławin and Czechów of the city of Lublin, and *C. stoebe* L. (= *C. rhenana*) which occurred at Pliszczyn near Lublin. The flowering of the *Centaurea* species in anthropogenic communities lasted, under Poland's conditions, continuously from mid-June to the first decade of September. The development of all disc florets in the capitulum lasted for ca. 2 days (*C. cyanus*), 4 – 5 days (*C. stoebe*), 5 – 8 days (*C. scabiosa*). *C. scabiosa* and *C. stoebe* form a similar number of pollen-yielding disc flowers per 1 m², averaging 95,000. In the case of *C. cyanus* only 5,800 flowers per 1 m² were found. The mass of pollen delivered was found to be species-related as dependent on anther size and productivity of the archesporial tissue. Dry matter weight of pollen per 100 stamen heads averaged from 3.93 mg to 6.12 mg. Pollen efficiency of *C. scabiosa* averages 283.3 kg per 1 ha, varying from year to year from 225 to 390 kg. *C. stoebe* may yield 173 – 213 kg of pollen per 1 ha, *C. cyanus* yielding only 14.3 kg per 1 ha. The species were visited in high numbers by *Apis mellifera* which accounted for 60 – 80% of all pollinators.

Keywords: *Centaurea* sp., blooming biology, pollen efficiency, pollinators.

INTRODUCTION

In Poland, there are 21 species belonging to the genus *Centaurea* associated mainly with communities belonging to the *Festuco – Brometea* class and with anthropogenic associations (Mirek et al. 2002). The best known species, *Centaurea cyanus* – the cornflower – was of very frequent occurrence in the past giving a colourful aspect to cereal fields. The species was especially common in the piedmont areas which used to be known for cornflower honey harvests (Rawski 1948, Demianowicz 1958). Listed as being of beekeeping value are, first of all, *Centaurea jacea*, *C. montana*, *C. rhenana*, and *C. scabiosa* (Gluchov 1958, Ostrowska 1981, Lipiński 1982, Bodnarczuk et al. 1993). The investiga-

tions of nectar secretion conducted in Puławy suggest that the honey efficiency of *Centaurea* species is high and may reach 200 – 800 kg/ha (Jabłoński et al. 1992). The presence of pollen of *Centaurea cyanus*, *Centaurea jacea* in pollen loads, bee bread and honey sediments from different regions of the country indicates that those species provide a valuable supplement to principal honey flows (Warakomska 1985, Wróblewska 2002). Warakomska (1972) was the only investigator to estimate pollen efficiency of cornflower. The lack of available data on pollen supplied to insects by other *Centaurea* species prompted the author to undertake a study on the blooming biology and pollen production of three representatives occurring in the wild in lowland Poland.

MATERIAL AND METHODS

The study was conducted in the years 2002 – 2004 in the city of Lublin and its vicinities. The following species were included:

1. *Centaurea cyanus* L. – the cornflower – occurring in scattered self-sustaining populations on abandoned farmlands in the district of Sławin
2. *C. scabiosa* L. – the greater knapweed – occurring in the district of Czechów in a plant community characterized by the occurrence of *Agrimonia eupatoria* and *Galium vernum*
3. *C. stoebe* (= *C. rhenana* (Bor.) Gugler) – the spotted knapweed – occurring at the village of Pliszczyn near Lublin. It formed dense stands near a xerothermic mid-field elevation at a roadside site with an underlying layer of gravel and sand.

Date and duration of flowering was observed by recording onset dates and duration of individual stages. Visitation by insects was also recorded (i.a. Jabłoński, Szklanowska 1997). In order to assess blooming abundance the number of capitula and the number of florets per capitulum were counted in successive ramifications of individual plants picked at random. The population densities were determined. The mean number of disc florets was based on the records taken from 30 capitula. The data were converted to number of florets per 1 m². Abundance of pollen delivery was estimated using the method by Szklanowska (1995). Determinations were made of dry matter weight of a pollen-containing anther, as well as weight and percentage of pollen in anthers. Fully grown disc florets with closed corollas were isolated from the capitula in the laboratory. Corollas were carefully separated from the lower ovary using a dissecting needle, corolla lobes were opened and

dissected stamen heads with their filaments removed were placed in each tared vessel. Viability was examined in acetocarmin, pollen grain size was measured in glycerin jelly slides.

The results were analyzed statistically. Correlation coefficient was used to determine the relationship between the dry weight of pollen-containing anthers and that of pure pollen. Two-way analysis of variance (ANOVA) was also used. The differences between means for different species and different study years were tested for significance using Duncan's test at $\alpha=0.05$.

RESULTS

Blooming. *Centaurea cyanus*, was the first to bloom, in the first decade of June, followed by *C. scabiosa*, mid-June, with *C. stoebe* blooming consistently several days later. *C. cyanus* i *C. stoebe* bloomed until mid-August reaching full bloom in the first decade of July. The average flowering time was 50 – 80 days. *C. scabiosa* bloomed the longest – until mid-September. An exceptionally early spring of 2002 did not make the investigated species to flower any earlier as compared to the flowering times recorded in the years to follow (Fig. 1).

The species formed monopodial inflorescence of capitula type. The peripheral florets are ligulate, sterile, brightly coloured from blue to light-violet to dark-violet. Pollen is yielded by the inner disc florets. The life span of disc floret in the capitulum of *Centaurea cyanus* is on average 1 day and 2 days *C. scabiosa* and *C. stoebe*. The florets of all the species under study are protandrous. In *C. scabiosa* and in *C. stoebe* on the first day of the lifetime of the disc florets the style extends and pushes its way through a tube formed by the constant number of 5 stamen heads, protrudes slightly above the corolla but the

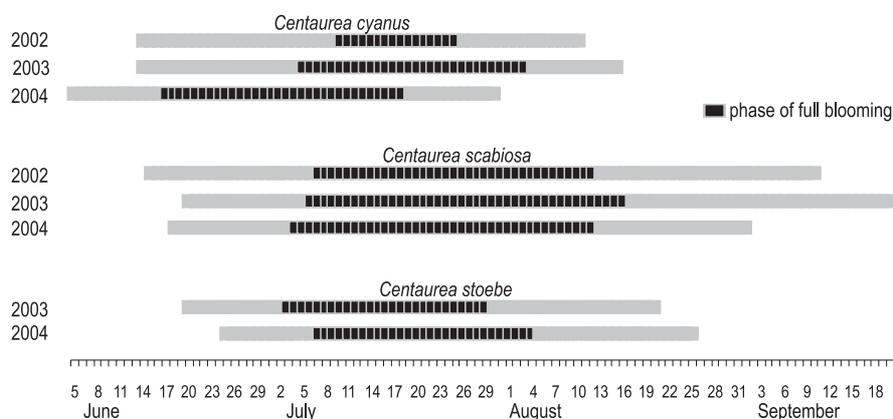


Fig. 1. Time and duration of blooming of *Centaurea* species in the years 2002-2005.

stigma remain closed. Then the pollen becomes released from the anthers which under sunny and dry weather lasts for about 3 – 4 hours. The process may extend for up to 8 hours should the conditions become less favourable, under declining temperature and rising relative air humidity. It is only on the second day that the stigma grows out above the stamens and becomes ready to receive pollen. The number of disc florets per capitulum proved to be a species-related (Table 1) and averaged 23.74 (*C. cyanus*), 58.2 (*C. stoebe*) and 97.9 (*C. scabiosa*). The trait also varied significantly with flowering stage (Table 2). The highest number of disc florets was found at the beginning of flowering and in the first order capitula formed by the main shoot. The capitula that developed on the successive branches had a significantly lower number of disc florets. The development of all pollen yielding florets in the capitula lasted for ca. 2 days (*C. cyanus*), 4 – 5 days (*C. stoebe*), 5 – 8 days (*C. scabiosa*).

The number of capitula per shoot was also found to be species-related and to vary over the study years. The highest average number of capitula was found on the shoots of *C. stoebe*, 36.9, an average of 21.97 capitula was developed by *C. scabiosa* and only 9.55 by *C. cyanus*. A substantially lower rate of capitula development was

found in *C. scabiosa* and *C. stoebe* in 2003 when winter was severe and long spells of drought occurred in early spring and in spring. At the same time, under those conditions the plants of those species developed a higher number of shoots per 1 m² than they did in the preceding years.

An average shoot density per 1 m² in the investigated communities was similar for *C. scabiosa* and *C. stoebe*, 43.2 and 47.15, respectively. The cornflower developed much fewer shoots, an average of 25.25 per 1 m². The number of disc florets per 1 m² varied with species and study year. *C. cyanus* was by far the least abundantly flowering species, forming from 3,300 to 8,500 florets per 1 m². The remaining species develop more than 90,000 florets per 1 m² of the investigated sites.

Pollen production and pollen efficiency.

The mass of pollen in anthers was found to be species-related (Table 3). There was also a year-to-year variation in the amount of pollen produced. Averaged across study years, dry weight of mature pollen-containing anthers was 25.39 mg (*C. scabiosa*), 16.39 mg (*C. stoebe*) and 13.74 mg (*C. cyanus*). Dry weight of pure pollen showed a clear positive correlation with anther size ($r = +0.73854$) and it was also related to the productivity of the archesporial tissue. The highest amount of pollen was

Table 1

The abundance of blooming of *Centaurea* species in 2002 – 2004.

Species	Year	Number of			
		disc florets per capitulum	capitula per shoot	shoots · m ⁻²	florets · m ⁻² (thousands)
<i>C. cyanus</i> L.	2002	23.6	9.08 a	15.50	3.32
	2003	22.13	10.06a	24.75	5.51
	2004	25.5	9.50a	35.50	8.59
	Mean	23.74	9.55	25.25	5.81
<i>C. scabiosa</i> L.	2002	95.9	22.14b	35.53	75.43
	2003	94.9	16.44a	52.46	81.87
	2004	102.9	27.33c	41.61	117.02
	Mean	97.9	21.97	43.20	91.44
<i>C. stoebe</i> L.	2003	56.8	31.17a	52.00	92.10
	2004	59.61	42.66b	42.30	107.56
	Mean	58.20	36.92	47.15	99.83

Table 2

The variability of some traits of *Centaurea* species in successive stages of blooming (averaged across study years).

Species	Stages of blooming	Number of		
		disc florets per capitulum	blooming capitula per shoot	disc florets · m ⁻² (thousands)
<i>C. cyanus</i> L.	beginning	28.50 c	1.90	1.36
	full	24.70 b	5.20	3.20
	end	18.20 a	2.40	1.10
<i>C. scabiosa</i> L.	beginning	110.40 c	3.32	15.79
	full	96.87 b	15.49	64.67
	end	86.80 a	3.33	12.45

yielded by the anthers of *C. scabiosa*, an average of 6.12 mg per 100 stamens. The stamens of *C. cyanus* produced an average of 5.06 mg of pollen which accounted for 36.8% of the total anther weight. Small stamens heads of *C. stoebe* with a low productivity of the archesporial tissue (only 23.9% of pollen in total anther weight) yielded on average of 3.93 mg of pollen per 100 stamens.

Pollen efficiency varied substantially with flowering abundance and pollen delivery rate (Fig. 2). Weather conditions had a modifying impact on the differences among study years. The highest amount of pollen flow was provided by the plants of *C. scabiosa*, an average of 283.3 kg per 1 ha, *C. stoebe* may yield 170 – 210 kg of pollen per 1 ha and *C. cyanus* only 14.3 kg. The estimated magnitude of pollen flow in the successive flowering stages is from

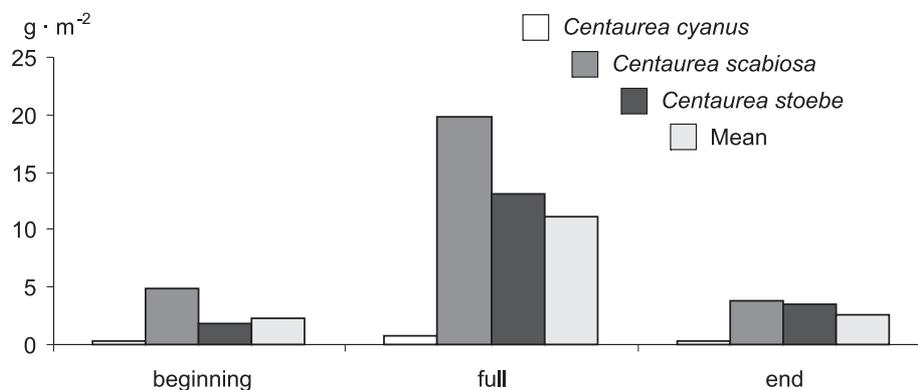


Fig. 2. The weight of pollen delivered in successive stages of blooming per 1 m² of associations with *Centaurea* species (averaged across study years).

Table 3

Pollen efficiency of *Centaurea* species in the years 2002-2004.

Species	Year	Dry weight			% pollen	Pollen efficiency	
		100 anthers (mg)		pollen per 100 anthers (mg)		100 capitula (g)	g · m ⁻²
		min - max	Mean				
<i>C. cyanus</i> L.	2002	12.8 – 13.7	13.25	5.13 a	38.7	0.61	0.83
	2003	13.4 – 14.9	14.05	5.45 ab	38.8	0.60	1.50
	2004	13.1 – 14.8	13.93	4.60 a	33.0	0.58	1.97
	Mean		13.74	5.06 B	36.8	0.60	1.43
<i>C. scabiosa</i> L.	2002	24.1 – 27.8	25.97	5.98 ab	23.0	2.87	22.52
	2003	23.5 – 24.7	24.07	5.73 ab	23.8	2.72	23.44
	2004	24.8 – 28.1	26.13	6.67 b	25.5	3.45	39.02
	Mean		25.39	6.12 C	24.1	3.01	28.33
<i>C. stoebe</i> L.	2003	16.2 – 20.8	19.25	4.64 a	24.1	1.32	21.36
	2004	13.2 – 14.0	13.53	3.22 a	23.7	0.97	17.32
	Mean		16.39	3.93 A	23.9	1.15	19.34

3.4 kg per 1 ha (*C. cyanus*) to 48 kg per 1 ha (*C. scabiosa*) at the initial stage. At full bloom the investigated species yield from 8.1 to 197 kg of pollen per 1 ha of the community and towards the end of flowering the estimated pollen flow is 25.2 kg per 1 ha on average (from 2.7 kg – *C. cyanus* to 38 kg – *C. scabiosa*).

The honeybee was the most frequent visitor of the species under investigation, accounting for 60% to 80% of total

pollinators (Fig. 3). Pollen foragers were the most numerous in the morning and in the evening. Bumblebees were also eager beneficiaries of the flow, especially of that provided by *C. stoebe*. Solitary bees and butterflies were also observed on the flowers of all three species.

The pollen loads made by the honeybee of the pollen of *C. scabiosa* and *C. stoebe* were yellow and the weight of one pair was 10.5 mg – 12.4 mg. The pollen loads made

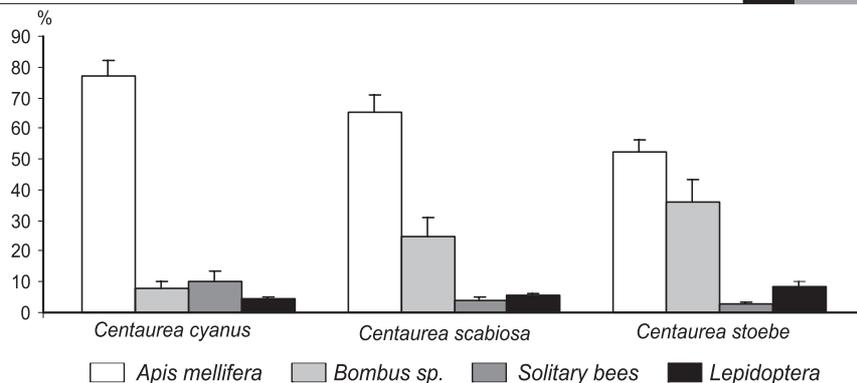


Fig. 3. The percent participation of pollinators on flowers of investigated species (average across study years) - SD are shown.

Table 4

The size and shape of pollen grains of *Centaurea* species (averaged across study years).

Feature	<i>Centaurea cyanus</i>		<i>Centaurea scabiosa</i>		<i>Centaurea stoebe</i>	
	min - max	mean	min - max	mean	min - max	mean
Length of polar axis (P) μm	35.0 - 40.0	37.50	32.5 - 45.0	39.57	30.0 - 35.0	32.0
Length of equatorial axis (E) μm	27.5 - 32.5	29.75	32.5 - 42.5	37.08	27.5 - 32.5	28.5
P/E		1.26		1.06		1.12

of the pollen of *C. cyanus* were slightly larger 11.5 mg – 14.2 mg and were dirty-white.

All three species were characterized by pollen grains of medium size (Table 4). The pollen grains of *Centaurea cyanus* were subprolatus those of the remaining species were prolato-spheroides. They were characterized by a high content of protoplasts. In all study years the viability exceeded 90%.

DISCUSSION

The results concerning the flowering and pollen efficiency of *Centaurea stoebe* and *C. scabiosa* growing in anthropogenic communities have no equivalent in literature reports.

The effective flowering of *Centaurea* species occurs in mid-summer when the demand by the *Apoidea* for pollen is on the rise. The flowering of *Centaurea* species in anthropogenic communities investigated in this study lasted on average longer by ca. 2 – 3 weeks than that determined for farming conditions by Ostrowska (1981) and Jabłoński et al. (1992). Those small discrepancies are probably due to climatic considerations, different weather patterns over the years of the study and, additionally, the population dynamics in the wild is always different from the dynamics of the same species under cultivation. The individuals under cultivation develop almost at the same time, whereas in natural habitats the development of cohorts is more spread in time.

The weight of pollen produced in the anthers of the *Centaurea* species was found to be directly related to the size of the stamen head. Such a positive correlation was demonstrated earlier for the species of different families e.g. Ranunculaceae (Szkłanowska 1995). The impact of the productivity of the archesporial tissue on the weight of pollen delivered was expressed as the percentage of pollen in the total weight of air dry pollen-containing anthers. The percentage of pollen in the total weight of anthers varied from species to species, a confirmation that the trait is species-related. Variation in productivity among study years within the taxons indicates a substantial impact of external factors such as weather conditions and habitat fertility on the differentiation and functioning of the archesporial tissue and the tapetum.

The amount of pollen delivered by the capitula of *Centaurea cyanus* as determined in this study does not depart from that reported by Warakomska (1972). The data obtained suggest a high suitability especially of *C. scabiosa* and of *C. stoebe* as pollen-yielding species. They may yield an average of 180 – 390 kg of pollen thus outperforming common mullein, St. John's wort or meadowsweet the pollen efficiency of which reaches 120 kg (Szkłanowska, Denisow 1999). The pollen efficiency of *Centaurea cyanus* of as little as 14 kg/ha as determined in this study was mainly due to the low plant populations per 1 m² and, consequently, to a low number of pollen-yielding flowers. Jabłoński et al. (1992) found much more abundant flowering when the species was cultivated. Since the mass of pollen in the anthers of *C. cyanus* does not depart from that determined for *C. scabiosa* and is higher than that in *C. stoebe*, with denser plant populations it is possible to reach pollen efficiency comparable to that estimated by Ostrowska (1981) based on forage intensity data.

The interest shown by the insects in forage and large pollen loads formed thereof provide additional evidence of the attraction held by those plants for apifauna. It is further corroborated by the data by Warakomska (1985), Wróblewska (2002) and Teper (2004) which demonstrate high frequency of the pollen of *Centaurea cyanus* and *Centaurea jacea* types in bee bread, and pollen load samples and in faeces of the representatives of the genus *Bombus*.

CONCLUSIONS

1. The flowering of *Centaurea* species in anthropogenic communities of south-eastern Poland provides pollen supply in an uninterrupted fashion from mid-June to the first decade of September.
2. When growing in anthropogenic communities *C. scabiosa* and *C. stoebe* develop a similar number of pollen-yielding flowers – an average of 95,000 per 1 m². *Centaurea cyanus* blooms much less abundantly – as little as 5,800 flowers per 1 m².
3. The mass of pollen in the anthers of *Centaurea* sp. is species-related and depends on anther size and archesporial tissue productivity, the latter being 24-36%.
4. Pollen efficiency of the species under investigation varied over the study years from 225 to 390 kg/ha (*C. scabiosa*), and had an average value of 195 kg per 1 ha (*C. stoebe*). *Centaurea cyanus* yielded only 8 – 20 kg of pollen per 1 ha in the studied associations.

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KWITNIENIE I POŻYTEK PYŁKOWY KILKU PRZEDSTAWICIELI Z RODZAJU *Centaurea* L.

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Streszczenie

Badania kwitnienia i pylenia trzech gatunków z rodzaju *Centaurea* prowadzono w latach 2002-2004. Uwzględniono *Centaurea cyanus* L. – chaber bławatek i *C. scabiosa* L. – chaber drakiewnik, rosnące w Lublinie w dzielnicy Sławin i Czechów oraz *C. stoebe* L. (= *C. rhenana*) – chaber nadreński występujący w Pliszczynie k/Lublina. Kwitnienie gatunków chabrow w zbiorowiskach antropogenicznych trwało w warunkach Polski południowo-wschodniej nieprzerwanie od połowy czerwca do pierwszej dekady września. Rozwój wszystkich kwiatów rurkowatych w koszyczkach trwał około 2 dni (*C. cyanus*), 4 – 5 dni (*C. stoebe*), 5 – 8 dni (*C. scabiosa*). *C. scabiosa* i *C. stoebe* wytwarzają na 1 m² podobną liczbę pyłkodajnych kwiatów rurkowatych – średnio 95 tys. W przypadku *C. cyanus* stwierdzano tylko 5,8 tys. kwiatów na 1m². Masa wytwarzanego w pylnikach pyłku okazała się cechą gatunkową, zależała od wielkości pylników oraz produktywności tkanki archesporialnej. Sucha masa pyłku w 100 główkach pręcikowych wynosiła średnio od 3,93 mg do 6,12 mg. Wydajność pyłkowa *C. scabiosa* wynosi średnio 283,3 kg z 1 ha, przy wahaniami pomiędzy latami 225 – 390 kg. *C. stoebe* może dostarczyć 173 – 213 kg pyłku z 1 ha, a tylko 14,3 kg z 1 ha *C. cyanus*. Badane gatunki licznie odwiedzała pszczoła miodna, która stanowiła 60-80% udziału zapylaczy.

Słowa kluczowe: *Centaurea* sp., biologia kwitnienia, wydajność pyłkowa, zapylacze.