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FLOWER-VISITING INSECTS ON *SOLIDAGO* ×*NIEDEREDERI* (ASTERACEAE): AN OBSERVATION FROM A DOMESTIC GARDEN

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Abstract

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In this study, we focused on flower-visiting insects on *Solidago* ×*niederederi*, a natural hybrid between the North American *S. canadensis* and the European *S. virgaurea*. Based on four-day observation in a domestic garden, we evidenced a high number of Diptera visits on hybrid flowers, per each hour of the recording, and a positive correlation between the number of insect visits and the length, the width and the number of secondary branches of synflorescence and the number of capitula. Moreover, the number of insect visits positively correlated with the air temperature and negatively correlated with the wind speed. The increasing number of insect visits with the increasing size of synflorescences suggests that capitula of the hybrid arranged in bigger panicles might be more visible and smell stronger. However, a high number of insect visits on the flowers within the same synflorescence may promote the occurrence of geitonogamy. The involvement of various insects in pollination of *S.* ×*niederederi* needs to be studied in the future.

Keywords: alien species, Diptera, flower visitor recording, hybrid plant, *Solidago*.

INTRODUCTION

Natural hybrids between alien and native plant species are treated as alien species (Pyšek et al., 2004) and can pose a threat to native biodiversity, especially when they are viable and fertile (Vilà et al., 2000; Daehler & Carino, 2001). It is commonly known that the process of pollination enables sexual reproduction in flowering plants and, aside from many environmental factors such as variation in the pattern of pollen flow associated with plant density, population size, and habitat fragmentation (Wilcock & Neiland, 2002), pollination in hybrid plants is usually limited by low pollen viability (Stace, 1975; Daehler & Carino, 2001). However, some self-incompatible and allogamous hybrids may be successfully pollinated by pollen grains of their parental species (Vilà et al., 2000; Daehler & Carino, 2001). In this respect, hybrids seem to be competitors not only for pollinators, but also for pollen grains produced by their parental species.

The genus *Solidago* L. (Asteraceae) comprises many natural hybrids (Nesom, 1994), including two hybrids between alien and native species evidenced in Europe, namely *S.* ×*niederederi* Khek, a hybrid between the North American *S. canadensis* L. and the European *S. virgaurea* L. (Pliszko, 2015; Pliszko & Zalewska-Gałosz, 2016), and *S.* ×*snarskisii* Gudžinskas & Žalneravičius, a hybrid between the North American *S. gigantea* Aiton and the European *S. virgaurea* (Gudžinskas & Žalneravičius, 2016). Numerous findings indicated that flowers of

Solidago species are a good source of pollen and nectar for bees and other insects, particularly in the late summer and autumn (Stefanic et al., 2003; Mader et al., 2011). Unfortunately, the diversity of insects visiting the flowers of *S. ×niederederi* and *S. ×snarskisii* and the effects of variability in floral display and synflorescence traits on insect attraction in these two hybrids have not been intensively studied so far. Interestingly, the studies on flower visitation in *S. altissima* L. (Weber, 2000), *S. canadensis* (Werner et al., 1980; Gross & Werner, 1983; Bopp, 1997; Hurej et al., 2012), *S. gigantea* (Voser-Huber, 1983; Bopp, 1997), *S. juncea* Aiton (Gross & Werner, 1983), and *S. nemoralis* Aiton (Gross & Werner, 1983; Robson, 2010) revealed a dominance of insects from the orders of Diptera and Hymenoptera. According to Dlussky et al. (2004), some species from the Asteraceae family with corolla tube length less than 10 mm (such as *Solidago* species) have yellow or white inflorescences and are visited primarily by flies. Moreover, several authors claimed that the number of insect visits is positively correlated with the number of capitula in synflorescences of *S. altissima* (Genung et al., 2010; Ikemoto et al., 2017). A similar correlation was evidenced in other species from the Asteraceae family, such as *Achillea ptarmica* L. (Andersson, 1991) and *Senecio jacobaea* L. (Andersson, 1996). Furthermore, the investigations conducted in various plant species (*inter alia* representing the Asteraceae family) revealed a substantial influence of environmental conditions on the number of visits of many insects representing the orders of Hymenoptera (Abrol, 1988; Puškadija et al., 2007; Seçmen et al., 2010; Kumar et al., 2012), Diptera (Kumar et al., 2012), and Lepidoptera (Seçmen et al., 2010). Most of the aforementioned authors have argued that the number of insect visits is positively correlated with the air temperature, and negatively with the humidity and wind speed.

In this study, considering the arrangement of capitula in *S. ×niederederi* (Nilsson, 1976; Gudžinskas & Žalneravičius, 2016) and the findings presented above, we aimed to test the hypotheses that (i) synflorescences (flowers) of the hybrid are visited more frequently by Diptera than by insects from the other orders regardless of the time of day, (ii) the number of insect visits on hybrid synflorescence (flowers) is positively correlated with the length and the width of synflorescence, the number of secondary branches and capitula within synflorescence, as well as with the location of synflorescence above the ground level, and (iii) the number of insect visits on hybrid synflorescence (flowers) is positively correlated with the air temperature and negatively correlated with the wind speed and humidity.

MATERIALS AND METHODS

Study species

Solidago ×niederederi is a perennial plant possessing intermediate morphological features between its parental species, especially in the size of capitulum and leaf shape and venation (Nilsson, 1976; Karpavičienė & Radušienė, 2016). Similarly to *S. canadensis* and *S. virgaurea*, it forms numerous capitula arranged in a panicle synflorescence and each capitulum includes two types of flowers of yellow corollas, namely outer female ray flowers and inner bisexual disc flowers (Nilsson, 1976). Within the capitulum of *Solidago* species, the ray flowers open before the disc flowers and each disc flower is protandrous, with pollen presentation preceding stigma receptivity (Bertin & Gwisc, 2002 and literature cited therein). In each capitulum of the hybrid, there are usually 12 ray and 9 disc flowers, with a length of about 5.5 mm and 4.5 mm of each other, respectively (Gudžinskas & Žalneravičius, 2016). *Solidago ×niederederi* has a long flowering period (from early August to early October), usually with a peak from the second half of August to early September. Generally, it shows self-incompatibility and out-crossing is the main way for seed production, which depends on the presence of insect pollinators (Pagitz, 2016). However, the seed-set in the hybrid is reduced due to its limited pollen viability (Migdałek et al., 2014; Karpavičienė & Radušienė, 2016). Furthermore, *S. ×niederederi* is treated as an alien species in Europe (Jażwa et al., 2018) with a tendency to be naturalized by the production of viable seeds (Pliszko & Kostrakiewicz-Gierałt, 2017). It occurs characteristically in anthropogenic habitats such as abandoned fields, quarries, railway embankments, roadside slopes, tree plantations, and arable fields with grass-legume mixtures, usually accompanied by both parental species (Nilsson, 1976; Burton, 1980; Pliszko, 2013; Stace et al., 2015; Pliszko & Jażwa, 2017; Pliszko & Kostrakiewicz-Gierałt, 2017).

Study site

The study was conducted in 2017 in a small domestic garden (25 m²) located near the farm buildings in Garbas Pierwszy, a village in the Polish part of the Lithuanian Lakeland, north-eastern Poland (GPS coordinates: 54°09.733′ N/22°37.145′ E; altitude: 183 m a.s.l.), where *Solidago ×niederederi* (F_1 generation) was planted in 2015 (Pliszko & Kostrakiewicz-Gierałt, 2017). This site lies in a transitory temperate climate zone with some influence from the continental climate (Górniak, 2000), showing the average annual air temperature of about 6.5°C and the average annual precipitation of about 650 mm (Lorenc, 2005). The vegetation within the radius of 200 m from the garden was represented mainly by anthropogenic plant communities of the classes *Stellarietea mediae* and *Artemisietea vulgaris* as well as by semi-natural plant communities of the classes *Molinio-Arrhenatheretea elatioris* and *Festuco-Brometea erecti*. Moreover, the area of the garden was under manual irrigation and weed removal system, with no fertilization and chemical control of pests, and the hybrid was the only cultivated plant in it. In 2017, there were 11 clusters (groups of ramets) of hybrid plants growing in two rows at the intervals of 0.5 m in the garden. Altogether, the clusters consisted of 235 flowering shoots (sexual ramets) and eight vegetative shoots (asexual ramets, shoots with no synflorescences). All the clusters of the hybrid plants cultivated in the garden originated most likely from a single clone (Pliszko & Kostrakiewicz-Gierałt, 2017). The number of shoots in clusters (with a predominance of flowering shoots) as well as the size of shoots and synflorescences were similar to those observed in many wild populations in Poland (Pliszko & Kostrakiewicz-Gierałt, 2017). Furthermore, based on preliminary observations on insects visiting the flowers of the hybrid conducted in four wild populations (located on abandoned fields near the farm buildings, in the Polish part of the Lithuanian Lakeland) in 2016, we assumed that in the presented domestic garden the flowers of the hybrid can be exposed to the same insect communities as in the wild.

Flower visitor recording

A total of 10 flowering shoots (sexual ramets) from 10 different clusters of the hybrid plants were selected for insect observation. The selection of shoots was followed by counting of open capitula within the panicles to estimate the peak flowering phase, which was established when the flowering shoots had more than 75% of open capitula. The selected flowering shoots were marked from 1 to 10 with an adhesive tape (attached at the middle part of the shoot) to make their recognition within the clusters of hybrid plants easier. The length (vertical distance between the base and the top of synflorescence), the width (horizontal distance between the extreme points of synflorescence) and the location above the ground level of synflorescence (distance between the base of synflorescence and the ground level as a perpendicular line) as well as the number of capitula and secondary branches (a total number of branches directly connected with the main axis of synflorescence) within the selected flowering shoots were taken under consideration to test their influence on the number of insect visits. The length, the width and the location above the ground level of synflorescence were measured using a self-retracting tape. The morphometric data of the selected synflorescences are summarized in Table 1.

Observations on flower visitors were made between 9 and 12 August 2017. Four times per day,

Table 1. Morphological characteristics of *Solidago ×niederederi* synflorescences (N = 10) selected for observation

Morphological character of synflorescence	Abbreviation	Mean (± SEM)	Range
Length (cm)	L	46.21 (± 4.00)	31.60–73.60
Width (cm)	W	26.20 (± 2.90)	13.20–45.50
Number of secondary branches	NSB	45.90 (± 2.90)	28–61
Number of capitula	NC	1311.60 (± 233.60)	540–3050
Location above the ground level (cm)	LAGL	99.14 (± 2.60)	81.60–110.50

SEM – standard error of the mean.

flower visitors were observed during 1 h periods with 2 h intervals, starting at 9:00 a.m. and finishing at 7:00 p.m. The order of observation followed the number of the selected flowering shoots (from 1 to 10). During 1 h period of the recording, on each of the selected synflorescences, flower visitors were observed for 5 min with 1 min interval and their visits were counted and noted. Simultaneously, the insects visiting synflorescence during 5 min of the recording were photographed using a SONY digital SLR camera (model no. DSLR-A200, with a 0.38m/1.3ft macro). The camera was operated manually keeping a distance of about 30 cm from synflorescence and comprising the whole synflorescence within the frame. A visit was defined as any physical contact between the insect and the flowers within capitula lasting at least 1 s. The multiple visits were also included when the visitor left the flowers and came again to the flowers of the same synflorescence during 5 min of the recording. The final number of insect individuals and their visits was estimated by revising the photographs and notes from direct observation. Moreover, air temperature, wind speed and humidity at the time of the recording were checked online as weather data for the nearly located village Filipów (https://m.meteo.pl/Filipow). The weather data are presented in Table 2.

Statistical analysis

Normal distribution of the data related to the number of insect visits was tested using the Kolmogorov-Smirnov test, while the homogeneity of variance was tested using the Levene test at the significance level of $p < 0.05$. As the values in some groups were not consistent with normal distribution, and the variance was not homogeneous, the Kruskal-Wallis H test for multiple comparisons was applied to check whether there are significant differences in the number of insect visits (considering the particular insect orders) between the hours of the recording. The Spearman coefficient (r) at the level of $p \leq 0.05$ was used to examine the strength and the direction of correlation between (i) the total number of insect visits on synflorescence and the morphological characters (length, width, number of secondary branches, number of capitula, and location above the ground level of synflorescence) and (ii) the total number of insect visits per each observation hour and weather conditions (air temperature, wind speed and humidity). The aforementioned analyses were performed using a STATISTICA 13 software package.

RESULTS

During four days of the recording, flowers of *Solidago ×niederederi* were visited 1179 times by a total of 646 insect individuals from the orders Coleoptera, Diptera, Hymenoptera, Lepidoptera and Neuroptera (Table 3). The highest number of insect individuals and the highest number of their visits were noticed in Diptera and Hymenoptera, reaching 69.97% and 27.71% of individuals and 75.83% and 22.90% of visits, respectively (Table 3). Among Diptera, the highest percentage of insect individuals and the highest percentage of their visits were noticed in Calliphoridae and Syrphidae, whereas among Hymenoptera – in Vespidae, reaching 28.95%, 22.6% and 21.82% of individuals, and 37.74%, 20.53% and 16.28% of visits, respectively (Table 3).

Considering the particular insect orders, differences in the total number of visits between the hours of recording were statistically significant, according to the Kruskal-Wallis H test results (Table 4).

A total number of insect visits on hybrid synflorescences were significantly positively correlated

Table 2. Air temperature, wind speed, and humidity in particular hours of the recording, based on four-day observation period (obtained from https://m.meteo.pl/Filipow)

Time of recording	Air temperature (°C)		Wind speed (m/s)		Humidity (%)	
	Mean (± SEM)	Range	Mean (± SEM)	Range	Mean (± SEM)	Range
9:00–10:00	21.2 (± 1.3)	19–25	3.0 (± 0.7)	2–5	70.0 (± 3.5)	65–80
12:00–13:00	23.7 (± 1.5)	21–28	3.7 (± 1.2)	2–7	66.5 (± 9.0)	50–90
15:00–16:00	25.5 (± 1.5)	22–29	3.5 (± 0.7)	2–5	62.2 (± 6.2)	46–72
18:00–19:00	22.7 (± 1.1)	20–25	2.2 (± 0.8)	1–4	66.0 (± 4.1)	55–75

SEM – standard error of the mean.

Table 3. General account of insect taxa recorded as visitors on flowers of *Solidago ×niederederi*, based on four-day observation period

Taxon	Total number of individuals	%	Total number of visits	%
Coleoptera	**12**	**1.86**	**12**	**1.02**
Cleridae	1	0.15	1	0.08
Coccinellidae	1	0.15	1	0.08
Curculionidae	2	0.31	2	0.17
Phalacridae	8	1.24	8	0.68
Diptera	**452**	**69.97**	**894**	**75.83**
Calliphoridae	187	28.95	445	37.74
Fanniidae	3	0.46	10	0.85
Muscidae	76	11.76	121	10.26
Sarcophagidae	40	6.20	76	6.45
Syrphidae	146	22.60	242	20.53
Hymenoptera	**179**	**27.71**	**270**	**22.90**
Apidae	24	3.72	57	4.83
Formicidae	12	1.86	19	1.61
Gasteruptiidae	2	0.31	2	0.17
Vespidae	141	21.82	192	16.28
Lepidoptera	**2**	**0.31**	**2**	**0.17**
Crambidae	1	0.15	1	0.08
Nymphalidae	1	0.15	1	0.08
Neuroptera	**1**	**0.15**	**1**	**0.08**
Chrysopidae	1	0.15	1	0.08
Total	**646**	**100**	**1179**	**100**

Table 4. Mean number (standard error of the mean) of visits on *Solidago ×niederederi* synflorescences made by the representatives of five insect orders, in particular hours of recording, based on four-day observation period

Insect order	Time of recording			
	9:00–10:00	12:00–13:00	15:00–16:00	18:00–19:00
Coleoptera	0.25 (± 0.25) ^{a}	0.75 (± 0.75) ^{ab}	0.50 (± 0.28) ^{ab}	1.50 (± 0.64) ^{ab}
Diptera	45.75 (± 19.77) ^{a}	59.00 (± 21.81) ^{a}	61.50 (± 19.60) ^{a}	57.25 (± 14.15) ^{a}
Hymenoptera	10.75 (± 4.17) ^{a}	19.00 (± 7.03) ^{ab}	27.75 (± 1.54) ^{ab}	10.00 (± 2.16) ^{ab}
Lepidoptera	0.25 (± 0.25) ^{a}	0.25 (± 0.25) ^{ab}	0.00 (± 0.00) ^{b}	0.00 (± 0.00) ^{b}
Neuroptera	0.25 (± 0.25) ^{a}	0.00 (± 0.00) ^{b}	0.00 (± 0.00) ^{b}	0.00 (± 0.00) ^{b}
The value of the Kruskal-Wallis H test	15.5**	15.4**	16.7**	17.7**

Asterisks indicate the level of statistical significance of $p < 0.01$. Different lowercase letters in superscripts indicate differences between the insect orders.

with all morphological characters, except the location above the ground level of synflorescence. The values of the Spearman coefficient ($p \leq 0.05$) for the length, the width, the number of secondary branches, the number of capitula, and the location above the ground level of synflorescence were 0.87, 0.81, 0.69, 0.85, and -0.01, respectively. A total number of insect visits per each observation hour were remarkably positively correlated with the air temperature, reaching the value of 0.75 of the Spearman coefficient ($p \leq 0.05$). Moreover, it was significantly negatively correlated with the wind speed and it was not correlated with the humidity, reaching the values of -0.53 and -0.05 of the Spearman coefficient ($p \leq 0.05$), respectively.

DISCUSSION

The present study revealed that flowers of *Solidago ×niederederi* can be visited by many wild insects, especially Diptera and Hymenoptera (Table 3). The hypothesis that flowers of the hybrid are visited more frequently by Diptera than by insects from the other orders regardless of the time of day can be fully accepted (Table 4). Our results showing a great contribution of insect visitors from Diptera correspond to the observations made by Dlussky et al. (2004), who have noticed that some species from the Asteraceae family with corolla tube length less than 10 mm (as *S.* ×*niederederi*) have yellow or white inflorescences and are visited primarily by flies, while the plants with longer corolla tube have violet or dark blue inflorescences and are pollinated by bumblebees.

Although pollination of the hybrid was not an objective of the present study, we assume that some of the recorded flower visitors may serve as pollinators, especially Syrphidae and Apidae, as it has been evidenced in the studies concerning the insect pollinators of *S. canadensis* and *S. virgaurea* (Werner et al., 1980; Nielsen, 2007; Moroń et al., 2009; Fenesi et al., 2015 and literature cited therein). Other insects such as Calliphoridae, Sarcophagidae, Coccinellidae, and Formicidae revealed in our study, seem to be very accidental pollinators. Nevertheless, it is known that the morphology of the ray and disc flowers in capitula of the Asteraceae promotes the pollination by insects of different mouthparts and lifestyle activities (Weberling, 1989). Moreover, Wilcock & Neiland (2002) have stated that many species of the Asteraceae are pollinated by a wide taxonomic diversity of pollinators and, therefore, the risk of pollination failure caused by the loss of pollinators is intermediate to low. The involvement of various insects in pollination of *S.* ×*niederederi* needs to be studied in the future, as well as the competition for insect pollinators between the hybrid and its parental species.

The hypothesis that the number of insect visits is positively correlated with the length and the width of synflorescence, the number of secondary branches and capitula within synflorescence as well as with the location above the ground level of synflorescence, cannot be fully accepted due to a lack of correlation between the number of insect visits and the location above the ground level of synflorescence. Nevertheless, the increasing number of insect visits with the increasing size of synflorescences suggests that the capitula arranged in bigger synflorescences might be more visible and smell stronger. The numerous case studies conducted in various habitats and regions showed that the number of insect visits is positively correlated with the inflorescence size and flower display (Willson & Bertin, 1979; Schmid-Hempel & Speiser, 1988; Eckhart, 1991; Ohara & Higashi, 1994; Goulson et al., 1998; Danderson & Molano-Flores, 2010; Suetsugu et al., 2015). Moreover, positive correlation between the number of insect visits and the number of capitula in synflorescences has been found in *S. altissima* (Genung et al., 2010; Ikemoto et al., 2017), the species closely related to *S. canadensis*, and other self-incompatible species from the Asteraceae family, such as *Achillea ptarmica* L. (Andersson, 1991), *Cirsium purpuratum* (Maxim.) Matsum. (Ohashi & Yahara, 1998) and *Senecio jacobaea* L. (Andersson, 1996). On the other hand, many species of the Asteraceae family, such as *Senecio integerrimus* Nutt. and *S. crassulus* A. Gray (Schmitt, 1983), have presented an inversed trend that presumably might contribute to avoidance of self-pollination. The production of numerous flowering shoots in clusters evidenced in wild populations of the hybrid in Poland (Pliszko & Kostrakiewicz-Gierałt, 2017) seems to be a good strategy to attract many insects, including the potential pollinators.

The hypotheses that the number of insect visits on hybrid flowers positively correlates with the air temperature and negatively correlates with the wind speed can be fully accepted, in contrast to the hypothesis that the number of insect visits negatively correlates with the humidity. A lack of statistically significant correlation between the number of insect visits and humidity might be explained by a short period of observation during which the values of humidity were not extreme (Table 2). Nevertheless, the performed observations seem to be consistent with the findings provided by many authors (Kevan & Baker, 1983; Puškadija et al., 2007) that the activity of insect pollinators is weather dependent. Interestingly, Inouye et al. (2015) have reported a considerable activity of dipterans during the warmest part of the day thanks to their small dimensions, reflective coloration, pilose body cover and strong cuticula. Furthermore, Ssymank et al. (2008) have asserted that the flies visiting flowers in the late afternoon have low energy requirements and may spend more time basking in flowers, compared to bees. Given this, it is important to identify the efficiency of Diptera in the pollination of *S.* ×*niederederi* in the future. Moreover, considering that the hybrid is a gynomonoecious plant as its parental species (Bertin & Gwisc, 2002) and the insects can visit the various flowers within the same synflorescence of the hybrid, there is a possibility of geitonogamy. This aspect of pollination ecology of the hybrid should be intensively studied and the expected results of such investigation might be similar to those evidenced for other species (Mamut et al., 2014 and literature cited therein) that the female ray flowers experience less geitonogamy and more outcrossing than the bisexual disc flowers. It is interesting that the geitonogamy may reduce seed production in self-incompatible plants (Ito & Kikuzawa, 2003) and, therefore, may negatively affect the naturalization and spread of the hybrid.

Finally, according to Salisbury et al. (2015), domestic gardens can be enhanced as habitats for insect pollinators by planting a variety of flowering plants, including selected alien plants to extend the flowering season and potentially provide resources for specialist groups. Despite the fact that *S. ×niederederi* has an ornamental value and might be an important source of pollen and nectar for bees and other beneficial insects, we do not recommend it for cultivation due to its ability to a relatively fast establishment and a highly probable risk of introgression with native *S. virgaurea*.

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SOLIDAGO ×NIEDEREDERI (ASTERACEAE) ŽIEDUS LANKANTYS VABZDŽIAI: STEBĖJIMAI NAMŲ SODE

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Santrauka

Šio tyrimo objektas buvo *Solidago ×niederederi*, natūralaus hibrido tarp *S. canadensis* iš Šiaurės Amerikos kilusios ir vietinės *S. virgaurea* rūšies, žiedus lankantys vabzdžiai. Remiantis keturių dienų stebėjimais, vykdytais namų sode, pastebėta, kad hibrido žiedus daugiausia lanko Diptera vabzdžiai. Nustatyta, kad vabzdžių apsilankymų skaičius kiekvieną jų stebėjimo valandą teigiamai koreliavo su augalo sudėtinio žiedyno antros eilės šakelių ilgiu, pločiu bei graiželių skaičiumi. Taip pat nustatyta teigiama koreliacija tarp vabzdžių apsilankymų skaičiaus ir oro temperatūros, tačiau neigiama – su vėjo greičiu. Vabzdžių apsilankymų skaičiaus didėjimas didėjant sudėtiniam žiedynui reiškia, kad graiželiai, išsidėstę didesnėse šluotelėse, yra labiau pastebimi ir stipriau kvepia. Tačiau didesnis vabzdžių apsilankymų skaičius to paties sudėtinio žiedyno žieduose skatina geitonogamijos atsiradimą. Ateityje reikėtų ištirti įvairių vabzdžių dalyvavimą *S. ×niederederi* žiedų apdulkinime.